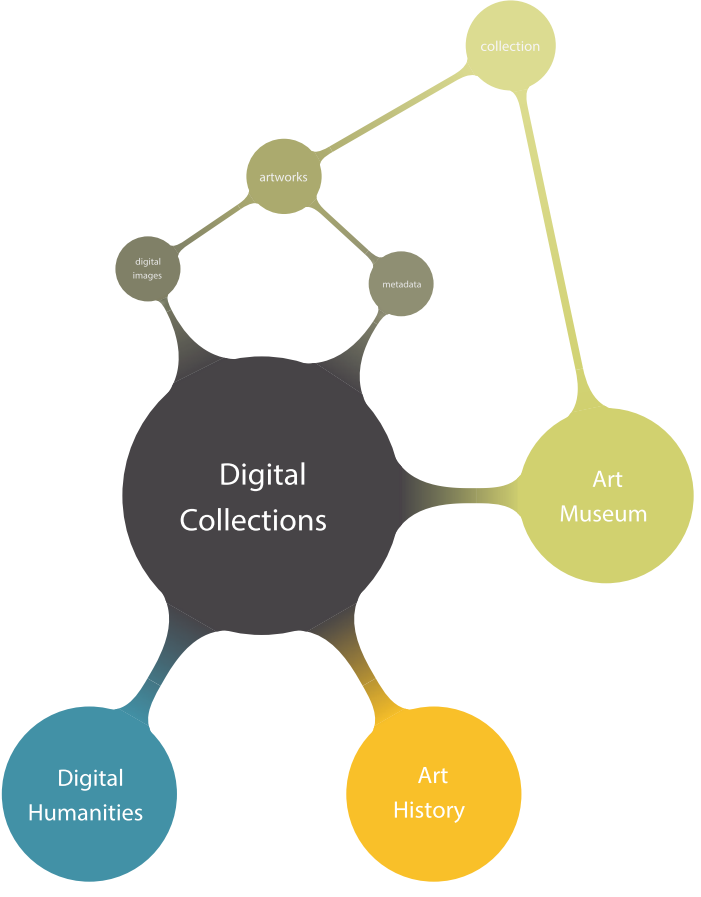
Sonja Gasser

Transformative Digital Collections of Art Data in Museums and Digital Art History



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Digital Humanities is an evolving, cross-cutting field within the humanities employing computer-based methods. Research in this field, therefore, is an interdisciplinary endeavor that often involves researchers from the humanities as well as from computer science. This collaboration influences the methods applied as well as the theories underlying and informing research within those different fields. These implications need to be addressed according to the traditions of different humanities' disciplines. Therefore, the edition addresses all humanities disciplines in which digital methods are employed.

Digital Humanities Research furthers publications from all those disciplines addressing the methodological and theoretical implications of the application of digital research in the humanities.

The series is edited by Silke Schwandt, Anne Baillot, Andreas Fickers, Tobias Hodel and Peter Stadler.

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Sonja Gasser

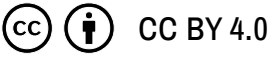
Transformative Digital Collections of Art

Data in Museums and Digital Art History

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Preface

Over the past few years, I have found it enlightening and exciting to observe the developments in digital technology and how it is increasingly being used within museums and the humanities. Writing a dissertation on digital collections of art has meant exploring an emerging and rapidly evolving field at the intersection of art history, digital humanities, and museums. My research revealed how digital collections of art, data, and digital methods open up new avenues for research, analysis, interpretation, and representation of art in art history and in museums. I am pleased to publish my findings in this comprehensive monograph.

The completion and current shape of this dissertation emerged from a stimulating environment that encouraged crucial discussions on the topic, as well as the invaluable support from various people. I would like to express my deepest gratitude to all those who have supported me during this research journey. I want to thank Professor Hubertus Kohle, who has been a supportive supervisor from the beginning. His openness to incorporating digital technologies into art history made it possible to start a dissertation at this thematic intersection. I would also like to thank Professor Tobias Hodel, another encouraging supervisor, for bringing in the digital humanities perspective. In his validation of my topic as a promising one, he encouraged me to make further progress. I am also deeply grateful to those who helped me take the final step. Special thanks to Sarah Amsler, Martin Gasser, Michaela Gruber, Mirjana Kovacevic, Ursula Loosli, Doctor Ina Mertens, and Doctor Lothar Schmitt for their help with proofreading and their valuable feedback as well as to Professor Stephan Hoppe for being the third-party examiner at the defense. I would like to express my sincere thanks to Erin K. Murphy for her contribution to editing the manuscript and improving the English for publication.

The dissertation benefited considerably from a network of people and institutions. The Digital Humanities Lab at the University of Basel and Professor Lukas Rosenthaler inspired this dissertation and were helpful in the discussion of and tips for technology related issues. Archives on the Move (ArchivesOnTheMove.org), which I realized at the Digital Humanities Lab in cooperation with the Kunsthalle Basel, allowed me to practically explore the topic. I would also like to thank Sören Schmeling, Kunsthalle Basel's head of photo archives at the time, for the many good discussions. Joining the Digital Art History group at the Department of Art History at the Ludwig-Maximilians-Universität München, under the direction of Professors Kohle and Hoppe and led by Doctor Harald Klinke, was a good forum for

knowledge exchange in monthly meetings.[1] Working as a research assistant at Kunsthaus Zürich for three years allowed me to gain insight into the current state of collection databases and how artworks are inventoried from the museum's perspective. Finally, the opportunity to act as a PhD researcher at the Digital Humanities of the Walter Benjamin Kolleg at the University of Bern, in combination with my collaboration with Professor Hodel, provided the ideal conditions to finalize the dissertation.

It has been quite a challenge to work on an interdisciplinary topic that is situated between art history and technology. As digital humanities, and more specifically digital art history, is an evolving field, it often requires the establishment of new structures to support research. Such research may not always be compatible with previous disciplinary practices or may necessitate special accommodations. This let me be a pioneering PhD student in the Digital Art History program within the Department of Art History at the Ludwig-Maximilians-Universität München, as well as at the University of Bern, where it became possible for the first time to matriculate in the digital humanities. Working on my dissertation was very intense and offered many opportunities. Summer schools in digital humanities and digital art history—two in 2015 in Munich and Heidelberg, one in 2016 in Zurich and Lausanne, and one in Rome in 2021 with the newly founded DHCH Digital Humanities Network Switzerland—are among the highlights. In 2017, I organized a summer school with Doctor Klinke in Munich. We wanted to bring together art historians and information and computer scientists to work in interdisciplinary groups on small projects.

Presentations at various international conferences and published articles were good opportunities to promote my topic within the research community. Furthermore, twice I had the opportunity to co-organize a section at the Swiss Congress for Art History: the section for young art historians with Valérie Clerc in 2016 and a section with Professor Béatrice Joyeux-Prunel and Angelica Tschachtli on art history and digital humanities in 2022. Another chance to bring the topic to the professional community was the 2021 workshop Digital Collections, from which the web forum vernetzt.museum emerged. Working on my dissertation made it possible for me to establish a broad network in academia and in the GLAM community.

I hope that this book will contribute to a broader understanding of the transformative power of digital collections of art, the use of data and digital methods, and the ways in which they are shaping the future of art history and museums. As a passionate advocate for the intersection of digital

1 "Digitale Kunstgeschichte," Institut für Kunstgeschichte, Ludwig-Maximilians-Universität München, accessed January 24, 2017, https://www.kunstgeschichte.uni-muenchen.de/forschung/digitalekg/index.html.

technology and art, I believe that digital collections of art are an essential tool in the field of art history and museum studies in the 21st century. I am excited to share my findings and insights with scholars, museum professionals, and anyone interested in digital collections of art in addition to communicating how digital technology enables data-driven approaches in museums and art history.

Since digital developments in this field are ever evolving, the book represents a snapshot of current trends at the time of writing. Although details change quickly and certain statements may become outdated, this points to the progress and professionalization of digital tools and resources in museums and art history, for which this book strongly advocates. Nevertheless, the principles, concepts, and approaches discussed in the book can provide valuable insights and serve as a starting point for ongoing exploration of the possibilities and potential of digital technology.

Zurich, April 24, 2025
Sonja Gasser

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1. Introduction: Digital Data in Art Museums and Art History

1.1 Transformative Digital Collections

Digital collections of art require museums, art historians, and digital humanities scholars to develop broad technological competencies and prioritize the digital image. *Transformative Digital Collections of Art: Data in Museums and Digital Art History* addresses challenges digital technology presents to both museums and art history. Starting with digitized collections, this book explores how museums can create digital offerings for a broad audience and, as providers of cultural data, make accessible information about artworks in the collection. The preparation and accessibility of data, according to the guiding thesis in this book, provides museums with a solid foundation for developing their own applications that increase reach in the digital space. In this context, applications are understood as providing users access to artworks in the collection via a browser and conveying related thematic content. Access to this data enables scholars to use digital images and artworks' metadata, which are essential for research utilizing digital methods. With this in mind, the central question of this book is therefore: How can museums and art historians best use digitized art museum collections? Fundamental to the argument is the assumption that for advanced engagement with digital collections, museums and art historian users must possess exceptional digital competencies and skills. A comprehensive understanding and intentional use of digital technology are indispensable success factors, as indicated in this research. Museums and art historians who skillfully approach digital collections are empowered to develop impactful digital offerings and conduct innovative research projects.

At the same time, the sheer breadth of what digital literacy encompasses, in relation to digital collections, has been commonly underestimated and underappreciated in these fields.[2]

The following chapters will detail topics related to digital collections of art museums while highlighting the importance of achieving digital literacy. In his influential book *Digital Literacy*, Paul Gilster introduced the term as the competence to find, understand, critically judge, and utilize a wide range of digital sources when relying on web-based

2 This has changed rapidly in recent years, and some museums and art historians are already making progress.

content.[3] These core competences include navigating nonlinearity, the interplay of different media, and information from diverse sources within a digital environment customized to one's needs using digital tools.[4] "Information" is a common and broadly used word and accordingly it can be vague in meaning, however, in this book the word refers to primarily digital images of artworks and the corresponding cataloging information in digital collections of art museums. From the perspective of information science, it can refer to any document or artifact found in the database of any cultural institution. Since information refers to the informational value of a digital source, content from databases is referred to in a more technical sense as "data" or, if it is only textual data or additional classification information, as "metadata." In information science, digital literacy encompasses the knowledge, skills, and attitudes required to effectively use information in digital environments.[5] Although digital literacy includes technological skills, it refers more to the user's ability to find, evaluate, understand, and use digital information sources. While these skills are valuable, they only partially meet the competencies this book identifies as essential for museums and art historians working with digital collections.

The research presented here shifts the focus from literacy as the ability to find and use existing information to skill-based literacy—emphasizing the ability to work with data from digital collections via the active use of digital technology. What this book explains and urges museums and art historians to do for a future-oriented approach to digital collections corresponds more with Jeremy Shapiro and Shelley Hughes's seven dimensions of literacy:

- **tool literacy:** understanding and use of software and hardware
- **resource literacy:** understanding formats and access methods of information resources
- **social-structural literacy:** understanding the social context of information and how it is produced
- **research literacy:** understand and use of digital tools for quantitative and qualitative analysis, as well as simulation
- **publishing literacy:** understanding and use of digital publishing, including multimedia content

3 Paul Gilster, *Digital Literacy* (Wiley, 1997).

4 Gilster, *Digital Literacy*, 3.

5 David Bawden and Lyn Robinson, *Introduction to Information Science* (Facet, 2012), 287, https://doi.org/10.29085/9781783300761.

- **emerging technology literacy:** ongoing adoption of emerging tools and resources
- **critical literacy:** understanding and critical evaluation of information technologies[6]

Museums and art historians proficient in these seven areas can effectively represent art, develop applications, conduct research, and publish using digital tools and technologies. Under these conditions, the application of programs and tools to digital collection data is carried out in ways that thoughtfully address prevailing social and digital conditions.

The digital transformation has reached museums and the humanities, bringing new perspectives in the examination, presentation, publication, and communication of art. Initial museum databases were established for collection management, followed by making collections available online for public access to essential artwork information. Many of these publicly accessible digital collections have matured into rich collections that contain comprehensive information, open up to a network of cultural data, as well as the reuse of data, and are linked to other applications. Using the digital collections of museums as the starting point, this book sheds light on the challenges and opportunities that art museums and art historians face today.

When museums proactively implement comprehensive digital access to their collections, they establish profound knowledge platforms and elevate users' engagement with collections. Data from digital collections are a distinct source that stimulates art historical research by necessitating the development of new research methods and questions. However, reaching a point where digital collections serve as both comprehensive platforms and sources of data effectively used in art historical research remains a significant challenge. The prerequisites for achieving this will be examined from multiple perspectives. The digital representation of art collections on the web makes it possible to look closely at aspects of the presentation, communication, exploration, and research of art under digital conditions. For this purpose, it is essential to consider current debates in the digital humanities and the context of digitization in museums.

The extent to which digital transformations are affecting museums, particularly with regard to collections that have become publicly accessible online, necessitates the evaluation of the appropriate use of technology for data-driven services. Questions about the kind of data and who has access to

6 Jeremy J. Shapiro and Shelley K. Hughes, "Information Literacy as a Liberal Art: Enlightenment Proposals for a New Curriculum," *Educom Review* 31, no. 2 (1996), accessed January 16, 2022, https://www.educause.edu/ir/library/html/erm/31231.html.

it, as well as the permissions to reuse that data are increasingly pressing, especially in a sector reliant upon government subsidies and support to maintain public services. With the arrival of digital images and metadata, a completely new type of object and source material has entered both the museum and art historical disciplines. This necessitates the consideration of the qualities and characteristics of artworks' representational data, as opposed to originals exhibited in museums or image reproductions in printed catalogs. For museums and art historians, novel tasks and approaches emerge when they embrace the challenges that data introduces. They must not only possess digital literacy and skills but also set priorities for pairing data from museum collections with technology.

As will be demonstrated, convincing applications for the presentation of digital collections require a balance between conceptual, technological, and art historical skills. The savvy use of data enables museums to expand their commitment to art and maintain a strong presence in the digital space with high-quality offerings. By providing third-party access to these data, users can tailor their own applications and test new research methods in the digital humanities. Some museums and art historians have established themselves as pioneers in the use of digital technologies, while others have yet to embrace the challenges of digital developments. This book addresses numerous issues related to digital collections and their presentation, pointing out the significance of the data they contain for use in both museum and research contexts. An in-depth discussion of the representation of digital collections of art is relevant for contemporary museum practices, helps further establish digital art history, and reflects ongoing developments in digital humanities and in information technology in a globalized society.

To date, no comprehensive overview exists that considers the dynamic field of digital collections and discusses institutional, cultural, technological, social, and scholarly realities. This book takes the digital collections of art museums and the presence of digital images as a starting point to draw attention to a field that is open in several directions. It is crucial to highlight the breadth of digital technology, art historical knowledge, and specifics of provision and use in order to fully grasp and understand the significance of digital collections and determine the best course of action. Therefore, it is necessary to explain what is important when providing access to and representing collections in the digital space; what interest exists in the use of the data by museums, the museum public, in digital art history and digital humanities; and associated technological, methodological, epistemological, and institutional implications.

From a technological perspective, mere access to collections online is only the beginning of what art collection data can provide for museums as

well as for art historians. Having data available is a new context in which to consider presenting art, public engagement, and doing research. Museums and art historians who are aware of the peculiarities of digital technology are able to use digital collections as valuable resources for the cultural institutions' purposes, the interests of visitors and users, but also for art history. This requires understanding what data is and how computing technologies can be applied to digital images and metadata for the retrieval, manipulation, analysis, visualization, presentation, and interpretation of data. However, skillful programming and computer scientific methods alone are not enough to assess data from art museums in meaningful ways. Being familiar with the cultural context, art history, an artist's oeuvre, or the collection from which the data originates is equally critical to ensure that technology is applied not only to investigate issues relevant to science but also to the humanities.

Especially in the cultural-technological context of digital collections, the digital image offers more than simply depicting an artwork. The aim is therefore to define the conditions associated with the digital image and to encourage the competent use of the properties of the digital image and the possibilities of digital technology both for the representation of museum collections and in art historical research. Since a digital interest is at the forefront, the digital image is the actual object of desire.[7] The reasons for engaging with art by means of digital images differ from the usual ways of dealing with and approaching art. The focus is therefore on the technological and theoretical conditions involved. In this way, the broad dimension of the possibilities for representing, analyzing, and interpreting art offered by the images and metadata accessible through museums' digital collections can be demonstrated.

The reason why there is a particular interest in the digital image is due to the changing status of the image as a reproduction of art. Moreover, digital images are in a context that is subject to fundamentally different rules. If the reproduction in analog contexts, e.g., in a catalog, serves as a reference to the original and thus as a surrogate, the original takes on a clearly superior status.[8] In the case of images in digital collections, which are initially the digitized counterparts of analog reproductions of art, a shift occurs. The presence

7 Sonja Gasser, "Das Digitalisat als Objekt der Begierde: Anforderungen an digitale Sammlungen für Forschung in der Digitalen Kunstgeschichte," in *Objekte im Netz: Wissenschaftliche Sammlungen im digitalen Wandel,* ed. Udo Andraschke and Sarah Wagner (transcript, 2020), https://doi.org/10.14361/9783839455715-019. Preference for the digital image and the need for technologically supported access to digital collections' data has been articulated previously.

8 For exhibition catalogs documenting exhibitions and the included artworks, see Gustavo Grandal Montero, "Art Documentation: Exhibition Catalogues and Beyond," in *The Handbook of Art and Design Librarianship*, ed. Paul Glassman and Judy Dyki, 2nd ed. (Facet, 2018), 110, https://doi.org/10.29085/9781783302024.015.

of images of art in a digital environment implies a dependence on digital technology and thus on conditions quite different from those possible in the analog domain. Integrated into digital infrastructures and dependent on storage media to keep the data available on the one hand and to display this data on devices in a way that can be perceived by humans on the other, digital art images become files that can be used flexibly. The aforementioned changes affect how museums see themselves and what they do, as well as how research in the humanities is conducted.

When, from the perspective of institutions shaped by the analog tradition, it is often proclaimed that digital offerings such as the collection online or virtual tours of the museum would not replace the physical visit to the museum, this continues to be based on the long-established premise that reproductions are inferior to the artwork as an original.[9] What is claimed is that the digital reproduction does not replace the original. When considering the artwork as a starting point, this is true. However, this ignores the fact that collections online and virtual tours are popular, but not the most adequate of the conceivable offers for a museum to be present with the collection in the digital realm. It is helpful to question the supremacy of the original to open-mindedly seek fruitful approaches of how to deal with the digital representation of art. A mode of presentation that relies solely on viewing and reading information about art has little to do with what museums, the museum public, scholars in art history and the digital humanities could and would do with digitized material if it were made available. The fundamental assumption throughout the chapters is therefore the inversion of the above claim: the original does not replace the digital reproduction either.[10] Taking the idea a bit further, curating exhibitions with originals does not replace the task of taking responsibility for the digital representation of artworks from the collection. Digitally available and accessible images of artworks, along with related metadata, provide a completely different starting

9 Clara Maier et al., "Ins Museum surfen: Das virtuelle Museum von der Website bis zur digitalen Transformation," in *Wissenschaftliches Jahrbuch der Tiroler Landesmuseen 2020*, ed. Peter Assmann et al. (StudienVerlag, 2020), 49; Katja Müller, "Digitale Objekte – subjektive Materie: Zur Materialität digitalisierter Objekte in Museum und Archiv," in *Dinge als Herausforderung: Kontexte, Umgangsweisen und Umwertungen von Objekten*, ed. Hans Peter Hahn and Friedemann Neumann (transcript, 2018), 52–53, https://doi.org/10.14361/9783839445136-004; and, questioning this assumption, Anika Meier, "Boom digitaler Ausstellungen: Virtuelle Museumsrundgänge killen nicht die Museen," *Monopol*, May 5, 2020, accessed January 18, 2022, https://www.monopol-magazin.de/virtuelle-museumsrundgaenge-killen-nicht-die-museen.

10 Sonja Gasser (@Sonja_Gasser), "Das Digitalisat ist durch das Original genauso wenig ersetzbar," Twitter (now X), October 28, 2018, https://x.com/Sonja_Gasser/status/1056456603388596224.

point than physical artworks and must therefore be treated according to the conditions determined by digital technology. Accordingly, digital reproduction is more than just a photograph that is digitally captured and stored in the same way as an analog recording of an artwork, as will become obvious in this book.

Bringing the digital image into focus allows for a closer look at associated specifics of digital technologies. Compared to artworks and images captured on film or printed, digital images offer new possibilities for how museums can fulfill their responsibilities in the digital environment and expand how art can be explored with digital technology. The book addresses methodological changes that, if applied, can advance museums as well as art history. Digital images of art are prioritized over the originals to underscore the special attention required for the digital image of art in the current digital age. The point is not to play the original and the digital image off against each other. On the contrary, the point is to consider the digital reproduction, which ultimately is inseparable from the original work, with the same rigor as when digital matters are concerned.

An outline of this book's chapters reveals aspects involved in an examination of digital collections. The chapters highlight how data and digital technology impact art museums and academic research in art history. Here in the first chapter, digital collections' significance and, more specifically, associated digital images and artwork metadata are problematized. This situates the topic as central to developments within the digital humanities, and particularly art museums and art history. Further, the chapter highlights the interdependence between museums and art history when it comes to the digitization process. Chapter 2 "Digital Collections and Data Accessibility" is devoted to the characteristics of digital collections, data accessibility, and lastly, the technological foundations and structure of data from collection databases. Building on this, the third chapter "Digital Collections: Searching and Browsing" looks at search technologies to explore the impact of data structure and database architecture on searching and finding visual content from digital collections. Meaning emerges when digital images and metadata are contextualized in applications. Against this background, chapter 4 "User, Space, Narration" considers interaction with content, what space means in the digital realm, the significance of users, and how knowledge can emerge and be conveyed through narration. Thus, aspects of curating and participation in the use of digital objects are discussed. Cultural data and the representation of art in digital applications are interpreted as a specificity by reflecting on the particularities of digital conditions for the presentation, mediation and communication of art. Following this, chapter 5 "Methods of Data and Image Visualization" explores how data visualizations use different

approaches to reveal interrelationships between larger datasets. Data visualizations can be used as an interface for accessing a collection and as a means for interpreting collection data. The targeted use of digital tools adapted to one's own needs for the analysis, presentation, mediation, and interpretation of digital images, metadata, and additional information is addressed in chapter 6 "Software and Tools for Images and Metadata." Commonly used approaches, software, and tools are introduced, which often require some programming skills, but can offer the flexibility to adapt them to the specific needs of a project. Chapter 7 "Digital Technology for Art History and Museums" synthesizes the conditions and benefits of advanced use of digital technology for both museums and art history.

The aim of this book is to explore the possibilities offered by current developments in digital technology related to digital collections, rather than presenting a wide range of tools for specific tasks. However, to reference the extensive resources of interest to museums and art historians for implementing digital projects, the chapters are followed by an extensive section of appendices. Lists in the appendices include a glossary (appendix A), hints where to find reusable datasets (appendix B "Digital Resources"), what software and tools exist for particular tasks (appendix C "Digital Tools"), links to guidelines and training opportunities (appendix D "Programming Tutorials and Guides"), and noteworthy examples of digital collections and applications (appendix E). Without claiming to be exhaustive, the appendices reference available resources and illustrative material that cannot be included in the chapters to this extent.

The book aims to illuminate what is unique to digital collections of art museums that consider current technological developments and how this affects digital offerings. Digital collections should not merely reproduce data from museum collection databases; they should provide resources by contextualizing, using, reusing, and enriching this data in myriad ways. By addressing users with diverse interests and making collection data available, this approach leads to a democratization of interpretations, paving the way for more data-driven insights. Looking at current debates and numerous examples of digital collections and applications, this book illustrates what constitutes a versatile platform.

For an empirical approach, the "Art Museum Digital Collections and Offerings Table" in appendix F (table 18) provides a comparative overview of digital collections and other digital offerings at 25 art museums. The list includes the five most-visited museums of 2019 in their respective categories: Switzerland (CH), Austria (AT), Germany (DE), Europe (EUR), and the United States (USA). These 25 museums serve as representatives of the many art museums worldwide that have made their collections digitally accessible.

Using visitor figures from 2019 reflects pre-pandemic levels before the significant decline in attendance caused by COVID-19.[11]

This selection, limited to German-speaking countries, Europe, and the United States, includes art museums of different sizes and takes into account developments in the English-speaking world, where digitization began earlier than in Europe. The table considers different regions and institution sizes, providing a sufficiently informative overview of the current landscape of digital collections. While this selection represents only museums in the Western world, the discussion theoretically applies to museums worldwide. The question remains whether evaluating museums in other parts of the world would yield fundamentally different findings. Furthermore, the list sidesteps the challenge of including museums in non-English- or non-German-speaking countries, thereby avoiding language barriers. For instance, after the Louvre, the second most-visited museum in the world in 2019 was the National Museum of China in Beijing, but its digital collection is available only in Chinese.[12] A broader and more inclusive research project of this kind would require a

11 See Emily Sharpe and José da Silva, "Visitor Figures 2020: Top 100 Art Museums Revealed as Attendance Drops by 77% Worldwide," *The Art Newspaper*, March 30, 2021, accessed February 1, 2022, https://www.theartnewspaper.com/2021/03/30/visitor-figures-2020-top-100-art-museums-revealed-as-attendance-drops-by-77percent-worldwide. The world's 100 most visited art museums recorded an average of only a quarter as many visitors in 2020 compared to 2019.

12 National Museum of China, Beijing (7,390,000 visitors in 2019, https://www.chnmuseum.cn/portals/0/web/zt/cangpin/colletionlist.html). For the bigger picture, the four other most visited museums outside Europe and the United States in 2019 were: State Hermitage, Saint Petersburg (4,956,529 visitors, https://www.hermitagemuseum.org/explore/artworks/?lng=en); National Palace Museum, Taipei (3,832,373 visitors; https://www.npm.gov.tw/Collection-Intro.aspx?sno=01000022&l=2); National Museum of Korea, Seoul (3,354,161 visitors; https://www.museum.go.kr/site/eng/relic/recommend/list); and Moscow Kremlin Museums (3,101,550 visitors; https://collectiononline.kreml.ru/en), source: *The Art Newspaper, Special Report: Art's Most Popular. Exhibition and Museum Visitor Figures 2019,* XXIX, no. 322 (April 2020): 3, 15. A good overview of "The 100 Most Visited Art Museums in the World in 2022" divided into North America, South America, Europe, Asia, and Oceania provides the following visualization, which is also based on the figures from *The Art Newspaper:* "The 100 Most Popular Art Museums in the World in 2022, Divided by Countries and Continents," Wikipedia, published October 4, 2023, https://en.wikipedia.org/wiki/File:Giacomin_Carolina_10921839.svg.

dedicated investigation conducted by experts in global art history.[13]

Extracts from the "Art Museum Digital Collections and Offerings Table" are included in the chapters, referencing systematically collected data that supports key discussions. While the table is central to the book's argument, the examples of digital collections and applications discussed in the chapters extend beyond the museums listed in the table. This broader scope allows for the exploration of other examples, regardless of visitor numbers, including topics relevant to global art history and significant projects from smaller institutions.

Analysis of digital collections of art centering the digital image requires both a technical approach and to situate the technological developments within the cultural context. This wide-ranging, interdisciplinary study is therefore based on literature at the intersection of museums, digital culture, digital art history, digital humanities, information science, data visualization, visual studies, media science, and computer science. In addition to numerous examples illustrating the structure and functionality of digital collections, this publication provides examples of more advanced applications for the presentation and mediation of art from the museum sector or from research projects in various disciplines. These demonstrate the technological requirements for the use of cultural data and illustrate possible fields of application in treatment of data from digital collections. Focusing on images and associated metadata from digitized art collections, digital tools for analyzing, presenting, and interpreting visual data are addressed.

It is crucial to acknowledge implications that art objects' data have for the humanities and museums. Recognizing these implications will enable stakeholders to ensure that data from digital collections becomes a valuable resource for the mediation and study of art history. In addition to art historians and museum staff, readers interested in interdisciplinary topics at the intersection of culture and digital technology may find this book enlightening and insightful. Those with backgrounds in communication, media or cultural studies, digital humanities, media design, programming, information or computer science, and related fields, may find it interesting to explore art museums' and art historians' approaches and their pressing

13 See "Research Projects," Laboratory for Experimental Museology (eM+), EPFL, accessed December 27, 2024, https://www.epfl.ch/labs/emplus/projects/; "Installations & Curated Exhibitions," Sarah Kenderdine, accessed December 27, 2024, https://sarahkenderdine.info/; and *Digital Benin*, Museum am Rothenbaum, accessed December 27, 2024, https://digitalbenin.org/. Sarah Kenderdine's projects are examples of digital applications using cultural content from Asia. Additionally, *Digital Benin* is an example of a platform resulting from a joint research project between researchers in Europe, the United States, and Benin City for the reappraisal of African cultural heritage.

questions regarding digital transformation. A thorough understanding of notable applications, features, and current developments—both with respect to museum visitors and those who rely on cultural data as a research resource—ensures that digital collections are presented in ways that meet diverse user expectations for access, representation, and data reuse.

The subsequent sections stress the most important aspects of the topic in more detail. First is a discussion of the current landscape of digital collections. Directly related to digital collections is the significance of the mediality of digital images, which is examined in section 1.3. Section 1.4 situates digital collections and digital images in a culture reliant on data and technologies. Under this cultural condition, section 1.5 identifies data as an important knowledge resource. Ultimately, section 1.6 positions digital collections and digital images as knowledge resources for collections, museums, and users—an issue that requires thorough consideration within the context of digital technology.

1.2 Digital Collections Landscape

Digital collections of art museums introduce a broad spectrum of topics, as the headings in table 18 illustrate (appendix F). This ranges from the content and functionality of digital collections to technologies used, supplementary digital offerings, and social media activities. These areas show that the mediality particular to digital images is associated with a variety of skill sets and responsibilities in the representation, accessibility, and use of artworks of digital collections. Table 18 provides a glimpse of how digital technology and digital images have become ubiquitous and anticipate richer digital collections with more utility. That said, museums approach the mediality of digital images in very different ways.

Public access to digital collections is common for most museums. The only exceptions in the table without public access to an online collection database are the Fondation Pierre Gianadda in Martigny, Switzerland, and the Leopold Museum in Vienna, Austria. In general, with the establishment of databases in museums for collection management, it has become standard practice to provide the public with digital access to information about the objects in the collection. Over time, digital collections have not only become richer in information, but are increasingly becoming part of a broader digital outreach effort. The trend in recent years among museums to bolster their collection's digital presence got an additional boost from COVID-19 closures and travel restrictions in spring 2020 and continuing sporadically after that. Still, there remains a divide between art museums that are still in the early stages of digital technology development and those

where the advanced use of these technologies has already become an integral part of daily operations. These differences become noticeable when evaluating digital collections from different museums and are also reflected in the scope of other digital offerings found on their websites.

Table 1. *Provided digital collection images and metadata.* Extract from table 18 (appendix F)

List number	Country code	Art museum	Image: high-res.; zoom	IIIF (International Image Interoperability Framework)	Use of public domain images	Public Domain Mark/Creative Commons (for public domain works)	Download: image	Download: metadata	Open data	Public API	Conclusion: traditional collection online?	Digital strategy	Digitorial: story; interactive feature	Digital offerings	Overview digital offerings
1	CH	Fondation Beyeler	×	×	×	×	×	×	×	×	yes	×	×	o	o
2	CH	Kunsthaus Zürich	×	×	×	×	~	×	×	×	yes	×	o	×	×
3	CH	Kunstmuseum Basel	×	×	o	×	o	×	×	×	yes	×	o	o	×
4	CH	Fondation Pierre Gianadda									none	×	×	×	×
5	CH	Zentrum Paul Klee	×	×	×	×	×	×	×	×	yes	×	o	o	×
6	AT	Kunsthistorisches Museum	o	×	o	×	o	×	×	×	yes	×	×	o	o
7	AT	Belvedere	o	o	o	×	o	×	o	×	no	×	×	o	o
8	AT	Albertina	o	o	o	×	o	o	×	×	no	×	×	o	×
9	AT	Leopold Museum									none	×	×	o	o
10	AT	MUMOK	×	×	×	×	~	×	×	×	yes	×	×	o	o
11	DE	Städel Museum	o	×	o	o	o	×	o	o	no	o https://www.staedelmuseum.de/de/digitale-strategie	o	o	o
12	DE	Alte Pinakothek	o	×	o	o	o	×	o	×	yes	o https://www.digital.pinakothek.de	×	o	×
13	DE	K20/K21	×	×	×	×	~	×	×	×	yes	o https://docplayer.org/28001904-Ein-neues-haus-fuer-die-kunstsammlung-nordrhein-westfalen-vorstellung-der-digitalstrategie.html	×	o	o
14	DE	Museum Barberini	o	×	×	×	×	×	×	×	yes	×	×	o	×
15	DE	Alte Nationalgalerie	×	×	o	o	~	×	×	o	yes	o https://www.preussischer-kulturbesitz.de/schwerpunkte/digitalisierung/digitales-manifest.html	×	o	o
16	EUR	Louvre	×	×	o	×	o	o	×	×	no	×	×	o	o
17	EUR	Musei Vaticani	o	o	×	×	×	×	×	×	yes	×	×	×	×
18	EUR	British Museum	o	×	o	×	o	×	×	×	yes	×	×	o	×
19	EUR	Tate Modern	o	×	o	o	×	×	o	×	no	o https://www.tate.org.uk/research/publications/tate-papers/19/tate-digital-strategy-2013-15-digital-as-a-dimension-of-everything	×	o	×
20	EUR	National Gallery	o	o	o	×	o	×	×	o	no	×	×	o	×
21	USA	The Met	o	o	o	o	o	×	o	o	no	o https://www.metmuseum.org/blogs/digital-underground/2015/next-steps-digital-revolution	o	o	o
22	USA	National Gallery of Art	o	o	o	o	o	×	o	×	no	×	×	o	×
23	USA	MoMA	o	×	×	×	×	×	o	o	no	o https://enfilade18thc.com/2014/02/12/fiona-romeo-appointed-momas-first-director-of-digital-content-and-strategy/	o	o	×
24	USA	National Portrait Gallery	o	o	o	o	o	o	o	o	no	o https://www.si.edu/content/pdf/about/web-new-media-strategy_v1.0.pdf	×	o	o
25	USA	Art Institute of Chicago	o	o	o	o	o	×	o	o	no	o https://www.artic.edu/articles/713/behind-the-scenes-of-the-website-redesign	o	o	o

o present, × not present, ~ save image possible

Usually, the more developed a digital collection platform, the better prepared a museum is to create sophisticated digital offerings and enable others to reuse collection data. Notably, museums' approaches to their digital collections can be seen in the extracted columns from the table 18, as presented in table 1. Some museums offer access to artworks in the traditional sense of a collection catalog, accessible via a database. Access is typically restrictive, with images displayed in limited resolution. These collection presences are classified as traditional collections online (marked "yes" in the yellow column). Others take an expanded approach, recognizing both the technological possibilities of digital collections and data sharing potential. They typically provide high-resolution images and grant access and usage rights to the digital images of public domain artworks as well as the associated metadata. These are classified as collections that exceed the scope of a traditional collection online (marked "no" in the yellow column). Museums that consider their digital collections as more than a catalog of works have a clear digital strategy and more advanced digital offerings. These digitally mindful institutions are also grappling with the central concern of this book, which is addressing the peculiarities of digital images.

The distinction between traditional and progressive approaches can be traced back to the development of digital collections. When art museums first began bringing their collections online, the primary goal was to provide public access, without fully considering the technological prerequisites that digital platforms demand. The presentation and mediation of art, as well as the transmission of knowledge, differ in the digital realm, which includes audiences who were previously unreachable. Museums' self-image, particularly in their mission to present and communicate art through their collections, must be redefined for the digital age. Instead of creating products that tightly integrate digital images into fixed representational structures, data flexibility and mobility should be prioritized. Once museums recognize their digital collections as valuable resources to engage the public, they can start creating customized applications for a range of purposes. Furthermore, images and metadata must be accessible for research that employs digital tools and workflows.

The use of images of public domain artworks, download options for images and metadata, and public APIs (application programming interfaces), as shown in table 1 (see p. 27, indicate that open data is beginning to take hold not only in American museums, but also in some museums in the Europe and Germany table categories. Museums are joining libraries and archives in the

release of unrestricted digitized collection data.[14] This enables an independent expert community—among them scholars of art history and the digital humanities, museum professionals, developers, and programmers—to create innovative applications by including images and metadata from such collections, facilitating new ways of knowledge acquisition.

Given the global impact of digitization on businesses, culture, and society, it makes sense that digital transformation extended to art history and art museums. The more familiar people are with elaborate applications in general, the more they expect services and products that make intelligent use of technology. As a result, cultural heritage institutions face the growing challenge of presenting their collections on the Internet while meeting the increasingly differentiated demands of diverse interest groups. The traditional museum visitor who enjoys looking at the artworks on display in an exhibition, uses an audio guide or books a guided tour, and buys a printed copy of the catalog in the museum store still exists. However, continuing to only serve this idea of a museum visitor prevents progress for entirely new engagements with art, which digitization makes possible. To satisfy the ever-demanding expectations of a broader audience—including the needs of scholars and scientists with a keen interest in data—requires additional efforts by museums for more distinctive and customized services.

Indeed, the presence of art in a digital environment implies a paradigmatic shift in key art historical vocabulary. "Artwork," "exhibition," and "viewer" have different meanings if technology defines how we encounter art. The experience of an artwork relies less on the original than on its digital counterpart. Artworks represented with digital images and metadata change the definition of what an exhibition is, since computer technology and data processing allow different engagements with art than an exhibition curated for museum spaces. Presenting art in a digital environment does not necessarily mean a curated exhibition or a digitally modeled structure that simulates physical gallery spaces. Given the technologically-defined circumstances, the perception and interaction of the viewer must consequently differ from a museum's visit. This places unique demands on museums in terms of how they make art digitally accessible.

With the digitization of cultural collections, museums, along with archives and libraries, "have become custodians not only of objects, but of data, and responsible for its structure, preservation, and presentation" as

14 Examples of joint platforms across Swiss libraries include: *swisscollections* (https://swisscollections.ch); *e-rara* (https://www.e-rara.ch) is a database of digitized rare books; *e-manuscripta.ch* is a repository for digitized manuscript material (https://www.e-manuscripta.ch); and *e-codices* (as of April 10, 2025) contains 2,959 Swiss manuscripts (https://www.e-codices.ch), all accessed April 10, 2025.

Mitchell Whitelaw states.[15] With the increasing presence of digital collections, "the question of how those collections are displayed, represented, and accessed, is a crucial one."[16] Art museums are confronted with new areas of stewardship in acting as qualified data providers as well as competent users of digital technology. Coincidently, the availability of artworks and other objects of interest, photographs, graphics, or written documents in databases necessitates art history determine suitable methods of doing research with digital resources. Data and technology allow an expanded analysis and evaluation of art historical sources including visual and audiovisual assets, documents, and text than ever before. This requires a sound understanding of what data and technology enable, new ways to ask questions, and adapted research methods in art history. While the goals, types of data use, and motivations for a particular tool may vary, the use of data from digital collections in conjunction with programming is central to museums and academic research. With that in mind, art museums and researchers in art history need advanced technological skills on top of specialist knowledge in their field. Moreover, collaboration with computer scientists is critical.

This book takes the publicly accessible online collections of art museums as a starting point to explore the nature of access and the types of digital representation of art that are most beneficial to the museums themselves, a general public, and professionals working with digital methods. "Digital collection" is a deliberately broad term for digital collection presences. Digital collections go beyond what a "collection online" offers, namely, the conventional database query to display an artwork's image along with basic cataloging details. The book therefore starts at a completely different point than Katja Müller's *Digital Archives and Collections*, in which her discussion focuses mainly on the question of what the online provision of heritage material changes in terms of the accessibility of cultural contents.[17] Her conception of "digital archive" and "digital collection" corresponds to what is understood here in a narrower sense as "collection online." This book's interest is less in the digital archive as a knowledge repository, but rather in how the digital images of artworks and corresponding metadata from such databases can be used in other digital contexts and what is important in the implementation of digital collections.

The broad understanding of what constitutes a digital collection goes far

15 Mitchell Whitelaw, "Visualising Archival Collections: The Visible Archive Project," *Archives and Manuscripts* 37, no. 2 (2009): 22–23, accessed December 8, 2020, https://publications.archivists.org.au/index.php/asa/article/view/10033/10027.

16 Whitelaw, "Visualising Archival Collections," 39.

17 Katja Müller, *Digital Archives and Collections: Creating Online Access to Cultural Heritage*, (Berghahn, 2021).

beyond merely providing digitized data for viewing individual records in a digital catalog of works. Rather, digital collections can be defined as mutually connectable sources of knowledge, open in all directions, with cultural data that is interrelated in terms of content. Digital images of artworks and descriptive metadata are thus available for a variety of purposes. Together with the possibilities offered by digital technology to both museums and art history, promising developments abound, and some have already been implemented.

What is explicitly not included in this publication, is a detailed discussion of the process and methods of collection digitization, but rather how to deal with the existing digital holdings after digitization. The central question in this book is how digital collections of art, respectively the digital images and metadata, can be used by museums and by art historians and what prerequisites are necessary. This implies that art museums make their digital collections available online in a user-friendly, inviting environment, primarily for a general public, and secondarily specialists. Approaching digital collections with a future-thinking mindset maximizes the value and impact by reimagining information organization and access. It is necessary to analyze which pioneering concepts already exist for achieving this goal, which functionalities are made available, and which cutting-edge technological possibilities for digital media are used in innovative applications. The interface of an online platform needs to be carefully designed in terms of content, presentation, and user experience. It exists as a new field of expertise but remains closely connected to other museum activities like documenting the collection, curating exhibitions, or executing educational programming. A key question is: What determines the visual practice of presenting artworks in a digital environment, and more fundamentally, what future-oriented perspective does the consideration of digital data hold for art history?

1.3 Mediality of Digital Images

Digital images are fundamental to digital collection representation and the application of digital research methods. To this end, the book approaches the digital image from the perspective of the digital presentation of art collections by museums on the Internet, as well as its use in research, particularly in the digital humanities and specifically in digital art history. This leads to the question of how the two domains of exhibition practice and research methods intersect in relation to the digital image. Central to the approach is understanding digital images from collections as something particular that has to be focused on. A digital image does not lack in qualities in comparison to the artwork it represents, but has its own qualities that surpass those of the original from a media theory and technology perspective.

This can be elaborated in more detail against a media theory background. The continuous shift of an artwork's appearance from the original, to reproductions in print or photography, to digitized images in digital collections, means that a single image is no longer bound to one specific medium. Instead, a close interrelationship is forged between different forms of media, all of which represent the same artwork. Jay David Bolter and Richard Grusin introduced the term "remediation" for this phenomenon.[18] They question how digital visual media "honor, rival, and revise linear-perspective painting, photography, film, television, and print."[19] In their understanding, no medium works "in isolation from other media," instead, new media "refashion other media" and "older media refashion themselves to answer the challenges of new media."[20] From the perspective of digital media, for example, video and photography can be interpreted in ways that were not previously possible within traditional film or photography theory. Moreover, one medium can be integrated into another medium. Under these circumstances, media technology constitutes networks that are shaped aesthetically, economically, physically, and socially. New digital media are situated in a certain cultural context and thus related to other media from the same or similar context.[21] Bolter and Grusin's theory of remediation is key to thoroughly analyzing digital collections, as it considers both media-related questions and the cultural context of presenting and mediating of art. An original artwork exists, but also various reproductions of it and each form has its purpose.

Bolter and Grusin's theory suggests an engagement with media that is suited specifically for digital media. In contrast, Walter Benjamin's thoughts about reproductions missing the "aura" in his famous essay "The Work of Art in the Age of Its Technological Reproducibility"[22] are not entirely suitable for reflecting on today's media reality. In the age of digital media, the question can no longer be what a reproduced artwork lacks compared to an original. It is much more appropriate to differentiate which forms of so-called originals *and* reproductions exist, in addition to their purposes and contexts. Each form has necessity and advantages depending on the specificities of the medium. A reproduction can become equal to or even more important than the original.

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18 Jay David Bolter and Richard A. Grusin, *Remediation: Understanding New Media* (MIT Press, 2000).

19 Bolter and Grusin, *Remediation*, 15.

20 Bolter and Grusin, *Remediation*, 15.

21 Bolter and Grusin, *Remediation*, 19.

22 Walter Benjamin, "The Work of Art in the Age of Its Technological Reproducibility: Second Version," in *Selected Writings: 1935–1938*, ed. Howard Eiland and Michael Jennings, vol. 3 (1935 in German; Harvard University Press, 2002), 101–33.

An artwork that is transferred to a new medium and also exists as a digital image adapts to the changed conditions. Under these circumstances, there are new ways of considering artworks by using the technological possibilities of digital media. Multiple images exist in parallel, ranging from the original work, to analog and digital reproductions, and reproductions of reproductions, all on top of the possibility of inserting one medium into another to distribute it through different channels. With this in mind, Walter Benjamin's aura that is intrinsically linked to an artwork and prioritizes the original over every other manifestation is no longer useful. More valuable is media theory that fosters a pluralistic view of the digital image without classifying it as a surrogate or reproduction that is subordinate to the original.

Digital collections consist of images that document artworks in the physical collection of a museum. The artworks themselves can be paintings, sculptures, drawings, prints, photographs, videos, installations, media art, or even digital art, but museum collections can also include architecture or functional objects. This means that several forms of media exist in parallel, each with its own purposes and meanings. Therefore, a photograph, for example, can be an aid to reproduce an artwork for its representation in a digital collection. However, photography can also be the technique used to create the artwork. While the originals as unique objects constitute collections and exhibitions in museums, reproductions are used to spread knowledge about the existence of this artwork among a wider public. Already at the time of Albrecht Dürer, when the invention of the printing press enabled mass distribution of copies, images were more common. Photography, television and, most recently, the Internet have contributed to the increase in available and accessible images. Just as Dürer and his contemporaries had to find ways to harness the unique qualities of a new medium, we are now at a comparable point where we must explore the specifics of digital technology and media to fully leverage their inherent advantages.[23]

Photography is used to reproduce a museum collection artwork for documentation in the archives, inventory purposes, evaluation of condition, or to be reprinted in a publication, but also as a digital image in an online database that has the function of a searchable collection catalog. Furthermore, an existing printed documentary photograph can be digitized to make it available in a database. This means that a digital document or image on the screen can be born-digital, as it is the case with new media art, or digitized by scanning or taking a digital photograph of the analog original, as it can be

23 Sonja Gasser and Julia Rössel, "Albrecht Dürers Adam und Eva im medialen Netzwerk: Beobachtungen zur kunsthistorischen Forschung mit digitalen grafischen Sammlungen," *NEUE Kunstwissenschaftliche Forschungen*, no. 3 (2017): 3–26, https://doi.org/10.11588/nkf.2017.3.34553. We highlight this analogy in this article.

found generally in the collection databases of museums. Jens Schröter points out that the term "digital image" is often used in an undifferentiated manner for images reproduced through digitization but also for images generated by algorithms.[24] Also in the context of collections, there exist databases that collect digital art. Rhizome, today associated with the New Museum of Contemporary Art in New York, founded *ArtBase* in 1999 to preserve net. art artworks, but also includes moving images, games, code-based art, and multiple mediums that are at risk of obsolescence due to rapidly changing software and browser technologies.[25] Oliver Grau led the *Archive of Digital Art (ADA)* as a research project at the Danube University Krems, aiming for a comprehensive documentation of media art, which is often process-based and context-dependent.[26] Also relevant are the recently emerged Non-Fungible Token (NFT) marketplaces, which are similar to digital collections of art museums, but primarily feature digital artworks rather than digitized versions of physical art.[27] It is therefore possible to distinguish between the use of digital technology in the production of contemporary artworks and its use in the context of collections and museums.[28]

Born-digital media art has existed for more than five decades.[29] Its characteristics raise numerous other research questions that should be discussed separately and in greater detail within the context of contemporary art. Further, digital art is more likely to be found at biennials and festivals than in the collections of museums.[30] With this in mind along with a different audience reached, it is no coincidence that digital art requires specialized museums and archives dedicated to "collect, preserve, explore, mediate and taxonomize digital culture."[31] This is connected to many more questions than

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24 Jens Schröter, "Gestaltung und Referenz in der analogen und digitalen Fotografie," in *Long Lost Friends: Wechselbeziehungen zwischen Design-, Medien- und Wissenschaftsforschung*, ed. Claudia Mareis and Christof Windgätter (Diaphanes, 2013), 65.

25 *ArtBase*, Rhizome, accessed January 13, 2017, https://rhizome.org/art/artbase/.

26 *Archive of Digital Art*, Center for Image Science, University for Continuing Education Krems, accessed January 13, 2017, https://www.digitalartarchive.at.

27 Examples include MakersPlace, accessed December 26, 2024, https://makersplace.com; SuperRare, accessed December 26, 2024, https://superrare.com/explore; Nifty Gateway Studio, accessed December 26, 2024, https://niftygateway.com/marketplace; fx(hash), accessed December 26, 2024, https://www.fxhash.xyz; and objkt.com, accessed December 26, 2024, https://objkt.com.

28 Oliver Grau et al., "Museum and Archive on the Move: Introduction," in *Museum and Archive on the Move: Changing Cultural Institutions in the Digital Era*, ed. Oliver Grau (De Gruyter, 2017), 17.

29 Grau et al., "Museum and Archive on the Move," 9.

30 Grau et al., "Museum and Archive on the Move," 9, 17.

31 Grau et al., "Museum and Archive on the Move," 9.

can be addressed in this book. Sara Cook and Beryll Graham published a book that comprehensively rethinks curatorial practice, which became necessary with the advent of new media art and it's basis in immateriality, time, and space because it involves interactivity, networks, and computation.[32] Digital art that is process-based, ephemeral, multimedial, interactive, and context-dependent requires specific modes of presentation and documentation.[33] Compared to traditional art documentation, new media art has its own requirements and conditions for conservation and preservation for many reasons, but namely due to the permanent transformation of hard- and software in addition to the limited durability of the storage media, and as a result, it is rarely collected systematically in most museum collections.[34]

Since most of the collections presented by museums on the Internet consist of traditional art genres, the book concentrates on these. Moreover, for legal reasons, works that are in the public domain are the primary focus, which means that the artist died at least 70 years ago. Archives dedicated to digital art, typically categorized as those focused on contemporary art, form a separate area of interest and are excluded from further consideration in the following. When discussing art presented in a digital environment in this book, it refers to artworks from physical collections that have been digitized.

The focus is on databases that museums have created as part of the digitization of their inventories, which support technologically enhanced collection documentation and management.[35] Such collections also include born-digital information. Therefore, the distinction between digital and digitized pertains more to the objects (in this case, artworks) than to the metadata. In this context, an artwork based on code or consisting of a file that must be viewed on a screen would be considered a digital artwork, while a painting that has been photographed and is represented by a digital image in a collection database would be classified as a digitized artwork. A group of digital artworks comprises a "digital collection" and a group of digitized images a "digitized collection." This would argue for calling the digitally accessible collections "digitized collections," since they contain the digitized copies of artworks but not the artworks themselves. "Digitized collection"

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32 Beryl Graham and Sarah Cook, *Rethinking Curating: Art After New Media*, (MIT Press, 2010).

33 Oliver Grau, "Datenbank für Virtuelle Kunst," in *Digitale Transformationen: Medienkunst als Schnittstelle von Kunst, Wissenschaft, Wirtschaft und Gesellschaft*, ed. Monika Fleischmann and Ulrike Reinhard (Whois, 2004), 208.

34 Grau, "Datenbank für Virtuelle Kunst," 207–208.

35 Stefan Hebenstreit, "Museen," in Jörg Becker, *Die Digitalisierung von Medien und Kultur* (Springer VS, 2013), 239, 246. In his chapter, Hebenstreit focuses on digital data and museums, with particular attention to the documentation of collections, while excluding born-digital media art.

makes mainly sense from the institutional perspective, while from the technological one, the collection would be described as digital. Therefore, the two terms "digital collection" and "digitized collection" are understood in this book as synonyms, meaning, an online accessible collection of a cultural institution. This contrasts with Jens Schröter's complaint about the blurriness of the term "digital image." For practical reasons, a "digital collection" may include works of media or digital art, but in most cases consists of the digital images of digitized artworks or other digitized documents.

Apart from the discussed media theoretical foundation, the book is situated in the broader context of developments in technology, current debates of digital humanities, digital art history, and issues regarding digital collections of art museums and a wider range of cultural heritage institutions from the GLAM sector (Galleries, Libraries, Archives, and Museums). For this reason, the next section places digital collections as topic within the cultural conditions of data and technology.

1.4 Culture of Data and Technology

The considerations throughout this book regarding digital collections of art are seen against the background of various social and technological developments in response to the digital transformation. The following discussions position digital collections of art museums and other cultural institutions within the current debates surrounding general attitudes towards cultural data, principles of open data, the Semantic Web, data visualization, and research in the digital humanities and digital art history. This means that social, technological, and scientific conditions play a role, all of which are discussed below.

In recent years, new conditions have emerged in the field of cultural heritage institutions due to collection digitization. Access to digital collections and users familiar with digital technology provide a fundamentally different starting point for engaging with cultural knowledge, which is increasingly an expectation. Instead of simple information consultation, which involves viewing images and reading texts, users want to interact directly with image data and metadata. However, this requires data owners to be aware of the need to provide such access and grant permission for further use.

Since digitization is not solely a development in the cultural sector, but also other public and private sectors, the global nonprofit Open Knowledge Foundation (OKFN)[36] came into being to draw attention to data in areas such as culture, the environment, finance, science, statistics, and weather that might be of interest for reuse. More specifically, OKFN's mission is

36 Open Knowledge Foundation, accessed June 13, 2022, https://okfn.org.

to raise awareness about open data's value. OKFN represents a worldwide network of people interested in open data, working with it, and creating and sharing knowledge. For that purpose, the organization aims to initiate a change in "cultures, policies and business models at large organisations to make opening up information acceptable and desirable."[37] In a nutshell, "knowledge is open if anyone is free to access, use, modify, and share it."[38] It stands to reason that this corresponds to how museums, as traditional knowledge mediators, ideally respond to the digital age by also making knowledge accessible for digital purposes.

Included in OKFN's activities, cultural institutions have a dedicated initiative: The Open GLAM[39] initiative is tailored to galleries, libraries, archives and museums (GLAMs) by promoting free and open access to digital cultural heritage.[40] In essence, their efforts are based on the definitive advantages that the Internet brings to cultural institutions and their audiences:

> The Internet presents cultural heritage institutions with an unprecedented opportunity to engage global audiences and make their collections more discoverable and connected than ever, allowing users not only to enjoy the riches of the world's memory institutions, but also to contribute, participate and share.[41]

There is a shift in focus from a passive audience, to whom something is presented, to one that is seen more as a community of active users with whom contact must be established. The goal is to encourage cultural institutions to provide access to their collection data in a sustainable manner that aligns with the OpenGLAM Principles. Until the value of open cultural data is widely recognized by both institutions and individuals, OpenGLAM and the Open Knowledge Foundation remain vital in raising awareness among potential data providers and users. The general attitude in the cultural sector is that information and data from GLAM institutions should be freely accessible

37 "About," Open Knowledge Foundation, archived May 19, 2019, at https://web.archive.org/web/20190502211438/https://okfn.org/about/.

38 "Open Definition, version 2.1," Open Knowledge Foundation, accessed December 8, 2024, https://opendefinition.org/od/2.1/en/.

39 Open GLAM, accessed June 13, 2022, https://openglam.org.

40 See Christine M. Angel and Caroline Fuchs, eds., *Organization, Representation and Description Through the Digital Age: Information in Libraries, Archives and Museums* (De Gruyter Saur, 2018). LAM, the shorted form of GLAM, stands for libraries, archives, and museums.

41 "OpenGLAM Principles," v. 1.0, accessed May 21, 2019, https://openglam.org/principles/. The quote is from the preamble of the *OpenGLAM Principles* and precedes technical and licensing requirements for the data, accompanied by exemplary links to leading museums and other GLAM institutions.

as long as there are no copyright restrictions.[42] The demand for open access to collections stems from the belief that museums should enhance their visibility and offer free access to objects that belong to the public, while also serving as valuable resources that should be easily accessible for research purposes.

Reservations on the part of museums about making images and metadata available to the public include legal uncertainties, fear of losing revenue streams, or that visitor numbers will decline.[43] However, the fear that digital collections prevent people from visiting the physical museum has long been refuted, as digital access to the collection encourages museum visits.[44] The physical visit and the virtual visit serve completely different purposes.[45] Whereas an average museum visit is for leisure and entertainment—apart from experts who consult art museums for research reasons—an online museum visit is more informational, which is why the museum website and the physical museum are entirely different information environments.[46] Furthermore, with regard to the digital transformation, museums and other cultural institutions do well by following a progressive approach over a conservative one. Available freely reusable cultural data, even in commercial projects, ensures that new applications, visualizations, services, or games can be created. This runs most smoothly when the data is provided in standardized formats, via a publicly available API, and as linked open data.[47]

Introduced in 2010 by Tim Berners-Lee, the inventor of the World Wide Web and the Semantic Web in 2001, linked open data (LOD) is published under an open license to be reused free of charge.[48] Whereas web pages on the World Wide Web are designed for humans to grasp the semantic content,

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42 Ellen Euler, "Open Access, Open Data und Open Science als wesentliche Pfeiler einer (nachhaltig) erfolgreichen digitalen Transformation der Kulturerbeeinrichtungen und des Kulturbetriebes," in *Der digitale Kulturbetrieb: Strategien, Handlungsfelder und Best Practices des digitalen Kulturmanagements*, ed. Lorenz Pöllmann and Clara Herrmann (Springer, 2019), https://doi.org/10.1007/978-3-658-24030-1_3.

43 Dorothee Haffner, "Datenausgabebedarfe, Open Access," in *Handbuch Museum: Geschichte, Aufgaben, Perspektiven*, ed. Markus Walz (J.B. Metzler, 2016), 196.

44 Claire Ross et al., "Measuring Impact and Use: Scholarly Information-Seeking Behaviour," in *Evaluating and Measuring the Value, Use and Impact of Digital Collections*, ed. Lorna Hughes (Facet, 2012), 95, https://doi.org/10.29085/9781856049085.008.

45 Ross et al., "Measuring Impact and Use," 95.

46 Ross et al., "Measuring Impact and Use," 96.

47 Euler, "Open Access, Open Data," 61–64.

48 Tim Berners-Lee, "Is your Linked Open Data 5 Star?" added in 2010 to the post "Linked Data," last updated June 18, 2009, accessed May 22, 2019, https://www.w3.org/DesignIssues/LinkedData.html; see also Tim Berners-Lee et al., "The Semantic Web: A New Form of Web Content That Is Meaningful to Computers Will Unleash a Revolution of New Possibilities," *Scientific American* 284, no. 5 (2001), https://doi.org/10.1038/scientificamerican0501-34.

the Semantic Web structures the content of web pages so that data can be processed not only by humans, but also by machines in a widely distributed information network.[49] Linked open data, or linked data (LD), offers promising opportunities for mapping manifold cultural contexts into a data structure. When computers can find and merge information from different sources, it enables automated web services to complete complicated tasks for users. The basis is an ontology, a formal semantic description of entities in data that defines complex relationships between resources, which allows the inference of new knowledge.[50] The Semantic Web is thus a model that approximates the complexity of the humanities. Although an ontology is technically easy to implement, the challenge is to create one that meets the needs of art history. The advantages are only briefly touched upon here and will become clearer as the chapters progress. If all museums published the data in their digital collections as linked open data and used the same ontology, it would be possible to search for artworks by a particular artist across different sources, regardless of different spellings in different languages.

If all art historical publications and research were treated the same way, existing sources could be used without having to reassemble large collections of information that someone else may have already compiled. Apart from processing the data, integrating it into an application to make it visible through an interface is also important.

Data visualization is the basis for making analyses of data understandable and thus interpretable. The volatility and changeability of data and the ability of users to manipulate the display for customized results requires particular visual communication when designing for the web. Information visualization, interactive visualization, generative design, human-computer-interaction (HCI), and user experience (UX) most influence an application's design. One of the leaders in sophisticated data visualization for collections is the Urban Complexity Lab at the University of Applied Sciences Potsdam.[51] Artworks in a collection are more meaningful when they are connected to each other in specific groupings or associations, based on the information provided by their metadata.

In this respect, visualizations serve as a powerful tool for an interested public to gain insight into a museum's collection and explore it individually. Furthermore, data visualization acts as an intermediate step, potentially facil-

49 Berners-Lee et al., "The Semantic Web," 36.

50 Nikolaos Simou et al., "Enriching and Publishing Cultural Heritage as Linked Open Data," in *Mixed Reality and Gamification for Cultural Heritage*, ed. Marinos Ioannides et al., 24 (Springer, 2017), 206, https://doi.org/10.1007/978-3-319-49607-8_7.

51 Urban Complexity Lab, University of Applied Sciences Potsdam, accessed May 25, 2019, https://uclab.fh-potsdam.de/.

itating other approaches to engaging with art historical content. To implement such data visualization projects, interdisciplinary teams, including individuals from both the humanities and computer science, are often required to carry out projects that integrate data, media, and information technology.

How technology gained prominence in the humanities can be illuminated by considering a few publications. What began as "humanities computing" in the early 1950s resulted in "digital humanities," which became the preferred term around 2006.[52] Starting around 2010, the digital humanities were more widely acknowledged by way of discussions on digital working methods in the humanities as well as by examining the digital humanities as an emerging field with different methodologies and techniques.[53] With their 2004 publication, *A Companion to Digital Humanities*, editors Susan Schreibman, Ray Siemens, and John Unsworth marked the point at which the digital humanities were considered a discipline in its own right by bringing together specialists who had been working in the field for decades.[54] With *A New Companion to Digital Humanities* in 2016, the same editors reflected on the changes in a broadening field.[55] In retrospect, they questioned whether the digital humanities indeed should be considered as a discipline or rather as "a set of related methods" but stated "that it is a vibrant and rapidly growing field of endeavor."[56] Due to the interdisciplinarity and the wide audience, shaping the digital humanities as a new field required a constant definition of boundaries, at least at the beginning.[57] The success of the digital humanities in recent years is obviously an expression of how the digital transformation manifests itself in humanities research and teaching at universities. Since 2015, many comprehensive books on digital humanities have been published.[58] Other publications address teaching digital humanities in

52 Melissa Terras et al., eds., *Defining Digital Humanities: A Reader* (Ashgate, 2013); Julianne Nyhan and Andrew Flinn, *Computation and the Humanities: Towards an Oral History of Digital Humanities* (Springer, 2016), 1–4, https://doi.org/10.1007/978-3-319-20170-2.

53 See Martin Gasteiner and Peter Haber, eds., *Digitale Arbeitstechniken für Geistes- und Kulturwissenschaften* (Böhlau, 2010); Anne Burdick et al., *Digital Humanities* (MIT Press, 2012); and Claire Warwick et al., eds., *Digital Humanities in Practice* (Facet, 2012).

54 Susan Schreibman et al., eds., *A Companion to Digital Humanities* (Blackwell, 2004), https://doi.org/10.1002/9780470999875.

55 Susan Schreibman et al., eds., *A New Companion to Digital Humanities* (Wiley Blackwell, 2016).

56 Schreibman et al., *Companion to Digital Humanities*, xvii.

57 Julie Thompson Klein, *Interdisciplining Digital Humanities: Boundary Work in an Emerging Field* (University of Michigan Press, 2015), https://doi.org/10.3998/dh.12869322.0001.001.

58 See David M. Berry and Anders Fagerjord, *Digital Humanities: Knowledge and Critique in a Digital Age* (Polity Press, 2017); Helene Hahn et al., eds., *Handbuch Digital Humanities. Anwendungen, Forschungsdaten und Projekte* (DARIAH-DE, 2015), accessed November

the classroom or are introductory textbooks.[59] The digital humanities have become a widely respected field in the humanities, encompassing a wide range of disciplines.

Even if there are important developments for all the humanities, the approaches in the digital humanities have long been too text-based for art history, which has a strong focus on the visual.[60] Therefore, digital art history emphasizes and contributes to developments within the digital humanities that enable art historians and scholars of other similar disciplines to engage with images and the visual.

Considering digital art history a separate field also makes sense when thinking about computer science. Data from digital collections that have become accessible through digitization at art museums and artworks' digital images are not only relevant for art history but also offer computer scientists an interesting starting point for research on visual data. Nevertheless, computer science, as an academic discipline with its own research questions, is likely to approach the same data differently than art history. For example, if computer scientists develop a brushstroke algorithm based on paintings by famous artists that transforms a random photograph into an image in the style of Vincent van Gogh or Georges Seurat, this has to do with art, but its contribution to art history is questionable.[61] If research is to be conducted with images of art from digital collections, that topic is a relevant

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26, 2019, https://handbuch.tib.eu/w/DH-Handbuch; Eileen Gardiner and Ronald G. Musto, *The Digital Humanities: A Primer for Students and Scholars* (Cambridge University Press, 2015); James Smithies, *The Digital Humanities and the Digital Modern* (Palgrave Macmillan, 2017), https://doi.org/10.1057/978-1-137-49944-8; and Patrik Svensson, *Big Digital Humanities: Imagining a Meeting Place for the Humanities and the Digital* (University of Michigan Press, 2016), https://doi.org/10.3998/dh.13607060.0001.001.

59 See Claire Battershill and Shawna Ross, *Using Digital Humanities in the Classroom: A Practical Introduction for Teachers, Lecturers and Students* (Bloomsbury Academic, 2017), https://doi.org/10.5040/9781350029781; Susanne Kurz, *Digital Humanities: Grundlagen und Technologien für die Praxis* (Springer Vieweg, 2015); and Fotis Jannidis et al., eds., *Digital Humanities: Eine Einführung* (J.B. Metzler, 2017).

60 Celia Krause and Ruth Reiche, *Ein Bild sagt mehr als tausend Pixel? Digitale Forschungsansätze in den Bild- und Objektwissenschaften* (vwh Verlag Werner Hülsbusch, 2016), 9, 11. "Anders als die mit Text arbeitenden Disziplinen sind bild- und objektbezogene Wissenschaften im Bereich der Digital Humanities im deutschsprachigen Raum noch vergleichsweise wenig vertreten." Krause and Reiche state as motivation for publishing their book, that—in comparison to disciplines that work with texts—image- and object-centered disciplines in German-speaking areas are comparatively rarely represented.

61 Yu Zang et al., "Stroke Style Analysis for Painterly Rendering," *Journal of Computer Science and Technology* 28, no. 5 (2013), https://doi.org/10.1007/s11390-013-1375-8. This computer science paper introduces a painting framework for transferring stroke-related artistic styles to photographs.

question from an art historical perspective, but computer scientists cannot be assumed to have an understanding of the cultural implications tied to the data. Conversely, humanities scholars are unlikely to have the necessary technical knowledge to be able to program complex applications with which they can evaluate and use their data material by applying computer technology. The best results from a technological point of view and taking into account the cultural content will therefore be achieved through interdisciplinary collaboration, with participants engaging as equals. Although sound technological application knowledge is important for digital image sources, this by no means makes art historical knowledge subordinate. Since artworks and other cultural content have become computer processable through digitization, computer scientists' skills are needed for advanced technological analyses of these data. However, a digital image requires knowledge of the cultural context in which the artwork was created, and thus the skills of humanities scholars. Comprehensive art historical knowledge is a prerequisite for ensuring consistent uses, analyses, and interpretations of digital collections. It is no coincidence that art historians with a strong interest in leveraging digital technology are advocating for a digital art history.

Art history's engagement with digital technology has only just started gaining momentum. Even though computer technology has advanced since the 1960s, museums and art history started only recently to engage fully with advanced technology.[62] In the late 1990s, the discourse on computers and art history revolved around electronic services such as databases, electronic bibliographies, storage, retrieval, and digitized images.[63] Even then, it became apparent that the fundamental question was less about how to transform the material into an electronic form only to do more work in the same way as before, but about how this changes research, teaching, and the direction a new generation of art historians will take.[64] The predictable development was that the electronic revolution would lead to the creation of personal databases, collaborative research, and interactive teaching as integral aspects of art historical activities.[65] This development remains ongoing.

62 Margarete Pratschke, "Geschichte und Kritik digitaler Kunst- und Bildgeschichte," in *Computing Art Reader: Einführung in die digitale Kunstgeschichte*, ed. Piotr Kuroczyński et al. (arthistoricum.net, 2018). Margarete Pratschke notes that digital art history's roots can be traced to the advent of computers in the 1960s.

63 Marilyn Aronberg Lavin, "Making Computers Work for the History of Art," *The Art Bulletin* 79, no. 2 (1997): 198.

64 Lavin, "Making Computers Work," 198.

65 Lavin, "Making Computers Work," 198.

Changes take time, but art history has already begun to adapt technology for its own purposes. Johanna Drucker's article "Is There a 'Digital' Art History?"[66] explored the lack of sensitivity to digital methods and tools that would be necessary for a research breakthrough in the field. The *International Journal for Digital Art History*, founded in 2015, made an attempt to formalize the discipline.[67] Thematic issues aimed to provide the emerging community a platform for relevant questions and methods for a digital art history.[68] Celia Krause and Ruth Reiche's book *Ein Bild sagt mehr als tausend Pixel?* (Does an Image Say More than a Thousand Pixels?) serves as an introductory work that highlights the potential of digital images for research approaches, particularly in art history and archaeology.[69] Most recently, the 2018 book series Computing in Art and Architecture, has helped digital art history become a respected discipline in German speaking areas.[70] *The Routledge Companion to Digital Humanities and Art History* stakes out the field at the intersection of art history, cultural heritage, digital technologies, and museum practices from an international perspective, addressing related developments and challenges.[71] Digital developments in art history and art museums often overlap, but there are also differences.

As in art history, art museums are increasingly aware of digital technology and its potential for representing digital collections effectively. Leading institutions, like the Rijksmuseum in Amsterdam or the UK's Tate, recognized early the relevance of technology for collections they put online and started advanced initiatives.[72] Technological transformations require that terms such as "artwork," "exhibition," "curation," "mediation," and "viewing art" be discussed with the specific peculiarities of a digital environment in mind.

The significance of digital technology and museums is evident from the growing number of publications. One of the first to address the issue was

66 Johanna Drucker, "Is There a 'Digital' Art History?" *Visual Resources* 29, no. 1–2 (2013), https://doi.org/10.1080/01973762.2013.761106.

67 *International Journal for Digital Art History*, accessed June 13, 2022, https://dahj.org.

68 Harald Klinke and Liska Surkemper, eds., *International Journal for Digital Art History: What is Digital Art History?* (Graphentis, 2015), accessed May 7, 2023, https://journals.ub.uni-heidelberg.de/index.php/dah/issue/view/2226/316.

69 Krause and Reiche, *Mehr als tausend Pixel?*

70 Computing in Art and Architecture, accessed December 27, 2024, https://books.ub.uni-heidelberg.de/arthistoricum/catalog/series/caa.

71 Kathryn Brown, ed., *The Routledge Companion to Digital Humanities and Art History* (Routledge, 2020), https://doi.org/10.4324/9780429505188.

72 Chris Dijkshoorn et al., "The Rijksmuseum Collection as Linked Data," *Semantic Web Journal* 9, no. 2 (2018), https://doi.org/10.3233/SW-170257; Jemima Rellie, "One Site Fits All: Balancing Priorities at Tate Online," *Museums and the Web*, 2004, accessed July 13, 2017, https://archimuse.com/mw2004/papers/rellie/rellie.html.

Werner Schweibenz, who, in his 2008 book, analyzed the virtual museum on the Internet.[73] His comprehensive survey outlined the challenges and the transformation of the traditional museum in the information age. The "virtual museum" is, in his understanding, accessible information on the museum's website that goes beyond the most practical information for visitors, but provides further insights into the collection by considering aspects of presentation and mediation.[74] It is a legitimate counterpart to the exhibitions shown in the physical museum with different but enriching contents.[75] The virtual museum is thus multifaceted.

Nonetheless, "virtual museum" as a term is vague in some respects, as it has been used to refer to various manifestations of a museum's presence on the Internet—ranging from museum websites and cultural portals to virtual reconstructions of exhibition spaces and web-based collection databases.[76] The problem with this term is that it can be understood either very narrowly or broadly. Presumably, many tend to understand it more in the narrow sense of a digital recreation of existing museum spaces and exhibitions that allow for virtual tours. However, Werner Schweibenz uses the term in a much broader sense, encompassing all of a museum's digital activities. This broader perspective supports a conception of digital art presentations as complementary to physical objects and exhibitions, making it the preferable interpretation. Nevertheless, in this book, the "virtual museum" specifically refers to the virtual recreation of museum spaces. In contrast, the term "digital collection" is understood in a very broad sense, often overlapping with what others might call a virtual museum.

Leaving aside the linguistic subtleties, Schweibenz centers the objects and the digitization of museum information to point out key aspects in order to succeed as a museum in the digital space.[77] The issues he discussed are still largely relevant today, although developments in museums and technology have advanced since then. In comparison, this book is more concerned with developments in technology and the humanities as well as technological possibilities that have emerged since then. The starting point is digitized collections and the possibilities for their presentation and use, especially through modern web technologies available today (particularly HTML5 in

73 Werner Schweibenz, *Vom traditionellen zum virtuellen Museum: Die Erweiterung des Museums in den digitalen Raum des Internets* (DGI, 2008).

74 Schweibenz, *Vom traditionellen zum virtuellen Museum*, 164.

75 Schweibenz, *Vom traditionellen zum virtuellen Museum*, 14.

76 Harald Kraemer, "Interaktive Impulse: Über Hypermedia und virtuelle Museen," in *Virtuelle Welten? Die Realität des Internets*, ed. Thomas Myrach and Sara Margarita Zwahlen (Peter Lang, 2008), 154.

77 Schweibenz, *Vom traditionellen zum virtuellen Museum*.

combination with JavaScript libraries and the Semantic Web). The situation is now different not only because of current web standards, but also because digital humanities and digital art history have become established.

The digital presence of museums can also be viewed less from an information science perspective and more from a museological perspective, as seen in Dennis Niewerth's *Dinge – Nutzer – Netze* (2018). It starts with the history of museums and the presentation of objects in the physical exhibition space for his discussion of the characteristics of virtual museums.[78] He conceives of the "virtual museum" as a social place, which is why it must be negotiated in the context of the traditional museum and new media.[79] He therefore prioritizes the conditions of exhibiting objects in physical space and the implications in relation to medial conditions of virtual space.[80] For Niewerth, the virtual is already inherent in the physical presentation of objects in exhibitions and merely extends to digital forms of representation, allowing both spheres to merge seamlessly.[81]

This book shares the view that digital activities should be considered within the broader context of an institution's overall activities. Less focus is placed on the history of the museum as an exhibition venue and its engagement with virtuality. The starting point is digitized collections and the digitized artworks themselves, exploring what it implies to consider these as a core subject. It is less of a museological matter what the museum is in the digital realm, but rather what the museum is or how its role changed as a result of digitization.

Integral to an institution's role is what the museums' digital presence means for users. Hubertus Kohle's *Museen digital* (2018) dealt extensively with how museums—especially those in English-speaking countries—use digital technology for art mediation, education, and communication to engage their public in new ways. This includes participatory (e.g., crowdsourcing) and interactive formats (e.g., applications like the Metropolitan Museum of Art's *Heilbrunn Timeline of Art History*[82]) or online collections with available free high-resolution images or an API.[83]

78 Dennis Niewerth, *Dinge – Nutzer – Netze: Von der Virtualisierung des Musealen zur Musealisierung des Virtuellen* (transcript, 2018), https://doi.org/10.14361/9783839442326.

79 Niewerth, *Dinge – Nutzer – Netze*, 23.

80 Niewerth, *Dinge – Nutzer – Netze*, 400.

81 Niewerth, *Dinge – Nutzer – Netze*, 400.

82 *Heilbrunn Timeline of Art History*, the Metropolitan Museum of Art, accessed June 13, 2022, https://www.metmuseum.org/toah.

83 Hubertus Kohle, *Museen digital: Eine Gedächtnisinstitution sucht den Anschluss an die Zukunft* (Heidelberg University Publishing, 2018), https://doi.org/10.17885/heiup.365.515.

Engaging with audiences is only one of the ways in which digital technology affects a museum. Others include internal and external workflows of museum staff and the requirements of putting information into data-processable formats for technologically savvy art historians, which was outlined in more detail in two articles published in *Museumskunde* and *Objekte im Netz*, respectively.[84] The articles address the implications for a digital collection's structure from a technical perspective to serve as a resource. This concerns museums using the collection for their own purposes, such as representing it online, but also providing appropriate access to art historians and other scholars in the digital humanities and computer science who intend to use digital collections for analysis, visualization, and interpretation. In summary, a detailed examination of digital collections of digitized artworks includes technological and information-specific considerations, questions of curating and exhibiting, communication and mediation for different target groups, various areas and forms of use, and organizational-operational aspects.

Digital technology in relation to museums encompasses various areas of activity, which have been addressed in different publications. *Museums and Digital Culture* explores the impact of digital culture on museums, with contributions highlighting its implications for exhibitions, collections, audiences, education, and other aspects of museum practice.[85] This exploration shapes the foundational framework of digital culture and museums relevant for curators, artists, educators, and audiences.[86] As a result, new roles and responsibilities accompany the shift from collection-focused institutions to user- and visitor-focused institutions.[87] Cultural institutions are at a crossroads, beginning to align their activities with new paradigms driven by factors beyond digital transformation, though digital technology is closely intertwined with these changes in many respects. This is also where *Der digitale Kulturbetrieb*, which is situated in the broader context of cultural management, picks up the discussion of strategies and fields of action related to the digital transformation.[88]

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84 Sonja Gasser, "Das digital transformierte Museum: Daten und Technologie nutzen für optimierte Dienstleistungen," *Museumskunde* 84 (2019), accessed October 26, 2024, https://www.museumsbund.de/wp-content/uploads/2020/04/final-gasser.pdf; Gasser, "Digitalisat als Objekt der Begierde."

85 Tula Giannini and Jonathan P. Bowen, eds., *Museums and Digital Culture: New Perspectives and Research* (Springer, 2019), https://doi.org/10.1007/978-3-319-97457-6.

86 Loïc Tallon, "Foreword," in *Museums and Digital Culture: New Perspectives and Research*, ed. Tula Giannini and Jonathan P. Bowen (Springer, 2019), vii.

87 Tula Giannini and Jonathan P. Bowen, "Preface," in *Museums and Digital Culture: New Perspectives and Research*, ed. Tula Giannini and Jonathan P. Bowen (Springer, 2019), ix.

88 Lorenz Pöllmann and Clara Herrmann, eds., *Der digitale Kulturbetrieb: Strategien,*

Museums and art historians have a close, interdependent relationship. With the digitization of collections, this long-standing connection extends beyond traditional print publications into the digital realm, where new forms of knowledge access exist. This book provides insights into the technological possibilities for how art historians in museums and research can engage with digital data, showcasing several outstanding examples throughout the chapters. The goal is to raise awareness of how digital art history projects can be methodologically shaped and realized. It serves as an introduction to the thinking and inquiry methods central to digital art history, aiming to familiarize art historians with key technological concepts and expose them to current discourses relevant to art history, with a focus on technological approaches and the digital humanities.

1.5 Data as Knowledge Resource

Advocacy for accessible data from museum collections occurs when data is understood as a valuable resource for knowledge. Data analysis becomes easier with computer technologies like computer vision algorithms, which, for example, can help retrieve images with particular features from large datasets. In a task of that scope, the research interest is less on the qualities of a single artwork or its placement within a narrower artistic, social, or historical context. Instead, it is important to define characteristic structures within datasets at the level of available digital images or metadata. For instance, researchers may analyze patterns in the distribution of iconographic themes across different periods or compare stylistic features in paintings through machine learning techniques. This broader perspective on datasets introduces quantitative approaches into art history. Findings—such as unexpected stylistic similarities across regions or recurring compositional patterns—must then be interpreted within a larger context.

Interpretation and contextualization can follow traditional paths and situate characteristics found through a computer-driven analysis within the current state of research knowledge published in catalog raisonnés, exhibition catalogs, and other scholarly publications. In this case, the method used to analyze digital sources is technology-based, while interpretation resists relying on technological tools. However, computational analysis can reveal distinctive patterns within the data, which can then be compared against art historical discourses around an artist's oeuvre, a style, an artistic genre, or whatever other art historical component is under consideration. It either

Handlungsfelder und Best Practices des digitalen Kulturmanagements (Springer, 2019), https://doi.org/10.1007/978-3-658-24030-1.

validates an already existing argument through the evaluation of new sources or makes evident an interpretation that previously has not been offered by art historians.

Another approach is to pursue an entirely technology-based analysis and interpretation. In that case, the resulting argument refers only to the digital collections used. Statements might be quite specific since analysis is restricted to a smaller group of considered artworks. The scope depends on the sources used, determining whether broader historical context is possible or conclusions remain narrowly tied to the analyzed data.

Within museums, the application of digital technology tends to be aimed at representing and communicating art, but the question remains how it alters collections and artworks. Data determines how artworks become visible. The most common method of providing access to a digital collection and displaying images is through a keyword search of the database, with the results presented as image tiles. Searching is a bit like randomly digging around in museum storage, the difference being that anyone who is interested and uses a computer can gain the privilege of access. However, a database search requires prior knowledge and a clear question to retrieve the right information, making it a tool most suitable for experts.

For the general public, a better option would be a thematic access to the contents of the collection along with additional background information. Curating objects in a digital collection under a specific theme creates a kind of exhibition within the digital environment. The digital environment provides a platform for art and can thus be interpreted as an exhibition space. Just as in physical space, assembling works requires someone to think about how the information can be presented and what information requires inclusion, so art enthusiasts can learn more about artworks. This approach is based on storytelling and guides users through a labyrinth of artworks connected by specific information. It is only a selected range of relevant artworks that can be navigated in this way. But it sparks curiosity about the collection and perhaps motivates them to search for other objects not categorized that way.

Combining a search with an application holds promise for flexible access to the digital collection, especially when considering serendipity as an important component. An effective way to enhance search appeal is through interactive data visualization. This approach gives users an idea of what can be found in the database and makes the content more tangible. Users are free to decide what interests them and to interact with the full range of records available. Visualizations allow an overview of the database contents by selecting certain categories, meaning the displayed results can vary from user to user. Visualizations change generatively depending on user selections. If a specific part of the visualization is selected and it shows objects from the

collection belonging to this category, this can be a vastly improved search. Relationships between different entities can be made evident—for example, how many works by one artist are in the collection compared to others, or which artists are related to one another. Such an approach allows users to discover connections and results they may not have thought of before.

Access type also impacts engagement with art. Art represented in a digital environment changes the role of the viewer. While a visitor of a museum exhibition must go physically to a specific location, a user of an application can access artworks from anywhere with a device and Internet access.

A museum visitor follows a path from one room to the next. The physical space determines how a visitor moves, but also the selections and intentions of the curator. Specific placement of a work draws a viewer to examine it in its full size and materiality. There are few individual choices about where to go to and what to see within a museum. Clear from the outset is what everyone who visits the exhibition will see, only the sequence may differ slightly. The focus is on the artwork, with minimal background details. In contrast, engagement with art in a digital space can be more information-oriented. Images remain important, but smaller in size and with fewer details. Images of artworks are necessary to illustrate an argumentation supported by background information in text or video streams. The user has the freedom to choose what to view, and can easily jump from one artwork to another and see many artworks at once. A viewer physically passing through an exhibition is a visitor who sees what is on display, while an active user is trying to locate and see content that is interesting to them. User is a term commonly used for those navigating the Internet and using software; in this case it refers to individuals looking at and examining images.

An application can include far more content than is possible to show in the limited space of physical rooms. What one will see or not can rely on curatorial decisions, but there are several options for the user as far as where to navigate and what to explore. In the digital environment, what somebody sees is highly selective and strongly linked to the user's interests, but users can be guided if a narrative exists, for example, by storytelling. An application democratizes what the user can do with the presented artworks. Everybody can freely use artworks that are available as digital images and metadata to arrange their own virtual exhibitions and share it with others. Somebody with strong computer skills can develop their own applications with the databases' content and create solutions a museum could never have foreseen.

The following chapters look closely at implications digital technology has on the artwork, exhibition, and viewer, in addition to providing concrete examples of aspects inherent to digital collection platforms at cultural institutions like museums. Focus on data instead of objects changes not only the

meaning of artwork, exhibition, and viewer but also the relationship between them. An exhibition must be understood in a more general and abstract sense. Instead of making visible artworks in their appearance, a digital visualization is a kind of exhibition that is specific to digital media. Abstract shapes may show the relations between quantities of selected categories without including images of artworks. The viewer becomes an active user who makes their own decisions and interacts with the content. Exhibitions are a kind of node in the virtual space where contents of the database accumulate according to a meaningful aspect. Such applications ideally ignite interest in searching for other works or to use the data for their own projects.

Digital art history goes far beyond knowing where to find digital sources; it requires connoisseurship and knowledge of which sources might be relevant and valuable. With technological capabilities, new approaches that combine qualitative and quantitative methods are becoming increasingly important. Additionally, a solid grasp of visual communication is essential for creating meaningful visualizations as a basis for interpretation. A visualization does not stand on its own but involves deliberate choices regarding data selection and an arrangement that suits human perception.

1.6 Digital Collections and Technology

Focusing on digital collections of art museums does not preclude consideration of digital collections of other GLAM institutions, particularly other museums, libraries, and archives whose holdings also contain visual resources. Certainly, the main research interest lies in the accessibility and advanced use of increasingly digitally available art collections—mainly images and metadata—by museums, art historians, and other users. In principle, other culturally and historically relevant objects, archival materials, and documents can be treated in the same way. The goal is especially to analyze, visualize, and communicate the contents of online accessible digital collections with respect to the possibilities digital technology offers. Topics such as visually based search methods are equally important as interactive storytelling or linking data from different sources. Moreover, there is a particular interest in the underlying structure that ensures various functionalities, which precipitates the discussion of associated technologies and standards like open data, linked data, data visualization, the *International Image Interoperability Framework (IIIF)*, APIs, and Creative Commons licenses. Visual resources in a digital environment aim to attract the general public but also scholars, and it is crucial to consider and evaluate different starting points.

Table 2. *Technological standards for digital collections.* Extract from table 18 (appendix F)

List number	Country code	Art museum	Authority data (artists): GND; ULAN; RKD; Wikipedia; Wikidata; etc.	Controlled vocabularies; keywords (works)	Vocabulary: Iconclass (works)	Citable URL / permalink / DOI	IIIF (International Image Interoperability Framework)	Use of public domain images	Public Domain Mark/Creative Commons (for public domain works)	Public API	Conclusion: traditional collection online?
1	CH	Fondation Beyeler	×	×	×	×	×	× © Photographer	×	×	yes
2	CH	Kunsthaus Zürich	o	o	×	×	×	× not specified; without ©	×	×	yes
3	CH	Kunstmuseum Basel	×	×	×	o very long	×	o own formulation: image data in the public domain – Kunstmuseum Basel	×	×	yes
4	CH	Fondation Pierre Gianadda									none
5	CH	Zentrum Paul Klee	× (m)	o	×	×	×	×	×	×	yes
6	AT	Kunsthistorisches Museum	o	×	×	o	×	o CC BY-NC-SA 4.0	×	×	yes
7	AT	Belvedere	o	o	o	o	o	o CC BY-SA 4.0	×	×	no
8	AT	Albertina	o	×	×	o	o	o Public Domain	×	×	no
9	AT	Leopold Museum									none
10	AT	MUMOK	×	×	×	o	×	×	×	×	yes
11	DE	Städel Museum	×	o	o	o	×	o CC BY-SA 4.0	o	o	no
12	DE	Alte Pinakothek	×	×	×	o	×	o CC BY-SA 4.0	o	×	yes
13	DE	K20/K21	×	×	×	×	×	×	×	×	yes
14	DE	Museum Barberini	×	o	×	×	×	×	×	×	yes
15	DE	Alte Nationalgalerie	×	×	×	o very long	×	o CC BY-NC-SA 4.0	o	o	yes
16	EUR	Louvre	×	o	×	o	×	o own formulation	×	×	no
17	EUR	Musei Vaticani	×	×	×	o	o	×	×	×	yes
18	EUR	British Museum	×	o	×	o	×	o CC BY-NC-SA 4.0	×	×	yes
19	EUR	Tate Modern	×	o	o	o	×	o CC BY-NC-ND 3.0 (Unported)	o	×	no
20	EUR	National Gallery	×	×	×	o	o	o CC BY-NC-ND 4.0	×	o	no
21	USA	The Met	×	o	o	o	o	o Public Domain (CC 0)	o	o	no
22	USA	National Gallery of Art	×	×	×	o	o	o Public Domain (CC 0)	o	×	no
23	USA	MoMA	o	×	×	o	×	×	×	o	no
24	USA	National Portrait Gallery	×	×	×	o	o	o CC 0	o	o	no
25	USA	Art Institute of Chicago	×	o	×	o	o	o CC 0 Public Domain Designation	o	o	no

o present, × not present, (m) monographic collection

Digitized collections and the different ways they are presented by museums and other cultural institutions serve as a starting point for exploration. Referencing outstanding examples helps establish a typology of technological possibilities for presenting digital collections. Pioneering institutions like Amsterdam's Rijksmuseum,[89] Städel Museum Frankfurt am Main,[90] Museum of Modern Art in New York,[91] but also *Google Arts & Culture*,[92] are innovators who initiated the use of technology well before it was best practice. These advancements range from search and browsing functionalities and user engagement strategies to considerations of whether and how third parties (such as skilled developers and programmers) can use the data for other applications, for instance via APIs and linked open data. In the meantime, these early adopters have been followed by other museums such as Museum für Kunst und Gewerbe Hamburg,[93] the Metropolitan Museum of Art,[94] the Cleveland Museum of Art,[95] the Art Institute of Chicago,[96] the National Gallery of Art in Washington, DC[97] the Getty Museum in Los Angeles,[98] and the Belvedere in Vienna,[99] who have started relying on standards like CC0, APIs, *IIIF*, LOD, or an open data policy for their digital collections. Table 2 situates a selection of these museums within the technological standards of the others featured in the table. To thoroughly understand what is state-of-the-art for digital collections and access to the artworks, other technological aspects must be considered. It is important to have an eye on technology in development, e.g., machine learning, computer vision, etc., to see where they

89 *Collection*, Rijksmuseum, accessed December 27, 2024, https://www.rijksmuseum.nl/en/collection.

90 *Digital Collection*, Städel Museum, accessed June 14, 2022, https://sammlung.staedelmuseum.de.

91 *The Collection*, the Museum of Modern Art, New York (MoMA), accessed June 14, 2022, https://www.moma.org/collection.

92 *Google Arts & Culture*, Google, accessed June 14, 2022, https://artsandculture.google.com.

93 *Collection*, Museum für Kunst und Gewerbe Hamburg, accessed September 1, 2021, https://sammlungonline.mkg-hamburg.de.

94 *The Met Collection*, the Metropolitan Museum of Art, accessed September 1, 2021, https://www.metmuseum.org/art/collection.

95 *Collection*, the Cleveland Museum of Art, accessed September 1, 2021, https://www.clevelandart.org/art/collection/search.

96 *The Collection*, Art Institute of Chicago, accessed September 1, 2021, https://www.artic.edu/collection.

97 *Our Collection*, National Gallery of Art, Washington DC, accessed September 1, 2021, https://www.nga.gov/collection.

98 *Museum Collection*, Getty, accessed September 1, 2021, https://www.getty.edu/art/collection.

99 *Sammlung Online*, Belvedere, Vienna, accessed September 1, 2021, https://sammlung.belvedere.at.

are applied and where there are future developments possible for digital collections of art.

In addition to technological foundations related to digital collections, it is also essential to address strategic and conceptual issues related to making art and data digitally accessible. An important consideration is how digital collections can be curated with a sensibility equivalent to the curation of physical exhibitions in museums. This includes questions about images and their roles in different media contexts, such as the original artwork, but also in different forms like analog and digital reproductions. Visualization is a powerful way to present data and make large amounts of information manageable. This precipitates questions about identifying narratives and themes that constitute such virtual museums or online exhibitions. These exhibitions go far beyond a virtually modeled room with four walls and images. Space is no longer dependent on gravity, physical locations, or other spatial constraints. It also transcends specific places and time. This space can integrate data from different institutions and is not limited to a single, unique masterpiece; instead, an artwork can exist simultaneously in multiple contexts. It behaves similarly to images used in publications, but the difference is that text is secondary to the image. Instead, emphasis is placed on a balanced combination of images, information, and graphic elements in participatory, interactive, and generative environments. Only when these entities rely on each other and enable the interpretation of individual objects in a specific context does the user gain knowledge.

With data visualizations, new methods and techniques become relevant to museums and art historians. For that reason, this book offers a differentiation of various visualization methods and the software suitable for them. The purpose is to outline what kind of questions art historians can pursue with the help of technology when dealing with digital collections, images, and metadata. Visualizations can be used in the context of museums for online presentations and enable the communication of content to a broad public. But digital technologies also offer powerful tools for humanities scholars to analyze and understand art history and its resources.

The next chapter addresses the technological background of databases and the accessibility of data in digital collections, which form the basis and underlying idea for all the topics discussed in the subsequent chapters.

2 Digital Collections and Data Accessibility

2.1 Introduction

Museums typically provide public access to digital collections after artwork assets have been digitized and a collection management database has been established. Digital collections' structure is determined by content, functionality, and technology. Since the structure of the data determines how artwork digital images and metadata can be accessed and used, it is worthwhile to address how digital collections are structured and their technological requirements. The functionality of a user's interaction with a digital collection depends on the database architecture, the structure of the metadata, the way the digital images and metadata are made available in the form of basic textual information about the artworks, and conceptual considerations. These technological foundations are intertwined with cultural and media theoretical dimensions in which digital collections are embedded as digital image archives. Art museums find themselves in a situation that affects their self-conception and the fulfillment of their mission in the face of technological challenges.

The digital collection, as a format, is based on formerly printed collection catalogs that publicly document a museum's artworks. With the transition into the digital realm, some crucial parameters change, which necessitates rethinking the digital representation of art collections. The digital image, its significance, and the existence of artwork metadata are important not just for the museum's activities but also for its role as a data provider. By offering access to fundamental information and knowledge about art, museums become data providers for third parties, namely the general public and art historians. Art historians have long relied on reproductions for their research and therefore find digital collections to be valuable resources—not only for high-quality reproductions but also for basic information on artworks, validated by the authority of the museum. This raises the question: What changes when reproductions or surrogates of artworks take the form of digital images?

In order to effectively access and work with digital images, good findability is just as important as databases not isolated in hermetically sealed silos. The traditional model of a self-contained, separately accessible database corresponds to those digital collections that exist in a dedicated section of a museum's website. Without linking to other content on the website or the collections of other institutions, insight into the collection can be gained

by looking up individual records. In contrast, digital collections that follow more modern approaches create connections among information and offer access that supports data sharing and reuse. To enable the use of digital images and metadata, there are some basic considerations when managing and making the data accessible.

Digitization in museums is no longer limited to two primary goals: using data in internal workflows and making collections accessible to the public online. Instead, it is essential to think more broadly about the potential uses of this data and the additional value it might provide. Beyond alternative data uses within the museum itself, prioritizing data sharing with other stakeholders is crucial—whether between museums or between museums and individuals.[100] Once data becomes available for reuse, it allows for broader consideration of potential applications.

For data to be shareable and reusable, certain technological requirements must be met regarding its structure in the database, the amount of metadata added, and whether it is enriched with authority data and controlled vocabularies. Public application programming interfaces (APIs) for data exchange between systems, along with granted usage rights, ensure flexibility, openness, and connectivity.

Databases store digital collections, serving as the digital counterpart to physical storage for museum collections. Preserving digital images is just as challenging as preserving physical artworks, and it presents its own set of problems. While analog artworks degrade through handling and exposure (e.g., light damage to works on paper or wear from transportation), making careful, secure storage preferable, the opposite is true for digital images in digital collections. Demand for data incentivizes its long-term availability. A robust infrastructure is imperative to preserve and keep available both the data and associated applications.

The goal of this chapter is to outline the technological foundations related to digital images and databases, in particular image archives, while also addressing legal aspects, such as copyright restrictions and licensing to support accessibility. The definition of collection documentation shifts when handling data rather than information. It is no longer just informational material about art that can be viewed and read, digital images and metadata can be utilized and contextualized differently to gain new insights and knowledge.

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100 Sonja Gasser, "Das digital transformierte Museum: Daten und Technologien nutzen für optimierte Dienstleistungen," *Museumskunde* 84 (2019), accessed October 26, 2024, https://www.museumsbund.de/wp-content/uploads/2020/04/final-gasser.pdf. This article discusses this issue in greater detail, where I explore how available data can be integrated into various services to streamline museum workflows by leveraging technological capabilities, and I propose potential solutions.

The digitally literate museum not only uses data for its own purposes but also understands how others will benefit from reusing it as source material. In the context of digital technology and museums, or organizations in general, there are three terms to distinguish: "digitization," "digitalization," and "digital transformation." "Digitization" is the conversion of analog media into digital content for the digital environment.[101] It differs from "digitalization," which describes the process of using digitized content with digital technologies, driven by the underlying principles of the digital realm.[102] The term "digital transformation" is even broader and is a strategic model for addressing changes associated with digital technology, usually resulting in changed products, organizational structures, or the automation of processes.[103] Building a digital collection through digitization is therefore only the beginning of a process that involves a significant change in the way museums operate and present themselves.

Taking a broad approach to the use of data, this chapter identifies the foundational criteria that constitute more advanced digital collections of museums. It examines what these criteria are, why they are critical, and for what purpose they are useful. The underlying premise is that an object record or an entire collection database should be connected to other entities rather than exist as an isolated unit of information. The vision for the future is that digital collections will become increasingly interconnected, linking objects, documents, people, and events.[104] Well-prepared records enable data to be used in novel ways and contexts.

In addition to standardization and technological considerations, it is also important to examine digital images from a visual and media studies perspective by querying what an image is, how images relate to one another, and how they function as a medium for communicating a message.

Photography, as the reproductive medium for images in digital collections, is only one aspect of digitization, which encompasses artwork reproduction, the collection of artwork information, and database architecture. The transformation of artworks into digital images and records is intrinsically linked to the definition of a digital image, the role of metadata,

101 Marisa Enhuber, "Art, Space and Technology: How the Digitisation and Digitalisation of Art Space Affect the Consumption of Art—A Critical Approach," *Digital Creativity* 26, no. 2 (2015): 122–23, https://doi.org/10.1080/14626268.2015.1035448.

102 Enhuber, "Art, Space and Technology," 122–23.

103 Thomas Hess et al., "Options for Formulating a Digital Transformation Strategy," in *Strategic Information Management: Theory and Practice*, ed. Robert D. Galliers et al., 5th ed. (Routledge, 2020), 151.

104 Oliver Grau et al., "Museum and Archive on the Move: Introduction," in *Museum and Archive on the Move: Changing Cultural Institutions in the Digital Era*, ed. Oliver Grau (De Gruyter, 2017), 13.

controlled vocabularies, and authority files, as well as ontologies, the Semantic Web, and linked open data.

Databases are indispensable for documenting artworks and making them publicly accessible. Publishing carefully maintained records from an internal collection management database online may seem like a small step, but the technical and conceptual challenges of collection digitization, especially regarding public access, should not be underestimated. Sustainable digitization requires addressing qualitative aspects, such as how artworks are digitally documented and how data is made accessible. Standards for documentation, data, and metadata exist for several reasons, and the way data and metadata access is structured determines the usefulness of a digital collection for different purposes. At the same time, it is important to critically question what might be lost even in the most comprehensive digitization. The next section begins by discussing how a digital collection is integrated into a museum's website. Using the Museum of Modern Art (MoMA) in New York as a case study illustrates the complexity of representing a collection online and sets the stage for a deeper exploration of the associated technological aspects.

2.2 Digital Collections

Public access to digital content is available typically through a museum's website, which offers a wide range of information. Different types of information of varying scope come together. This satisfies user's different needs, depending on the purpose a piece of information serves and its source. In general, museum websites are comparable in structure to websites for archives and libraries, where users can find three types of information. Usually, users first encounter general information to get a quick overview of the institution's purpose or opening hours, and so on.[105] Second, electronic archives and library catalogs serve as finding aids for the collection holdings, and any archival material and printed books must be consulted at the institution.[106] Third, digital collections provide both object information and the files, making source materials such as images or texts directly accessible online for further research.[107] Digital collections of art museums can often be found under the menu item "collection" or "research" on museum websites. While traditional digital collections are intended more as a finding aid and can be

105 Lutz Jahre, "Digitale Archive und Bibliotheken," in *Zum Bedeutungswandel der Kunstmuseen: Positionen und Visionen zu Inszenierung, Dokumentation, Vermittlung*, ed. Harald Krämer and Hartmut John (Verlag für Moderne Kunst, 1998), 161.

106 Jahre, "Digitale Archive und Bibliotheken," 161.

107 Jahre, "Digitale Archive und Bibliotheken," 161.

classified as belonging to the second group, digital collections are moving in the direction of the aforementioned third group by also functioning as online resources for digital materials. The composition and emphasis of the three key information units on museum websites—general information, finding aids, and digitized source material—affect the appearance and potential uses of digital collections. This is evident when comparing various digital collection platforms.

For museums, offering a collection online makes informative data about artworks accessible not only to internal staff but also to external audiences. Digital access to collections increases public interest in art, encourages loan requests from other museums, and provides valuable resources for scholarly research. Digital access typically prioritizes search functionality as a core feature, coupled with a distinctive information structure. Users can search and browse the collection to learn more about individual artworks. The information in an artwork record is often accompanied by a documentary photograph of the artwork. A detailed analysis of an exemplary online collection and its associated functionalities highlights the specific characteristics of digital collections and provides a basis for identifying differences in other digital collection presences. This examination considers what is most suitable and useful for accessing and representing a collection online.

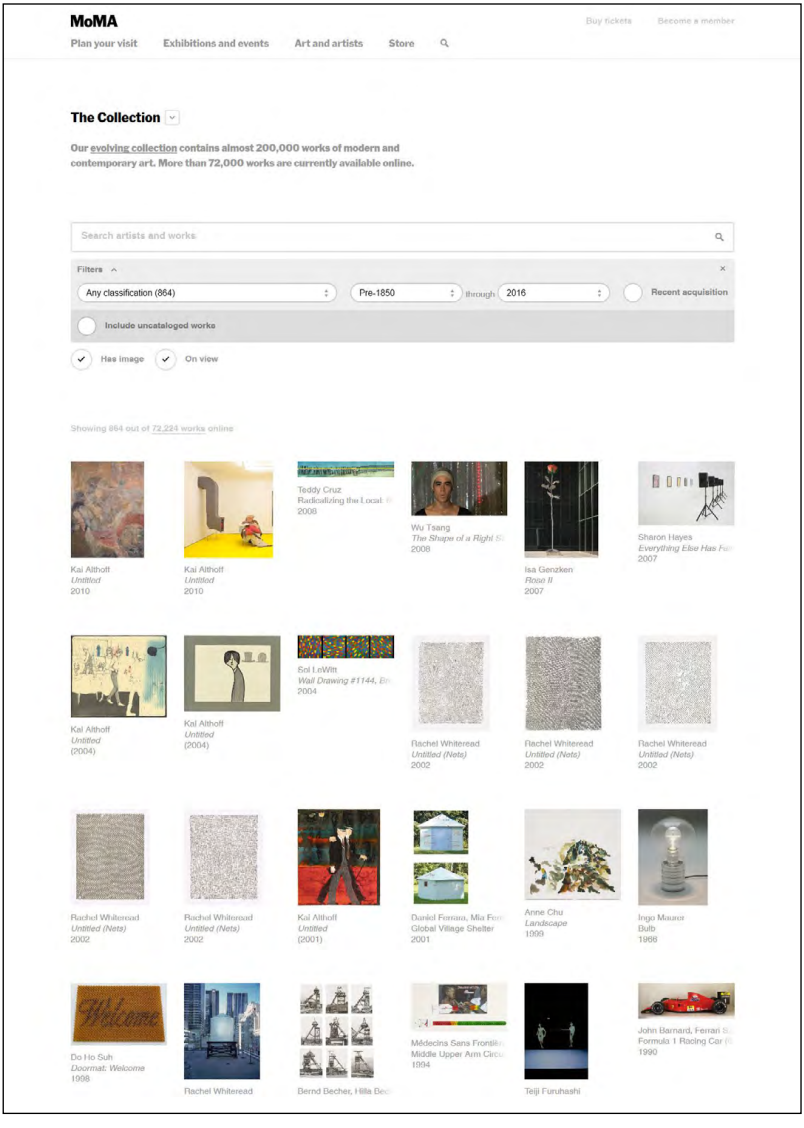


Figure 1. *Landing page featuring a search field, filters, and randomly displayed images at* The Collection*, MoMA, accessed December 12, 2016,* https://www.moma.org/collection/

Digital Representation of Collections

While the digital representation of collections differs between museums, there are certain common elements. MoMA's digital collection as an example of an advanced digital collection presence, will be examined as a basis for subsequent observations and differences. MoMA's collection is a well-developed model in terms of scope and linking information and digital features within a record. But there are other digital collections that offer more functionalities from a technical and reuse perspective. With this in mind, MoMA's digital collection can serve as a model for other institutions while also lagging behind other existing digital collections in certain areas.

When navigating to a museum's digital collection, users tend to assume that they are searching the entire collection, which is usually not the case. Therefore, it is advisable to indicate the completeness of the available online content. As the digitization of large collections is a lengthy, laborious, and expensive process, only part of MoMA's collection is available online, as is the case with many other museums. Which artworks are digitized depends on priorities, needs, and other factors, and therefore tends to be random. Although this makes it difficult to communicate exactly what is in the digital collection and what is missing, MoMA clearly states that about half of the artworks in the collection are currently accessible and more are being added continuously.[108] On the landing page of *The Collection*[109] (fig. 1), there is a brief description of what the database contains and a link to another page with more detailed information about the collection. Basic information about the content of the collection gives the user an orientation on how and for what to search.

Users often visit digital collections to find specific artworks or information. Several principles facilitate the search and refinement of results. In MoMA's *Collection*, users can immediately search for artists or artworks. Below the search field, thumbnails of a random selection of artworks from the collection are displayed along with artist name, work title, and year. Keyword search and image gallery are two basic options for access to digital collections. While a keyword search allows users to find desired content in a targeted manner, browsing images provides an intuitive way to explore the collection without a predefined query. Filters help refine search results. MoMA's filter options include predefined classifications, a year range, and selections like "recent acquisition," "include uncatalogued works," "has image," and "on view." Once the results match the desired criteria,

108 *The Collection*, MoMA, accessed June 7, 2022, https://www.moma.org/collection/. In 2022, 94,000 of approximately 200,000 artworks were online. As of May 12, 2024, the number of works online increased to 103,000.

109 *The Collection*, MoMA, accessed April 2, 2022, https://www.moma.org/collection.

individual artwork records can be examined in more detail.

Clicking on an artwork in the search results opens a new page featuring a larger image along with cataloging information about the artwork. The length of the record varies depending on the extent of the documentation and the availability of supplementary materials. Additionally, the record may include useful services that enhance the user experience. For example, indicating whether a work is currently on display in the museum is a valuable feature for visitors seeking to view the original artwork. Direct links to other works by the same artist within the digital collection encourage exploration and serendipitous discovery. MoMA also welcomes public expertise: at the bottom of the page, users are invited to share their knowledge and report errors via email. While this feature may be used infrequently, it provides an avenue for valuable feedback to reach the museum.

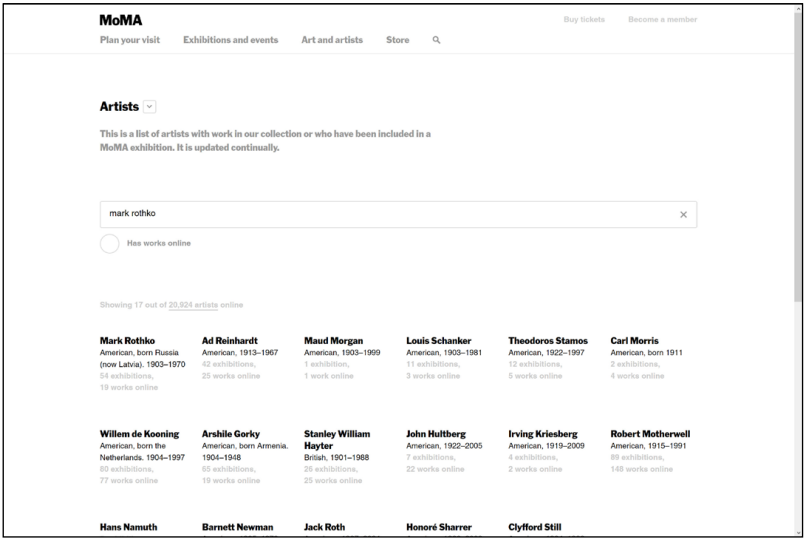


Figure 2. *Search query "mark rothko" at* Artists*, MoMA, accessed December 13, 2016,* https://www.moma.org/artists/

In addition to *The Collection* search, MoMA offers alternatives like a search for *Artists*[110] (fig. 2). Also noted is the total number of artists included in the digital collection. With almost 28,000 MoMA artists online to-date, a

110 *Artists*, MoMA, accessed April 2, 2022, https://www.moma.org/artists.

complete alphabetical list is unwieldy.[111] Either the search field must be used or one of the previewed artists must be selected. For a rough overview, the artist's name, nationality, and lifespan are displayed along with information on how many works are online. When searching for an artist, that artist is shown as the first result (assuming there is a match), followed by other similar artists. It is not clear what criteria are used to select the others, but their work is obviously similar, as are their life dates. In this way, other artists may be found who might be of interest, but whom the user does not know or did not initially think of.

The depth of information on an artist's page (fig. 3) varies, but for major artists, detailed biographical information from the *Wikipedia* entry and from Getty's *Union List of Artist Names (ULAN)*[112] record is displayed.[113] Information about an artist that already exists elsewhere can be reused to bolster the digital collection with additional content. The page also links to the artist's works in the collection, along with MoMA exhibitions that included works by the artist.

111 *Artists*, MoMA, accessed February 9, 2025, https://www.moma.org/artists/. The current number of digitized artist records is indicated directly under the artist search bar, as seen in figure 2.

112 *Union List of Artist Names (ULAN)*, Getty Research Institute, accessed June 7, 2022, https://www.getty.edu/research/tools/vocabularies/ulan/.

113 *Artists*, MoMA, accessed February 9, 2025, https://www.moma.org/artists/. See examples: Mark Rothko (https://www.moma.org/artists/5047); Vincent van Gogh (https://www.moma.org/artists/2206); and Sophie Taueber-Arp (https://www.moma.org/artists/5777).

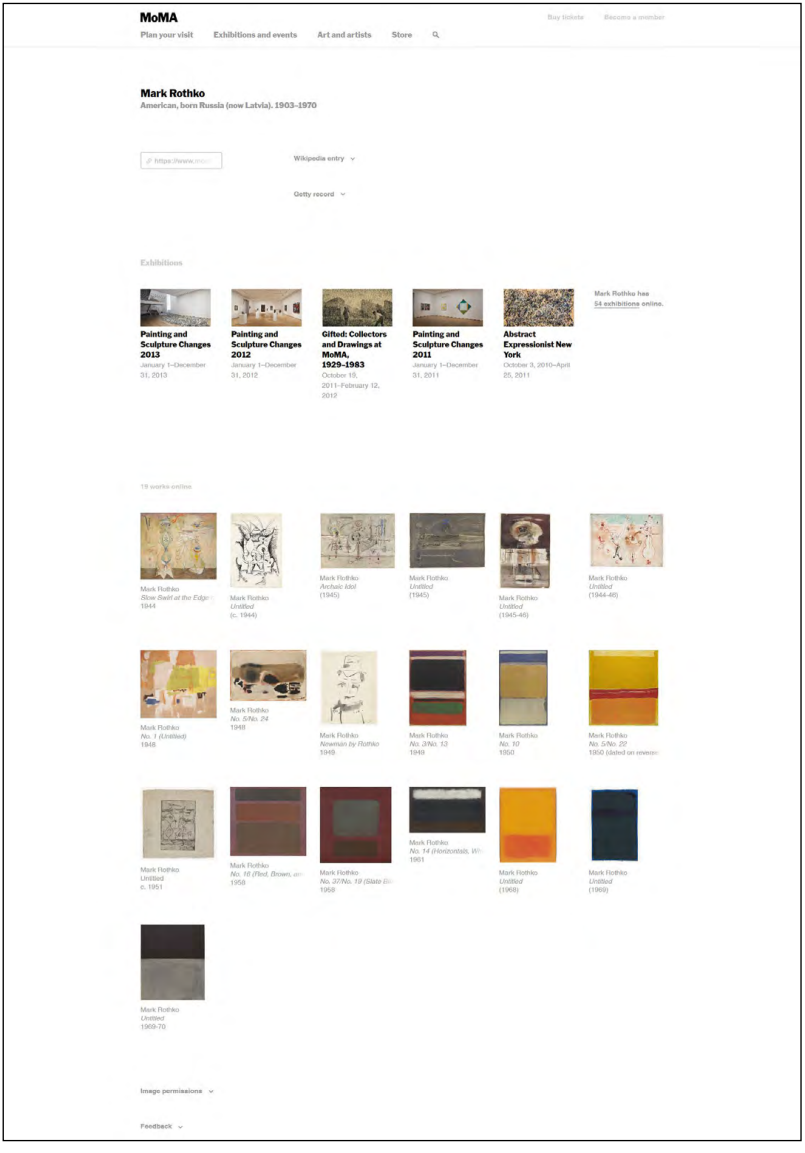


Figure 3. *Mark Rothko artist record at* Artists*, MoMA, accessed December 13, 2016, https://www.moma.org/artists/5047*

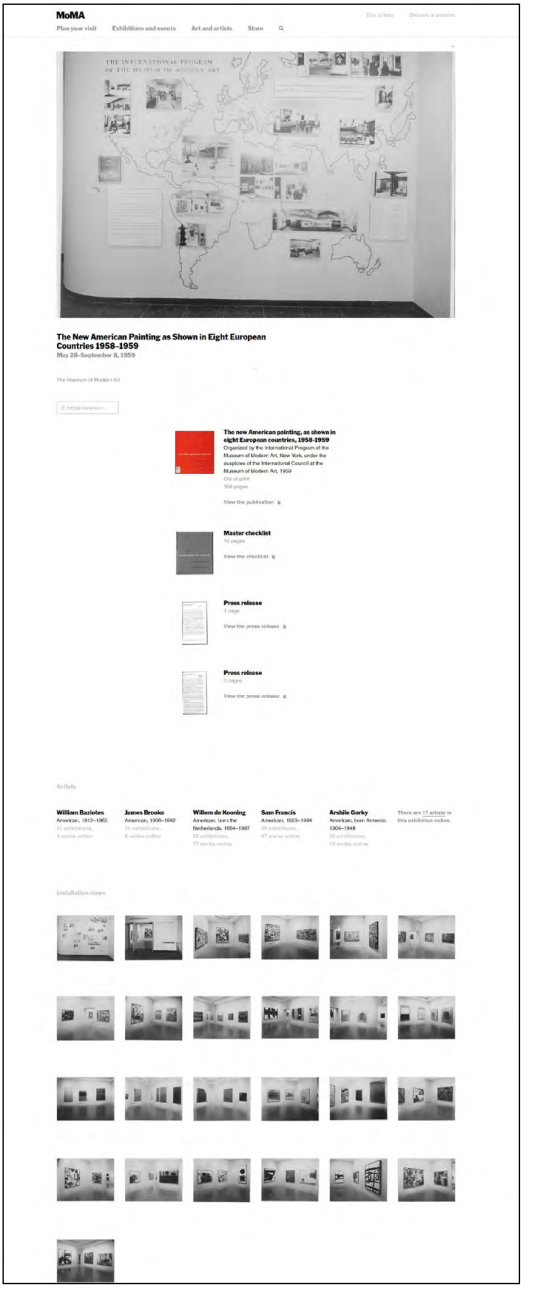


Figure 4. *Exhibition record for* The New American Painting as Shown in Eight European Countries 1958–1959 *(May 28 to September 28, 1959) at* Exhibition History, *MoMA, https://www.moma.org/calendar/exhibitions/1990, accessed December 13, 2016*

MoMA's website stands out in terms of digital representation of the collection because it serves as a platform linking different datasets across various areas, from the collection to artists to exhibitions. Its *Exhibition History*[114] (fig. 4) contains an archive of all exhibitions since MoMA's founding in 1929. This section combines digitized documentary photographs of historical exhibition views with the exhibition titles, featured artists, and additional exhibition-related information.

MoMA is one of the museums that view their digital collection not only as a means of accessing individual works and artist entries, but as a way of bringing together and linking different types of information from multiple internal databases. As a result, the work entries are enriched by other digitized material that provides information about the exhibitions since the museum's founding in the form of digitized installation photography and other archival documents such as checklists of works or digitized exhibition catalogs. MoMA's digital collection is compelling, but it does not offer everything that other collections have implemented. In contrast, Cambridge's Fitzwilliam Museum[115] has a digital collection exceptionally rich in metadata and technical functionality. It offers linked keywords in the artwork information, provides text and code snippets to cite or embed the work in analog and digital contexts, and offers download options for the data in various file formats, even as a QR code. It is possible to zoom into the high-resolution image by opening it in a separate viewer (*Mirador*). Interestingly, there is a separate record for the image itself in which its metadata is disclosed, like the camera used and exposure time.[116] Additionally, colors extracted from the image can be downloaded as a color palette, the image itself can be cited, or its machine-readable data downloaded. The Fitzwilliam Museum's digital collection illustrates the possibilities when digital collection data is made available. Examining the Fitzwilliam Museum's digital collection against MoMA's further shows that digital collections can be improved upon with additional archival materials, data, and tools to enhance functionality. This comparison highlights disparities in the amount of information and the type of access museums provide to artworks and data in their digital representations of the collections. The next section focuses on platform types and their differences.

114 *Exhibition History,* MoMA, accessed December 14, 2016, https://www.moma.org/calendar/exhibitions/history.

115 *Collection*, the Fitzwilliam Museum, accessed May 20, 2024, https://fitzmuseum.cam.ac.uk/explore-our-collection.

116 *Collection*, the Fitzwilliam Museum. Image view.

Digital Collection Terminology

Under the current technological conditions, the question arises about what this means for the digital representation of an art collection as opposed to printed collection catalogs. Artworks from the museum's collections no longer hang exclusively on the walls, provided that the works are visible at all and not locked away in storage. Artworks gain increased visibility via online collections usually titled "*Collection Online*," "*Online Collection*," "*Digital Collection*," or simply "*Collection*."

Table 3 lists the five most visited museums in Switzerland, Austria, Germany, Europe, and the United States in 2019. Notably, among museums in German-speaking countries, "*Collection Online*" is the preferred designation for the digital collection (*dark yellow*), while those in English-speaking countries use simply "*Collection*" (*light yellow*). Since these designations reveal different attitudes toward digital collections, this observation is crucial.

Collections referred to as "*Collection Online*" offer a limited range of functions primarily geared towards providing the public with the contents of the collection database. Such digital collections draw heavily from the early model of how museums took their collections online. The appearance and operation are kept simple: Through a search, users usually find an image and basic information about the work, sometimes also short descriptions.[117] Searches are often limited to very few categories, such as artist name or date, and include only the contents of the collection database, without considering data from other databases within the same museum.[118] The term "*Collection Online*" emphasizes that online access to the collection is entirely distinct from the museum's physical collection.

Digital collections labeled "*Collection*" represent a more inclusive idea of what constitutes a collection. By dispensing with "online," the separation between physical collection objects and the digital collection is eliminated, bringing the collection in its entirety into focus, independent of the media context. Further differences between more traditional digital collections and those that recognize the digital presence of the collection as a fundamentally new field of activity are discussed in later chapters.

"*Collection Online*" refers to a museum's digital presence that provides basic access to artwork records. "*Digital Collection*," while used as a synonym for "*Collection Online*," implies a more advanced online presence, incorporating applications that present collection contents in engaging ways and offering access to data (images and metadata).[119] Therefore, "*Digital Collection*" is preferred when

117 Kirk Alexander, "The Visualization of Art History: The Role of Databases in Visual Thinking," *Visual Resources* 13, no. 3–4 (1998): 285, https://doi.org/10.1080/01973762.1998.9658423.

118 Alexander, "Visualization of Art History," 285.

119 For the definition of and difference between "*Collection Online*" and "*Digital Collection*," see

referring to a more comprehensive and sophisticated digital presence.

Table 3. *Digital collection terminology.* Extract from table 18 (appendix F)

List number	Country code	Art museum	Naming of digital collection	URL
1	CH	Fondation Beyeler	Sammlung	https://www.fondationbeyeler.ch/sammlung
2	CH	Kunsthaus Zürich	Sammlung Online	https://collection.kunsthaus.ch
3	CH	Kunstmuseum Basel	Sammlung Online	https://sammlungonline.kunstmuseumbasel.ch/eMP/eMuseumPlus
4	CH	Fondation Pierre Gianadda	none	none
5	CH	Zentrum Paul Klee	Sammlung online	http://www.emuseum.zpk.org/eMuseumPlus
6	AT	Kunsthistorisches Museum	Online-Sammlung	https://www.khm.at/objektdb
7	AT	Belvedere	Sammlung Online	https://sammlung.belvedere.at
8	AT	Albertina	Sammlungen Online	https://sammlungenonline.albertina.at
9	AT	Leopold Museum	none	none
10	AT	MUMOK	Onlinesammlung	https://www.mumok.at/de/collection/online-collection
11	DE	Städel Museum	Digitale Sammlung	https://sammlung.staedelmuseum.de
12	DE	Alte Pinakothek	Online-Sammlung	https://www.sammlung.pinakothek.de
13	DE	K20/K21	Highlights der Sammlung	https://www.kunstsammlung.de/de/collection/artists/
14	DE	Museum Barberini	Sammlung	https://sammlung.museum-barberini.de
15	DE	Alte Nationalgalerie	Online-Datenbank der Sammlungen	https://www.smb-digital.de/eMuseumPlus
16	EUR	Louvre	Collections	https://collections.louvre.fr
17	EUR	Musei Vaticani	Catalogo online	https://catalogo.museivaticani.va
18	EUR	British Museum	Collection online	https://www.britishmuseum.org/collection
19	EUR	Tate Modern	Our Collection	https://www.tate.org.uk/search
20	EUR	National Gallery	Collection	https://www.nationalgallery.org.uk/paintings
21	USA	The Met	Collection	https://www.metmuseum.org/art/collection
22	USA	National Gallery of Art	Collection	https://www.nga.gov/collection
23	USA	MoMA	The Collection	https://www.moma.org/collection
24	USA	National Portrait Gallery	The Portraits	https://npg.si.edu/portraits
25	USA	Art Institute of Chicago	The Collection	https://www.artic.edu/collection

also Gasser, "Das Digitalisat als Objekt der Begierde: Anforderungen an digitale Sammlungen für Forschung in der Digitalen Kunstgeschichte," in Objekte im Netz: Wissenschaftliche Sammlungen im digitalen Wandel, ed. Udo Andraschke and Sarah Wagner (transcript, 2020), 266, https://doi.org/10.14361/9783839455715-019.

Openness and Accessibility of Data in Digital Collections

Table 4. *Types of digital collection data access.* Extract from table 18 (appendix F)

List number	Country code	Art museum	Citable URL / permalink / DOI	Image: high-res.; zoom IIIF (International Image Interoperability Framework)	Use of public domain images	Public Domain Mark/Creative Commons (for public domain works)	Download: image	Download: metadata	Open data	Public API	Conclusion: traditional collection online?	Digital strategy
1	CH	Fondation Beyeler	×	×	×	×	×	×	×	×	yes	×
2	CH	Kunsthaus Zürich	×	×	×	×	~	×	×	×	yes	×
3	CH	Kunstmuseum Basel	o very long	×	o	×	o	×	×	×	yes	×
4	CH	Fondation Pierre Gianadda									none	×
5	CH	Zentrum Paul Klee	×	×	×	×	×	×	×	×	yes	×
21	USA	The Met	o	o	o	o	o	×	o	o	no	o https://www.metmuseum.org/blogs/digital-underground/2015/next-steps-digital-revolution
22	USA	National Gallery of Art	o	o	o	o	o	×	o	×	no	×
23	USA	MoMA	o	o	×	×	×	×	o	o	no	o https://enfilade18thc.com/2014/02/12/fiona-romeo-appointed-momas-first-director-of-digital-content-and-strategy/
24	USA	National Portrait Gallery	o	o	o	o	o	o	o	o	no	o https://www.si.edu/content/pdf/about/web-new- media-strategy_v1.0.pdf
25	USA	Art Institute of Chicago	o	o	o	o	o	×	o	o	no	o https://www.artic.edu/articles/713/behind-the-scenes-of-the-website-redesign

o present, × not present, ~ save image possible

The distinction between "*Collection Online*" and a "*Digital Collection*" becomes clearer when comparing a few technical details. The degree of openness and accessibility of a museum's collection depends on several factors. Looking at another extract from the overall table 18 (table 4), which provides insights into the accessibility of images and metadata for data reuse, the difference between the Swiss and American museums becomes particularly evident. American museums' artwork records are citable via stable and short links, images can be viewed in high resolution, and, in most cases, the download of images is explicitly permitted using the Creative Commons public domain dedication tool (Creative Commons Zero) for public domain works. Access to data is permitted via a machine-readable interface (API). Behind this is an "Open Data Policy"[120] that communicates the institution's attitude

120 "Open Data Policy," Rijksmuseum, accessed December 27, 2024, https://www.rijksmuseum.nl/en/research/conduct-research/data/policy; "Open Access Policy," Met, accessed

and is tied to a digital strategy[121] that defines a framework and goals for the museum's digital initiatives. Swiss museums are comparatively restrictive in that images can only be displayed in a limited size, and the further use of the data by third parties is not considered. As a result, neither data access is offered, nor does the institution have a digital strategy. A self-contained online collection can be defined as a traditional digital collection, while a digital collection is open to different users and is understood as a resource for other applications.

Museums' online collections provide a large number of images and information about documented artworks. One advantage is that fragile artworks and those not on public display are thereby accessible to everyone online. A major drawback from a data-oriented perspective is that many museums limit their digital collections and corresponding data to the bare essentials, overlooking how digital images and technology are reshaping established approaches. Art historians have long referred to printed reproductions rather than originals for research. Today, digital images and computational tools offer new ways to explore and analyze artworks, moving beyond printed books and catalogs. Cultural institutions' digital collections should therefore meet user needs specific to the medium, ultimately laying the foundation for knowledge generation in the digital age. When images

December 27, 2024, https://www.metmuseum.org/about-the-met/policies-and-documents/image-resources, Cleveland Museum of Art, accessed December 27, 2024, https://www.clevelandart.org/open-access, Art Institute of Chicago, accessed December 27, 2024, https://www.artic.edu/open-access/open-access-images, National Gallery of Art, accessed December 27, 2024, https://www.nga.gov/notices/open-access-policy.html; "Open Content Program," Getty, accessed December 27, 2024, https://www.getty.edu/about/whatwedo/opencontent.html; and "Open Content Policy," Belvedere, accessed December 27, 2024, https://sammlung.belvedere.at/opencontent. GLAM-E Lab, accessed December 27, 2024, https://www.glamelab.org/. Open data policies, called various names and titles, are accessible online. Additionally, the GLAM-E Lab provides guidelines and templates for museums developing open access policies.

121 See examples: "Digitale Strategie," Bayerische Staatsgemäldesammlungen, accessed December 27, 2024, https://www.digital.pinakothek.de; "Ein neues Haus für die Kunstsammlung Nordrhein-Westfalen: Vorstellung der Digitalstrategie," Kunstsammlung Nordrhein-Westfalen, accessed March 19, 2022, https://docplayer.org/28001904-Ein-neues-haus-fuer-die-kunstsammlung-nordrhein-westfalen-vorstellung-der-digitalstrategie.html (site discontinued); "Digitale Strategie," Städel Museum, accessed December 27, 2024, https://www.staedelmuseum.de/de/digitale-strategie; "Digitales Manifest," Stiftung Preußischer Kulturbesitz, accessed December 27, 2024, https://www.preussischer-kulturbesitz.de/schwerpunkte/digitalisierung/digitales-manifest.html; "Tate Digital Strategy 2013–15: Digital as a Dimension of Everything," Tate, accessed December 27, 2024, https://www.tate.org.uk/research/tate-papers/19/tate-digital-strategy-2013-15-digital-as-a-dimension-of-everything.

and artwork information are understood as data and as material for use in other projects, certain technological foundations for organizing and structuring information become essential. These are discussed in the next section 2.3.

2.3 Foundations of Collection Databases

Studying digital collections requires examining the importance of databases in museum collection management, as they are inextricably linked to publicly accessible digital collection. Additionally, databases serve as repositories of digital images for art historical research, raising the question of what role museums' digital collections play in this regard. The cataloging of artworks, as seen in digital collections today, predates the use of digital technology for this purpose.

A look at the roots of cataloging tools and knowledge systems clarifies the core principle behind using databases for collection management. Institutions have always needed to maintain a collection overview in assembling basic information about its objects. Historically, this information was organized by creating inventory catalogs—a principle that has remained unchanged since the medieval era.[122] Structuring this information according to specific categories ensures that content can be easily found in large collections.

Within institutions, a practical question related to information structure is how to organize physical objects in a collection so they can be stored and effortlessly found. In the analog era, different solutions emerged in libraries and museums, which still form the basis for database structures used for library catalogs and collection management. In librarianship, the *Dewey Decimal Classification System (DDC)* and the *Library of Congress Classification System (LCC)* emerged as two numbering systems to physically organize books on the shelves by subject and author.[123] Museum objects are managed and organized similarly. Unlike a library classification, which is a unique number for a book and also indicates its location on the shelf, two complementary numbering systems, an inventory number and a location number must be combined to find museum objects.

Inventory numbers for each collection object are unique and available to the public. In contrast, location numbers, which are assigned to storage areas

122 Michael W. Handis, "The Historical Use of Catalogs in the Arrangement of Knowledge in Libraries, Archives, and Museums: A Survey," in *Organization, Representation and Description Through the Digital Age: Information in Libraries, Archives and Museums*, ed. Christine M. Angel and Caroline Fuchs (De Gruyter Saur, 2018), 13, https://doi.org/10.1515/9783110337419-002.

123 Handis, "Historical Use of Catalogs," 14.

rather than individual objects, are known only to museum staff and help track an object's whereabouts within museum storage. Location numbers are not static, as objects may be relocated due to loans, exhibitions, conservation work, or reorganization. Without both the inventory and location numbers, finding a specific object in a large collection can be challenging. A location number may also reflect an artwork's materiality, as paintings, sculptures, drawings, prints, photographs, and other media require different storage conditions and are usually kept in separate areas. This physical separation makes it difficult to find works by the same artist across different media or to locate artworks based on thematic categories like landscapes. The list of chronologically assigned numbers in an inventory book is overwhelming as well. For that reason, card catalogs provided a solution for a long time, allowing objects to be indexed and retrieved based on alternative classifications and categories.

In art museums, artist names are usually a prerequisite for locating the works via analog directories. If subjects like portraits of women also need to be findable, a second card catalog organized by subject must be maintained, including this particular category. In the era of analog documentation, the logical structure of numbering systems and finding aids determined the criteria by which artworks could be located. Today, the use of databases for collection management has the advantage that any recorded information can be accessed through full-text search, with results easily filtered. This enables countless access points and specific search queries. To ensure that various accesses and searches yield meaningful results, more advanced classifications than those used in analog systems are required for consistent, well-structured data. Databases offer the flexibility to continuously enrich data records and link them in different constellations.

Museum Databases

The facilitation that databases bring to keep track of collections is why information technologies now play an important role in museums, archives, and libraries in managing collections and running day-to-day operations. Museum management databases like *MuseumPlus* and *The Museum System (TMS)* not only include the inventory of the collection, but also serve for organizing internal exhibitions, loans to other museums, transportation, or

contact management.[124] Each cultural institution and its collection is unique and work processes differ in various sectors. Different software is used in museums, archives, and libraries, and it may even vary slightly from one institution to another. There are nevertheless technological criteria that apply to them all that must be taken into account when digitizing collections.

In short, museum documentation consists of collecting information about objects, structuring and classifying it, and adding it to an inventory catalog.[125] For the inventory in databases, controlled vocabularies and thesauri are integral to transferring data into a documentation and system language, for classification, and to ensure retrieval of information.[126] Usually, the digital record of an artwork includes metadata like title, artist, dating, technique, material, measures, provenance, literature entries, and so on, along with a documentary image and sometimes a short text for wall labels or to be included in the digital collection record. Digital collection management makes it easier to find artworks by providing more search categories that draw on all the information available in a record in addition to being able to cross-reference or link artworks. This is a critical advantage over more rigid analog recording systems in which, for example, the chronological order in which the works were acquired by the institution and written down can be limiting. Information can be updated daily, for example, to add new acquisitions, additional documentary information, or to record when an artwork is temporarily on loan to another museum. Furthermore, databases can provide a digital workflow for museum staff, enable automatic export of loan agreements, and support contact management. A database offers much flexibility for the daily operations of a museum.

Documentation based on a collection management database means centralizing and linking information that was previously scattered in analog form across various sources, often spanning many decades of an institution's collecting activities. By storing information centrally in one place for immediate access, documentation is more comprehensive than ever before, but it is labor-intensive for museum staff to systematically process all

124 *MuseumPlus*, developed by Zetcom, https://www.zetcom.com/en/products_en/; and *The Museum System (TMS)*, developed by Gallery Systems, https://www.gallerysystems.com/ are the most widely used museum and collection management software. The following sources provide overviews of commercial and noncommercial museum software: "Choose Collections Software," Collections Trust, accessed March 19, 2022, https://collectionstrust.org.uk/software/; "Museumssoftware," Capterra, accessed March 19, 2022, https://www.capterra.ch/directory/30745/museum/software; "Best Museum Software," G2, accessed March 19, 2022, https://www.g2.com/categories/museum; "Best Museum Software," SourceForge, accessed March 19, 2022, https://sourceforge.net/software/museum/.

125 Hildegard Katharina Vieregg, *Museumswissenschaften: Eine Einführung* (Wilhelm Fink, 2006), 24.

126 Vieregg, *Museumswissenschaften*, 24.

information for the entire collection. Digitalization of the collection takes time and therefore parallel structures of analog and digital documentation coexist.[127] General information about an object such as inventory number, artist's name, work title, material, technique, location, exhibition history, and bibliographical references may be found in a card catalog. Further information like purchase prices and donors is recorded in an inventory book, which lists the objects in chronological order by accession number. More recent acquisition documents are collected in documentary dossiers. Information about the donor and the year of acquisition can be looked up in museum's annual reports. The measurements must be taken by inspecting the original artwork. For documenting provenance, invoices and bills of lading contain information.[128] Gathering many bits of information from consulting a wide variety of sources is a laborious process that requires human and financial resources, as well as considerable time before the information is fully available in the database. The creation of an image for each artwork is another step in the long process. For this reason, it takes years before a museum's collection is fully accessible to the public online. Initially, only the most important information about the artworks was prioritized, but this is changing.

Users of digital collections, especially researchers, should bear in mind that these often do not represent the entire physical collection.[129] The material that has already been digitized may be complete on certain topics and include, for example, the most prominent works in the collection, which are often accessible via a highlights category. In most cases, it can be assumed that the available material is random. While paintings are probably well represented, there are likely to be numerous gaps in the often much larger holdings of works on paper. For outsiders, it is usually not obvious what or why something is in a digital collection or in what state they may find it. For

127 Dorothee Haffner, "Standardisierung der Daten und der Datenstruktur, automatisierte Abläufe," in *Handbuch Museum: Geschichte, Aufgaben, Perspektiven*, ed. Markus Walz (J.B. Metzler, 2016), 192–193.

128 For a comprehensive list of the most commonly used metadata categories in art museum databases in line with cataloging standards, refer to *Categories for the Description of Works of Art (CDWA)*, J. Paul Getty Trust, published and revised in 2024, accessed December 27, 2024, https://www.getty.edu/research/publications/electronic_publications/cdwa/categories.html; and *Cataloging Cultural Objects (CCO)*, Visual Resources Association, accessed December 27, 2024, https://www.vraweb.org/cco.

129 *Otevřené sbírky*, Wikimedia Česká republika, accessed December 27, 2024, https://otevrenesbirky.cz. This interactive application shows that there are 414 museums in the Czech Republic in the register of public collections with the Ministry of Culture. In 2022, 5.3 % (1,300,000) of collection objects were accessible online, 9.2 % (2,400,000) collection objects were digitized but not yet online, and 85.5 % (22,600,000) objects were not yet digitized.

this reason, it is useful when museums communicate that digitization is still in progress and outline which parts of the collection have already been digitized.[130]

Early on, it was recognized that the use of databases in museums facilitated collection management by providing centralized access to documentation for curators, conservators, registrars, and ultimately the general public.[131] Documenting a collection to meet museum needs is just one perspective on indispensable art information; another is scholarly interest. Michael Greenhalgh explores teaching and learning in art history in the age of digital collections, arguing that digital humanities should engage not only lecturers and students but also curators, museum staff managing large collections, and other historians working with images.[132] Considering a diverse group of stakeholders is essential, as the documentation of artworks is valuable beyond museums. Since different users have varying requirements for digital collections, museums must address both internal needs and those of researchers when publishing their collections online.

Table 5. *Digital collection vocabularies and structured data*

Vocabulary / Repository of structured data	URL
Virtual International Authority File (VIAF)	https://viaf.org
Library of Congress Name Authority File (LCNAF)	https://id.loc.gov/authorities/names.html
Gemeinsame Normdatei (GND)	https://www.dnb.de/gnd
Art & Architecture Thesaurus (AAT)	https://www.getty.edu/research/tools/vocabularies/aat/
Union List of Artist Names (ULAN)	https://www.getty.edu/research/tools/vocabularies/ulan/
Thesaurus of Geographic Names (TGN)	https://www.getty.edu/research/tools/vocabularies/tgn/
Cultural Objects Name Authority (CONA)	https://www.getty.edu/research/tools/vocabularies/cona/
Iconclass	https://www.iconclass.org
Wikidata	https://www.wikidata.org

Data Standards

Data standards both structure the data within the database and support different user needs. Along with the use of databases and increasingly comprehensive and structured information, terminology is important and should be used consistently throughout the collection to ensure the data's machine

130 See "Facts About the Collection," Statens Museum for Kunst (SMK), accessed March 1, 2022, https://www.smk.dk/en/article/smk-open/; or "About the Online Collections," Georgia O'Keeffe Museum, accessed March 1, 2022, https://collections.okeeffemuseum.org/about/.

131 Michael Greenhalgh, "Art History," in *A Companion to Digital Humanities*, ed. Susan Schreibman et al. (Blackwell, 2004), 31, https://doi.org/10.1002/9780470999875.ch.

132 Greenhalgh, "Art History," 31.

processability. Standards used across institutions are therefore advantageous. While field catalogs define and structure essential information, controlled vocabularies (in the form of authority files), classifications, and thesauri enable standardized entries.[133] Table 5 gives an overview of the most important authority files, vocabularies, and repositories of structured data for digital collections of art. The first two authority files originate from the library sector, as libraries have been at the forefront of developing controlled vocabularies. The *Virtual International Authority File (VIAF)* combines multiple authority files from libraries, archives, and museums to form one authority service. This includes the *Library of Congress Name Authority File (LCNAF)*, which contains proper names, organizations, places, events, and titles. The equivalent used in German-speaking countries is the *Gemeinsame Normdatei* (*GND*, in English: Integrated Authority File), the international authority file for the organization of proper names, corporate bodies, subject headings, and geographical place names. From an international perspective and in the context of multilingual digital collections, it is a disadvantage that the *GND* is focused on the German-speaking world. The limitations of library authority files for art museum databases stem not only from linguistic factors but also from the need for more specialized standards to ensure adequate coverage of art.

The Getty Research Institute (GRI) is a leading international player dedicated to the creation of controlled art history vocabularies, all of which are available as linked open data (LOD). Several *Getty Vocabularies*[134] serve different purposes and include terms in multiple languages. Using these vocabularies in collection databases enhances the connectivity of entries and the discoverability of artists and artworks across individual institution databases worldwide. Due to the ongoing translations, which are being carried out in collaboration with documentation and translation projects worldwide, the terms in these vocabularies only partially cover certain areas and languages beyond English.[135] This limits the vocabularies' usefulness for databases in other linguistic regions. For systematic art recording, *Art & Architecture Thesaurus (AAT)* includes terms to describe fine art, architecture, decorative arts, material culture, and archival materials. The *Union List of Artist Names (ULAN)* is available for unambiguous referencing of an artwork's creator, but also other parties involved like designers, manufacturers, and corporate

133 Haffner, "Standardisierung der Daten," 191.

134 *Getty Vocabularies*, Getty Research Institute, accessed December 27, 2024, https://www.getty.edu/research/tools/vocabularies/.

135 Regarding additions to the vocabularies, see "Contribute to the Getty Vocabularies," Getty Research Institute, accessed December 27, 2024, https://www.getty.edu/research/tools/vocabularies/contribute.html.

bodies, in addition to, biographical information, relationships, and sources. *Thesaurus of Geographic Names (TGN)* contains place names, including historical ones, unlike *GeoNames*,[136] addressing a challenge specific to the cultural domain of place names that may have changed over time. Finally, the *Cultural Objects Name Authority (CONA)* aims to standardize object descriptions. In addition to *Getty Vocabularies*, *Iconclass* must be mentioned, which was started before the computer era as an iconographical classification system for art but is now available in machine-readable format as linked open data.[137] *Iconclass* is a multilingual, subject-specific classification system for the iconographic description of art used by museums and art institutions. There is some overlap between *Iconclass* and *AAT*, but the content and focus largely differ.[138] Art historians, researchers, and curators use it to describe, classify, and examine the subject of images represented in various media. Additionally, *Wikidata* contains structured data from *Wikipedia* and other Wikimedia projects, but also integrates *VIAF*, *GND*, *AAT*, *Iconclass*, and data from museums.[139] As the repository for structured data used in Wikimedia projects, it can be understood as an extensive vocabulary.[140] Nevertheless, as a multilingual knowledge graph, *Wikidata* is a rich resource for digital collections extending well beyond vocabulary. Karim Tharani defines *Wikidata*'s ability to connect collection databases in a broad global context, which allows computers to analyze interlinked data sources as follows.

> **Wikidata is an open, free, collaborative, and centralized knowledgebase of structured linked data that serves as a global hub for integrating and linking local metadata with a network of multilingual and machine-readable metadata over the web.[141]**

136 GeoNames, Unxos GmbH, accessed December 27, 2024, https://www.geonames.org.

137 Greenhalgh, "Art History," under "Text Databases."

138 Anna Breit, "Interlinking Iconclass Data with Concepts of Art & Architecture Thesaurus," in *Proceedings of the 1st International Workshop on Artificial Intelligence for Historical Image Enrichment and Access*, ed. Yalemisew Abgaz et al. (European Language Resources Association, 2020), 11–12, accessed October 26, 2024, https://aclanthology.org/2020.ai4hi-1.2/.

139 Angela Kailus and Regine Stein, "Besser vernetzt: Über den Mehrwert von Standards und Normdaten zur Bilderschließung," in *Computing Art Reader: Einführung in die digitale Kunstgeschichte*, ed. Piotr Kuroczyński et al. (arthistoricum.net, 2018), 135–136.

140 Sharon Mizota, "Change Is Good: Navigating Wikidata as a Controlled Descriptive Vocabulary," *Descriptive Notes*, March 30, 2021, accessed June 11, 2023, https://saadescription.wordpress.com/2021/03/30/change-is-good-navigating-wikidata-as-a-controlled-descriptive-vocabulary/.

141 Karim Tharani, "Much More Than a Mere Technology: A Systematic Review of Wikidata in Libraries," *The Journal of Academic Librarianship* 47, no. 2 (2021): 4, https://doi.org/10.1016/j.acalib.2021.102326.

The Georgia O'Keeffe Museum uses *AAT*, *ULAN*, *LCNAF*, and *Wikidata* to connect its different collections (artworks, photographs, archives, library, etc.) and, through linked open data, enables objects to be linked to other museum collections worldwide.[142] Hierarchically organized collections of definitions for objects, people, events, and concepts that are the subject of an image enhance the retrieval of works both within one and across databases.

In contrast to an enumerative scheme like libraries' strict *Dewey Decimal Classification System (DDC)*, a thesaurus has a more flexible polyhierarchy, where a subject term can appear in multiple places within the structure.[143] Hierarchical structures create relationships from broader to narrower categories, with an entry being a type of another category, a part of a category, or an instance of a category.[144] For example, an oil painting is a type of painting, the predella is a part of an altar, Vincent van Gogh's *The Starry Night* (1889) is an instance of artwork.

Digitization in Museums

Libraries have advanced quicker than museums in digitalization because they started using digital technologies early on for cataloging and building their digital infrastructure.[145] Since libraries do not usually collect unique objects, they formed alliances to exchange data. Data import and the associated standardization have therefore been a longtime issue. Likewise, it is a common practice for libraries to employ staff specialized in information management. Among museums, professionalization of infrastructure and organizational structure for effective use of digital technologies is still ongoing. Progress in digitization depends on the size of the collection, financial and human resources, and leadership's awareness of the importance of digitization.[146] Digitizing a collection is a mammoth undertaking that requires staff, time, financial resources, and ongoing maintenance of the data. Sustainability is achieved when the digital content is continuously used and technological advancements are regularly implemented. Digitization requires employees who are ready to embrace it. For younger generations, who are more comfortable with technology, working with databases is a matter of course because they appreciate the benefits and flexibility of data-driven

142 "Linking O'Keeffe: Collections Online as Linked Open Data," Georgia O'Keeffe Museum, accessed March 1, 2022, https://collections.okeeffemuseum.org/about/.

143 Richard Gartner, *Metadata: Shaping Knowledge from Antiquity to the Semantic Web* (Springer, 2016), 71.

144 Gartner, *Metadata*, 71.

145 Haffner, "Standardisierung der Daten," 192.

146 Haffner, "Standardisierung der Daten," 192.

work and are eager to push developments further.[147]

Certain functionalities that are common procedures in library and university databases could be useful in the data management of museums. For example, automated processes for machine-readable data exchange via standardized application programming interfaces (APIs), such as importing title data of publications by means of internationally standardized identifiers such as ISBN or DOI from library catalogs into reference management software.[148] Museum staff appreciate any timesaving automated tasks like importing literature references for artworks, import options for artworks from other collections or metadata for creating artist records, integration of controlled vocabularies through web services, or smooth data export and import for loans, from one database to another with a common data format.[149] Recently, the International Council of Museum's (ICOM) CIDOC Documentation Standards Working Group released the *Exhibition Object Data Exchange Model (EODEM)*, which will allow lending museums to export object's data from their database and borrowing museums to import the data into their database, all with a click of a button.[150] For museums, the transfer of data between different systems is in its infancy, but is an exciting foreseeable development.

Museums usually use commercially available database software for collection documentation and management. Databases serve first of all for the inventory and documentation of the collection, as well as for object management, exhibition management, organizing loans, and supporting workflows.[151] Museum employees are intended to be end-users of the museum management software, which is why no one at the museum is entrusted with programming tasks to continuously develop the system. As a result, users depend on external developers from the software company for any additional features, with progress and timelines governed by the company's

147 Haffner, "Standardisierung der Daten," 192.

148 Haffner, "Standardisierung der Daten," 193. Examples of well-known reference management software include: Zotero, developed by the Corporation for Digital Scholarship, accessed December 24, 2024, https://www.zotero.org; Citavi, developed by Lumivero, accessed December 24, 2024, https://www.citavi.com; Endnote, developed by Clarivate, accessed December 24, 2024, https://endnote.com; and Mendeley, developed by Elsevier, accessed December 24, 2024, https://www.mendeley.com.

149 Haffner, "Standardisierung der Daten," 193.

150 "EODEM," ICOM International Committee for Documentation (CIDOC), accessed April 14, 2023, https://cidoc.mini.icom.museum/working-groups/documentation-standards/eodem-home/.

151 Monika Hagedorn-Saupe, "Digitalisierung in deutschen Museen," in *Kulturgut aus Archiven, Bibliotheken und Museen im Internet: Neue Ansätze und Techniken*, ed. Gerald Maier and Thomas Fricke (Kohlhammer, 2004), 38–39.

schedule. Furthermore, financing must be available to commission further development and customization. General Director of the Bayerische Staatsgemäldesammlungen,[152] Bernhard Maaz, argues that the major disadvantage of proprietary software is the dependence on software suppliers and their schedule, and he dreams of a uniform software that could be used by all museums in Germany for free.[153] A centralized, flexible, and adaptable open-source software would be promising insofar as it could be continuously developed in-house to meet a museum's specific needs, requiring staff with programming skills. This capability would enable museums to drive developments in digital collections and easily and continuously expand offerings.

That said, the use of digital technology in museums has not significantly advanced beyond the three steps Monika Hagedorn-Saupe outlined almost two decades ago in the digitalization of museums. The first step she identified is working with computers. The second step is using databases, primarily for collection documentation, which typically follows the digitization of artworks through photography and the saving of digital images. The third step is the museum's presence on the Internet, which can include databases for research or virtual tours. This third step also includes for her interactive multimedia kiosks for visitors within the physical museum or online services that enhance engagement with art beyond the museum visit.[154] The distinction between collection documentation as an internal museum activity and using this data to engage the public, which is an external activity, remains relevant. Digital activities can be offered either online or within the museum. Nowadays, an app on a visitor's device is a great way to access digital content at the museum. The range of digital applications on a museum website can capture interest independent of going to a museum, like preparing for a visit or delving deeper into interesting content. Before being able to use a digital collection for advanced presentation and outreach, however, a functional system architecture is mandatory.

Collection and Digital Asset Management

Using and implementing databases in museums is complex, due to challenges such as coordinating various departments, managing a large collection, and dealing with historically developed structures. Typically, the implementation of such a system triggers processes that museums must navigate, as

152 Bayerische Staatsgemäldesammlungen (The Bavarian State Painting Collections) include Alte Pinakothek, Neue Pinakothek, Pinakothek der Moderne, Sammlung Schack, Museum Brandhorst in Munich, and more than a dozen state galleries across Bavaria.

153 Bernhard Maaz, *Das gedoppelte Museum: Erfolge, Bedürfnisse und Herausforderungen der digitalen Museumserweiterung für Museen, ihre Träger und Partner* (Walther König, 2020), 67.

154 Hagedorn-Saupe, "Digitalisierung in deutschen Museen," 39–40.

illustrated by the case of the Metropolitan Museum of Art in New York (Met). While consolidating multiple databases into one is beneficial, it also requires the standardization of data entry fields to ensure consistency across departments.[155] Since every department at the Met was responsible for their own collection when they started to use computer database systems in the 1980s, multiple systems existed as data silos within one department.[156] When one department began to use *The Museum System (TMS)* in 1994 for documentation of the collection, the existing databases were converted to *TMS* in the following years. However, seventeen curatorial departments were all using their separate version of the system until 2013 when the data was consolidated into a single database and made accessible to the public via web access.[157] Bringing together data from different sources requires a manual with institution-wide cataloging standards, defining field usage, establishing terminology, setting conventions for time periods and dates, standardizing authority entries, eliminating duplicates, and performing data clean-ups to ensure efficient searching and usability.[158] One advantage is that the registrar's workflow can be included in the database once it has become a centralized system with the records from all departments included "to track and document outgoing loans, with details about borrowers, venues, exhibitions, insurance costs, and display requirements."[159] In addition, a wide variety of reports can be generated within the database, among them official museum documents like acquisition and loan agreements, exhibition checklists, and packing lists.[160]

Collection management databases serve many purposes in the museum workflow but quickly reach their limits when managing media files created and used for various communication purposes. Therefore, image files documenting artworks and other media files created in different museum contexts are maintained separately in a digital asset management (DAM) system to keep them ready for different uses. The Met's DAM includes "master images of objects in its collections …, digitized historic images, visual records of special events, gallery views, construction photos, PDFs, audio files, and

155 Jennie Choi and Giovanna Fiorino-Innace, "Information Management Systems at the Metropolitan Museum of Art," in *Organization, Representation and Description Through the Digital Age: Information in Libraries, Archives and Museums*, ed. Christine M. Angel and Caroline Fuchs (De Gruyter Saur, 2018), 119–20, https://doi.org/10.1515/9783110337419-009.

156 Choi and Fiorino-Innace, "Information Management Systems," 122.

157 Choi and Fiorino-Innace, "Information Management Systems," 119–22.

158 Choi and Fiorino-Innace, "Information Management Systems," 123–26.

159 Choi and Fiorino-Innace, "Information Management Systems," 126.

160 Choi and Fiorino-Innace, "Information Management Systems," 126.

video."[161] The DAM delivers new files not only directly to *TMS*, the collection management database, but also to "the museum's various digital platforms, including the website, audio guide, gallery kiosks, and mobile app."[162] Automated synchronization with the collection database updates the artwork information (metadata) in the DAM and adds the image to the work record in the collection database. Therefore, content in the digital collection or another sophisticated platform on the museum website is sourced from both the museum database and the DAM. Museums rely on a comprehensive digital infrastructure to meet the requirements of various internal workflows and to provide data for various applications. Compared to the digital collections of museums, which include contents of complex databases, image archives created in art history departments at universities generally have a simpler structure. Image databases used for digital images of artworks in art historical research are comparable to a museum's DAM, which stores images and their metadata.

Digital Image Archives

Image archive databases for scholarly use have arisen out of art historians' need for flexibility in working with digital images. These digital image archives are the latest successors in the long tradition within university art history departments of collecting reproductions of artworks for teaching, with photography playing a leading role.[163] For a long time, only a few museums had digital collections, but by no means was the entire collection discoverable. Lack of access to digital images of artworks for research has led art historians to scanning images from printed exhibition catalogs and then organizing their digital images in databases for research and teaching.[164] Project-based work, as is common in academia, means that image archives assembled for personal research purposes and the digital images they contain are at high risk for loss.[165] Accompanying the digital transformation have been developments

161 Choi and Fiorino-Innace, "Information Management Systems," 122.

162 Choi and Fiorino-Innace, "Information Management Systems," 122.

163 See "Durch das Objektiv. Fotografie als Lehrmittel der Kunstgeschichte," Department of Art History, University of Innsbruck, accessed December 27, 2024, https://www.uibk.ac.at/kunstgeschichte/ausstellungen/durch-das-objektiv. Martina Baleva and Felix Tenhaef, together with their students, traced the development of the Department of Art History's teaching materials collection at the University of Innsbruck, emphasizing the relevance of photography as a key reproductive medium for art history.

164 Joan E. Beaudoin, "Specters in the Archive: Faculty Digital Image Collections and the Problems of Invisibility," *The Journal of Academic Librarianship* 37, no. 6 (2011), https://doi.org/10.1016/j.acalib.2011.07.005.

165 Beaudoin, "Specters in the Archive," 488–493.

that mitigate this problem.

Personal image archives stored locally on one's own computer are those with the highest risk of getting lost. The increasing practice of also publishing research data in a repository in accordance with the *FAIR Principles*[166] when publishing journal articles counteracts this loss.[167] However, for legal reasons, it may be impossible to publish an image dataset, as opposed to the compiled metadata. Image archives in university departments of art history are maintained on an institutional level and therefore more permanent. As aggregators of the content of databases created and maintained by various university departments of art history, databases like *ARTstor*[168] or *Prometheus*[169] give access to images for art historical research and enable searches across the content of the different databases. In addition to these databases operated by nonprofit organizations, both of which require a license and bring together scholarly content and images, the digital collections of GLAM institutions are also relevant to art historians as sources for research, presentations, and teaching.

Digital Collections and Images as Knowledge Resources

Unlike image databases, which are for researchers and require a password, anyone can access the image collections of museums, archives, and libraries. The uses for the images remain varied. Some institutions are quite restrictive with images of their collection and charge a license fee to generate revenue, while others, like the Rijksmuseum and the Met, as well as an increasing number of others, provide generous access to freely usable high-resolution images.[170] In recent years, digital collections have seen a surge in development, with more and more high-quality images becoming available directly from museums, representing valuable source material for art historical research. Files and data released directly by collecting institutions will become more important in the future. A cultural institution offering collection images and metadata typically provides higher-quality material than what is available in *Prometheus*, where images are frequently scanned from books and restricted to academic use due to legal reasons. Use of image material in

166 *FAIR Principles*, Go Fair, accessed December 27, 2024, https://www.go-fair.org/fair-principles/.

167 Two generalist repositories for research data are: Figshare, accessed December 27, 2024, https://figshare.com and Zenodo, CERN, accessed December 27, 2024, https://zenodo.org.

168 *ARTstor*, Ithaka, accessed August 1, 2023, https://www.artstor.org.

169 *Prometheus*, Kunsthistorisches Institut der Universität zu Köln, accessed December 27, 2024, https://www.prometheus-bildarchiv.de.

170 Michael Lesk, "The Convergence of Curation," in *Handbook of Science and Technology Convergence*, ed. William Sims Bainbridge and Mihail C. Roco (Springer Reference, 2016), 99, https://doi.org/10.1007/978-3-319-07052-0_83.

applications open to the public can be supported by the owning institution by adding licenses to the files and data that allow for reuse. For example, *Prometheus* has started incorporating the content of open access image databases such as the Rijksmuseum, HeidICON, or Corpus Vitrearum Medii Aevi.[171] This not only enhances the image archive itself but also gives works from a museum or cultural collection additional visibility.

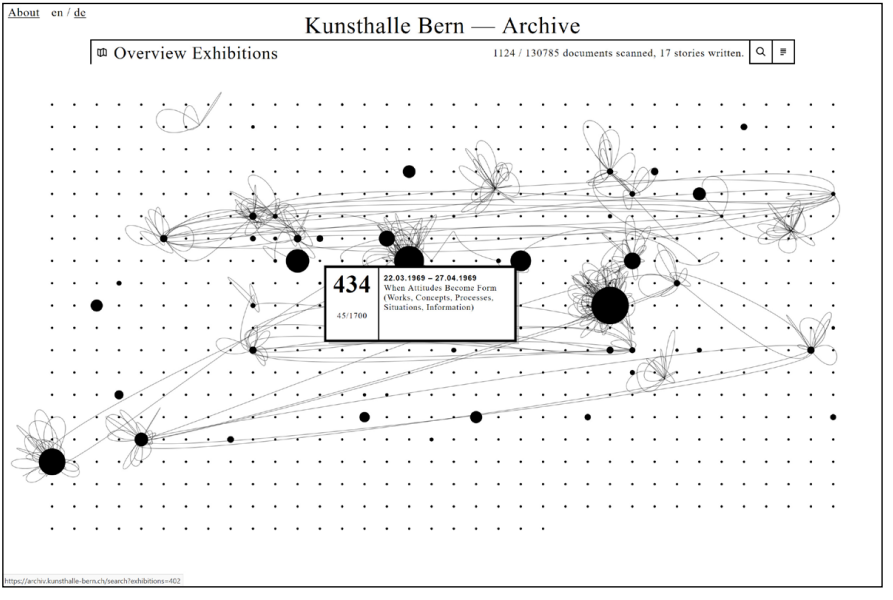


Figure 5. *Context menu for Kunsthalle Bern exhibition* When Attitudes Become Form *at* Kunsthalle Bern Archive*, accessed December 11, 2020, https://archiv.kunsthalle-bern.ch/en/overview*

For reasons of efficiency and to avoid frequent handling of fragile artworks or archival documents, it makes sense for institutions to provide unrestricted good quality digital images of a collection or archival material (within the limits of the law). When digitized material is not available and scholars create their own digital archives by taking pictures or scanning material they need for research, these digital images are only available to the individual researcher and are of low quality.

Kunsthalle Bern found a creative solution in connection with the

171 *Prometheus* lists all open access collections available on its website here: Open Access, *Prometheus*, accessed August 1, 2023, https://prometheus.uni-koeln.de/de/sources/open_access.

digitization of its archives to make individual researchers' efforts fruitful for others. An installed scanning system at the Kunsthalle lets archive visitors do the digitization to serve future researchers. When researchers visit the Kunsthalle archive, they are asked to digitize the documents they need using this system. By providing a customized database, the scans are then stored on the server making the documents available online. Aside from the technical infrastructure, the interface is also a central component by transparently showing the public what has already been digitized and what has not (fig. 5).[172] Displaying the exhibitions as dots in this data visualization supplies users an overview, while the size of the dots indicates how many documents from the archive have already been digitized. Moreover, connection lines map the research traces left by archive users who have scanned documents. These traces serve as access points to archive stories, where researchers briefly describe their topics and link to the documents they referenced in the text. The interactive application enables users to explore the archive. The documents' metadata, which include curator and artist names or keywords, build a network among assets and records. This makes digitized archival documents, such as correspondence related to a specific exhibition, accessible to anyone. This outstanding interface for accessing cultural data demonstrates that collaboration between cultural institutions, designers, and programmers is promising and can lead to compelling solutions for all stakeholders. Engaging the public is most effective when participants are intrinsically motivated to perform a task, like when it aligns with their personal interests. If their efforts also serve others, this adds additional incentive. When an institution like Kunsthalle Bern provides the technical infrastructure to facilitate specific tasks and users are willing to invest time and effort, it makes the maintenance and use of digital collections more sustainable. A transparent digitization process reveals the current state of the project to everyone, builds trust, and can be seen as an open invitation for others to participate.

Within a technological ecosystem, a basic prerequisite is keeping the users and their needs in mind, as well as the particularities of digital images. In an information society, museums and other institutions are content providers, just as archives and libraries. This makes collaboration between archives, libraries, and museums essential since they all contain similar material and have limited resources for new forms of information communication.[173] As a result, there is an increasing exchange of best practices and technological

172 "Online Archive," Kunsthalle Bern, accessed September 28, 2025, https://archiv.kunsthalle-bern.ch/en/.

173 Gerald Maier and Thomas Fricke, eds., *Kulturgut aus Archiven, Bibliotheken und Museen im Internet: Neue Ansätze und Techniken* (Kohlhammer, 2004), 9.

solutions for making cultural heritage accessible and solving problems in joint projects.[174]

In networked databases, images become mobile: they can move from one platform to another, be networked within a database or with external resources, and can be shared and annotated.[175] Digital images are more than just representations of artworks or objects; they play an active, multifaceted role in the production of knowledge.[176]

Users of Digital Content

When the boundaries between images, collections, and institutions dissolve, museums are called upon to pursue their mission on networked platforms that emerge as new spaces.[177] Users should be considered a diverse group of stakeholders, without making a division into producers inside the museum and consumers outside the museum.[178] Dissolution of the traditional division of roles between the curator who organizes a museum exhibition and the visitor who views works is essential when a museum gives access to collection data. If a museum decides to develop a digital application to attract users, it should understand that this is just one way of using collection data. People who engage with the digital collection might have other interests. Some may want to interact with the collection themselves, such as arranging their own small exhibition and sharing it publicly online, which Rijksmuseum offers (see page 224 for more details), for example. Others may want to use collection data for research using digital methods, and in this case, it is not enough to read individual records; access to the data itself is required. Similarly, the museum could benefit from a mutual exchange with the public. Users could help supplement the data with additional metadata, communicate corrections, or add information about the object if the museum allows and invites others to do it. Since crowdsourced tags are usually quite varied, this can be better controlled if there are controlled vocabularies in place. Furthermore, crowdsourced tags can be stored in the database separately from institutionally maintained metadata, so that it is clear from which source they originate and their accuracy can be vetted. The Los Angeles County Museum of Art has implemented such a feature so users can easily

174 Maier and Fricke, *Kulturgut aus Archiven*, 9.

175 Anne Beaulieu and Sarah de Rijcke, "Networked Knowledge and Epistemic Authority in the Development of Virtual Museums," in *Museums in a Digital Culture: How Art and Heritage Become Meaningful*, ed. Chiel van den Akker and Susan Legêne (Amsterdam University Press, 2016), 75.

176 Beaulieu and Rijcke, "Networked Knowledge," 75–77.

177 Beaulieu and Rijcke, "Networked Knowledge," 77.

178 Beaulieu and Rijcke, "Networked Knowledge," 77.

comment on and tag artworks in its *Collection*.[179] In this way, a museum can gain more knowledge from experts than previously reflected in an artwork's record. User-generated keywords can also make a work discoverable via vocabulary other than the terms assigned by the museum, which are often very general or very specialized, making them primarily relevant to experts. However, crowdsourcing must always overcome the challenge of incentivizing users to become contributors, which usually means that the museum's efforts must go beyond simply implementing a form in the digital collection. User-created metadata can be individually contributed or crowdsourced and addresses the specific needs and vocabularies of communities, such as affinity groups or hobbyists, and lies beyond information professionals would add.[180] User-generated metadata augments existing metadata in a relatively inexpensive way, but the museum also relinquishes some control over the data.[181] Despite its potential, contributions by the public are not utilized in most digital collections.

179 *Collection*, Los Angeles County Museum of Art, accessed December 27, 2024, https://collections.lacma.org.

180 Anne J. Gilliland, "Setting the Stage," in *Introduction to Metadata*, ed. Murtha Baca, 3rd ed. (Getty Research Institute, 2016), 8, accessed June 23, 2021, https://www.getty.edu/publications/intrometadata/setting-the-stage/.

181 Gilliland, "Setting the Stage," 8.

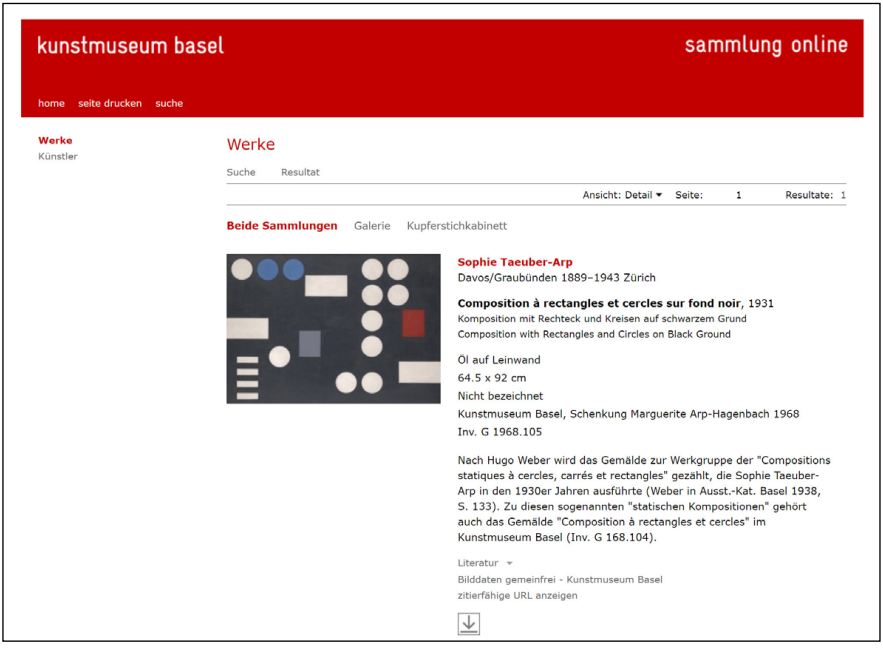


Figure 6. *Artwork record for Sophie Taeuber-*Arp's Composition with Rectangles and Circles on Black Ground *(1931) at* Sammlung Online*, Kunstmuseum Basel, accessed October 22, 2019, https://sammlungonline.kunstmuseumbasel.ch/eMuseumPlus?-service=ExternalInterface&module=collection&objectId=1568&viewType=detailView*

Linking Information, Objects, and Collections

Many museums' digital collections are still largely centered around traditional features when online collections first emerged. They are intended as an information source that can be consulted by users but cannot be modified or expanded. User activity is restricted to searching a relational database within a limited selection of data fields. Restricting search options at a very general level often only partly meets a user's needs. If search capabilities are limited to predefined categories and minimal published artworks information, much of digital technology's potential remains untapped. Moreover, the repetitive structure of how the artworks are found and represented makes the user experience monotonous. One such example is Kunstmuseum Basel's *Collection Online*, which has featured its current interface since 2010 (fig. 6). It provides a minimal search interface for finding artists and artworks and viewing individual artwork records. This presentation follows a uniform and

static principle: a keyword search and, unlike Kunstmuseum Basel, images of works from the digital collection make up an interface that offers access to information previously written on catalog cards or published in a printed collection catalog. The record for each item consists of a photograph and catalog information. Users can search the collection, zoom, crop, or move the image, print the image file, email it or save it to their desktop, and create their own collection on the platform.[182] The available information is confined to what is stored in the database and is intended for online presentation, thus forming a data silo. User interaction with the contents in such collection presentations is very limited. Museums could get more engagement by ensuring that the data is easier to use and linked. By processing data according to technological standards and providing machine-readable interfaces, it becomes possible to combine content from databases of different museums. This is crucial for the creation of knowledge, which results from the combination of many sources and rarely from the artworks in a single institution's collection.

Over the past two decades, initiatives have emerged to integrate collections from different institutions. The need for searches across various collections led to cultural heritage portals like *Europeana*,[183] *Deutsche Digitale Bibliothek (DDB)*,[184] or *Digital Public Library of America (DPLA)*[185] that allow searching across different databases on a unified discovery portal. Most of them include not only museums but also libraries and archives. The greatest potential of cultural heritage portals will be reached when the data-providing institutions support the Semantic Web. This requires that they enrich the metadata semantically using authority files (e.g., *GND*) and vocabularies (e.g., *Getty Vocabularies*). Semantically linking information creates relationships that support comprehensive searches.[186] When the platform provides the appropriate infrastructure, as is the case with *DPLA*, it supports GLAM institutions contributing to the network of linked open data on the web.[187] This holds true regardless of whether they encode their metadata as linked data, as an API provides access to metadata in the linked data format

182 Beaulieu and Rijcke, "Networked Knowledge," 79.

183 *Europeana*, Europeana Foundation, accessed December 27, 2024, https://www.europeana.eu/de.

184 *Deutsche Digitale Bibliothek (DDB)*, accessed December 27, 2024, https://www.deutsche-digitale-bibliothek.de.

185 *Digital Public Library of America (DPLA)*, accessed December 27, 2024, https://dp.la.

186 Ellen Euler et al., "Kulturportale im Web: Eine Einführung," in *Handbuch Kulturportale: Online-Angebote aus Kultur und Wissenschaft*, ed. Ellen Euler et al. (De Gruyter Saur, 2015), 9.

187 Samantha Norling, "Bringing the Archives Out of the Art Museum: Local Metadata Planning Within a Global Context," in *Organization, Representation and Description Through the Digital Age: Information in Libraries, Archives and Museums*, ed. Christine M. Angel and Caroline Fuchs (De Gruyter Saur, 2018), 257, https://doi.org/10.1515/9783110337419-018.

JSON-LD.[188] Shared infrastructures enable numerous cultural institutions to keep pace with the latest technological developments, which they might not be able to do independently.

As digital collections become increasingly sophisticated platforms, they rely on more complex technological foundations. To keep pace with other cultural institutions, inevitably museums will need to adapt to these changes. Cultural databases in libraries, archives and museums are moving towards linking structured data in the Semantic Web.[189] In contrast to the static, read-only websites of the early Internet and the cataloging of objects within community-specific domains with varying degrees of interoperability, the use of shareable metadata, advanced technological infrastructure, and tools has transformed how cultural institutions manage data.[190] These tools facilitate easy discovery and use of metadata, enabling the linking of cultural institutions' data within the Semantic Web.[191] By interlinking information about artworks, artists, historical events, and related concepts through linked data, a new structure emerges. This structure is formally represented in a domain-specific ontology that defines concepts, relationships, and properties. The resulting knowledge graph enables the discovery of new insights and correlations. This approach significantly enhances the exploration, research, and understanding of artworks, artists, and the broader cultural context within museums and art history.

188 Norling, "Bringing the Archives Out," 257.

189 Christine M. Angel and Caroline Fuchs, "Introduction," in *Organization, Representation and Description Through the Digital Age: Information in Libraries, Archives and Museums*, ed. Christine M. Angel and Caroline Fuchs (De Gruyter Saur, 2018), 1–10, https://doi.org/10.1515/9783110337419-001.

190 Christine M. Angel and Caroline Fuchs, "Preface," in *Organization, Representation and Description Through the Digital Age: Information in Libraries, Archives and Museums*, ed. Christine M. Angel and Caroline Fuchs (De Gruyter Saur, 2018), ix, https://doi.org/10.1515/9783110337419-202.

191 Angel and Fuchs, "Preface," ix.

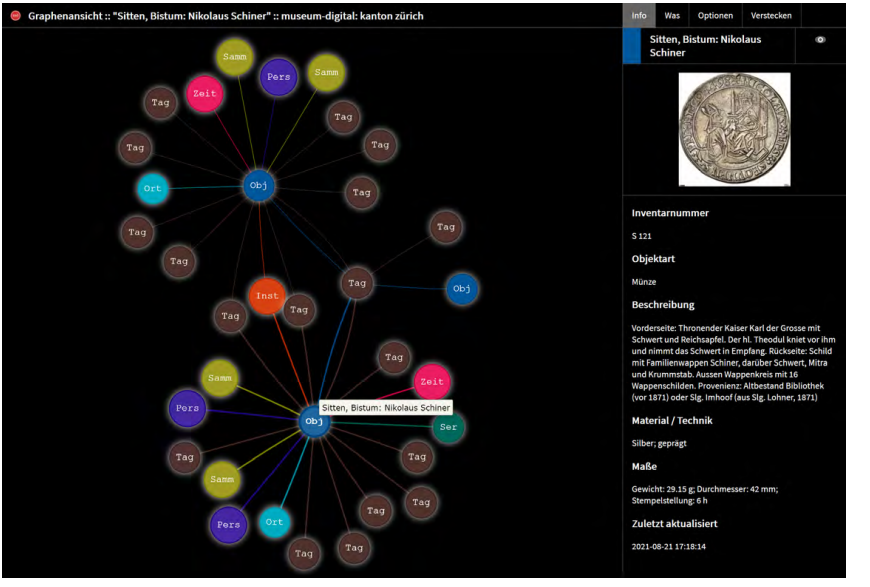


Figure 7. *Graph view of the silver coin* Sitten, Bistum: Nikolaus Schiner *(1498) showing relationships to two related objects at* Münzkabinett und Antikensammlung der Stadt Winterthur*, museum-digital, accessed September 10, 2021, https://zh.ch.museum-digital.org/graph.php?t=objekt&oges=211*

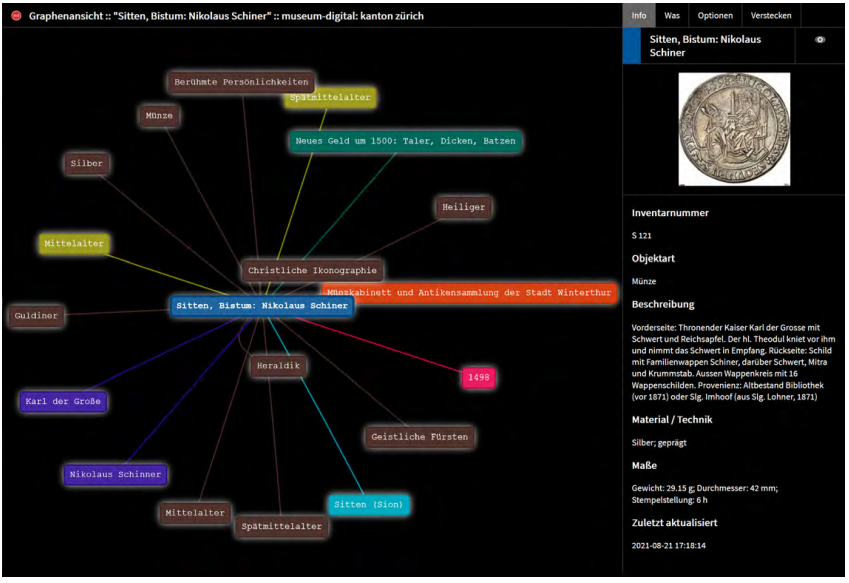


Figure 8. *Graph view of the silver coin* Sitten, Bistum: Nikolaus Schiner *(1498) featuring tags at* Münzkabinett und Antikensammlung der Stadt Winterthur*, museum-digital, accessed September 10, 2021, https://zh.ch.museum-digital.org/graph.php?t=objekt&oges=211*

To capitalize on linked data, a museum must either build the infrastructure itself or join an existing one like the community-driven initiative *museum-digital*.[192] The joint platform using linked open data was created in response to the need of local museums with limited personnel and financial resources to make the collection accessible to the public, and now also serves as an inventory and museum management solution.[193] When institutions join forces, no matter their size, they can be at the forefront of digitization and benefit from the use of linked data and shared tools to access and visualize the col-

192 *museum-digital*, accessed December 27, 2024, https://museum-digital.org.

193 See "museum-digital," museum-digital, accessed December 27, 2024, https://en.about.museum-digital.org/; and "musdb," museum-digital, accessed December 27, 2024, https://en.about.museum-digital.org/software/musdb/.

lection.[194] This data structure makes it possible for the platform to provide access to individual museum collections, but it also supports cross-institutional searching by offering alternative access to find objects in collections of all participating institutions or in those of a specific country.[195] *Museum-digital* exemplifies mutual connectivity between different collections as well as the findability of objects beyond the holdings of a single institution. Linked open data means that numerous controlled vocabularies are in use for metadata of the objects and that the data from all participating collections can be flexibly used in various visualizations. Users have the option of switching to a graph view, which makes visible an object's linked data structure, as seen in the example of a coin from the Münzkabinett Winterthur[196] (fig. 7). In such a network, terms from controlled vocabularies are represented by different colored bubbles, indicating the institution (*orange*), tags (*brown*) or persons (*dark blue*), date (*pink*), and building the linking nodes to other objects (*blue*). More meaningful than the node category is the object or term the individual node represents. For further insight, the tag view (fig. 8) displays the title of the coin as the object in the center, surrounded by the keywords from controlled vocabularies, including the institution: Coin Cabinet Winterthur (*orange*), date: 1498 (*pink*), the person: Charlemagne, who is the subject depicted enthroned on the coin, but also the tag: coin (*brown*), etc. The graph view of a single collection object demonstrates the LOD's potential when interconnected objects and a range of knowledge resources form a comprehensive network of cultural data.

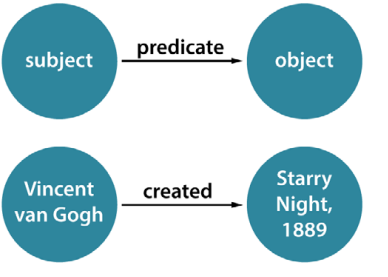


Figure 9. RDF triple*, which consists of a subject, predicate, and object*
Designed by Sonja Gasser, CC BY 4.0

194 *KIMnet*, Kulturerbe Informationsmanagement Schweiz (KIM.ch), accessed December 27, 2024, https://www.kimnet.ch/; and *Porta Cultura*, Amt für Kultur Graubünden, accessed December 27, 2024, https://portacultura.gr.ch/. Both projects went live in April 2024 and share similar objectives. While *KIMnet* is a platform of 50 Swiss local museums from the cantons of Aargau, Basel-Landschaft, Bern, and Solothurn, *Porta Cultura* combines collections of local museums from the canton of Grisons.

195 The global access point to *museum-digital* is: https://global.museum-digital.org; and the German portal is: https://nat.museum-digital.de.

196 *Münzkabinett und Antikensammlung der Stadt Winterthur*, museum-digital, accessed March 27, 2023, https://zh.ch.museum-digital.org/index.php?t=institution&instnr=1.

Museums must make their records shareable as LOD across institutions in order to contribute to the global network of cultural knowledge. With LOD, information is organized in the Resource Description Framework (RDF) data model, which is a directed graph consisting of semantic triples in a subject-predicate-object form (fig. 9).[197]

When referring to objects or digital objects and the Semantic Web, they are not necessarily identical to the object in a museum's collection or its digitized counterpart. "Object" in the museum field means a physical cultural artifact that becomes a "digital object" in the digitized version. However, the term "object" is also used in computer science, often in the context of databases, information structures, and the Semantic Web. In this sense, the object is a data object. Such data objects can be a value or a group of values that create meaning, have a unique data type, are referenced with an identifier, and are represented in a data model establishing relationships between data objects. A "digital object" like a digital image or a record of an artwork, is also a "data object." When the term is used throughout this book, "object" in some cases refers to an artwork in a collection, and in other cases to a data object, depending on the context.

Technically, data objects are uniquely addressable to ensure stable connections for queries. In the context of linked data, each element of an RDF triple is associated with a unique Universal Resource Identifier (URI).[198] SPARQL serves as the query language for searching within the RDF graph.[199] The effectiveness of this structure relies on metadata standards that describe the content of the data. Dublin Core,[200] for example, is a metadata standard for a general description of digital objects and documents. For more detailed descriptions, the RDF model is used, which organizes data into triples that are usually taken from formal authority files.[201] LOD means that the objects and subjects in one database are linked to similarly structured data in other databases.[202] Ontologies, semantic triples, authority files, and controlled vocabularies enable a deeper, human- and machine-readable indexing of digital information.[203] Using a common ontology enables information exchange between heterogeneous sources by semantically defining disparate

197 Lesk, "The Convergence of Curation," 103.

198 Piotr Kuroczyński, "Neuer Forschungsraum für die Kunstgeschichte: Virtuelle Forschungsumgebungen für digitale 3D-Rekonstruktionen," in *Computing Art Reader: Einführung in die digitale Kunstgeschichte*, ed. Piotr Kuroczyński et al. (arthistoricum.net, 2018), 169.

199 Lesk, "The Convergence of Curation," 103.

200 Dublin Core, Dublin Core Metadata Initiative, accessed September 2, 2020, https://dublincore.org/.

201 Lesk, "The Convergence of Curation," 105.

202 Kuroczyński, "Neuer Forschungsraum für die Kunstgeschichte," 169–170.

203 Kuroczyński, "Neuer Forschungsraum für die Kunstgeschichte," 170.

data through LOD and the RDF standard.[204] The formal representation of data in RDF triples embeds each item in a context with other data.[205] RDF triples are usually composed of items from a domain-specific ontology.[206] In the domain of museums, *CIDOC CRM*, the Conceptual Reference Model (CRM) developed by ICOM's International Committee for Documentation (CIDOC), is the ontology dedicated to the needs of cultural heritage institutions.[207] A community of museum and cultural heritage professionals developed *Linked Art*,[208] a shared data model based on *CIDOC CRM* and the *Getty Vocabularies*, designed for art museums to publish linked open data and describe artworks.

CIDOC CRM is a robust metadata schema that, in contrast to the lightweight schema of Dublin Core, offers a more complex data model suitable for the diversity of museum objects, which often exist in various contexts, involve several people with different roles, and have different locations for creation, use, and storage. *CIDOC CRM* is an event-based model with entities and properties to describe the relations between objects but also to people and events.[209] The British Museum pioneered using *CIDOC CRM* for its collection data. "The 'subject' in the triples is a British Museum object identifier, the 'predicate' is one of the specific lists from *CIDOC CRM*, and the 'object' comes from lists of geographic locations, dates, materials, or other knowledge bases."[210] Persistent identifiers and also structured classifications of the individual elements of an object through metadata are the key to the machine readability of objects and their long-term retrieval.[211] Moreover, if digital objects are searched and used across individual collection databases, each needs to have a unique identifier.[212] Persistent identifiers allow linking objects, which leads

204 Lorna Hughes et al., "Digital Methods in the Humanities: Understanding and Describing Their Use Across the Disciplines," in *A New Companion to Digital Humanities*, ed. Susan Schreibman et al. (Wiley Blackwell, 2016), 160–161.

205 Lesk, "The Convergence of Curation," 105.

206 Lesk, "The Convergence of Curation," 105.

207 *CIDOC CRM*, International Committee for Documentation (CIDOC), accessed September 2, 2020, https://www.cidoc-crm.org.

208 *Linked Art*, Linked Art Editorial Board, accessed December 27, 2024, https://linked.art.

209 Dorothee Haffner, "Datenausgabebedarfe, Open Access," in *Handbuch Museum: Geschichte, Aufgaben, Perspektiven*, ed. Markus Walz (J.B. Metzler, 2016), 195.

210 Lesk, "The Convergence of Curation," 105.

211 Celia Krause and Ruth Reiche. *Ein Bild sagt mehr als tausend Pixel? Digitale Forschungsansätze in den Bild- und Objektwissenschaften* (vwh Verlag Werner Hülsbusch, 2016), 22.

212 "Developing Identifiers for Heritage Collections," Towards a National Collection, accessed April 15, 2023, https://tanc-ahrc.github.io/PIDResources/. The Heritage PIDS project created a valuable resource that documents different aspects of developing persistent identifiers (PIDs) in the context of heritage collections.

to linked data (LD), or when the data that can be freely used, linked open data (LOD), which contributes to the Semantic Web.[213] In museums, digitization means not only creating digital material, but also dealing with data models, database structures, and metadata.

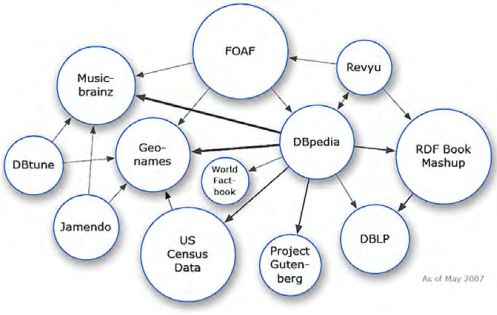


Figure 10. The Linked Open Data Cloud*, 2007. First visualization with 12 datasets published in the linked data format*
(source: *The Linked Open Data Cloud*, lod-cloud.net, accessed August 4, 2021, https://lod-cloud.net/versions/2007-05-01/lod-cloud.png. Image: CC BY 4.0)

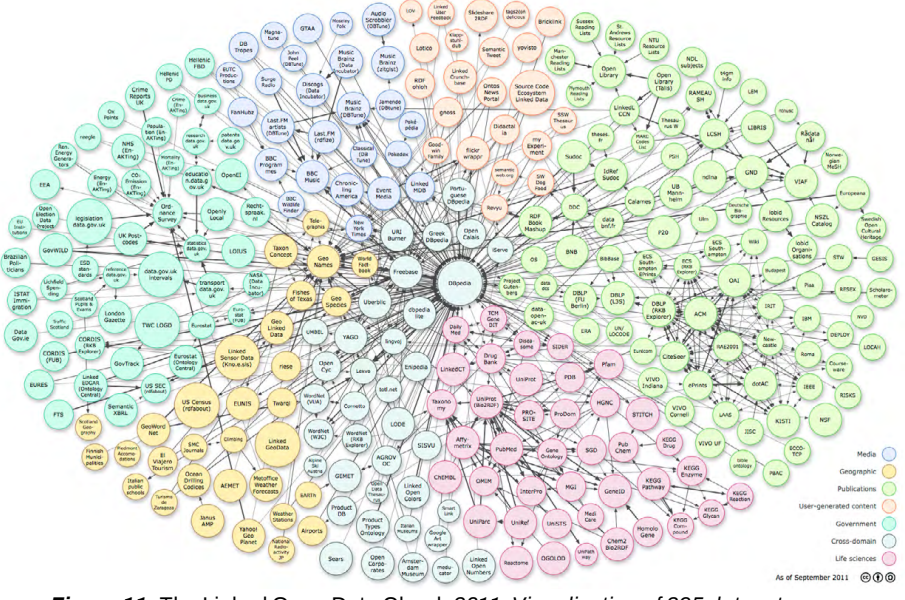


Figure 11. The Linked Open Data Cloud*, 2011. Visualization of 295 datasets published in the linked data format* (source: *The Linked Open Data Cloud*, lod-cloud.net, accessed August 4, 2021, https://lod-cloud.net/versions/2011-09-19/lod-cloud_colored.png. Image CC BY-SA)

213 Haffner, "Datenausgabebedarfe," 195.

Linked data's semantic power becomes particularly evident when considering how the different datasets published in this form are linked. This means that entities defined in one dataset can be mapped with equal entities in other datasets, expanding the range of entities that can be covered in a system through the interoperability between the corresponding knowledge bases. When the *Linked Open Data Cloud*[214] was first visualized in 2007, it included 12 datasets (fig. 10). The number has since increased to 295 datasets in 2011 (fig. 11), and to 1,301 datasets in 2021, which now requires exploring the visualization directly on the website https://lod-cloud.net rather than including it as an image. Strikingly, *DBpedia*'s dataset is the center in these visualizations with the most connections to other datasets. *DBpedia*[215] extracts information on a broad range of topics, geographic regions, and languages from *Wikipedia* to organize it as linked open data for the Semantic Web.[216] Interlinking *DBpedia* with knowledge bases that are available as RDF like *GeoNames*,[217] Project Gutenberg,[218] and WordNet,[219] allows the connection of *Wikipedia* content with other information systems.[220] *DBpedia* dataset access is offered in several ways for both humans and computers, including bulk downloads of the dataset and ontology, as well as a SPARQL endpoint.[221]

Metadata for the Description of Digital Objects

Metadata is crucial for processing the data resulting from museum collection digitization in systems and for facilitating the networking of knowledge. The boundaries between data and metadata are sometimes fluid. Metadata is data about data; it describes data by providing information about its origin and context, making it more useful and valuable.[222] The term "metadata" is

214 *Linked Open Data Cloud,* lod-cloud.net, accessed August 5, 2021, https://lod-cloud.net.

215 *DBpedia*, DBpedia Association, accessed December 27, 2024, https://www.dbpedia.org.

216 Mihály Héder and Illés Solt, "DBpedia Mashups," in *Semantic Mashups: Intelligent Reuse of Web Resources*, ed. Brigitte Endres-Niggemeyer (Springer, 2013), https://doi.org/10.1007/978-3-642-36403-7_4.

217 "GeoNames Ontology," GeoNames, December 27, 2024, https://www.geonames.org/ontology/documentation.html.

218 Project Gutenberg, accessed December 27, 2024, https://www.gutenberg.org/ebooks/offline_catalogs.html.

219 "WordNet RDF," Insight Centre for Data Analytics, National University of Ireland Galway, archived December 24, 2022, at https://web.archive.org/web/20221224144258/http://wordnet-rdf.princeton.edu/about.

220 Héder and Solt, "DBpedia Mashups," 123.

221 "DBpedia Databus," DBpedia, accessed December 27, 2024, https://databus.dbpedia.org; and Héder and Solt, "DBpedia Mashups," 132.

222 Hunter Whitney, *Data Insights: New Ways to Visualize and Make Sense of Data* (Morgan

understood differently depending on whether the purpose is to design, create, describe, maintain, or use information systems or information resources.[223] A created information object—or a digital object—may consist of a single item, multiple items, or an entire database, and can be addressed and manipulated by both humans and machines.[224] Information objects consist of metadata related to the content, context, and structure of the object.[225]

Table 6. *Three categories of metadata* (source: Gartner, *Metadata*, 6–8)

Category	Content
1. descriptive metadata (or: finding metadata)	information about the object (artist, title, etc.)
2. administrative metadata	
• technical metadata	technical metadata (file format, etc.)
• rights metadata	rights information (copyright, ownership, usage)
• preservation metadata	accessibility in the long-term
3. structural metadata	structures of complex objects (pages of a book, series of prints)

Marilyn Deegan and Simon Tanner emphasize that "many humanists ... may be considering digital images as primary source materials rather than as secondary surrogates."[226] Once image data is identified as a valuable resource, it is important to document images with high-quality metadata to ensure long-term availability and to inform future users.[227] Metadata is critical to the use of digital assets and is generated at various stages of data creation and management.[228] The creation of metadata should be done as carefully as the data creation, resulting in a well-formed digital object, which increases the likelihood of its long-term survival.[229] The best archival-quality digital master files are useless if they don't have meaningful filenames or descriptive metadata about the content.[230]

Richard Gartner identified three categories of metadata by distinguishing

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Kaufmann, 2013), 26.

223 Gilliland, "Setting the Stage," 1.

224 Gilliland, "Setting the Stage," 2.

225 Gilliland, "Setting the Stage," 2.

226 Marilyn Deegan and Simon Tanner, "Conversion of Primary Sources," in *A Companion to Digital Humanities*, ed. Susan Schreibman et al. (Blackwell, 2004), 491, https://doi.org/10.1002/9780470999875.ch32.

227 Deegan and Tanner, "Conversion of Primary Sources," 502.

228 Deegan and Tanner, "Conversion of Primary Sources," 502.

229 Deegan and Tanner, "Conversion of Primary Sources," 502.

230 Deegan and Tanner, "Conversion of Primary Sources," 502.

descriptive metadata from administrative metadata and structural metadata (table 6). Descriptive metadata is the information users find when they look at a record in a *Collection Online*, such as the artist name, medium, or other work information. Since descriptive metadata serves to identify and locate an item, it is also called finding metadata. Administrative metadata consists of three subtypes: technical, rights, and preservation. Technical metadata includes information like a digital image's file format, its size in pixels, or the color space used. This subtype of administrative metadata is usually generated automatically by a system and remains invisible to the user. Rights metadata is the information about copyright, ownership rights, and rights granted to users to control levels of access to a digital object. Preservation metadata, the third type of administrative metadata, documents who did what and when to the data, which ensures that the data remains usable in the future independently of the creators. Structural metadata holds together component parts of a more complex digital object, for example, single pages of a book or a series of prints.[231]

In museum databases and digital collections, multiple types of metadata converge, and well-organized data enables a variety of applications. Users cannot always see all metadata, but what can be extracted often exceeds what is visible.

Table 7. *Digital collection data standards*

Standard	URL
Cataloging Cultural Objects (CCO)	https://vraweb.org/resourcesx/cataloging-cultural-objects/
Categories for the Description of Works of Art (CDWA)	https://www.getty.edu/research/publications/electronic_publications/cdwa/introduction.html
CIDOC Conceptual Reference Model (CRM)	https://www.cidoc-crm.org
Dublin Core Metadata Initiative (DCMI)	https://www.dublincore.org
Lightweight Information Describing Objects (LIDO)	https://www.lido-schema.org
Metadata Encoding & Transmission Standard (METS)	https://www.loc.gov/standards/mets/

231 Gartner, *Metadata*, 6–8.

When looking beyond a single database, metadata standards are imperative that ensure quality, consistency, and interoperability in data exchange.[232] Markup languages (e.g., HTML and XML), schemas, and metadata formats provide standardized structures for machine processing.[233] These standards can be divided into different types:

- **Data structure standards:** *MARC (Machine-Readable Cataloging) format, Dublin Core Metadata Initiative (DCMI),* and *Categories for the Description of Works of Art (CDWA)*
- **Data value standards:** *Getty Art & Architecture Thesaurus (AAT), Union List of Artist Names (ULAN),* and *Iconclass*
- **Data content standards:** *Cataloging Cultural Objects (COO)*
- **Data format standards (in machine-readable form):** *Resource Description Framework (RDF), LIDO XML,* and *Simple Dublin Core XML*[234]

Growing awareness of standards and data exchange, which libraries took advantage of early on, has established the use of several key standards (table 7 also see table 5, p. 74) in the museum sector, as Anne Gilliland summarizes:

> Consensus and collaboration were slower to build in the museum community, where the benefits of standardization of description, such as shared cataloging and exchange of descriptive data, were less readily apparent until relatively recently. Since the late 1990s tools such as *Categories for the Description of Works of Art (CDWA)*, the *CIDOC Conceptual Reference Model (CRM)*, *Cataloging Cultural Objects: A Guide to Describing Cultural Works and Their Images (CCO)*, the *LIDO (Lightweight Information Describing Objects) XML* schema, and more generic standards such as *Dublin Core* and *METS* have been considered and implemented by museums.[235]

Lightweight Information Describing Objects (LIDO) is an international data exchange format for museums. It is event-based, like *CIDOC CRM,* supports references to controlled vocabularies, and allows content in multiple languages. *LIDO* includes five groups of metadata: object classification, object identification, events, relationships, and administrative metadata and is mainly used for the aggregation of museum data on the Internet (for

232 Gilliland, "Setting the Stage," 2.

233 Gilliland, "Setting the Stage," 2–3.

234 Gilliland, "Setting the Stage," 3.

235 Gilliland, "Setting the Stage," 4.

example, to deliver data to *Europeana* or *Graphikportal*).[236] Gudrun Knaus, Regine Stein, and Angela Kailus published a *LIDO* handbook for participating *Graphikportal* institutions that standardized the inclusion of comprehensive data from collections of prints and having the ability to merge these collections.[237] Metadata standards build consensus among institutions, but they are not easy to implement, as evidenced by the sheer breadth of the *LIDO* handbook, nor is it easy to keep track of the myriad standards.

Jenn Riley created an impressive visual map of metadata standards used in the cultural heritage sector.[238] Each community—archives, libraries, museums, and the information industry—has its own standards, which means that for the vision of a large knowledge network, the metadata must be aggregated.[239] The semantics of different schemes must be reconciled to map one standard against another standard so that the metadata continues to be interpreted properly. This becomes a challenge when schemes like MARC, which emphasizes precision and narrow definitions, must be reconciled against more generic schemes like Dublin Core, which deliberately uses broad definitions in favor of a simpler implementation.[240] Sometimes data is moved from a narrower to a broader semantic element to share metadata more widely, even if some details or nuances get lost.[241]

Since the structuring of information objects supports searching, manipulating, and linking with other information objects, it makes sense that museums consider and manage metadata.[242] Different types of metadata cover several functionalities and are used for administration, description, preservation, or they are technical or usage metadata.[243] Rich metadata ensures good search capabilities within one database, but is also relevant for searches across different collections or to bring together records from different repositories, provided that the format of the descriptive metadata records is consistent across the databases and formats or can be mapped to other formats.[244] Thorough and consistent metadata enable optimal information management and end-user access because it makes possible multi-version-

236 Haffner, "Datenausgabebedarfe," 196.

237 Gudrun Knaus et al., *LIDO-Handbuch für die Erfassung und Publikation von Metadaten zu kulturellen Objekten: Band 1: Graphik* (arthistoricum.net, 2019).

238 Jenn Riley, "Seeing Standards: A Visualization of the Metadata Universe," 2010, accessed October 24, 2024, https://jennriley.com/metadatamap. See the poster PDF here: https://jennriley.com/metadatamap.

239 Gartner, *Metadata*, 38.

240 Gartner, *Metadata*, 55.

241 Gartner, *Metadata*, 55–56.

242 Gilliland, "Setting the Stage," 6.

243 Gilliland, "Setting the Stage," 9.

244 Gilliland, "Setting the Stage," 16.

ing, data mapping and mining in new and unexpected ways.[245] Ultimately, metadata is essential to understand and gain knowledge from the data.[246]

Metadata for the Retrieval of Digital Text and Images

Metadata is equally important for both text and image collections, but there are differences between digitizing images and written documents. A scanned page of text is usually only moderately useful, which is why optical character recognition (OCR) is commonly applied. This process adds a second layer containing OCR-generated text on top of the image layer in PDF files, making the document searchable—though OCR often introduces errors due to misrecognized characters. Born-digital text files offer greater flexibility when designed fundamentally differently for digital environments than printed texts. To fully utilize the digital medium, publications must go beyond static reading, enabling dynamic queries, customizable arrangements, and diverse presentation formats.[247] In digital critical editions, structure is created using markup languages. However, preparing such texts for research requires specialized expertise throughout the process, as publishers typically do not format publications with the level of precision needed for scholarly work.[248]

Even though scanned, OCR-processed texts can be found by full-text search, retrieving images by content is more challenging. For a concept-based retrieval of images, controlled vocabularies, which are often hierarchical lists of terms, represent descriptive and semantic information about an item.[249] An entirely different concept is content-based retrieval (CBR) which analyzes image pixels using algorithms to detect features like color, texture, or shape for computer-based object recognition.[250] One approach to train the algorithms to recognize objects in images is to use images already labeled by humans. Machine-learning makes possible automated computer annotation that assigns tags to feature-level output of algorithms.[251] Both approaches, concept-based and content-based (CBR) image retrieval, are suitable for

245 Gilliland, "Setting the Stage," 19.

246 Gartner, *Metadata*, 12.

247 Gábor Kecskeméti, "Electronic Textual Criticism: A Challenge to the Editor and to the Publisher," in *New Publication Cultures in the Humanities: Exploring the Paradigm Shift*, ed. Péter Dávidházi (Amsterdam University Press, 2014), 92.

248 Kecskeméti, "Electronic Textual Criticism," 93.

249 Corinne Jörgensen, "Photos: Flickr, Facebook and Other Social Networking Sites," in *Managing Digital Cultural Objects: Analysis, Discovery and Retrieval*, ed. Allen Foster and Pauline Rafferty (Facet, 2014), 144, https://doi.org/10.29085/9781783301539.008.

250 Jörgensen, "Photos," 145.

251 Jörgensen, "Photos," 146.

dividing a large collection into categories with different human and computational effort and accuracy.[252] Image retrieval remains challenging because vocabularies of a system and a user are not necessarily congruent, and formulating precise query input can be difficult.[253] Another approach is web-based retrieval based on tags associated with images in social media. User-supplied tags come from a vocabulary of everyday language, with the advantage of more diverse viewpoints than those of only experts.[254] Although greater access to images is desirable, museums often have concerns about including user-generated tags in their digital collections due to confusing, unstructured, or incorrect tags.[255] Some GLAM institutions make available their digitized photo collections on Flickr's Commons to enrich the metadata with tags added by the public.[256] Another possibility is to allow users to add tags to the online collection on the museum website.[257] There are control mechanisms for ensuring the quality of the tags, including tag validation and storing the public-authored ones separate from those by museum staff. It is advisable to reconsider past best practices in favor of a more flexible approach to digital collections and their documentation.

Samantha Norling urges cultural institutions to take an open approach to data due to "its capacity for cross-disciplinary application, and the result has been an emerging awareness among [G]LAM institutions and professionals of the need to break down traditional barriers to bring disparate collections together in the digital realm."[258] She continues, "as linked open data continues to gain traction throughout the [G]LAM community, institutions may find that their existing systems for managing collections data and digital assets no longer meet the needs of an increasingly connected online environment."[259] Supplementing the digitized images and text documents, a crucial part of the collection data, with metadata at various levels enhances discoverability, facilitates new connections, and aids in the creation of knowledge.

252 Jörgensen, "Photos," 147.

253 Jörgensen, "Photos," 147.

254 Jörgensen, "Photos," 149.

255 Jörgensen, "Photos," 149.

256 Find the current list of participating institutions: "Participating Institutions," Flickr: The Commons, accessed September 10, 2020, https://www.flickr.com/commons/institutions/.

257 Jörgensen, "Photos," 152.

258 Norling, "Bringing the Archives Out," 256.

259 Norling, "Bringing the Archives Out," 257.

Sustainability of Data and Metadata

With the increasing volatility of objects in museums, resulting from digitization initiatives related to the collection database and digital collection, digital preservation is a critical issue. Ensuring long-term preservation of digital cultural heritage requires appropriate technical solutions, organizational strategies, and an institutional culture that values this form of preservation and is supported by staff.[260]

Digital objects are more likely to survive in the long term if the data and metadata remain in continuous use. Since museum workflows rely on museum management databases, staff members perform tasks based on existing data while enriching it with new records and additional information. Digital collections also depend on this data and can remain up to date if data exchange occurs regularly. In addition to data maintenance, another major challenge is the obsolescence of hardware and file formats over time. Addressing this issue requires not only migrating files from one storage medium to another but also, in some cases, emulating data when the original file format is no longer supported or converting it into a new format. It becomes more difficult in a large information environment with unclear boundaries, many linked files, and a lot of interactivity.[261] Then, it is not just about saving a work, but also about saving different behaviors.[262] Nonetheless, in the context of digital museum collections, at least the data should be preserved over the long term. The application interface for data presentation is a separate component, and its appearance is subject to change due to advancements in technology, web standards, and hardware. It is at least debatable to what extent archiving an application in its current state is meaningful, especially if the relationship between the data and its presentation through a particular interface is loose. A multitier architecture, which separates data management from application processing and presentation, is a reasonable approach to ensure system flexibility and expandability.

2.4 Cultural Impact of Digitization

Digital collections of art are not limited to a technological context; they also exist in a cultural context. This section outlines the cultural-theoretical foundations of digital collections of art and analyzes the implications of digital images in art historical research. Information in museums is not

260 Peter Lyman and Howard Besser, "Defining the Problem of Our Vanishing Memory: Background, Current Status, Models for Resolution," in *Museums in a Digital Age*, ed. Ross Parry (Routledge, 2010), 337.

261 Lyman and Besser, "Defining the Problem," 337–338.

262 Lyman and Besser, "Defining the Problem," 338.

merely a matter of documentation but is integral to the perception of art and the museum's broader work. Art information shapes how artworks are understood, including those represented in digital collections.[263] Museum information culture oscillates between information, description, and documentation that emerge from examining, viewing, and experiencing artworks in changing situations.[264] The documentation of artworks is never complete, and limited by gaps, sources, and time, as well as the adequacy of information spaces, frameworks, and standards.[265] Especially in contemporary art, the artwork itself raises questions and is often complex, ephemeral, performative, and difficult to define. Basic identification may not suffice to fully capture such artworks.[266] Some gaps are inherent to the artwork, because ambiguity and the absence of information spark the viewer's imagination and invite interpretation.[267] Capturing artwork data in collection management systems allows museums to identify gaps in information, fill them, and know about them.[268] Collection management systems help museums identify and address gaps in information, but their structured nature can impose limitations. While databases facilitate systematic data collection across entire collections, they may struggle to capture the unique characteristics of individual works, especially in encyclopedic collections. The diversity of materials, techniques, and historical contexts means documentation can only partially reflect an artwork's true nature. Museum management systems are effective as long as queries align with their structured data, but they reach their limits when addressing broader, more interpretative questions.[269] Similarly, thesauri and controlled vocabularies like the *Art & Architecture Thesaurus (AAT)* have limitations and are only partially helpful for contemporary art.[270] The *Media Art Research Thesaurus*,[271] developed by Oliver Grau and his team for

263 Layna White, "Art Information Culture: Contemporary Disruptions in Museums," in *Organization, Representation and Description Through the Digital Age: Information in Libraries, Archives and Museums*, ed. Christine M. Angel and Caroline Fuchs (De Gruyter Saur, 2018), 130, https://doi.org/10.1515/9783110337419-010.

264 White, "Art Information Culture," 130.

265 White, "Art Information Culture," 130–131.

266 White, "Art Information Culture," 131–141.

267 White, "Art Information Culture," 145.

268 White, "Art Information Culture," 145.

269 White, "Art Information Culture," 141.

270 White, "Art Information Culture," 146.

271 *Media Art Research Thesaurus*, TemaTres, accessed December 27, 2024, https://www.vocabularyserver.com/mediaart/. The thesaurus in use: *Media Art Research Thesaurus*, Center for Image Science, University for Continuing Education Krems, accessed December 27, 2024, https://mediaartresearch.org.

the *Archive of Digital Art (ADA)*,[272] is helpful for conducting research on digital art. However, its usefulness to museums depends on whether they hold digital media art in their collections. Notably, one of the thesaurus's goals is to overcome the divide between digital art collections and conventional digital collections of art. Its "subject" branch includes therefore some more generic "terms established in art history and Media Art Histories, as well as concepts that enable both descriptive and interpretative approaches to the subject of works" that help bridge this gap and link collections of digital art with other digital collections of more traditional art forms.[273] As a proof of concept, search results in *ADA* include prints from the Graphic Art Collection Göttweig Abbey.[274] The heterogeneity of artworks alone, apart from the technological challenges, makes it a demanding task to prepare collections for digital access, and this is especially true for digital art.

Janina Hoth describes digital art's characteristics, issues with its documentation in databases, strategies for its archiving and preservation, and reasons why it is treated differently than traditional fine art.[275] In the case of digital art, art historical interpretation and classification intersect with media-archaeological and technology-historical aspects, as these factors fundamentally shape the nature of the work.[276] While the structure of an archive and its collected documents form the basis for historical knowledge, they ultimately reflect only a particular perspective. Analyzing artworks through this lens leads to a historization shaped by their preserved state as documents.[277] It is important to recognize that database records capture only certain aspects of an artwork, while others may be absent due to limited documentation or the inherent ephemerality, processuality, and modularity

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272 *Archive of Digital Art (ADA)*, Center for Image Science, University for Continuing Education Krems, accessed December 27, 2024, https://www.digitalartarchive.at.

273 Oliver Grau, "Resisting a Total Loss of Digital Heritage: Web 2.0-Archiving & Bridging Thesaurus for Media Art Histories," in *Digital Art Through the Looking Glass: New Strategies for Archiving, Collecting and Preserving in Digital Humanities*, ed. Oliver Grau et al. (Edition Donau-Universität, 2019), 199, https://doi.org/10.25969/mediarep/13352.

274 Graphic Art Collection Göttweig Abbey, Center for Image Science, University for Continuing Education Krems, accessed December 27, 2024, https://www.gssg.at/gssg/; Oliver Grau, "Digital Art's Complex Expression and Its Impact on Archives and Humanities: For a Concerted Museum-Network of Expertise and Preservation," in *Museum and Archive on the Move: Changing Cultural Institutions in the Digital Era*, ed. Oliver Grau (De Gruyter, 2017), 109–110).

275 Janina Hoth, "Historicization in the Archive: Digital Art and Originality," in *Digital Art Through the Looking Glass: New Strategies for Archiving, Collecting and Preserving in Digital Humanities*, ed. Oliver Grau et al. (Edition Donau-Universität, 2019), 145–146, https://doi.org/10.25969/mediarep/13349.

276 Hoth, "Historicization in the Archive," 147.

277 Hoth, "Historicization in the Archive," 147.

of digital art, which can only be approximated within a database.[278] Hoth suggests adapting documentation and preservation to consider performative and ephemeral qualities of artworks to adequately represent processual and modular digital artworks in databases.

> Rather than as a static and unchangeable object, documents should incorporate the processual dynamics of digital artworks by making them accessible as reusable data. A digital art archive in the future could function more like a distributed version control and source code management than a traditional art collection.[279]

This scenario can be easily envisioned when digital collections include 3D models of objects. Notwithstanding this, it is useful to view digital collections as open and processual, positioning museums not only as content providers but also sources of reliable information that evolves over time through data refinement and the addition of new information and sources. This requires a broader understanding of archiving, as Hoth defines it by distinguishing between "conservation as institutional method and archiving as collective method."[280] Institutional conservation as a method is about preserving a digital artwork to keep it technologically in a state that it can be exhibited at any time as intended and approved by the artist.[281] Digital archiving as a method refers to reusable and interoperable documents, such as images and metadata, stored in a digital platform and database, but are not considered the original artwork.[282] This future-oriented approach recognizes that digital collections are not static repositories of data provided by museums. Instead, digital archiving is designed to allow flexible data usage by various users, including researchers, and to accommodate new content contributions over time, including those from external individuals interested in the data.

Digital Libraries, Archives, and Collections

"Digital collections," "digital archives," and "digital libraries" can all be understood as publicly accessible databases that provide digital source material. Rather than referring to entirely different functionalities from a technological perspective, these terms primarily reflect the institutional contexts from which they originate, leading to significant overlap.

278 Hoth, "Historicization in the Archive," 149.

279 Hoth, "Historicization in the Archive," 153.

280 Hoth, "Historicization in the Archive," 153.

281 Hoth, "Historicization in the Archive," 154.

282 Hoth, "Historicization in the Archive," 154.

Isto Huvila describes an archive as a concept that practically and theoretically captures the aims of digitizing while also preserving digital artifacts.[283] This is regardless of an archive's size, or whether it is publicly accessible or private, transient, or long-lived.[284] "Archive" is a multifaceted term that encompasses different concepts of document collections as well as various organizational forms, leading to multiple meanings. It can refer to an institution dedicated to preserving society's important documents or to digitized cultural content stored in a database. Theories and practices differ depending on whether an archive is a long-enduring institution managing vast amounts of physical documents—only recently incorporating digital content—or a database or online archive representing physical documents in the digital realm. The latter is fundamentally different, as it is created after digitization and designed specifically to manage digital data. In such cases, digital infrastructure and the archive's usability take on a central role.

Similarly, digital libraries integrate a wide variety of systems, including digital object and metadata repositories, archives, content management systems, and digital library services and support for research.[285] A digital library can also refer to a collection of digital image, text, video, and audio objects that is organized, maintained, and made accessible and retrievable.[286] The latter definition from the library sector aligns with how "digital collection" is used in this book, since the focus is on museum collections. Museums, archives, and libraries face similar challenges in managing databases and providing public access. Consequently, literature from art history, museum studies, archival science, and library and information science is equally relevant. While terminology may vary slightly across these fields, it often describes the same concepts. In this book, "digital library" is only used only when referring to cited literature; otherwise "digital collections" is the preferred term. Crucially, "digital collection" and "digital library" extend beyond mere digitization for online accessibility; they also encompass technological determinants and modes of access to digital objects. Humanities research benefits from digital libraries not only through easier access to source material but also by enabling research methodologies that were previously

283 Isto Huvila, "Archiv," in *Digitalisierung: Theorien und Konzepte für die empirische Kulturforschung*, ed. Gertraud Koch (Herbert von Halem Verlag, 2017), 89.

284 Huvila, "Archiv," 89.

285 Dagobert Soergel, "Digital Libraries and Knowledge Organization," in *Semantic Digital Libraries*, ed. Sebastian Ryszard Kruk and Bill McDaniel (Springer, 2009), 9.

286 Ian H. Witten et al., *How to Build a Digital Library*, 2nd ed. (Morgan Kaufmann, 2010), xvi, https://doi.org/10.1016/C2009-0-19701-5.

impossible or highly impractical.[287] This necessitates ensuring that digital library data is available for humanities research, with particular attention to preservation, collection linking, and standards.[288] Faster and broader access to source material in digital libraries should not simply be seen as an enhancement of traditional research but as an opportunity to explore fundamentally new approaches.[289] This transformative potential makes digitization an innovation, with the digital archive as its product.[290] Digitization disrupts previous technical and organizational paradigms, significantly altering how we engage with cultural heritage in the long term.[291] Digitization of cultural heritage is situated between two extremes. On the one hand, there is a utopian vision of unlimited archival possibilities—an aspiration to comprehensively preserve everything.[292] On the other hand, there is a dystopian fear of cultural memory loss due to rapid technological advancements and hardware obsolescence, which threaten the longevity of digital data.[293]

The use and cultural impact of technology are shaped not only by the technology itself but also by the ways it is allowed, intended, or made possible to be used.[294] There is a paradigm shift in open data and archives away from the pull principle of offering data only on request, towards the push principle that offers free access and use of all archival data, under consideration of privacy rights and data protection regulations.[295]

The role of public archives is to authenticate the archival material and their digital reproductions.[296] The same is true for museums and other cultural heritage institutions. As keepers of objects for which they can guarantee authenticity and cultural significance, they provide valid information through related archival documents as well as digital reproductions and records. The significance of an archive must be understood in light of its limitations, as

287 Howard Besser, "The Past, Present, and Future of Digital Libraries," in *A Companion to Digital Humanities*, ed. Susan Schreibman et al. (Blackwell, 2004), 557, https://doi.org/10.1002/9780470999875.ch36.

288 Besser, "Past, Present, and Future," 557.

289 Besser, "Past, Present, and Future," 558.

290 Marion A. Weissenberger-Eibl and Sebastian Ziegaus, "Die Zukunft des digitalen Erbes: Perspektiven der Innovationsforschung," in *Neues Erbe: Aspekte, Perspektiven und Konsequenzen der digitalen Überlieferung*, ed. Robertson-von Trotha, Caroline Y. and Robert Hauser (KIT Scientific Publishing, 2011), 297.

291 Weissenberger-Eibl and Ziegaus, "Die Zukunft," 297.

292 Weissenberger-Eibl and Ziegaus, "Die Zukunft," 299.

293 Weissenberger-Eibl and Ziegaus, "Die Zukunft," 299.

294 Weissenberger-Eibl and Ziegaus, "Die Zukunft," 303.

295 Weissenberger-Eibl and Ziegaus, "Die Zukunft," 303.

296 Marcel Lepper and Ulrich Raulff, "Idee des Archivs," in *Handbuch Archiv: Geschichte, Aufgaben, Perspektiven*, ed. Marcel Lepper and Ulrich Raulff (J.B. Metzler, 2016), 8.

not everything is archived, either due to the scope of a collection or deliberate omissions that shape historiography, as Cornelia Vismann aptly put it: "What is not in the records in the first place can hardly be remembered."[297] In the digital age, it could be also said that anything not digitized and made accessible through a digital archive risks being overlooked and forgotten.

Photography as a reproductive medium plays an important role in making cultural content available digitally. Historically, it was the first medium to enable the automatic storage of visual data, inherently connecting it to the archive. Even today, photography remains one of the most important reproduction processes. The key difference between analog and digital photography is that for online archives, it is necessary to transfer data to users' computers. Jens Schröter succinctly describes this shift as the transition from photographic archiving to post-photographic transfer.[298] Faced with the question of the transferability and use of digital images, cultural institutions are increasingly urged to rethink their attitudes. Rijksmuseum's painting *The Milkmaid* (c. 1660) by Johannes Vermeer has become a well-known example representative of the challenges associated with digital images of art.[299] The museum discovered more than 10,000 images of their famous painting on the Internet.[300] Many of the reproductions were yellowish and of poor quality, which is why visitors were skeptical that the postcards in the museum shop showed the original painting. For that reason, the Rijksmuseum decided to provide high-resolution images and open metadata on the web.[301] It is entirely up to museums to make available professional, authorized images of artworks. Making the images available under a free license paves the way for their widespread distribution, benefiting both the museum's visibility and the artists' recognition.

There are many reasons for making metadata freely available, and there are also arguments against it. Benefits of open metadata for cultural institutions are increasing in relevance in today's digital society. Data enrichment, brand value, discoverability, new customers, fulfilling the public mission to give access to cultural heritage, as well as spill-over effects resulting from the creation of new businesses by the institutions and creative industries that

297 Cornelia Vismann, "Out of File, Out of Mind," in *New Media, Old Media: A History and Theory Reader*, ed. Wendy Hui Kyong Chun and Thomas Keenan (Routledge, 2006), 98.

298 Jens Schröter, "Archiv: post/fotografisch," *Medien Kunst Netz*, 2004, accessed October 26, 2024, http://mediaartnet.org/themen/foto_byte/archiv_post_fotografisch/.

299 Harry Verwayen et al., "The Problem of the Yellow Milkmaid: A Business Model Perspective on Open Metadata," *White Paper*, no. 2 (2011), accessed October 26, 2024, https://pro.europeana.eu/files/Europeana_Professional/Publications/Whitepaper_2-The_Yellow_Milkmaid.pdf.

300 Verwayen et al., "Yellow Milkmaid," 2.

301 Verwayen et al., "Yellow Milkmaid," 2.

strengthen the knowledge economy are only a few examples.[302] Risks include loss of quality, control, unity, brand value, attribution, income, unwanted spill-over effects, and privacy.[303] The fear of losing income involves a change of mindset that favors allowing anyone to create new services, including commercial ones, based on open data.[304] Cultural heritage professionals are convinced that the benefits of open sharing and distribution are preferable in favor of greater visibility and relevance.[305]

The demands for open metadata from cultural institutions are inextricably linked to the changes brought about by the digital image, provoking different approaches than museums are accustomed to with analog images and physical artworks. William Vaughan points out that the digital image "is a transformation of an image" that is "re-performed according to a set of encoded instructions" when it is displayed on a screen and differs from an analog image and exists as more than a reproduction.[306] In contrast to the aura that Walter Benjamin identified as a quality of an artwork tied to its uniqueness, the digital image is infinitely reproducible—a quality that deserves particular attention from a digital perspective.[307]

Digitization as a Game Changer

Digital transformation requires museums to take an active role in the implementation of digital technology rather than being customers who "make their purchases on the new technology market and place them at the disposal of their captive audience," as David Vuillaume aptly puts it.[308] Museums should resist the pressure to buy digital equipment just to project the appearance of being technologically progressive, because that only turns "a potential customer into a consumer."[309] The best approach is when the professionals know the available technologies and use them according to the institution's goals.[310]

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302 Verwayen et al., "Yellow Milkmaid," 14.

303 Verwayen et al., "Yellow Milkmaid," 14–15.

304 Verwayen et al., "Yellow Milkmaid," 19.

305 Verwayen et al., "Yellow Milkmaid," 20.

306 William Vaughan, "History of Art in the Digital Age: Problems and Possibilities," in *Digital Art History: A Subject in Transition*, ed. Anna Bentkowska-Kafel et al. (Intellect, 2005), 5.

307 Vaughan, "History of Art," 6.

308 David Vuillaume, "What About the Need for New Media Technologies in Museums," in *The Museum in the Digital Age: New Media and Novel Methods of Mediation*, ed. Régine Bonnefoit and Melissa Rérat (Cambridge Scholars Publishing, 2017), 66.

309 Vuillaume, "What About the Need," 67.

310 Vuillaume, "What About the Need," 67.

Marisa Enhuber identifies three fundamental advantages of the digitization of artworks and digitalization of the museum. The conversion of "physical art objects into computer processable data" has a democratizing effect because artworks become accessible online to anyone at any time.[311] From an educational point of view, digitalization enables new participatory learning approaches, such as augmented and virtual reality applications that enhance engagement with art and shifts the experience from passive to active.[312] Communication through social media adds a social component, allowing visitors to share their experiences, interact with the museum, and enabling institutions to reach a broad audience online at relatively low cost.[313] Therefore, the digital presence of art "has a democratising, educational and socialising effect on the consumption of art."[314] Art presented inside the museum or on digital channels serve completely different purposes. To this end, the digital art space should be seen as a supplement to the real visit, not a replacement.[315] In a digital environment, digital objects do not necessarily have to be represented as two-dimensional images, but can be supplemented with other documents, experienced via video or in three-dimensional models. This requires different scanning techniques, which depend on the object to be digitized as well as on the intended representation.

Priorities in creating digital material of not born-digital objects move usually from simpler to more complex media.[316] What began with text (books) for its simplicity was followed by images (flat artworks), video (time-based media), and finally, 3D models (three-dimensional objects).[317] This progression is also evident in catalogs, which initially only listed items but have evolved to include images and, more recently, sophisticated digital representations that enable automated research and new study methods.[318] Digitization of books to convert them into machine-readable form has been done since the 1950s, at that time by typing the text on punch cards or paper tape.[319] Libraries had digitization projects for their catalogs early on.[320] With scanners, it was easy to digitize flat artworks like prints, digital cameras

311 Enhuber, "Art, Space and Technology," 134.

312 Enhuber, "Art, Space and Technology," 134.

313 Enhuber, "Art, Space and Technology," 134.

314 Enhuber, "Art, Space and Technology," 134.

315 Enhuber, "Art, Space and Technology," 127.

316 Michael Lesk, "From Descriptions to Duplicates to Data," in *Electronic Visualisation in Arts and Culture*, ed. Jonathan P. Bowen et al. (Springer, 2013), 9, https://doi.org/10.1007/978-1-4471-5406-8_2.

317 Lesk, "From Descriptions to Duplicates," 9.

318 Lesk, "From Descriptions to Duplicates," 9.

319 Lesk, "From Descriptions to Duplicates," 11.

320 Lesk, "From Descriptions to Duplicates," 11.

allowed for the digitization of paintings, and photogrammetry, structured light, and laser scanning make possible scanning 3D-objects.[321]

With digitization, users' preferences are also changing. Instead of insisting on paper copies of books, scientists now read most research papers online.[322] This is also occurring in the humanities, which is slightly behind science in that practice. The flexibility of electronic texts, which can include full-text searches and electronic management of research literature, outweighs the physical properties and design that books have to offer, to which the interest in subject matter has rarely been related anyway.[323] Similarly, access to artworks in digital collections offers more flexibility. Even if art historians might prefer to study the original artwork over time, there is a tradition of using images, which is continued with digital images albeit under changed circumstances. Aby Warburg used reproductions of artworks for study, allowing for direct side-by-side comparisons.[324] The challenge with such surrogates is that they often fail to convey the original artwork's size and context. When an object is viewed in isolation on a screen, its scale and surrounding environment are typically lost. Virtual tours through a museum, like those that *Google Arts & Culture* developed by using Google Street View scanning technology,[325] give an impression of the object's context in the museum and a sense of scale. The application gives a feeling of walking through a 3D model even if it actually is not one.[326] The creation of digital 3D models originates from architecture, where architects use CAD to design and construct buildings.[327]

Archaeology uses a variety of digital technologies to preserve, study, and make cultural heritage items accessible for research, education, and public engagement. Dongming Lu and Yunhe Pan identify a close connection between developments in computer science and digital preservation technologies:

> With the recent development of information technologies, especially computer graphics, computer vision, artificial intelligence, virtual reality, computer networks, and so on, digital preservation technologies for heritage items are also growing, including digitalization, research aiding, conservation aiding, digital exhibition, and digital utilization.[328]

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321 Lesk, "From Descriptions to Duplicates," 12.

322 Lesk, "From Descriptions to Duplicates," 13.

323 Lesk, "From Descriptions to Duplicates," 13–14.

324 Lesk, "From Descriptions to Duplicates," 15.

325 "Street View," *Google Arts & Culture,* accessed October 15, 2020, https://artsandculture.google.com/project/street-view.

326 Lesk, "From Descriptions to Duplicates," 15.

327 Lesk, "From Descriptions to Duplicates," 15.

328 Dongming Lu and Yunhe Pan, *Digital Preservation for Heritages: Technologies and Applications* (Springer, 2010), 211.

Digitalization in archaeology facilitates documentation and prevents the loss of information from excavation sites, murals, sculptures, and artifacts in museums.[329] The reproduction of large two- and three-dimensional objects and architecture, including surfaces and internal structures, requires a wide range of scanning techniques. Digital photography is used for planar images of large paintings or murals.[330] Three-dimensional objects are captured using 3D scanning and 3D information processing technologies, and surface information is added through texture mapping.[331] X-ray and neutron photography provide information about the internal structure of objects.[332]

Apart from using digital technology to digitize objects, computer-aided quantitative analysis can be applied for shape analysis, identification, measurement, among other characteristics. Databases are essential for managing documents and information related to cultural heritage items. Virtual restoration allows the simulation of color restoration or the assembly of fragments, all without the need to physically handle the original object.[333] Digital objects can be presented in online exhibitions, site reconstructions, and as interactive applications in museums.[334] The pressing question then becomes how to present related historical, cultural, and scientific knowledge in a way that serves both educational and entertainment purposes.[335] This approach holds great potential for museums and art history, offering ways to present and study art through applications that provide interactive access to layers of visual, textual, and numerical information.

Beryl Graham differentiates between the "archive as documentation of art" and the "archive as a collection of art," highlighting that the former contains information about artworks but not the artworks themselves, while the latter provides access to born-digital works like digital video or net.art.[336] A third variant, the "archive as a space for the representation of art," could be added for applications that place artworks within a broader context to convey knowledge about art. Together, these three concepts trace the development from the creation of online collections, to digital art archives, culminating in comprehensive museum offerings that facilitate both digital mediation and the flexible use of data.

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329 Lu and Pan, *Digital Preservation for Heritages*, 211.

330 Lu and Pan, *Digital Preservation for Heritages*, 211.

331 Lu and Pan, *Digital Preservation for Heritages*, 211.

332 Lu and Pan, *Digital Preservation for Heritages*, 211.

333 Lu and Pan, *Digital Preservation for Heritages*, 212.

334 Lu and Pan, *Digital Preservation for Heritages*, 213.

335 Lu and Pan, *Digital Preservation for Heritages*, 213.

336 Beryl Graham, "Modes of Collection," in *New Collecting: Exhibiting and Audiences After New Media Art*, ed. Beryl Graham (Ashgate, 2014), 48.

Jussi Parikka proposes viewing museums and archives in the era of online digital collections not as places but as addressable entities, emphasizing a systems-based perspective.[337] The focus is on the management of protocols, software structures, and query patterns, which can open new avenues for user interaction while making data storage and continuous dissemination increasingly interdependent.[338] As cultural heritage institutions adapt to an increasing shift from analog media to networked and interactive digital documents, it is imperative to extend the museum's mission of preserving, documenting, and making collections accessible also to digital objects.[339] The challenge of handling digital documents is not exclusive to archives; for art museums, it introduces questions about collecting and preserving media and digital art. Artworks and their digital surrogates, comprising images and metadata, hold equal significance. Unlike the relatively stable conservation of media like paper or film, preserving digital objects requires more than simply storing their physical carriers. Instead, a dynamic conservation approach is needed—one that separates information from its medium, making IT-based archiving and ongoing maintenance essential. This is relevant not only for archives but also for museums and libraries.[340] Heinz Werner Kramski defines four properties of digital archival objects that must be taken into consideration for long-term preservation:

1. unique, private vs. exists multiple times, published
2. analog, digitizable vs. born-digital
3. carrier-bound, on-site, completed vs. carrierless, online, branched
4. static vs. interactive[341]

The two principal strategies for the preservation of digital objects and applications are format migration and emulation. Format migration involves converting a digital object from an obsolete file format to a current one. Emulation replicates the original hardware and software environment on a modern system, allowing digital objects—such as applications—to run without modification.[342] Data preservation strategies should be built into the everyday work of the museum.

337 Jussi Parikka, "Archives in Media Theory: Material Media Archeology and Digital Humanities," in *Understanding Digital Humanities*, ed. David M. Berry (Palgrave Macmillan, 2012), 91.

338 Parikka, "Archives in Media Theory," 91.

339 Heinz Werner Kramski, "Digitale Dokumente im Archiv," in *Handbuch Archiv: Geschichte, Aufgaben, Perspektiven*, ed. Marcel Lepper and Ulrich Raulff (J.B. Metzler, 2016), 178.

340 Kramski, "Digitale Dokumente Im Archiv," 178–179.

341 Kramski, "Digitale Dokumente Im Archiv," 179.

342 Kramski, "Digitale Dokumente Im Archiv," 189–190.

A more forward-thinking museum concept moves beyond viewing the museum solely as a space for presenting, archiving, and researching artworks. Instead, it envisions the museum not just as a collection of originals but as a dynamic forum for public discussion and criticism, serving as a hub of documentation and information.[343] Digital collections can function as such information pools, facilitating the dissemination, collection, and generation of new knowledge—by museum staff, researchers, and the public alike. Moreover, since original artworks in museums are often removed from their functional contexts, digital access to supplementary information can help reconstruct or at least partially convey these lost connections.

A museum that prioritizes presenting and communicating its collection in the digital environment as one of its areas of responsibility needs employees with advanced digital skills. If the relevant knowledge, skills, and new ways of thinking are already taught during studies, this will lead museums into a promising future.[344] The importance of digital culture challenges museums to rethink their role, missions, and relationships with their communities.[345] As digital evolution impacts how we think, perceive, and research, it also changes how we learn, communicate, and behave as humans, which further affects how we engage with museum content.[346] Digital skills are essential for museum professionals. Added to the role of the curator is the role of a digital curator, extending to digital formats the communication of the collection's meaning and history. Communication, conversation with audiences, and community outreach are key skills for curators and leaders who leverage digital tools and technologies to make connections between objects and ideas to convey meaning.[347] The museum is transforming from a collections-based model to one that is visitor-, user-, and community-centric.[348] Museums are no longer focused solely on building collections and preserving cultural heritage; they are evolving into communicative platforms in the cultural and educational spheres, sharing collections and

343 Andreas Speigl, "Das Museum: Auf seinem Weg vom Ort zum Raum, vom Archiv zum Pool und zurück," in *Zum Bedeutungswandel der Kunstmuseen: Positionen und Visionen zu Inszenierung, Dokumentation, Vermittlung*, ed. Harald Krämer and Hartmut John (Verlag für Moderne Kunst, 1998), 28–31.

344 Tula Giannini and Jonathan P. Bowen, "Transforming Education for Museum Professionals in the Digital Age," in *Museums and Digital Culture: New Perspectives and Research*, ed. Tula Giannini and Jonathan P. Bowen (Springer, 2019), 458, https://doi.org/10.1007/978-3-319-97457-6_23.

345 Giannini and Bowen, "Transforming Education," 458.

346 Giannini and Bowen, "Transforming Education," 458.

347 Giannini and Bowen, "Transforming Education," 473.

348 Giannini and Bowen, "Transforming Education," 473.

knowledge about art.[349] For this digital transformation to occur, certain foundations must be established.

Digital Strategy for Successful Digital Transformation

Museums have increasingly begun implementing digital strategies (appendix F)—one of the most profiled being the Tate Gallery of Modern Art in London, which began doing so as early as 2010—to meet the challenges of digital transformation.[350] A digital strategy is a fundamental, long-term, and sustainable approach that guides a museum's digital activities by defining and controlling projects, resources, structures, competencies, actions, values, costs, and benefits.[351] It requires a digital mindset and an attitude that digital technology is relevant to the museum's mission.[352] Developed in alignment with the institution's mission statement, a digital strategy expands on it, establishes core parameters for digital initiatives, and articulates positions for both the institution and the public.[353] Ideally iterative, it allows for experimentation and adaption to evolving conditions.[354] When seamlessly integrated into daily operations, a well-defined digital strategy enables a museum to act as a competent and professional leader in digital technology, providing a clear vision, defining key frameworks, and serving as a strategic compass for all digital endeavors.

Accordingly, Lorenz Pöllmann and Clara Herrmann situate museums, theaters, and concert halls in an environment where new digital cultural management and expertise are essential for integrating digital technologies flexibly and effectively through digital strategies and offerings.[355] Visitors and users, who no longer distinguish between online and offline or analog and digital, require new forms of culture and communication from cultural institutions due to the emergence of new points of contact.[356] Cultural institutions must engage new digital business models, forms of communication, and mediations of art and ideas to exploit the virtual possibilities, which

349 Giannini and Bowen, "Transforming Education," 476.

350 Christian Gries, "Das digital kompetente Museum – digitale Strategien für Museen," in *Der digitale Kulturbetrieb: Strategien, Handlungsfelder und Best Practices des digitalen Kulturmanagements*, ed. Lorenz Pöllmann and Clara Herrmann (Springer, 2019), 100–101, https://doi.org/10.1007/978-3-658-24030-1_5.

351 Gries, "Das digital kompetente Museum," 102.

352 Gries, "Das digital kompetente Museum," 102.

353 Gries, "Das digital kompetente Museum," 102.

354 Gries, "Das digital kompetente Museum," 102–3.

355 Lorenz Pöllmann and Clara Herrmann, "Vorwort," in *Der digitale Kulturbetrieb: Strategien, Handlungsfelder und Best Practices des digitalen Kulturmanagements*, ed. Lorenz Pöllmann and Clara Herrmann (Springer, 2019), v.

356 Pöllmann and Herrmann, "Vorwort," v-vi.

must go beyond digitization and include developments in virtual and augmented reality, artificial intelligence, robotics and 3D technology.[357] Pöllmann and Herrmann emphasize that the digital transformation affects both the contents and the organizational structures of cultural institutions.[358] While some cultural institutions are still expanding the digital infrastructure and digital workplaces, for others, digital cultural mediation has already become part of their work.[359] A playful and experimental approach to high culture with open exhibition formats, applications on the Internet, or for a creative and participatory reuse is promising for artistic production, mediation, and communication of art and culture.[360]

As institutions adapt to the digital realm, they respond to the needs of both the general public and professionals. Without adjustments to new conditions, parallel developments arise—much like the coexistence of analog slide and photo collections in art history departments alongside museum documentation archives. A digital parallel emerged when university art history departments began digitizing images of artworks for teaching and research, independent of museum digitization efforts. To meet the need for digital images, these departments developed their own image databases, often relying on scanned book illustrations—a workaround due to the initial scarcity of high-resolution digital images. This phenomenon highlights a gap between technological advancements and the availability of suitable content, in this case, digital images of artworks.

In the meantime, the number of museum digital collections, their completeness, as well as the provided digital image resolutions have increased. The need for digital access to artworks from museum collections is largely satisfied, but due to increased interest in technology, we have again reached a point where the current technological state of digital collections lags behind the needs. It is no longer sufficient to look at images and read descriptive work data, but there are art historians who are interested in using the material in the collections as data—the image files and metadata. Some museums, libraries, and archives are already responding to this need by publishing their collection metadata, and also the images of public domain artworks, as open data with as few legal and technical restrictions as possible. This makes the data available for free use, including for commercial purposes.

357 Pöllmann and Herrmann, "Vorwort," vi.

358 Pöllmann and Herrmann, "Vorwort," vi.

359 Pöllmann and Herrmann, "Vorwort," vii.

360 Pöllmann and Herrmann, "Vorwort," vii.

Enabling Free Use of Images and Metadata

Online availability of museum and other cultural collections raises questions about the changes digital images of artworks introduce to art history. Research with reproductions of artworks that were once prints, photographs, or images in books takes on a new dimension in digital collections. The impact of digital technology on art historical research extends beyond accelerating workflows and expanding image access; it raises deeper questions about how it transforms the discipline and its research methods.[361] Further, media-specific questions about the definition of a digital image versus an analog one, how the image as an object transmits information, but also the status an image has in a particular context, are abundant. In response, programs like The Digital Image[362] by the German Research Foundation (DFG) have funded a number of projects from multiple disciplines investigating aspects of the digital image from a digital humanities perspective.[363] The projects address challenges in the presentation of digital images, automatic 3D pattern recognition, digital art based on programming, the visual representation of architecture, curating digital images by the public, social media as public image repositories for machine learning, the digital recoloring of black-and-white film, similarities in image datasets, and others.[364] The interest in digital images in humanities research parallels the development of image data in digital collections at museums.

Historically, the representation of museum collections—and thus art historians' access to them—can be divided into three phases beginning with the printed collection catalog, then the *Collection Online*, and finally current digital collections that enable the reuse of image files and information as metadata. The printed image in a collection catalog is a static image, since the reader can do nothing but look at the reproduction, which is supposed to mediate knowledge about the appearance of the artwork. *Collections Online*, which only allow users to view the images and read the artwork information, function as digitized equivalents of earlier printed collection catalogs. Digital images in collection databases are primarily digitized images that represent physical artworks. The image in an online museum collection becomes

361 Chris Bailey, "Introduction: Making Knowledge Visual," in *Revisualizing Visual Culture*, ed. Chris Bailey and Hazel Gardiner (Ashgate, 2010), 2.

362 See "SPP 2172: Das digitale Bild," Deutsche Forschungsgemeinschaft (DFG), accessed December 27, 2024, https://gepris.dfg.de/gepris/projekt/402352280; and Das digitale Bild, Ludwig-Maximilians-Universität München, accessed December 27, 2024, https://www.digitalesbild.gwi.uni-muenchen.de.

363 Hubertus Kohle and Hubert Locher, eds., *The Digital Image: A Transdisciplinary Research Cluster*, DAHJ Editions 1 (Graphentis, 2021).

364 Kohle and Locher, *The Digital Image*.

search-, filter-, and zoomable and is sometimes downloadable, which means that there is interaction to some degree. An image in an online collection is, thus, an interactive image. Finally, images in most current digital collections that enable reuse, downloading, machine-readable access via an API, and the use of Creative Commons licenses, CC0, or the Public Domain Mark for images and metadata make it possible to share the images, use them in other contexts and applications, and to create new products. The image becomes mobile, enables user participation, and is available for everyone's purposes. This leads to humanities-related questions about how digital images alter the handling of information and data and what the associated cultural impacts are.

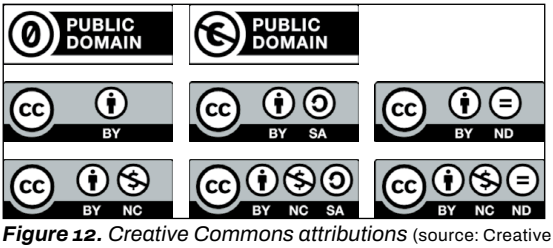


Figure 12. *Creative Commons attributions* (source: Creative Commons, accessed August 13, 2021, https://creativecommons.org/about/downloads)

In digital environments, individually negotiating reuse permissions for each digital asset with separate institutions is impractical. Therefore, standards have been established to clearly indicate permissible uses of data. The Public Domain Mark, CC0, and Creative Commons licenses[365] support the mobility of images by clearly stating the rights to reuse data without being forced to go through the time-consuming process of obtaining permissions (fig. 12). Moreover, public domain tools and Creative Commons licenses are human- and machine-readable. For copyrighted material, the RightsStatements.org[366] have been released as complementary to Creative Commons licenses. RightsStatements.org is a joint initiative of *Europeana* and the *Digital Public Library of America (DPLA)* to provide complementary, standardized, machine-readable, and interoperable rights statements for online cultural heritage. The rights statements allow institutions to describe the copyright and reuse

365 See "Public Domain," Creative Commons, accessed December 27, 2024, https://creativecommons.org/share-your-work/public-domain/; "About CC Licenses," Creative Commons, accessed December 27, 2024, https://creativecommons.org/about/cclicenses; and "How Do CC licenses operate?" Creative Commons, accessed December 27, 2024, https://creativecommons.org/faq/#how-do-cc-licenses-operate.

366 RightsStatements.org, accessed December 27, 2024, https://rightsstatements.org.

status of artworks in situations in which the Creative Commons licenses are not suitable.[367] Some Creative Commons licenses are very restrictive, especially if they only allow noncommercial uses (e.g., CC BY-NC-SA). The Creative Commons license spectrum visualizes the differences in openness (fig. 13). For cultural institutions, those in the dark green area—CC0, CC BY, and CC BY-SA—are recommended.[368]

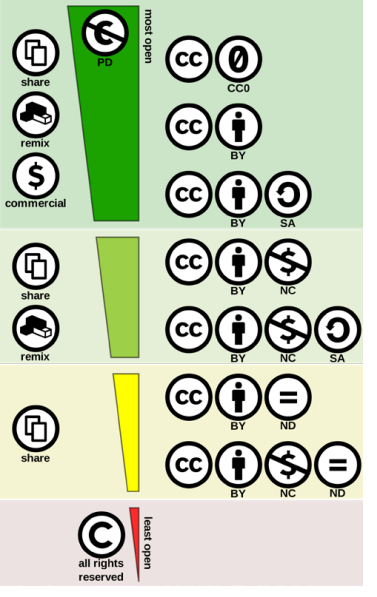


Figure 13. *Creative Commons license spectrum* (source: By Shaddim, original CC license symbols by Creative Commons, CC-BY-4.0, accessed December 23, 2018, https://commons.wikimedia.org/wiki/File:Creative_commons_license_spectrum.svg)

These licenses are a prerequisite for publishing any image on *Wikimedia Commons*.[369] Images from *Wikimedia Commons* can be incorporated into *Wikipedia* articles, which helps collection objects to gain additional reach, and thus greater visibility than if they were only to be found in the digital collection of a museum. Another reason is that these three license types have the advantage that the image data can be made available for cultural hacka-

367 "Frequently Asked Questions," RightsStatements.org, accessed December 27, 2024, https://rightsstatements.org/en/documentation/faq.html.

368 See "Understanding Free Cultural Works," Creative Commons, accessed December 27, 2024, https://creativecommons.org/share-your-work/public-domain/freeworks/.

369 "What licenses do the files I want to upload have to use?," *Wikimedia Commons*, accessed December 27, 2024, https://commons.wikimedia.org/wiki/Commons:FAQ#Copyright_questions.

thons and used there. Cultural hackathons, such as Coding da Vinci[370] in Germany, the Swiss Open Cultural Data Hackathon,[371] or Coding Dürer,[372] aim to obtain cultural datasets for free use so they can bring together participants from bot technological and cultural backgrounds to experiment with data and show in prototypical projects what is possible when data and technology intersect. The recommendation to use only the three aforementioned Creative Commons licenses in the context of cultural data is to ensure that nothing prevents the use of this data in third-party applications (whether in academia, by a museum, or privately). If barrier-free use of the data is guaranteed, what is developed from it can in turn be made publicly available.

Table 8. *Museums digital collections using CCo public domain dedication*

Museum	URL
Art Institute of Chicago	https://www.artic.edu/collection
Cleveland Museum of Art	https://www.clevelandart.org/open-access
Getty Museum	https://www.getty.edu/art/collection
Metropolitan Museum of Art	https://www.metmuseum.org/art/collection
Museum für Kunst und Gewerbe Hamburg	https://sammlungonline.mkg-hamburg.de
National Gallery of Art	https://www.nga.gov/collection
Paris Musées	https://www.parismuseescollections.paris.fr/fr/recherche/image-libre/1
Rijksmuseum	https://www.rijksmuseum.nl/en/rijksstudio
Statens Museum for Kunst	https://open.smk.dk

However, it is highly recommended for cultural data to use the Public Domain Mark or CC0 for artwork images in digital collections no longer

370 Coding da Vinci, accessed December 27, 2024, https://codingdavinci.de; Barbara Fischer, "Coding da Vinci: oder für eine Renaissance der Allmendekultur mit digitalen Mitteln," in *Der digitale Kulturbetrieb: Strategien, Handlungsfelder und Best Practices des digitalen Kulturmanagements*, ed. Lorenz Pöllmann and Clara Herrmann (Springer, 2019), https://doi.org/10.1007/978-3-658-24030-1_19.

371 Swiss Open Cultural Data Hackathon, OpenGLAM CH, December 27, 2024, https://glam.opendata.ch/hackathons.

372 Coding Dürer, Institut für Kunstgeschichte, Ludwig-Maximilians-Universität München, accessed December 27, 2024, https://codingdurer.de; Sonja Gasser, "Coding Dürer: International Interdisciplinary Hackathon for Art History and Information Science," *International Journal for Digital Art History*, no. 3 (2018), https://doi.org/10.11588/dah.2018.3.49918.

protected by copyright (i.e., 70 years after the artist's death).[373] Among the museums that mark digital reproductions of works in the public domain with the CC0 public domain dedication[374] are Art Institute of Chicago, Cleveland Museum of Art, Getty Museum, Metropolitan Museum of Art, Museum für Kunst und Gewerbe Hamburg, National Gallery of Art in Washington, DC, Paris Musées, Rijksmuseum, and Statens Museum for Kunst (table 8). Many well-known museums have led the way and others have already followed, so this practice will become better established in the museum sector.

Gertraud Koch offers four different perspectives on how cultural analysis can engage with the digital: First, the transformation culture undergoes through hardware and software, eventually ending up in code. Second, cultural practices that arise from the digital and are possibly converted into analog practices. Third, technology's potential to offer humans entirely new interpretations, and lastly, the reappraisal of existing cultural concepts and theories in relationship to the digital.[375] All these approaches can be considered across different stages of the digitization process.

The first step is digitizing artworks and information by setting up a database that contains digital images and metadata. At this stage, the museum is performing the bare minimum to maintain inventory records in a database, along with public online access to the collection records. Users can access the collection via computer and perform database-specific tasks, such as keyword searches across various categories—functionality that was previously limited when using inventory cards, which were often organized only by criteria like artists' names. Art collection databases allow users to quickly switch from one artwork to the next and gain insight into the collection at the individual object level. What is completely absent in this scenario is the mediation of the collection contents for a broader public, as well as the convenient reuse of the provided data.

Museums must understand users' digital experiences and expectations

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373 For a comprehensive, practice-oriented discussion of the Public Domain Mark and the CC0 license in relation to an Open Content Policy by cultural heritage institutions, see Klaus Bulle et al., *Open Access Policy: Ein Leitfaden für Kulturerbe-Einrichtungen in Hessen,* ed. Deutsches Dokumentationszentrum für Kunstgeschichte – Bildarchiv Foto Marburg and Christian Bracht, arthistoricum.net, 2022, https://doi.org/10.11588/arthistoricum.1023. See also "Public Domain," Creative Commons, accessed April 1, 2022, https://creativecommons.org/share-your-work/public-domain/ and "OpenGLAM Principles," OpenGLAM, accessed April 1, 2022, https://openglam.org/principles/.

374 "CC0 1.0 Universal," Creative Commons, accessed December 27, 2024, https://creativecommons.org/publicdomain/zero/1.0.

375 Gertraud Koch, "Einleitung: Digitalisierung als Herausforderung der empirischen Kulturanalyse," in *Digitalisierung: Theorien und Konzepte für die empirische Kulturforschung*, ed. Gertraud Koch (Herbert von Halem Verlag, 2017), 13.

for collections. The challenge is to harness technology effectively to engage their audience and reach new target groups. Being able to compare random images with each other, zoom in and out, or search for particular details directly from the images with the help of algorithms, are only a few of the powerful tools for the users to interact with the provided content. Permitting people to share content on social networks is only one way to promote interactivity and participation, but at the same time, this indirectly opens up a marketing channel for a viral distribution of information. Another possibility is to provide applications that allow people to learn something about broader context, a group of artworks, and interrelationships between them. Giving an overview of the full holdings of the database through data visualization makes the content also much more perceivable, meaningful, and explorable.

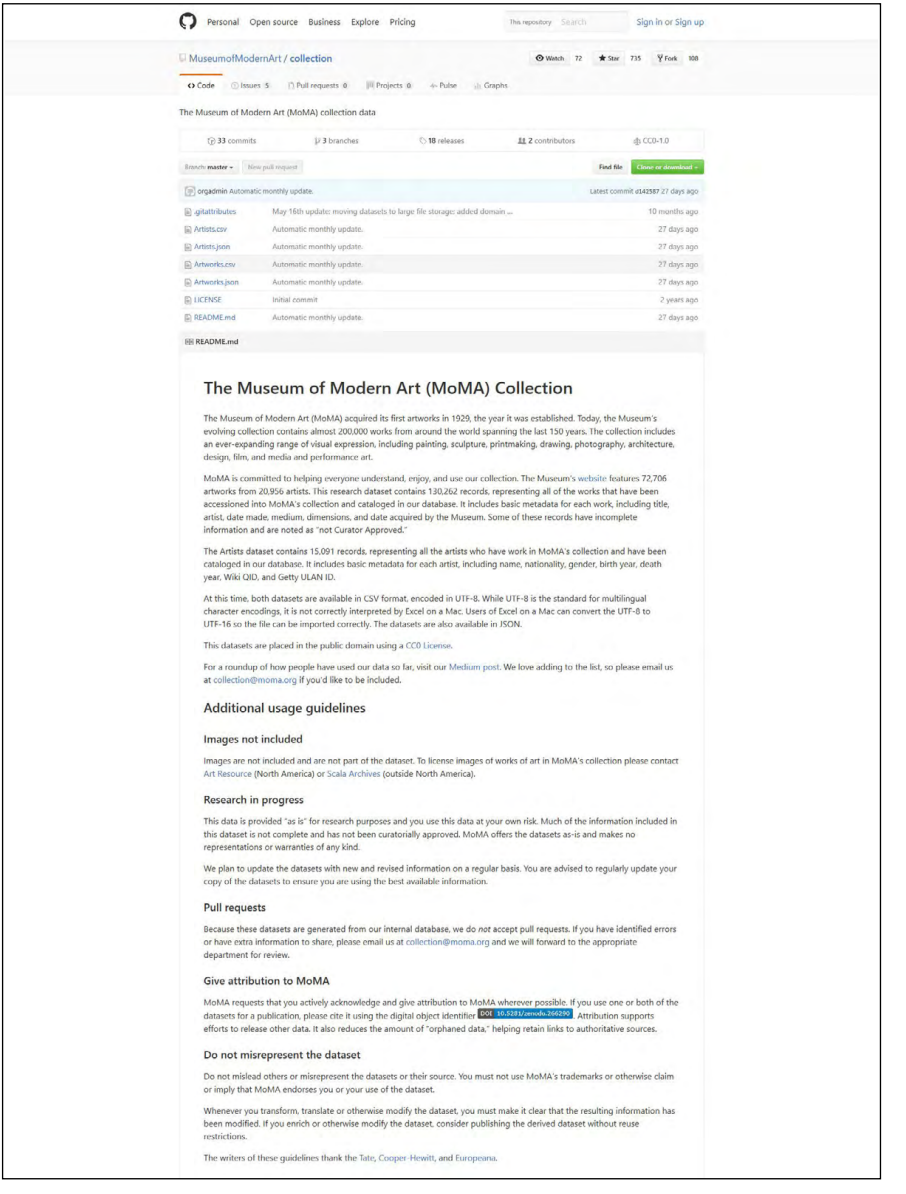
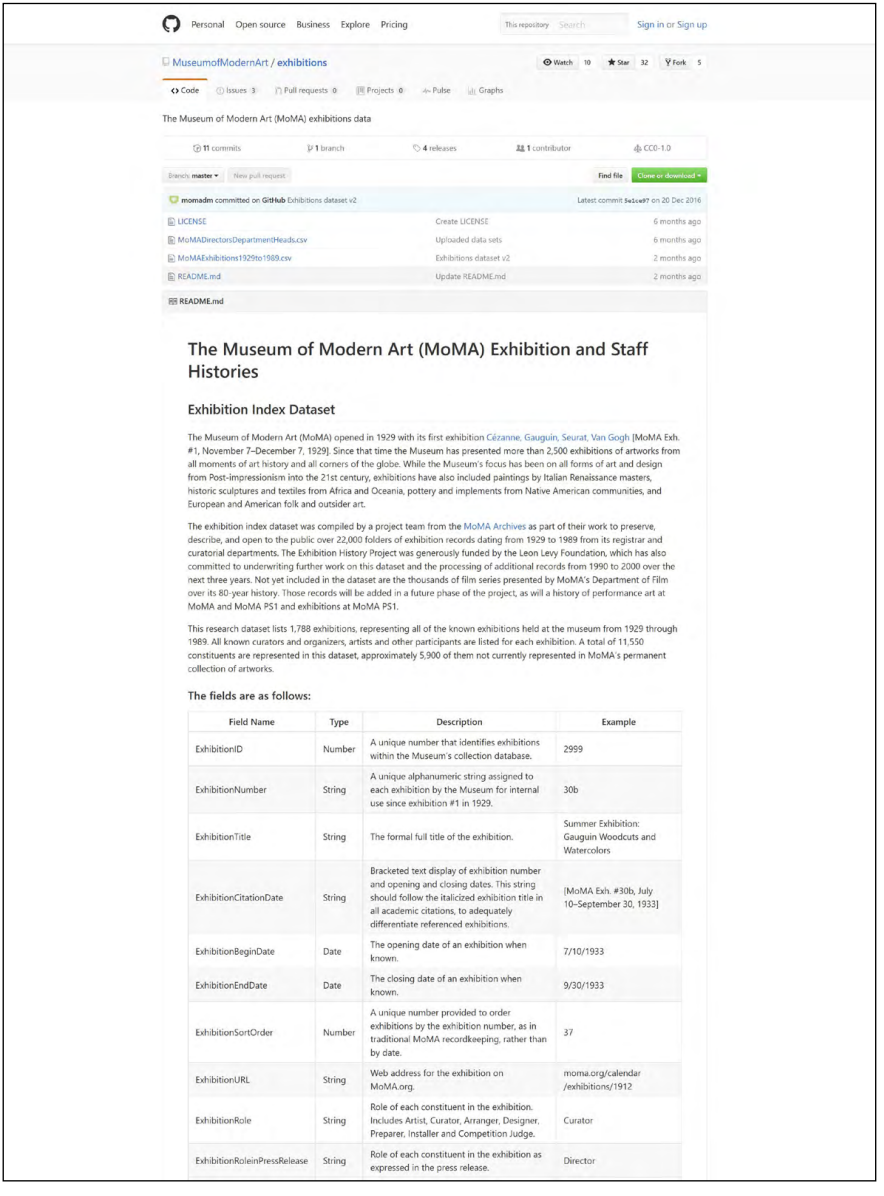


Figure 14. *Available collection datasets at "The Museum of Modern Art (MoMA) Collection," GitHub, accessed February 28, 2017, https://github.com/MuseumofModernArt/collection*



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This repository Search Sign in or Sign up

MuseumofModernArt / exhibitions

Watch 10 Star 32 Fork 5

Code Issues 3 Pull requests 0 Projects 0 Pulse Graphs

The Museum of Modern Art (MoMA) exhibitions data

11 commits 1 branch 4 releases 1 contributor CC0-1.0

Branch: master New pull request Find file Clone or download

momadm committed on GitHub Exhibitions dataset v2 Latest commit 5a1ca97 on 20 Dec 2016

LICENSE	Create LICENSE	6 months ago
MoMADirectorsDepartmentHeads.csv	Uploaded data sets	6 months ago
MoMAExhibitions1929to1989.csv	Exhibitions dataset v2	2 months ago
README.md	Update README.md	2 months ago

README.md

The Museum of Modern Art (MoMA) Exhibition and Staff Histories

Exhibition Index Dataset

The Museum of Modern Art (MoMA) opened in 1929 with its first exhibition Cézanne, Gauguin, Seurat, Van Gogh [MoMA Exh. #1, November 7–December 7, 1929]. Since that time the Museum has presented more than 2,500 exhibitions of artworks from all moments of art history and all corners of the globe. While the Museum's focus has been on all forms of art and design from Post-Impressionism into the 21st century, exhibitions have also included paintings by Italian Renaissance masters, historic sculptures and textiles from Africa and Oceania, pottery and implements from Native American communities, and European and American folk and outsider art.

The exhibition index dataset was compiled by a project team from the MoMA Archives as part of their work to preserve, describe, and open to the public over 22,000 folders of exhibition records dating from 1929 to 1989 from its registrar and curatorial departments. The Exhibition History Project was generously funded by the Leon Levy Foundation, which has also committed to underwriting further work on this dataset and the processing of additional records from 1990 to 2000 over the next three years. Not yet included in the dataset are the thousands of film series presented by MoMA's Department of Film over its 80-year history. Those records will be added in a future phase of the project, as will a history of performance art at MoMA and MoMA PS1 and exhibitions at MoMA PS1.

This research dataset lists 1,788 exhibitions, representing all of the known exhibitions held at the museum from 1929 through 1989. All known curators and organizers, artists and other participants are listed for each exhibition. A total of 11,550 constituents are represented in this dataset, approximately 5,900 of them not currently represented in MoMA's permanent collection of artworks.

The fields are as follows:

Field Name	Type	Description	Example
ExhibitionID	Number	A unique number that identifies exhibitions within the Museum's collection database.	2999
ExhibitionNumber	String	A unique alphanumeric string assigned to each exhibition by the Museum for internal use since exhibition #1 in 1929.	30b
ExhibitionTitle	String	The formal full title of the exhibition.	Summer Exhibition: Gauguin Woodcuts and Watercolors
ExhibitionCitationDate	String	Bracketed text display of exhibition number and opening and closing dates. This string should follow the italicized exhibition title in all academic citations, to adequately differentiate referenced exhibitions.	[MoMA Exh. #30b, July 10–September 30, 1933]
ExhibitionBeginDate	Date	The opening date of an exhibition when known.	7/10/1933
ExhibitionEndDate	Date	The closing date of an exhibition when known.	9/30/1933
ExhibitionSortOrder	Number	A unique number provided to order exhibitions by the exhibition number, as in traditional MoMA recordkeeping, rather than by date.	37
ExhibitionURL	String	Web address for the exhibition on MoMA.org.	moma.org/calendar/exhibitions/1912
ExhibitionRole	String	Role of each constituent in the exhibition. Includes Artist, Curator, Arranger, Designer, Preparer, Installer and Competition Judge.	Curator
ExhibitionRoleinPressRelease	String	Role of each constituent in the exhibition as expressed in the press release.	Director

Figure 15. *Available exhibition datasets at "The Museum of Modern Art (MoMA) Exhibition and Staff Histories," GitHub, accessed February 28, 2017, https://github.com/MuseumofModernArt/exhibitions*

Table 9. *Art Metadata fields for artist records in "Artists.csv," using the "Vincent van Gogh" entry* (source: MoMA, GitHub, accessed December 22, 2024, https://github.com/MuseumofModernArt/collection/blob/main/Artists.csv)

Artists	
Metadata	**Example**
ConstituentID	2206
DisplayName	Vincent van Gogh
ArtistBio	Dutch, 1853–1890
Nationality	Dutch
Gender	Male
BeginDate	1853
EndDate	1890
Wiki QID	Q5582
ULAN	500115588

One function of a digital collection is the user's ability to view the collection through the user interface; it is another function entirely to access the underlying data. When a museum provides the latter, access is granted often through a different pathway. MoMA's *Collection* is an example of how museums present their collections of art online. Their exhaustive exhibition history, containing digitized installation views and digitized archival material, stands out in comparison with other museums and also underlines just how much data exists at museums. At the beginning of 2022, about 93,000 of the approximately 200,000 works in MoMA's ever-evolving collection were online, along with 26,900 artists.[376] The exhibition history presented online contained 5,215 exhibitions.[377] In addition to the museum's search and user interface, this vast amount of data is also accessible independently. Lists with metadata about artists, artworks (fig. 14), exhibitions, and the museum directors and department heads (fig. 15) are available on GitHub in machine-readable formats (CSV and JSON), well documented, and available for reuse in public domain under a CC0 license.[378] The datasets do not include images, largely because most artworks are still protected by copyright.

376 For current numbers, see "About the Collection," MoMA, accessed February 26, 2022, https://www.moma.org/collection/about.

377 For more information, see *Exhibition History,* https://www.moma.org/calendar/exhibitions/history and "About Our Exhibition History," https://www.moma.org/calendar/exhibitions/history/about.

378 "The Museum of Modern Art (MoMA) Collection," MoMA, GitHub, accessed February 26, 2022, https://github.com/MuseumofModernArt/collection.

Table 10. *Metadata fields for artwork records in "Artworks.csv," using the entry for Vincent van Gogh's painting* The Starry Night (source: MoMA, GitHub, accessed December 22, 2024, https://github.com/MuseumofModernArt/collection/blob/main/Artworks.csv)

Artworks	
Metadata	**Example**
Title	The Starry Night
Artist	Vincent van Gogh
ConstituentID	2206
ArtistBio	(Dutch, 1853–1890)
Nationality	(Dutch)
BeginDate	-1853
EndDate	-1890
Gender	(Male)
Date	Saint Rémy, June 1889
Medium	Oil on canvas
Dimensions	29 x 36 1/4" (73.7 x 92.1 cm)
CreditLine	Acquired through the Lillie P. Bliss Bequest
AccessionNumber	472.1941
Classification	Painting
Department	Painting & Sculpture
DateAcquired	10.06.1941
Cataloged	Y
ObjectID	79802
URL	https://www.moma.org/collection/works/79802
ThumbnailURL	https://www.moma.org/media/W1siZiIsIjEzMzA3NSJdLFsicCIsImNvbnZlcnQiLCIt-cmVzaXplIDMwMHgzMDBcdTAwM2UiXV0.jpg?sha=ddf906f8cf4a531b
Circumference (cm)	
Depth (cm)	
Diameter (cm)	
Height (cm)	73.7
Length (cm)	
Weight (kg)	
Width (cm)	92.1
Seat Height (cm)	
Duration (sec.)	

Table 11. *Metadata fields for individual records in "MoMADirectorsDepartmentHeads.csv," using the entry for "Alfred H. Barr, Jr."* (source: MoMA, GitHub, accessed December 23, 2018, https://github.com/MuseumofModernArt/exhibitions/blob/master/MoMADirectorsDepartmentHeads.csv)

Directors and Department Heads	
Metadata	**Example**
DepartmentFullName	Department of Painting and Sculpture
DepartmentBeginYear	1929
DepartmentEndYear	
ConstituentID	9168
DisplayName	Alfred H. Barr, Jr.
PositionNote	as Director of the Museum and Curator of the Department
PositionBeginYear	1940
PositionEndYear	1943
ConstituentType	Individual
AlphaSort	Barr Alfred H. Jr.
FirstName	Alfred
MiddleName	H.
LastName	Barr
Suffix	Jr.
Nationality	American
ConstituentBeginDate	1902
ConstituentEndDate	1981
ArtistBio	American, 1902–1981
Gender	Male
VIAFID	109252853
dataID	Q711362
ULANID	500241556

Table 12. *Metadata fields for exhibition records in "MoMAExhibitions1929to1989.csv," using the entry for* Fourteen Paintings by Vincent van Gogh (source: MoMA, GitHub, accessed December 23, 2018, https://github.com/MuseumofModernArt/exhibitions/blob/master/MoMAExhibitions1929to1989.csv)

Exhibitions Metadata	**Example**
ExhibitionID	3729
ExhibitionNumber	293
ExhibitionTitle	Fourteen Paintings by Vincent van Gogh
ExhibitionCitationDate	[MoMA Exh. #293, August 3-August 26, 1945]
ExhibitionBeginDate	08.03.1945
ExhibitionEndDate	8/26/1945
ExhibitionSortOrder	358
ExhibitionURL	moma.org/calendar/exhibitions/2366
ExhibitionRole	Artist
ExhibitionRoleinPressRelease	Artist
ConstituentID	2206
ConstituentType	Individual
DisplayName	Vincent van Gogh
AlphaSort	Gogh Vincent van
FirstName	Vincent
MiddleName	
LastName	van Gogh
Suffix	
Institution	
Nationality	Dutch
ConstituentBeginDate	1853
ConstituentEndDate	1890
ArtistBio	Dutch, 1853–1890
Gender	Male
VIAFID	9854560
WikidataID	Q5582
ULANID	500115588
ConstituentURL	moma.org/artists/2206

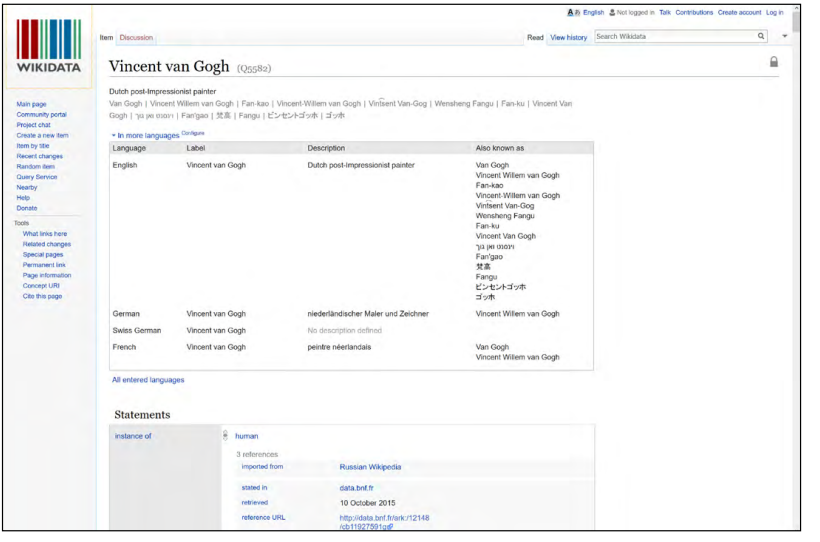


Figure 16. *Vincent van Gogh's record on* Wikidata*, accessed March 8, 2017, https://www.wikidata.org/wiki/Q5582*

Examining the metadata fields in MoMA's CSV files for artists (table 9), artworks (table 10), museum directors and department heads (table 11), and exhibitions from 1929 to 1989 (table 12) highlights the richness of the available metadata. Life dates of artists, periods of activity of directors and curators, creation dates of artworks, and exhibition durations are examples of temporal data that can be used for data linking or timeline visualizations. It is also notable that *ULAN*, *VIAF*, and *Wikidata* IDs are recorded in the datasets. This means that beyond information captured in the CSV tables, additional information available in the authority records can be added, like alternative spellings of artists' names in other languages, relationships to other entities, other resources, and IDs as seen via *Wikidata* (fig. 16). Metadata provided by a museum and the potential to add to it with additional metadata from other sources only leads to flexible use of this data and expands the scope of possible questions that can be addressed.

Linking data becomes particularly interesting when other extensive sources, such as those from art historical research institutions, become accessible in machine-readable form that are not directly related to an individual collection. One example is the Getty Provenance Index,[379] which is also

379 "Collecting and Provenance Research," Getty Research Institute, accessed December 27, 2024, https://www.getty.edu/research/tools/provenance.

available as CSV file on GitHub.[380] The Getty Provenance Index includes archival inventories for the period from 1550 to 1840; sales catalogs from auctions in Belgium, France, Germany, Great Britain, the Netherlands, and Scandinavia between 1650 and 1945; as well as public collections with the description and provenance of paintings by artists born before 1900 from public American and British institutions between 1500 and 1990. Another example are the web services for artist and image data from the RKD Netherlands Institute for Art History, a documentation and research institute that works in collaboration with museums, heritage institutes, universities, and private institutes.[381] Elaborately compiled art historical resources then become accessible to others, who can draw on them and integrate them into their own systems and projects.

Table 13. *Museums providing raw collection data*

Museum	Content	Format	Access	URL
Louvre	artworks	CSV	Collections	https://collections.louvre.fr
	artists, artworks	JSON	API	https://collections.louvre.fr/en/page/documentationJSON
Tate	artists, artworks	CSV, JSON	GitHub	https://github.com/tategallery/collection
MoMA	artists, artworks (monthly updated)	CSV, JSON	GitHub	https://github.com/Museumof-ModernArt/collection
	directors/department heads, exhibitions	CSV	GitHub	https://github.com/Museumof-ModernArt/exhibitions
	artworks, exhibition, artists, images	JSON, XML	API	https://api.moma.org
Met	artworks	CSV	GitHub	https://github.com/metmu-seum/openaccess
National Gallery	objects, relation-ships, etc. (daily updated)	CSV	GitHub	https://github.com/National-GalleryOfArt/opendata
Georgia O'Keeffe	objects	JSON-LD	Collections	https://collections.okeeffemu-seum.org
Museum	collections data	TSV, JSON, RDF	GitHub	https://github.com/okeeffemu-seum/collections-data

380 "CSV exports of the Getty Provenance Index," Getty Research Institute, accessed December 27, 2024, https://github.com/thegetty/provenance-index-csv.

381 "Services & Tools," RKD Netherlands Institute for Art History, archived September 22, 2023, at https://web.archive.org/web/20230922015643/https://rkd.nl/en/collections/services-tools. The new website provides information about digital resources via "Digital Collection," RKD Netherlands Institute for Art History, accessed December 27, 2024, https://www.rkd.nl/en/collection/digital-collection.

For scholarly purposes or cultural hackathons, the ability to create tables with a list of selected data directly from the system is indispensable, yet only a few digital collections support this so far. Some museums that give access to the collection data in different ways are shown in table 13. One is the Louvre's *Collections* database that allows the download of metadata for all works in a search result as a CSV table.[382] Others like MoMA, such as the Tate, Metropolitan Museum of Art (Met), and National Gallery of Art in Washington, DC, have made their collections' metadata files available via GitHub. Tate published the dataset in 2014 and is no longer updating it, which is problematic because the data in digital collections are constantly growing and changing. MoMA circumvents this issue by automatically updating the files on a monthly basis. The National Gallery of Art updates numerous tables containing various aspects of the objects on a daily basis. Integrating data access directly into the digital collection for a custom download seems to be a more sustainable solution in the long-term than posting the data as CSV and JSON files on GitHub without updating it. With linked open data and the Semantic Web in mind, the Georgia O'Keeffe Museum provides access to JSON-LD-files for each object in the collections of art, photography, and archive as well as for people and organizations. Supporting applications that use data from a collection, be it for applications developed by museums or in external scholarly digital humanities projects, requires that the contents be accessible, not only human-readable, but also machine-readable, ideally via a good documented application programming interface (API) like MoMA's.

Museums make their data available for reuse in two ways. One approach is to provide only metadata, as seen with institutions that share CSV and JSON files on GitHub. The other, and perhaps more compelling option, is to grant access to both metadata and image files. Amsterdam's Rijksmuseum was one of the first museums to make its data available without restrictions under the CC0 license.[383] *Images d'art*,[384] a platform that aggregates artworks from the collections of all French museums, provides an API for accessing the data,[385] and the images can be used for noncommercial purposes.

Viewing an artwork in a museum, looking at a picture in a catalog, or reading printed text are completely different perceptual experiences com-

382 See example: *Collections*, Louvre, accessed December 16, 2021, https://collections.louvre.fr/en/recherche?q=lion. The "export.csv" option at the bottom of the search results allows data export.

383 MoMA, GitHub, accessed December 19, 2018, https://github.com/MuseumofModernArt/.

384 *Images d'art*, Réunion des musées nationaux et du Grand Palais des Champs-Elysées, accessed December 27, 2024, https://art.rmngp.fr.

385 "Welcome to the Images d'Art API," *Images d'art*, accessed December 27, 2024, https://api.art.rmngp.fr.

pared to those with digital images. Digital images are no longer merely visual representations; their underlying binary code allows for analysis using statistical methods and algorithms. Virtual and augmented reality applications, as well as three-dimensional digital objects, further transform how users perceive and interact with art. These shifts necessitate a reassessment of both reproductions and original artworks. The representation of art must be reconsidered, not only in contrast to long-established formats like museum exhibitions and reproductions in books but also in terms of the unique possibilities digital environments offer. The adequacy of terms such as artwork, image, curating, exhibition, visitor, and viewer needs to be questioned and reevaluated to see whether they need to be understood more broadly than they were before the advent of the digital, or whether it is necessary to juxtapose definitions that allow the same terms to be used in an explicitly digital context. Beyond conceptual changes, digital transformation also exposes limitations in existing copyright laws, which often fail to address the complexities of digital media. This discrepancy highlights the need to clarify the evolving role of the digital image and its growing significance in the discourse on art and its accessibility.

2.5 Digital Image as Digital Object

As museums present their collections online and art history engages with digital images as new research, this has implications for the aesthetic and critical analysis of art. The digital image gains significance due to its compatibility with technological infrastructures, raising questions about why digital images (as reproductions of artworks) are such an intriguing research subject for art historians. Theoretically, these questions can be addressed through the discipline of image studies (Bildwissenschaften).

Existing theories address databases as sources, digital media, or aspects of the image. William J. T. Mitchell's "pictorial turn" in 1992 and Gottfried Boehm's "iconic turn" in 1994 mark a shift in the theoretical approach to images.[386] Christoph Wagner notes that these concepts highlight the need for art history to go beyond merely expanding its subject matter quantitatively or applying traditional methods to new image phenomena.[387] With the emergence of Bildwissenschaften, art history broadened its scope by

386 William J. Thomas Mitchell, "The Pictorial Turn," *Artforum* 30, no. 7 (1992): 11–34; Gottfried Boehm, "Die Wiederkehr der Bilder," in *Was ist ein Bild?*, ed. Gottfried Boehm (Wilhelm Fink, 1994), 13–14.

387 Christoph Wagner, "Grenzen der Bilder: Malerei und Fotografie im visuellen Wettbewerb," in *In Bildern denken? Kognitive Potentiale von Visualisierung in Kunst und Wissenschaft*, ed. Ulrich Nortmann and Christoph Wagner (Wilhelm Fink, 2010), 196.

incorporating a wider range of visual culture beyond artworks, including images and objects from everyday life as legitimate research subjects. Instead of focusing solely on an artwork's value within an art historical framework, the question shifts to what defines an image's significance within a broader cultural context. Given the mass of images that exist today, it is especially important to identify visual criteria what distinguishes certain images from others. In the context of digital art collections, one criterion is the quality of the artwork as represented in its digital reproduction. Another consideration is the analysis of images circulating on the internet, which contribute to the increasing ubiquity of visual material.

Digitization in memory institutions like libraries, archives, and museums is a prerequisite for providing research resources for those in the humanities.[388] The value of converting analog cultural artifacts into digital form lies not just in creating content for an institution's database, but also for digital humanities research.[389] It is now common for memory institutions to use digitization to improve access to cultural and historical documents, artifacts, and artworks they hold, thus promoting a better understanding of the materials in their collections.[390] Digitization is a technical part of collection documentation, but as a cultural technique, it also aims to enable an extended examination of cultural-historical content. Successful digitization and documentation necessitate not only technical infrastructure and equipment but also qualified personnel with the appropriate expertise to carry out the often lengthy processes. Establishing the foundations for digital access and research based on digital sources thus demands significant effort. The key question is always to what extent and within what time frame resources are allocated to digitization. Nevertheless, digitization enhances cultural knowledge by making sources more accessible and available on an unprecedented scale, facilitating broad and extensive research on art and its historical contexts. Its value lies not only in the ability to process large quantities of digital images but also in how the files themselves, depending on the digitization technology used, serve as carriers of information. Access to this information enables fundamentally different approaches to analyzing art and generating knowledge.

388 Melissa Terras, "Digitization and Digital Resources in the Humanities," in *Digital Humanities in Practice*, ed. Claire Warwick et al. (Facet, 2012), 47, https://doi.org/10.29085/9781856049054.004.

389 Terras, "Digitization and Digital Resources," 47.

390 Terras, "Digitization and Digital Resources," 47.

Creating Digital Image Files

The peculiarity of the digital image is that it is a technical image. This makes it possible to capitalize on the properties inherent to digital systems when creating, storing, using, researching, and presenting digital images, allowing for different possibilities than the analog field. The digital image's processing with digital methods depends on the source object, the scanning technique used to create the file, and the metadata embedded in the file. There exist various digitization processes to digitize artifacts, images, text, video, and audio to make cultural and historical content available online.[391] Digitization techniques include scanning, photographing, typing in texts or applying OCR (optical character recognition), text encoding for marked-up digital resources, digital video and audio recording, and three-dimensional scanning methods for objects.[392] When designing digital resources, it must be taken into account that the needs of humanities scholars are not homogeneous, which is why their search behavior for digital content can only be predicted to an extent.[393] To maximize future use and the analysis potential of files, it is advisable to use digitization techniques that support the widest possible range of methods.

The quality of digital images is determined not only by the conditions under which they are captured but also by technological factors, such as the file format. Ensuring high data quality is essential for a digital image file to possess the right properties for a wide variety of potential uses. Essentially, a digital image is a file that encodes the distribution of brightness in binary code and becomes visible to humans only when a computer decodes the file and displays the image in visual form.[394] Artworks digitized through photography are captured using consistent settings, stable lighting conditions, and color calibration with a ColorChecker Chart.[395] There are a range of file formats for images. Digital images of artworks are produced in an uncompressed format, often as TIFF (Tagged Image File Format) files, to

391 Terras, "Digitization and Digital Resources," 48.

392 Terras, "Digitization and Digital Resources," 47–48.

393 Terras, "Digitization and Digital Resources," 55.

394 Rudolf Gschwind, "Virtualität, Materialität und Funktionalität: Das analoge Archiv im digitalen Zeitalter," in *Über den Wert der Fotografie: Zu wissenschaftlichen Kriterien für die Bewahrung von Fotosammlungen*, ed. Nora Mathys et al. (hier + jetzt, 2013), 84.

395 Michael Baumgartner et al., "Paul Klee digital – eine Fallstudie," in *Elektronische Bildverarbeitung & Kunst, Kultur, Historie: Konferenzband EVA 2005 Berlin*, ed. Gerd Stanke et al. (EVA et al., 2005), 96, accessed November 17. 2020, https://books.ub.uni-heidelberg.de/arthistoricum/reader/download/176/176-17-76150-1-10-20161111.pdf.

store a high-resolution image file as a master file.[396] As an alternative to TIFF, the lossless compressible JPEG 2000 (developed by the Joint Photographic Experts Group) is also used as a digital archiving format. Usually, TIFF or JPEG 2000 master files are used to create copies in reduced file size and resolution in the compressed JPEG (Joint Photographic Expert Group) file format. These reduced-size images are used on the Web and for various information, communication, and publishing purposes.[397] Reducing the resolution and using compression in file formats like JPEG results in smaller file sizes, but it also inevitably leads to a loss of image information compared to the master file.[398] For text and vector graphics, where the display of precise lines are necessary, GIF (Graphics Interchange Format) or PNG (Portable Network Graphics) are suitable file formats.[399] Furthermore, the quality of JPEG files decreases with every save because the compression is applied each time.[400] GIF supports good image quality for vector graphics (fonts, line drawings, and simple shapes) and is also suitable for animated images.[401] The file format depends entirely on the intended use.

Less obvious is that certain metadata can be stored in the image data itself, which can be useful, for example, when visualizing the data. For this purpose, it is useful to know the standards associated with digital photography.

The *IPTC Photo Metadata Standard*[402] specifies the administrative, descriptive, and rights-related properties of photographs that are transported with the image file. *IPTC Photo Metadata* properties are supported by imaging software and the values can be processed by software. *IPTC* does not cover the technical metadata digital cameras capture, such as generic camera information, ICC profiles, and positioning data.[403] For digital collection images, it is of particular relevance that *IPTC* provides a very detailed metadata structure for an "Artwork or Object in the Image."[404]

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396 Baumgartner et al., "Paul Klee digital," 96; Gerald Maier, "Qualität, Bearbeitung und Präsentation digitaler Bilder," in *Digitale Archive und Bibliotheken: Neue Zugangsmöglichkeiten und Nutzungsqualitäten*, ed. Hartmut Weber and Gerald Maier (Kohlhammer, 2000), 149.

397 Baumgartner et al., "Paul Klee digital," 96; Maier, "Qualität, Bearbeitung und Präsentation," 149–150.

398 Maier, "Qualität, Bearbeitung und Präsentation," 149.

399 Maier, "Qualität, Bearbeitung und Präsentation," 150.

400 Maier, "Qualität, Bearbeitung und Präsentation," 150.

401 Maier, "Qualität, Bearbeitung und Präsentation," 150.

402 "Photo Metadata," International Press Telecommunications Council (IPTC), accessed November 21, 2020, https://iptc.org/standards/photo-metadata/.

403 IPTC Photo Metadata Working Group, *IPTC Photo Metadata Standard 2019.1*, v. 1c, January 24, 2020, accessed November 21, 2020, https://www.iptc.org/std/photometadata/specification/IPTC-PhotoMetadata.

404 IPTC Photo Metadata Working Group, *IPTC Photo Metadata Standard 2019.1*. See para-

Digital cameras usually embed metadata tags in the Exchangeable Image File Format (EXIF) standard to an image file, including information such as the date and time when the photo was taken, GPS coordinates, camera settings (model, orientation, aperture, shutter speed, focal length, metering mode, and ISO speed), as well as descriptions and copyright details. This information can be used to put photos in context with each other.[405] For instance, the location information can be used to visualize architectural photographs or art in public space on a map. This metadata is only relevant for contemporary digital photographs and not photographs that have been digitized or pictures of artworks that have been shot all in the same photo studio.

Digital technology, which brings changes to the consumption and production of culture, requires museums to reconsider their role and mission, as well as their relationship with their audiences as users of cultural content.[406] Digital technologies are enabling museums to improve access to their collections and user reuse of artwork information.[407] In doing so, museums relinquish some of the control and authority to contextualize artworks and cultural objects,[408] while at the same time providing primary source materials for humanists.

Currently, museum digital collections consist largely of static, two-dimensional images of artworks with cataloging information manually entered into the database. This is the simplest way to digitize. Also valuable in digital collections are texts, videos, and three-dimensional objects. Time-based media and three-dimensional objects present their own challenges since they require more sophisticated technologies, hardware, software, and create larger files than when digitizing text or images.[409] More advanced digitization techniques not only expand the range of digital representation options for artworks but also enable the inclusion of other content with additional information about the artworks. This includes publications, conveying objects in their spatial environment, or offering multiple perspectives on the artworks.

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graphs 11.1 to 11.1.17.

405 Hendrik S. Ziezold, *Situative Karten: Orientierung, Exploration und Navigation mit spezialisierbaren Karten* (Springer Vieweg, 2012), 150–151, https://doi.org/10.1007/978-3-8348-2366-3.

406 Enrico Bertacchini and Federico Morando, "The Future of Museums in the Digital Age: New Models for Access to and Use of Digital Collections," *International Journal of Arts Management* 15, no. 2 (2013): 60.

407 Bertacchini and Morando, "Future of Museums," 60.

408 Bertacchini and Morando, "Future of Museums," 60.

409 Deegan and Tanner, "Conversion of Primary Sources," 489.

Table 14. *Art historical research source types*

Sources for art history		
1. Artworks (objects of study)	**2. Additional** (sources from the time)	**3. Secondary literature** (state of research)
Painting	Letters	Scholarly publication
Sculpture	Chronologies	Exhibition catalog
Drawing	Archival documents	Catalog raisonné
Print	Auction catalog	Reference work
Manuscript	Art criticism	etc.
Architecture	etc.	
Photograph		
Video		
Performance		
Installation		
Digital media art		
etc.		

Expanded Digitization of Sources

Museums increase their investment in digitization by scanning not only the artworks in their collection (paintings, sculptures, drawings, prints, and other mediums) but also archival documents (including, but not limited to written documents, printed documents, photographs that document the exhibition history, and digitized exhibition catalogs), resulting in more extensive sources and, as they expand, platforms that facilitate comprehensive approaches to knowledge acquisition. Apart from studying the original, research in art history usually includes other sources of information from the time (e.g., letters, chronologies, archival documents, auction catalogs, art criticism) and scholarship done by others (scholarly publications, exhibition catalogs, catalogs raisonnés, encyclopedias, and dictionaries of art and artists). Table 14 shows these three source categories: artworks as objects of study, additional historical sources providing contextual information from the time of the artwork's creation, and finally secondary literature that represents the state of interpretation and development within a broader context.

Whereas collections online will allow finding the sources listed in column one in table 14, the other types of sources are often stored in separate locations. If a museum provides digitized archival material at all, it may be necessary to conduct a search in another database entirely. Archival material related to an artwork may be part of another institution's collection, like a library or archive, which means that their database needs to be consulted.

Secondary literature may be open access on the Internet or, in the case of exhibition catalogs, may be available as a digital or digitized copy at the museum that published it. Even catalogs raisonnés are increasingly published as databases as well as reference works.[410] Keeping these three categories in mind makes it possible to distinguish the value of different data sources. When using these data for an application, it may be important to treat them separately to achieve a result that is valid for art history, rather than mixing all image data from a wide variety of sources in a way that renders interpretation meaningless.

Table 15. *Source material digitization approaches* (types and materials from: Deegan and Tanner "Conversion of Primary Sources," 488–489)

Source type	Source material	Representation type	Digitization method
Documents	manuscripts, printed artifacts	text	photography, scan, OCR, transcription
Visual materials	images, paintings, drawings, prints, photographs	still image	photography, scan
Time-based media	film, video, sound	moving image, audio stream	digital recording
Three-dimensional objects and artifacts	museum objects, sculpture, architecture	3D-scan, 3D-model	photogrammetry, laser scanning, 3D-modeling

Table 15 captures various digitization methods based on four object types and corresponding materials: documents, visual materials, time-based media, as well as three-dimensional objects and artifacts.[411] The division between the four digitization principles is not strict and hybrid forms are also possible. For example, if the original appearance of a digital document is in focus, it can also belong to the category of visual materials, made accessible together with the machine-readable text or a text overlay (as in digital editions or in PDFs).

Primary sources represented in a digital system can be manipulated, processed, transmitted, and cross-linked, unlike the analog source media.[412] The approach used to digitize artifacts depends on the materials, purpose,

410 Ingrid Pérez de Laborda et al., eds., *Handbuch Werkverzeichnis – Œuvrekatalog – Catalogue raisonné* (De Gruyter, 2023), https://doi.org/10.1515/9783110734492. Several contributions to this publication imply this.

411 Deegan and Tanner, "Conversion of Primary Sources," 488–89. Object types and corresponding materials were taken from this source.

412 Deegan and Tanner, "Conversion of Primary Sources," 490.

technical and financial resources, and intended use.[413] Advantages of digitization for humanities scholars include the availability of out-of-print materials, access to archival material or objects from collections from anywhere, virtual integration of dispersed collections, manipulation of digital images (size, sharpness, color contrast, etc.), the use as teaching and research materials, better search capabilities and full-text searches, and a large volume of images or documents that can be used for analysis and comparison.[414]

3D mass digitization of cultural heritage is trickier than for 2D, therefore, the digitization of 3D objects is less efficient.[415] 3D digitization as a reconstruction of cultural heritage objects is useful for documentation, preservation, and new forms of presentation.[416] These visualization and interaction technologies are not just valuable for representing collections, but also for research.[417] This means that 3D models can be created and used for various purposes: accessibility, conservation, documentation, exhibitions, as well as new applications and formats.[418]

The representation of most digital collections, not only by museums but also libraries and archives, is largely limited to a public database searchable by keywords.[419] Irene Lopatovska et al. identified five main categories of features seen on digital collection websites and what this means a user might be able to do in more detail:

- **search/browse:** browse, advanced browse, suggestive spelling, advanced search, refine search filters, return to search/replicate search
- **image manipulation:** download, print, save, zoom
- **interactive features:** site membership, sharing via social media, email, comment, tagging, games

413 Deegan and Tanner, "Conversion of Primary Sources," 490.

414 Deegan and Tanner, "Conversion of Primary Sources," 491.

415 Pedro Santos et al., "Acceleration of 3D Mass Digitization Processes: Recent Advances and Challenges," in *Mixed Reality and Gamification for Cultural Heritage*, ed. Marinos Ioannides et al. (Springer, 2017), 101, https://doi.org/10.1007/978-3-319-49607-8_4.

416 Santos et al., "3D Mass Digitization Processes," 101.

417 Santos et al., "3D Mass Digitization Processes," 101.

418 Santos et al., "3D Mass Digitization Processes," 101–102.

419 See example *Collections Online*: Kunstmuseum Basel, https://sammlungonline.kunstmuseumbasel.ch; Kunstmuseum Luzern, https://www.kunstmuseumluzern.ch/sammlung/sammlungskatalog-online; *Photo Archive*, Kunsthalle Basel, https://data.dasch.swiss/kuhaba; or collections of libraries such as the Swiss Poster Collection, https://nb-posters.primo.exlibrisgroup.com/discovery/search?vid=41SNL_53_INST:posters&lang=fr&sortby=rank; the Schweizer Kleinmeister, Swiss National Library, https://kleinmeister.ch; or visual material from Swiss libraries and archives, https://swisscollections.ch.

- **aesthetics/interface:** simplicity, images emphasis vs. text
- **usability/site architecture:** intuitive design, links to internal and external related material[420]

While their 2013 framework remains relevant, it primarily reflects a perspective focused on user actions based on the features enabled by interface design. Moving forward, it makes sense to add new features that facilitate users working with data: linked data, *IIIF* for bringing together images from various collections, not only download options but also APIs for the images as well as the metadata, and licenses that specify what one is allowed to do with the data.

The digitization of traditional research materials is costly, and the risk of loss is high if the data is not constantly monitored. To keep digital images available in the long term, this requires a long-standing institutional commitment to comprehensive information management to preserve digital images, develop appropriate definitions and standards for preservation, and integrate technology procedures and processes.[421]

Paul Conway differentiates between three kinds of applications that are created to protect, represent, or transcend originals.[422] Applications that provide access to digital copies protect the original documents and make them more easily available to the public.[423] Even more advanced is a system that represents the originals in high resolution, strives for rich content and all-encompassing information capture, and also incorporates emerging and proven practices.[424] Such a system opens up new possibilities for research and use, potentially transforming service offerings.[425] Examples of advanced applications extend beyond the capabilities of the original and include imaging techniques that reveal hidden details through special lighting, capture images at extremely high resolution to examine minute details, or include searchable full-text content.[426] Another advantage of digital objects lies in their ability to consolidate widely scattered research materials.[427]

The question arises as to whether digital images have a shorter lifespan

420 Irene Lopatovska et al., "Exploring Requirements for Online Art Collections," *Proceedings of the Association for Information Science and Technology* 50, no. 1 (2013): 3, https://doi.org/10.1002/meet.14505001109.

421 Paul Conway, "Rationale for Digitization and Preservation," in *Museums in a Digital Age*, ed. Ross Parry (Routledge, 2010), 366.

422 Conway, "Rationale for Digitization," 369.

423 Conway, "Rationale for Digitization," 369.

424 Conway, "Rationale for Digitization," 369.

425 Conway, "Rationale for Digitization," 369.

426 Conway, "Rationale for Digitization," 369.

427 Conway, "Rationale for Digitization," 369–370.

than originals (like film photographs or artworks), since digital preservation might be riskier and more expensive.[428] Storage must be secured for the long term and periodic migration is necessary as technology changes, so it therefore might be preferable to choose a preservation method that produces print images on paper to archiving rather than archiving copies through digitization.[429] There is always doubt that digitized images will survive as long as the original. The question of the durability of digitized images also relates to the developments in digital technologies. In a few years, when other or more advanced digitization technologies become established, the existing digitized collections may be replaced by images of higher quality, whether in terms of resolution or recording techniques that assign additional properties to the digital object, such as three-dimensionality. It makes sense to build a digital collection as a system that allows for development and change over time, and whose strength is seen in the information and knowledge that can be drawn from it.

Images of artworks in a cultural institution's database are part of that institution's collection, which means they share a common connection. However, since collections usually consist of a variety of media, techniques, and objects from different time periods, the result is a variety of images that does not inherently generate meaning between them. This makes it challenging to understand an image without additional context or explanation. Either the images must be presented in groups that create meaning, like artworks by the same artist or in the same exhibition. If this is not provided, background information through metadata, descriptions, or linkage of additional sources need to be added. According to Detlef Kannapin, it depends on the context in which a viewer sees certain images whether the images convey a lot of information or none at all. However, he also emphasizes that images always reflect something about the circumstances in which they were created. In that sense, it is important to consider the intention behind the production of an image. Ultimately, the production and interpretation of images are shaped by an individual's experiences, knowledge, and perception.[430]
Even if some images show the same motif, this does not mean that each arises from the same context. As outlined in more detail in a 2018 article, three photographs showing an empty exhibition space share the identical

428 Graham Diprose and Mike Seaborne, "Back to Paper? An Alternative Approach to Conserving Digital Images into the Twenty-Third Century," in *Electronic Visualisation in Arts and Culture*, ed. Jonathan P. Bowen et al. (Springer, 2013), 59, https://doi.org/10.1007/978-1-4471-5406-8_5.

429 Diprose and Seaborne, "Back to Paper?" 59.

430 Detlef Kannapin, "Bild," in Jörg Becker, *Die Digitalisierung von Medien und Kultur* (Springer VS, 2013), 53–54.

motif. However, a closer look at the contexts in which these images have been created and are used makes evident that each photograph communicates something totally different than the others.[431] One institution repeatedly uses a photograph of its empty space for communication purposes. They use it as a symbolic image that visually refers in a general manner to the available space for exhibitions that will be installed there.[432] The photograph of another institution is an installation view documenting an invisible artwork.[433] And the third photograph is an artwork itself. It is the authorized work of an artist who crafted a model of a fictive empty museum space to create an illusory image.[434]

Table 16. *Digital collection image types*

Type of image	Digitized	Born-digital
Artwork • the visual object created by an artist • a primary documentation of an ephemeral piece valid as artwork, authorized by the artist	reproductions that represent an artwork in the collection	a digital media artwork
Document • Historical material from archives with information about an artwork – Produced by the museum staff (press release, exhibition documentation, catalog) – Produced by externs (press and media) • Scholarly publications	reproductions from physical sources	digital publications and documents

In conclusion, it is necessary to distinguish between multiple types of images and their purposes, which are tightly bound to their authorship. A digital or digitized image in the context of a museum and its collection, but also an audio stream or a video, can be an artwork, document an artwork or an exhibition, or represent archival material like text documents, audio-visual material created for audio guides, radio, or television reports, exhibition posters, or catalogs. Two main categories can be identified: the kind of art-related object is represented, as well as the quality of a digital object of being either digitized or born-digital as shown in table 16.

An image is not just an image but is embedded in various medial and

431 Sonja Gasser, "Disposition Ausstellungsraum: Im Zustand zwischen Nicht-Ort und erklärter Leere," *Kritische Berichte* 46, no. 3 (2018): 83–91.

432 Gasser, "Disposition Ausstellungsraum," 88.

433 Gasser, "Disposition Ausstellungsraum," 88.

434 Gasser, "Disposition Ausstellungsraum," 88.

functional contexts. Beyond images from digital collections that reproduce artworks, there is an increasing number of images of archival materials, such as installation views and documents, each with distinct characteristics and purposes.[435] The trend toward digitization of a broad spectrum of art-related material, which can already be observed in the digital collections of some museums (e.g., Tate, Georgia O'Keeffe Museum), will lead to a wealth of digitally accessible information. This body of digitized content should be considered, especially when developing applications with data from museums, to avoid a confusing and incomprehensible presentation.

From an institutional point of view and in the interest of researchers and other potential users, it makes sense to digitize a diverse range of the collection instead of selecting only the most representative artworks. Since it is hard to predict who will be interested in what, when, and for what reason, a restrictive selection of the available content is limiting depending on the intent of the user. Perceptions of objects in a collection can change and are reevaluated over time. Artworks that seem unimportant may move into interest, while interest in others may wane. This change can be triggered by the work of cultural institutions with their collections, for example, when they select a work that is little- or unknown to the public for an exhibition or include an image in a publication. Knowledge of the existence of a particular artwork can generate interest in that work.[436] Furthermore, background knowledge empowers users to understand artworks.

Someone with an art historical background can identify, at least in some cases, an artist or the motif of an image, whereas another person might not be able to. Therefore, an important concern for institutions is how the organization and design of a collection database can foster knowledge production. When Kannapin remarks that the present technological inventions create new problems for which solutions must be found through technology, and that technological progress is further along than the understanding of

435 Kunsthalle Basel's *Photo Archive* provides access to digitized installation views of past exhibitions, accessed December 27, 2024, https://www.kunsthallebasel.ch/en/photo-archive. Tate provides digitized archival material, accessed December 27, 2024, https://www.tate.org.uk/search?type=archive, as well as exhibition views, accessed December 27, 2024, https://www.tate-images.com/collections.asp?collection=exhibitions. MoMA offers access to various kinds of digitized archival material, exhibition views, and catalogs, accessed December 27, 2024, https://www.moma.org. Kunsthaus Zürich's library provides access to digitized artist letters, exhibition catalogs, and its collection on Dadaism, accessed December 27, 2024, https://digital.kunsthaus.ch.

436 Peter Pfrunder, "Aufwerten, umwerten, abwerten: Vom Fotoarchiv zum kulturellen Gedächtnis," in *Über den Wert der Fotografie: Zu wissenschaftlichen Kriterien für die Bewahrung von Fotosammlungen*, ed. Nora Mathys et al. (hier + jetzt, 2013), 31–36.

it within society,[437] this describes very well the process that cultural institutions experience with their digital collections. The digitization of images is only the starting point, followed by the online access of collections, and ends with questions about how to deal with digital data in a digital environment. The representation of data requires different responsibilities and novel approaches to presenting and communicating art.

Walter Benjamin's well-known essay "The Work of Art in the Age of Its Technological Reproducibility"[438] effectively describes how new reproductive media such as film and photography have transformed the perception of cultural products and artworks. Images mechanically produced in a series are indistinguishable from one another. Seriality and industrial production prevent these outputs from possessing the individual character typically associated with original artworks, which bear the traces of the artist's hand. However, the idea that reproduced cultural content lacks an "aura" tied to the original is no longer entirely applicable to digital media. Content can now exist across different media in multiple, slightly varied forms in parallel without necessarily being seen as problematic. The various states and manifestations an object can take foster a plurality of contexts and situations in which it is used. Historically, reproductions have played a crucial role in research—whether in the form of prints, slide projections, images in exhibition catalogs and books, or digital image collections digitized at university art history departments or cultural institutions. Scholars have long relied on such reproductions rather than consulting original artworks directly. This practice has enabled engagement with cultural heritage from various locations and across widely dispersed collections, reducing the need for time-consuming travel. The next step in this direction is the increased accessibility of large collections online. Such digital resources make it possible to assemble and analyze even larger datasets, further enhancing research and broadening access to cultural heritage.

For Christian Schönholz, the concepts of original and copy remain relevant in the digital context, even though he rejects the idea of treating them as opposing categories. Rather than adhering to a historically evaluative perspective, he argues that original and copy undergo continuous rearticulation and transformation.[439] This blurs the dividing line between

437 Kannapin, "Bild," 56.

438 Walter Benjamin, "The Work of Art in the Age of Its Technological Reproducibility: Second Version," in *Selected Writings: 1935–1938,* ed. Howard Eiland and Michael Jennings, vol. 3 (Harvard University Press, 2002).

439 Christian Schönholz, "Jede Kopie ein Original! Aspekte eines kulturellen Grössenverhältnisses," in *Digitalisierung: Theorien und Konzepte für die empirische Kulturforschung*, ed. Gertraud Koch (Herbert von Halem Verlag, 2017), 158.

the two and contributes to the terms' changing and flexible relationship. This is consistent with Jay David Bolter and Richard Grusin, for whom digital and analog visual media coexist in a common cultural, social, and economic structure and are in a network of interdependencies.[440] What is true for different media genres like painting, photography, film, or print applies just as much to the relationship between original and copy.

Legal Aspects of Digitization

The "Policy Paper on the Digitization of Museum Collections" is likely one of the most recent and comprehensive publications to address legal issues museums face in making digital collections available.[441] The paper provides an overview of "applicable general copyright law principles for the relevant stakeholders in the museum community worldwide" and formulates "policies to facilitate museum activities in the digital environment."[442] It sheds light on "museums as users of third parties copyrighted materials," but less on the "museums as creators of their own copyrighted works."[443] It is a useful document for museum staff tasked with applying the correct rights as an institution but less useful when considering how museums provide their digitized images and metadata in a manner that makes it easily reusable for third parties within the digital environment. Nevertheless, the authors suggest that museums "upon acquiring new contemporary artworks, they may also encourage artists to immediately license or assign rights" which allows the museums as rights owner to open up the digitized collections.[444] The authors also emphasize that museums should open up their digital collections whenever possible and encourage the public to use the images.[445] In particular, they state that museums in countries where images of artworks are subject to copyright should negotiate with rights holders to allow these images to be used by the public.[446] The authors advocate "open cultural data policies, that allow data to be combined in novel ways to develop new products and services, play an important role in furthering research, learning and stimulating economic growth."[447]

The Deutscher Verband für Kunstgeschichte, the German Association for

440 Jay David Bolter and Richard A. Grusin, *Remediation: Understanding New Media* (MIT Press, 2000), 15, 19.

441 Anne Laure Bandle et al., "Policy Paper on the Digitization of Museum Collections," 2020, accessed December 14, 2020, https://www.digitizationpolicies.com/.

442 Bandle et al., "Policy Paper on the Digitization," 3.

443 Bandle et al., "Policy Paper on the Digitization," 3.

444 Bandle et al., "Policy Paper on the Digitization," 5.

445 Bandle et al., "Policy Paper on the Digitization," 17.

446 Bandle et al., "Policy Paper on the Digitization," 17.

447 Bandle et al., "Policy Paper on the Digitization," 26.

Art History, published a guide to image rights in art historical practice, summarizing the most important legal concerns when using images in art history or art museums.[448] Paul Klimpel's legal primer provides a good foundation for which rights are important in digitization projects at cultural institutions and what to look for in order to enable free use of digitized material.[449]

The use of image material in the context of art and museums is subject to various rights. There is the artist's copyright of the artwork, and also the copyright of the photo depicting the artwork.[450] As a result, when using an image of an artwork, permission must be obtained both from the artist (until 70 years after their death) and from the entity that created the photograph, unless the images were published with a license (Public Domain, Creative Commons) granting the relevant permission.[451]

When digital archives containing portrait photography are made available to the public, other rights must be considered. If people are visible, they need to consent to publication due to personality rights, unless they are persons of public interest. Furthermore, the photographer holds the copyright to the photograph until 70 years after their death, which is why they (or the legal successor) must also give permission.[452] Additionally, if a photograph shows artworks, the artist holds copyright until 70 years after their death. If an image of a work in a museum collection is used that a museum has created, a license to use it must be obtained from the institution. In summary, it can be quite complicated and time-consuming to check all these rights.

For contemporary art, the advantage is that usually the artists are still alive and cooperation is possible to avoid legal issues. Oliver Grau has gone this route with the *Archive of Digital Art (ADA)*, where artists are members, which avoids copyright issues and allows artists to upload their information.[453]

448 Veronika Fischer, *Bildrechte in der kunsthistorischen Praxis: Ein Leitfaden*, ed. Verband Deutscher Kunsthistoriker e.V., v. 2, 2022, https://doi.org/10.11588/artdok.00007769.

449 Paul Klimpel, *In Bewegung: Die Rechtsfibel für Digitalisierungsprojekte in Kulturerbe-Einrichtungen* (Digitales Deutsches Frauenarchiv, 2022), accessed October 26, 2024, https://nbn-resolving.de/urn:nbn:de:0297-zib-86485.

450 Angela Karasch, *Erfolgreich recherchieren: Kunstgeschichte* (De Gruyter Saur, 2012), 40.

451 Karasch, *Erfolgreich recherchieren*, 40.

452 Birgit Jooss, "Vom Umgang mit Portraitfotografien in den Nachlässen des Deutschen Kunstarchivs: Das Projekt 'DigiPortA'," in *Fotografie und Film im Archiv: Sammeln, Bewahren, Erforschen*, ed. Irene Ziehe and Ulrich Hägele (Waxmann, 2013), 24–25.

453 Oliver Grau, "The Complex and Multifarious Expressions of Digital Art and Its Impact on Archives and Humanities," in *A Companion to Digital Art*, ed. Christiane Paul (Wiley Blackwell, 2016), 33.

2.6 Conclusion

Collection digitization is driven by various motivations and serves different purposes. The digital collection, as a reminiscence of an inventory or collection catalog from the analog era, is only the beginning of what collections digitization and digital images can enable. The list below summarizes various interests in digitization and usage, as well as the potential developments. These will be explored in greater depth in the subsequent chapters.

1. **Digital collection:** collection digitization, management, keyword search, and data provision
2. **Image search:** algorithm-based image search by clustering, similarity, computer vision, machine learning, and deep neural networks
3. **Simulation:** virtual reality and augmented reality, reconstruction of architecture, immersive museum spaces, 3D models of objects, Reflectance Transformation Imaging (RTI) for the simulation of surfaces
4. **Linking data:** networks of knowledge, contextualization for narration and storytelling
5. **Data visualization:** visual access to database content via generative and interactive diagrams, charts, timelines, and maps
6. **Programming:** application development by museums for participation and interaction with digital content, art historical research in reusing museum data

It is vital to understand digital images and metadata in libraries, archives, and museums as specific kinds of objects with their own purposes. Being aware of digital data's characteristics as well as the technological possibilities prevents museums from merely simulating the common analog modes of art presentation or workflows in a digital environment.

We have reached a point where there are many interesting data sources on offer from museums and other cultural institutions. This requires that humanities scholars know how to use these rich data sources for research and develop new questions and methods. The key is to bring together dispersed data sources and metadata in meaningful ways. Independently existing data sources, when combined, create completely new knowledge spaces and data connections.

As an example, Kunsthalle Basel's digitized photo archive[454] offers a good selection of images (about 20,000) that document the history of exhibitions and of the institution over a nearly 100-year-period. Many of the artists shown in the Kunsthalle are also included in the Getty vocabulary *Union List of Artist Names (ULAN)*[455] in the linked open data (LOD) format suitable for the Semantic Web (like JSON). This means that the record with the artist's ID includes further information (name variants in different languages, biographical data, roles, and related artists). Similarly, *fotoCH*[456] offers data about Swiss photographers and provides an API to use these data for other third-party applications. This means that for most of the 300 photographers in the photo archives of Kunsthalle Basel—those who took the photos of the exhibitions, artworks, artists, or the people at the openings—additional information exists that can be linked and used. Such metadata sources, to name only a few, allow a powerful supplementation of datasets from digital collections of art museums that often contain limited information. Bringing together data from different sources and databases enables humanities research to leverage technological possibilities, fostering the identification of new methods and research questions. To be able to do this conveniently, a digital research infrastructure is necessary. The DaSCH Service Platform (DSP)[457]—a virtual research environment for knowledge organization, representation, and annotation in the humanities—exists for that purpose. The state-of-the-art platform applies the industry-standards RDF, SPARQL, RESTful API, which supports scholars in the knowledge organization, representation, and annotation of, mainly visual, digital sources.

The highest accuracy in data reuse will be achieved once all source materials are digitally accessible, not only for viewing but also as machine-readable data. This requires the complete digitization of both digital collections and secondary literature, enabling a fully digital workflow in humanities research. While the foundations for this ideal have been established, the ability to access all documents digitally remains only partially realized to date. Despite this, there are already numerous international museum collections and datasets like the *Getty Vocabularies* or the *Gemeinsame Normdatei (GND)* that provide additional information about artists and other entities. This makes it an ideal time to utilize these resources for a theoretical study of

454 *Photo Archive*, Kunsthalle Basel, accessed November 28, 2021, https://data.dasch.swiss/kuhaba.

455 *Union List of Artist Names,* Getty Research Institute, accessed January 24, 2017, https://www.getty.edu/research/tools/vocabularies/ulan/.

456 *fotoCH*, Büro für Fotografiegeschichte Bern, accessed January 24, 2017, https://foto-ch.ch/.

457 "DaSCH Service Platform," DaSCH Swiss National Data and Service Center for the Humanities, accessed December 27, 2024, https://www.dasch.swiss/plattform-characteristics.

digital collections. The goal is to outline various aspects of digital collections as a foundation for a digital art history but also for the representation of art collections in a museum context within a digital environment. The discussion extends beyond the basic principles of collection digitization, focusing instead on how artifacts from these collections can be leveraged when available as digital objects. In the near future, major advances can be expected in digital art history, following the discussions and developments in the digital humanities, where they contribute to the visual domain.

Image databases have the potential to profoundly transform both the representation of art collections and art historical research methods. This transformation occurs primarily because the digital image, in some ways, functions as a participatory medium. It is no longer seen solely as a vehicle for conveying knowledge; rather, it also serves as a tool for gaining insights from different narrative dimensions (e.g., through data analysis of the digital image). Digital images and metadata possess distinct material quality, defined by their manipulability, storability, and transferability, which enables entirely different uses compared to physical artworks, objects, and even analog reproductions.

Having reviewed the architecture of databases and how digital objects are organized within now leads to the question: How can the collected data be retrieved? The role of metadata, controlled vocabularies, and authority files becomes particularly evident for database searches, as they help users to find the desired content. The more carefully data is structured and organized within databases, the better the user experience, as this facilitates more advanced and cross-database searches. Chapter 3 discusses the usability of digital collections and their content, for which search and browse opportunities are critical.

3 Digital Collections: Searching and Browsing

3.1 Introduction

Since the most common way to access a museum's digital collection is through keyword-based database searches or by browsing artworks by clicking on image tiles, this chapter will examine the importance of searching and browsing for access to digital collections. It also explores how data structuring and database architecture significantly support search functionality tailored to diverse user needs. Search and findability are the foundation of digital collection access and are core principles for any user interface. Understanding key search concepts provides insight into the underlying mechanics of search functionality and the specific considerations involved in designing interfaces, applications, and interactive data visualizations for digital collections. Searching, browsing, and filtering data via an interface help users navigate large datasets by refining vast collections into a manageable selection of relevant records.

Both for a targeted search and for random clicks on images, certain properties lead to results as close as possible to what is being searched for. Well-prepared data records and a well-structured database make it possible to expand the functionality of the search for improved findability. Clearly defining and organizing artworks is good preparation for supporting various forms of searching and browsing. Common forms of searching and browsing rely on available metadata and database structures, while more advanced ones require computational analysis of digital images or a more sophisticated data model.

Image searches are often based on the assigned metadata such as artwork information, descriptions, categories, keywords, and vocabularies. Apart from a text-based keyword search, content-based image retrieval (CBIR)

using computer vision techniques is an emergent research topic.[458] Both textual and visual searches have advantages and disadvantages, but both allow completely different approaches to the contents of digital collections. Several factors contribute to advanced search capabilities. Fuzzy searches and networks of similar terms support the discovery of content of which one is not necessarily aware, which is why this chapter takes a closer look at serendipity and the semantics of linked data. A linked data structure that contains myriad paths for exploring the contents of a database also lays a foundation for personalization. Developments in artificial intelligence (AI), neural networks, machine learning, and the role of search algorithms must be considered as advanced technologies for powerful search engines.[459]

Searching databases involves data retrieval but also the presentation or display of search results. Keyword-based and image-based retrieval must be distinguished from one another. A detailed search, exploratory search, and recommender system for contextual results by similarity through networks are for different purposes and also function differently. Data visualizations are an alternative approach to a search field or a list of results. Generative data visualizations simultaneously function as visual interfaces for doing searches and as the display for search results. The better the existing data foundation of a digital collection, the better searches can be performed.

458 Originating in the computer science discipline, CBIR is an emergent research topic in digital humanities and art history, as seen in the following scholarship: Pavel N. Druzhkov and Valentina Dmitrievna Kustikova, "A Survey of Deep Learning Methods and Software Tools for Image Classification and Object Detection," *Pattern Recognition and Image Analysis* 26, no. 1 (2016): 9–15, https://doi.org/10.1134/S1054661816010065; Scott Krig, *Computer Vision Metrics: Textbook Edition. Survey, Taxonomy and Analysis of Computer Vision, Visual Neuroscience, and Deep Learning*, 2nd ed. (Springer International Publishing, 2016), https://doi.org/10.1007/978-3-319-33762-3; Melissa Terras, "Image Processing in the Digital Humanities," in *Digital Humanities in Practice*, ed. Claire Warwick et al. (Facet, 2012), https://doi.org/10.29085/9781856049054.005; Peter Bell et al., "Nonverbal Communication in Medieval Illustrations Revisited by Computer Vision and Art History," *Visual Resources* 29, no. 1–2 (2013): 26–37, https://doi.org/10.1080/01973762.2013.761111; Nuria Rodríguez Ortega, "Image Processing and Computer Vision in the Field of Art History," in *The Routledge Companion to Digital Humanities and Art History*, ed. Kathryn Brown (Routledge, 2020).

459 See: Igor Boris Gurevich and Yurii Ivanovich Zhuravlev, "Computer Science: Subject, Fundamental Research Problems, Methodology, Structure, and Applied Problems," Pattern Recognition and Image Analysis 24, no. 3 (2014): 333–346, https://doi.org/10.1134/S1054661814030195; Matej Uličný et al., "Robustness of Deep Convolutional Neural Networks for Image Recognition," in Intelligent Computing Systems: First International Symposium, ISICS 2016, Mérida, México, March 16–18, 2016, Proceedings, ed. Anabel Martin-Gonzalez and Victor Uc-Cetina (Springer, 2016), https://doi.org/10.1007/978-3-319-30447-2; Emily L. Spratt, "Dream Formulations and Deep Neural Networks: Humanistic Themes in the Iconology of the Machine-Learned Image," kunsttexte.de, no. 4 (2017): 1–15, https://doi.org/10.18452/18693.

Apart from controlled vocabularies and authority files, crowdsourcing can generate additional keywords for new search category metadata.

Since a search field provides no indication of the content available, visitors to a collection website without a specific question in mind may quickly lose interest. Similarly, a search restricted to only a few categories, such as artist names and work titles, can be frustrating for users seeking specific information that falls outside these constraints. The difficulty of grasping a database's contents from the outside, combined with limitations that hinder intended search queries, illustrate the complexity of search functionality. Therefore, facilitating access for both the general public and experts through various approaches to searching, filtering, and browsing is essential. These strategies make collections more accessible and allow for both simple and highly sophisticated queries.

3.2 Database Searches

Digital collections include search capabilities like those found in other databases. A search slot, often prominently placed on the website, serves for simple keyword searches to quickly access the contents of the database. However, for a more specific query, an advanced search interface provides a search mask with multiple options for searching specific categories. Other technical aspects, if provided, that contribute to the success of a search include enabling advanced search input by accepting Boolean operators (AND, OR, NOT) for combining search terms or providing term suggestions to assist users in formulating queries.[460] Filters and facets are another increasingly implemented standard to narrow down an overwhelming list of search results. While predefined filters allow limiting the range within which the search is conducted (e.g., only works with an image, works from a certain period, or works currently on view in the museum), facets are created dynamically depending on the search result in order to narrow it down even further.

Faceted search, along with exploratory search, personalized information retrieval, result categorization or clustering, mixed-initiative interaction, or interactive user modeling, are some of the more sophisticated search modalities that hold promise for digital collections, but they are rare.[461] Addressing these basic modes for a more sophisticated and dynamic search is recom-

460 Wilko van Hoek and Philipp Mayr, "Assessing Visualization Techniques for the Search Process in Digital Libraries," in *Wissensorganisation und -repräsentation mit digitalen Technologien*, ed. Stefan Andreas Keller et al. (De Gruyter, 2014), 67–69.

461 Tuukka Ruotsalo et al., "Supporting Exploratory Search Tasks with Interactive User Modeling," *Proceedings of the Association for Information Science and Technology* 50, no. 1 (2013): 2–3, https://doi.org/10.1002/meet.14505001040.

mended, as they are a central component of interfaces that, for example, may rely on interactive data visualizations. Exploratory search is iterative and occurs through a constantly adapting interface.[462] Often only parts of the search space can be visualized on the interface due to the size of a digital collection.[463] Therefore, the search space is narrowed down for the display to the relevant parts by personalization, faceted search, result categorization or clustering, and relevance feedback methods and continuously adapted according to user feedback.[464] Personalized information retrieval is based on rankings that take into account the implicit feedback that users provide through their data trails such as clicked links or search queries.[465] Faceted search, in contrast, relies on explicit feedback that the user can provide for information filtering along topical categories that reflect the content.[466] Result categorization or clustering provides an overview of the entire digital collection, which can then be refined and narrowed down to clusters of particular interest.[467] In mixed initiative interaction, the system situationally assesses what might assist the user in accomplishing his or her task and provides appropriate navigation options.[468] While the outlined search methods are among the more advanced techniques and will be revisited when discussing interfaces that use visualizations, a keyword search is still the most common way to access a digital collection. For this reason, the following discussion will focus on keyword search in the sense of using a string of characters as input to search for matches in specific fields or in the full text of the metadata. This mode of accessing database information will be explained along with other related techniques and technologies relevant to searching digital collections.

The principles of basic search, advanced search, and filtering can be found for most online digital collections, although the interface often combines the three approaches by presenting multiple search inputs as well as filtering options above a selection of preview images. Common search categories for art collections include key data fields like artist, work title, place of origin, date, genre, material, and subject. These are either presented as separate search fields or a drop-down list allows the selection of a category in which the keyword exists. Drop-down lists can also be used to directly access, for example, all works by a specific artist by selecting their name. Sometimes the metadata in the record of a work consists of clickable links,

462 Ruotsalo et al., "Supporting Exploratory Search Tasks," 2.
463 Ruotsalo et al., "Supporting Exploratory Search Tasks," 2.
464 Ruotsalo et al., "Supporting Exploratory Search Tasks," 2.
465 Ruotsalo et al., "Supporting Exploratory Search Tasks," 2.
466 Ruotsalo et al., "Supporting Exploratory Search Tasks," 3.
467 Ruotsalo et al., "Supporting Exploratory Search Tasks," 3.
468 Ruotsalo et al., "Supporting Exploratory Search Tasks," 3.

which allows the user to find other works by the same artist, period, style, and other relevant details. This makes it possible to explore a collection and discover previously unknown works and artists. From the user's perspective, searching and browsing allow for seamless transitions between systematic and unsystematic exploration.

Observations about user interactions with digital collections and what they find important provide insight into how data should be structured to achieve good search results. Search queries can be simple or complex, depending on the context in which they are formulated and how directly the answer is contained in the data. Claire Ross et al. conducted a survey to investigate scholarly information-seeking behavior in online museum collections.[469] Understanding how collection database users behave is a prerequisite for the design of intuitive systems that meet researchers' needs. The authors contend that it is entirely unknown how users employ digital collection material and if that material changes how museum objects are engaged.[470] They emphasize that humanities scholars' needs and associated behaviors are different to those in the sciences and social sciences, even though digital resource design often assumes similarities.[471] Information-seeking behaviors of humanities scholars are diverse, and the resources they rely on—including archival documents, publications, digital databases, and visual materials—vary widely in type and period of origin.[472] Their 2011 survey revealed that half of the users consulted the British Museum's *Collection Database Online* for academic research (including scholars, students, and curators or curatorial staff); about one-sixth for personal interest; roughly one-eighth for nonacademic professional research; and smaller user groups for picture research, school studies (pupils), research for school teaching, or planning a visit.[473] The authors shared,

> Respondents expected to be able to search the *Collection Database Online* predominately by type of object (47.9 %) and by free text search (46.8 %). This was followed by date and then in close succession by people, theme, culture and museum number.[474]

The majority of scholars are searching for a known object, which means that

469 Claire Ross et al., "Measuring Impact and Use: Scholarly Information-Seeking Behaviour," in *Evaluating and Measuring the Value, Use and Impact of Digital Collections*, ed. Lorna Hughes (Facet, 2012), https://doi.org/10.29085/9781856049085.008.

470 Ross et al., "Measuring Impact and Use," 85.

471 Ross et al., "Measuring Impact and Use," 87.

472 Ross et al., "Measuring Impact and Use," 87.

473 Ross et al., "Measuring Impact and Use," 89–90.

474 Ross et al., "Measuring Impact and Use," 90.

they search the database with a goal-driven intent.[475] It is striking that despite strong skills in refining their search, the academic respondents prefer to use the free text search.[476] About one third of the respondents were using the *Collection Database Online* for the first time, another third occasionally, and the rest, monthly or more often than that.[477] There are two approaches for image retrieval in the British Museum's *Collection Database Online*. The first is a text-based method uses the metadata or textual descriptions of the object for the query.[478] The other method, content-based image retrieval (CBIR), draws on low-level features of the digital image (such as color and texture) to find objects that are similar to a selected object.[479] Most users in the study were successful in their search, using precise search terms including time period, object name, description, and inventory number to find what they were looking for.[480]

Digital collections, images, and technology do not just concern museums and their public. From an academic art historian's perspective, the use of digital images and technology presents similar challenges, but with different priorities.[481] Digital art history goes beyond searching databases for art historical resources such as images and publications; it also engages with the technological foundations of data processing and search techniques, which will be discussed in this chapter. Art historians rely on a variety of research tools, including library catalogs, bibliographies, reference works, Internet search engines, publication databases, and repositories, as well as art historical image databases.[482] These specialized finding aids highlight the limitations of general Internet search engines for scholarly research. Nevertheless, Google,[483] the most widely used search engine, cannot be discounted.

475 Ross et al., "Measuring Impact and Use," 91.

476 Ross et al., "Measuring Impact and Use," 92.

477 Ross et al., "Measuring Impact and Use," 92.

478 Ross et al., "Measuring Impact and Use," 95.

479 Ross et al., "Measuring Impact and Use," 95.

480 Ross et al., "Measuring Impact and Use," 96.

481 Hubertus Kohle, *Digitale Bildwissenschaft* (vwh Verlag Werner Hülsbusch, 2013), https://doi.org/10.11588/artdok.00002185.

482 For a comprehensive overview, see Angela Karasch, *Erfolgreich recherchieren: Kunstgeschichte* (De Gruyter Saur, 2012).

483 Google, accessed December 27, 2024, https://www.google.com.

Search Engine Fundamentals

Google's search services, which have evolved over time, represent the complexity and diversity of approaches: *Google Scholar*[484] and *Google Books*[485] are geared towards searching for scholarly articles and publications. *Google Images*,[486] the search-with-an-image feature,[487] and *Google Arts & Culture*[488] all have different approaches to searching for images and artworks. Finally, the *Google Knowledge Graph*[489] supports the representation of knowledge from multiple sources in the semantic linking of information as it appears in the results of a Google search in an information box in the margin. All of these, among other Google services, have established themselves as routinely used tools. Google illustrates the changes in the production and distribution of information.[490] Digitalization, the Internet, and the networking of devices have fundamentally transformed how information is accessed and managed, as data can be copied lossless, stored in compressed form, machine-processed, and transmitted over long distances.[491] Computational and information science techniques such as crawling, scraping, indexing, and ranking are extensively used to gather data for search engines. Richard Rogers states:

> They refer to algorithms that determine relevance and authority and thereby recommend information sources as in Google's famed PageRank, but also boost all manner of items, from songs and "friends" to potential "followers."[492]

Google's power is rooted in enormous amounts of data. However, while a Google search delivers a broad range of results and often ranks highly relevant hits, it can also be a drawback, as cultural institutions—although more reliable sources of information—do not necessarily appear at the top of the search

484 *Google Scholar*, Google, accessed December 27, 2024, https://scholar.google.com.

485 *Google Books*, Google, accessed December 27, 2024, https://books.google.com.

486 *Google Images*, Google, accessed December 27, 2024, https://images.google.com.

487 "Search with an Image on Google," Google Search Help, accessed December 27, 2024, https://support.google.com/websearch/answer/1325808.

488 *Google Arts & Culture*, Google, accessed December 27, 2024, https://artsandculture.google.com.

489 "Introducing the Knowledge Graph," Google, published May 16, 2012, https://blog.google/products/search/introducing-knowledge-graph-things-not/.

490 Jan Hodel, "Recherche: Google – and Far Beyond," in *Digitale Arbeitstechniken für Geistes- und Kulturwissenschaften*, ed. Martin Gasteiner and Peter Haber (Böhlau, 2010), 25.

491 Hodel, "Recherche," 25.

492 Richard Rogers, "Foundations of Digital Methods: Query Design," in *The Datafied Society: Studying Culture Through Data*, ed. Mirko Tobias Schäfer and Karin van Es (Amsterdam University Press, 2017), 76.

results.[493] To even appear in a Google search, which is usually the first general gateway to information, requires cultural institutions like museums to ensure that the content of their databases is optimized to be found and indexed by search engines. An artwork that appears in Google results potentially leads users to the museum's website, and thus to the institutionally validated and culturally significant source material. If the information in the preview of the results comes from the institution that holds the artwork in the collection, the record of the digital collection is a reliable source because the museum authorizes the quality of the image and the artwork information. Overall, the breadth of Google search results is helpful, but for research purposes, the information is often too general to be useful. That is why museums' digital collections, with their thematic, clearly defined focus, are particularly valuable. Although smaller collection databases face different challenges compared to large Internet search engines, the underlying concepts are applicable to both.

Image searches present greater challenges than text searches.[494] As a result, image retrieval relies heavily on metadata and descriptive text associated with images, such as artwork information or any textual content in the image's vicinity. Due to the importance of written information in image search, it is essential to address text-based search functionalities and recognize their limitations, where visual methods can complement and enhance the process. An effective method for making scanned text documents or publications machine readable and searchable is to process them with optical character recognition (OCR). Text search engines work based on statistical measures like word frequency and inverse document frequency.[495] Word frequency means that documents with a higher occurrence of a searched term are more likely to be relevant.[496] Inverse document frequency is relevant to lower the relevance of terms that appear frequently across many documents in the corpus, reducing their weight and increasing the relevance of less common terms.[497] Therefore, when documents are retrieved using these statistical parameters—where a term appears frequently in one document but infrequently across the rest of the corpus—the probability is high that the search will return the most significant documents.[498] Apart from this, search

493 Matthias Oberli, "Jeder sein eigener Vasari? Künstlerbiographik und digitale Quellenkritik im Internet," in *Die Biographie – Mode oder Universalie?*, ed. Beate Böckem et al. (De Gruyter, 2016), 277–78, https://doi.org/10.1515/9783110404425-022.

494 Raghavan Manmatha, "Bildsuche: Image Retrieval," in *Digitale Arbeitstechniken für Geistes- und Kulturwissenschaften*, ed. Martin Gasteiner and Peter Haber, (Böhlau, 2010), 67.

495 Manmatha, "Bildsuche," 69.

496 Manmatha, "Bildsuche," 69.

497 Manmatha, "Bildsuche," 69.

498 Manmatha, "Bildsuche," 70.

engine algorithms utilize other principles like consideration of synonyms, and Google also takes into account the structure of links on the Internet and the statistical distribution of links on pages.[499] The relevance and weighting of search hits is essential when dealing with large amounts of data.

The simplicity of an interface with just a search field works well for search engines like Google, where users typically arrive with a specific question in mind. However, this keyword-based search approach is less effective for the cultural realm. When access to a museum's digital collection is restricted to keyword searches, it can be problematic, as it requires users to have a clear question and prior knowledge of the collection's contents. To better engage a wider audience, this approach can be limiting and should be made more inviting. Mitchell Whitelaw has already pointed out this issue:

> While search is a very effective technique for delivering records in response to a specific query, it has significant limitations. As an access tool, search assumes that a user is able to provide a query; but a user who is unfamiliar with the collection's scope, contents, or structure, may not be in a position to query it effectively.[500]

Search fields are an exclusionary obstacle for someone who is simply curious and wants to learn about the collection, for which an exploratory approach would be useful. Users without an idea in mind want to interact with a digital collection to satisfy their interest in art led by curiosity, assistance, and orientation. For users like these, they must be able to get an overview of the collection and its contents. This can be achieved by creating connections between datasets, which facilitates connections. Instead of a targeted search, an exploratory approach is preferable when the focus is on casual engagement with collection contents and on generating interest in particular topics.

Search and browse are the two principal methods to access digital data. A search requires users to articulate their interest, while browsing allows users to explore and connect with interesting works presented on the interface.[501] Both searching and browsing are useful for the general public as well as for professionals performing specific queries, but also in the discovery of new artworks.

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499 Manmatha, "Bildsuche," 70.

500 Mitchell Whitelaw, "Visualising Archival Collections: The Visible Archive Project," *Archives and Manuscripts* 37, no. 2 (2009): 24, accessed December 8, 2020, https://publications.archivists.org.au/index.php/asa/article/view/10033/10027.

501 Gabriele Blome and Jochen Denzinger, "netzspannung.org: Online-Archiv und Labor für Digitale Kunst und Kultur," in *Digitale Transformationen: Medienkunst als Schnittstelle von Kunst, Wissenschaft, Wirtschaft und Gesellschaft*, ed. Monika Fleischmann and Ulrike Reinhard (Whois, 2004), 203.

Browsing Collections

Unlike a keyword search, which aims to find something specific, browsing provides a more intuitive approach by allowing users to explore the contents of a database. An exploratory search brings content to the forefront, posing fewer barriers than searching for a particular item. Digital collection interfaces therefore usually feature preselected images as eye-catchers that provide direct access to those works. This is often achieved by displaying images randomly in a cascading grid layout or within small thematic image galleries. Upon closer examination, browsing interfaces that provide optimal search conditions for accessing digital collections represent a distinct area for in-depth exploration, a concept for which Mitchell Whitelaw introduced the term "generous interfaces."[502] The limitations of a keyword search lie in the overwhelming volume of results, which often represent a subset of the collection that is difficult to categorize or interpret.[503] In contrast, a generous interface provides insight into the depth and richness of the collection.[504] This includes allowing users to access and interact with the data in a variety of ways, with as few restrictions as possible and in a manner that promotes understanding and knowledge.[505] An exploratory approach should be supported just much as a targeted search. According to Whitelaw, an interface should enrich the interpretation of the available contents by showing connections and structures within a collection.[506] Contextualizing the artworks increases user comprehension.

502 Mitchell Whitelaw, "Generous Interfaces for Digital Cultural Collections," *Digital Humanities Quarterly* 9, no. 1 (2015): 3, accessed August 20, 2017, https://www.digitalhumanities.org/dhq/vol/9/1/000205/000205.html.

503 Whitelaw, "Generous Interfaces," 1–2.

504 Whitelaw, "Generous Interfaces," 3.

505 Whitelaw, "Generous Interfaces," 3.

506 Whitelaw, "Generous Interfaces," 46.

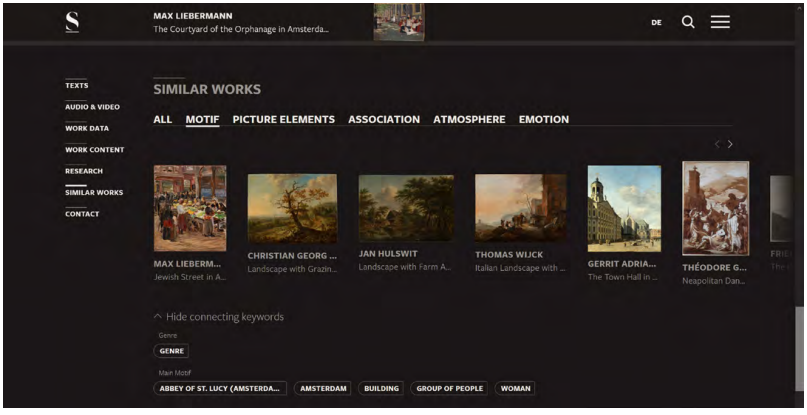


Figure 17. *"Similar Works" at* Digital Collection*, Städel Museum, accessed February 7, 2021, https://sammlung.staedelmuseum.de/en/work/the-courtyard-of-the-orphanage-in-amsterdam*

Many digital collections display a selection of artworks using different strategies to help users begin exploring. The better and more complex these interfaces are, the more they meet the requirements of a generous interface. The Städel Museum Frankfurt am Main's *Digital Collection*[507] is an advanced example for browsing by offering several entry points at once: a changing background image behind the basic search field with a link to the artwork, an image grid, a kind of slot machine that combines three keywords to show an artwork, thematic image galleries, and highlights of the collection. All these options encourage collection exploration and users to seek out information about an artwork. Apart from artwork information and an image, the records are enhanced with multimedia like texts, video streams, or audio streams that situate the artwork in art historical contexts and make the collection interesting to a general public. The user is engaged and can intuitively browse the collection because not only specialist terms relate to the records but also terms from everyday vocabulary, such as concrete objects or abstract emotions. Metadata tags link one artwork to others inviting users to explore the collection (fig. 17). While many digital collections searches are limited to keyword searches and grid layouts restricted to a single criterion, Städel Museum's digital collection offers a more dynamic approach. It features competing and complementary browsing options, allowing users to discover content through multiple parallel access points. Beyond the com-

507 *Digital Collection*, Städel Museum, accessed December 27, 2024, https://sammlung.staedelmuseum.de/en.

monly used grid layout, other approaches support browsing a collection. Even enriching the record of an artwork with more multimedia content further leads users to potentially interesting material.

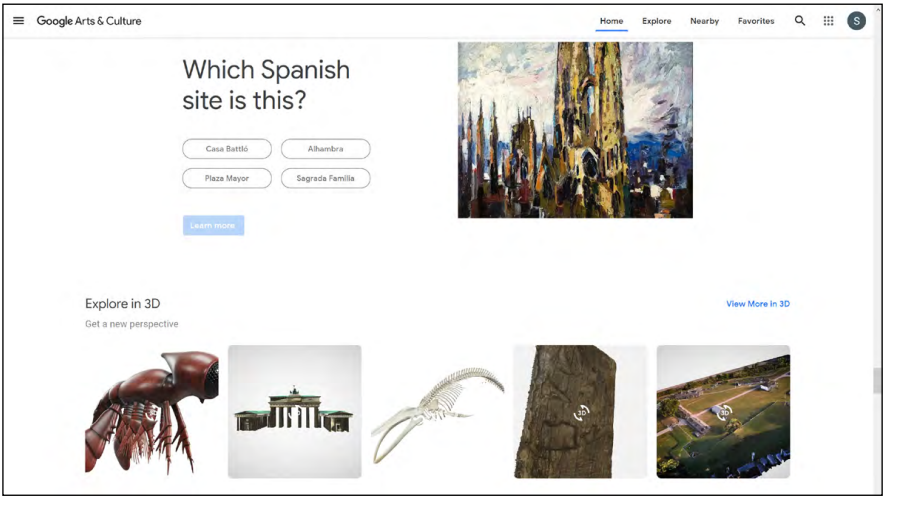


Figure 18. *Home, Quiz and Explore in 3D at* Google Arts & Culture*, accessed February 7, 2021, https://artsandculture.google.com/?hl=en*

An even more comprehensive browsing interface than Städel's is *Google Arts & Culture*.[508] Browsing the collections in various forms is the guiding principle for the interface. A keyword search is possible, but almost hidden behind the myriad other options of an interactive experience, a museum to explore, a favorite color, a 3D model for augmented reality, a suggested artwork, an activity, an artist, a game, and a range of ways to access content interlinked with each other (fig. 18). The variety of search and browse options, along with the various applications providing diverse access to artworks tailored to specific interests, makes *Google Arts & Culture* one of the best collections online by masterfully, and broadly, implementing the requirements of a digital collection. This allows audiences to engage with art in an entertaining way.

Compared to museums, Google has significant resources at its disposal to implement a digital platform. Therefore, it would be unrealistic to expect museums with their own digital collections to compete with Google and its services and initiatives, such as the *Street View*[509] technology or *Google Arts*

508 *Google Arts & Culture*, https://artsandculture.google.com.

509 *Street View*, Google Maps, accessed December 27, 2024, https://www.google.com/streetview.

& Culture Experiments.[510] Nonetheless, this should not discourage museums from exploring ways to expand their digital collections. Even with fewer resources, museums can find opportunities to develop their own projects or draw on what has been created by others. In addition, museums are free to partner with *Google Arts & Culture*, utilizing its digital infrastructure to establish a presence in a space that could reach a wider audience than their own digital platforms, activities, and offerings.[511] That said, the strength of museums' digital offerings lies in their ability to offer more detailed and comprehensive information about the works and the collection than is available through *Google Arts & Culture*. The autonomy of individual institutions enables them to create tailored applications and solutions that align with their specific goals, visions, and the distinctive characteristics of their collections, without having to apply these approaches to fit for all collections. Art historians can utilize *Google Arts & Culture* to view images by well-known artworks in high-resolution, but the general information provided is likely insufficient for research purposes. In that case, the direct link to the institution that owns the artwork is helpful to find all the information available within their digital collection. Museums have the advantage of presenting much more detailed, up-to-date information about their collections. Museum collections usually include not only the masterpieces, but also lesser-known artworks, which may be the preferred research subjects. It can be argued that both a general platform like *Google Arts & Culture* and individual museum's digital collections serve different types of users and, therefore, both have their value. *Google Arts & Culture* is suitable for an audience seeking general art-related entertainment or information without a specific institution in mind. In contrast, visiting a museum's digital collection requires a preexisting interest in the institution and the intent to explore more specific content.

Even without the backing of an international technology company like Google, art museums face the challenge of using digital technology to present their digital collections in an engaging and effective way. After all, visitors expect compelling digital offerings to be available directly on a museum's website rather than on third-party platforms. This requires a solid understanding of technological possibilities and careful consideration of how best to represent art in digital formats. Openness to technology and innovative approaches to art mediation provide a strong foundation for developing engaging applications. Enhancing access to digital collections and the artworks they contain is becoming an increasingly urgent task for

510 *Google Arts & Culture Experiments*, Google, accessed December 27, 2024, https://experiments.withgoogle.com.

511 "Partner with us," https://about.artsandculture.google.com/partners/.

museums. A fundamental aspect of this endeavor is the structured organization of data. Well-structured metadata is essential not only for ensuring accurate documentation but also for facilitating effective search and retrieval within digital collections.

3.3 Text-Based Image Retrieval (TBIR)

Metadata is important at multiple levels for text-based retrieval in digital collections. For this reason, museums pay special attention to metadata, in the form of artwork data, descriptions, keywords, categories, and vocabularies, when adding artwork records to databases. Consistent and purpose-oriented metadata is essential for successful searching. Metadata limited to external descriptors—such as artist, title, and year—is insufficient if image content is also to be searchable. In such cases, the level of detail and accuracy in metadata becomes a determining factor in the effectiveness of retrieval.

Subject access to images presents challenges in the description of motifs. The level of specificity in metadata can range from generic terms (e.g., "church" or "man") to precise identifiers (e.g., the name of a specific building or an individual).[512] Whether a general or exact description is more appropriate depends on the searcher's intent. To support different approaches to searching, it makes sense to have metadata for both the exact name of, for example a particular building, along with generic keywords like "cathedral," which can be integrated into a hierarchical thesaurus with "church" as a broader term.[513] This supports precise as well as more generic searches. An accurate subject access for images depends on the vocabulary choices that have been made for the metadata.[514] When preparing metadata for records, best practices emphasize data consistency across the collection database and following institutional standards.

Text-based image search is reliant upon the extent of indexing, which is based on suitable methodologies and terminologies.[515] The description, cataloging, and indexing of artworks and their corresponding images using metadata schemas and controlled vocabularies form the foundation for a data structure that offers optimal subject retrieval.[516] As seen on page 74

512 Sara Shatford Layne, "Subject Access to Art Images," in *Introduction to Art Image Access: Issues, Tools, Standards, Strategies*, ed. Murtha Baca (Getty Research Institute, 2002), 1–2.

513 Layne, "Subject Access," 15.

514 Layne, "Subject Access," 15.

515 Patricia Harpring, "The Language of Images: Enhancing Access to Images by Applying Metadata Schemas and Structured Vocabularies," in *Introduction to Art Image Access: Issues, Tools, Standards, Strategies*, ed. Murtha Baca (Getty Research Institute, 2002), 20.

516 Harpring, "The Language of Images," 20.

in chapter 2, art historical communities can draw on a range of specialized controlled vocabularies. *Iconclass* is useful for iconographic themes and is organized hierarchically by alphanumeric identifiers that describe artworks' subject matter. The *Art & Architecture Thesaurus (AAT)* includes terms to describe architectural subjects or objects, while the *Thesaurus for Graphic Materials (TGM)* by the Library of Congress provides object type or medium the vocabulary. Getty's *Thesaurus of Geographic Names (TGN)* includes names of places depicted in art. The *Union List of Artist Names (ULAN)* provides preferred and variant spellings for artist names.[517] Each of these controlled vocabularies ensures valuable metadata, but implementing them takes considerable effort.

Putting time and energy into developing data structures and indexing subjects is integral to record preparation for as many search needs and different types of users as are possible.[518] Well-organized metadata is sustainable in the long term because it can be reused for different projects and migrated when inevitably technological development requires a system change.[519] Responsible management of extensive artwork metadata—meticulously recorded using controlled vocabularies and established standards—is essential for delivering a search experience that effectively serves the general public, art historians, and other experts in locating relevant works.[520] Image content is the category most commonly used—after the artist—to find art historical content, meaning that accurate metadata is required to ensure retrieval of the subject or iconographic content.[521] The only alternative is content-based image recognition (CBIR) based on algorithms, in which great progress has been made recently and is further discussed in section 3.4.[522] Standardization is the key to interoperability to enable the exchange and reuse of metadata. Linked data allows mixing vocabularies through semantic

517 Harpring, "The Language of Images," 35.

518 Harpring, "The Language of Images," 35.

519 Harpring, "The Language of Images," 35.

520 Harpring, "The Language of Images," 38.

521 Colum Hourihane, "It Begins with the Cataloguer: Subject Access to Images and the Cataloguer's Perspective," in *Introduction to Art Image Access: Issues, Tools, Standards, Strategies*, ed. Murtha Baca (Getty Research Institute, 2002), 40–41.

522 Ibtihaal M. Hameed et al., "Content-Based Image Retrieval: A Review of Recent Trends," *Cogent Engineering* 8, no. 1 (2021), https://doi.org/10.1080/23311916.2021.1927469; Matthias Springstein et al., "iART: A Search Engine for Art-Historical Images to Support Research in the Humanities," in *Proceedings of the 29th ACM International Conference on Multimedia*, ed. Heng Tao Shen et al. (ACM Special Interest Group on Multimedia Systems; Association for Computing Machinery, 2021), https://doi.org/10.1145/3474085.3478564.

models.[523] Instead of record-centric approaches as in relational databases, linked data models and shares structured data in a bottom-up approach, making representations more responsive to the nuances specific to cultural heritage resources.[524]

Once databases from different institutions are linked together—or in multilingual contexts—different languages pose a challenge in retrieving all relevant records when searching in a single language. Daniela Petrelli and Paul Clough conducted a user experiment to test cross-language information retrieval (CLIR) in a digitized image archive of historical photographs, emphasizing the importance of understanding and accounting for users' search behaviors.[525] Images in digital collections "are often accompanied by textual metadata (e.g., assigned free-text or terms from a vocabulary, tags, or captions), which describe properties of the image, such as its contents or creation history."[526] Retrieval is successful if the user has chosen a search term that exists in the metadata. "The implementation of cross-language image retrieval systems is typically a combination of standard cross-language information retrieval and image retrieval techniques."[527] One method is to use machine translation for the search terms, user interface, and search results. Another approach is a dictionary-based query translation.[528]

Implemented language-based services on the back end of a system have subtle effects on the user experience that should not be ignored. For example, auto-completion of terms being typed into a search field is a helpful feature that assists a user in doing searches. Keyword searches for images themselves rely on the comprehensiveness of associated metadata,[529] added by the professional community using controlled vocabularies and thesauri,[530]

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523 Richard J. Urban, "Representation Patterns for Cultural Heritage Resources," *Proceedings of the Association for Information Science and Technology* 50, no. 1 (2013): 1, https://doi.org/10.1002/meet.14505001123.

524 Urban, "Representation Patterns," 1.

525 Daniela Petrelli and Paul Clough, "Analysing User's Queries for Cross-Language Image Retrieval from Digital Library Collections," *The Electronic Library* 30, no. 2 (2012): 199, https://doi.org/10.1108/02640471211221331.

526 Petrelli and Clough, "Analysing User's Queries," 200.

527 Petrelli and Clough, "Analysing User's Queries," 200.

528 Petrelli and Clough, "Analysing User's Queries," 200.

529 Anne J. Gilliland, "Setting the Stage," in *Introduction to Metadata*, ed. Murtha Baca, 3rd ed. (Getty Research Institute, 2016), accessed June 23, 2021, https://www.getty.edu/publications/intrometadata/setting-the-stage/.

530 Harpring, "The Language of Images"; Mary S. Woodley, "Metadata Matters: Connecting People and Information," in *Introduction to Metadata*, ed. Murtha Baca, 3rd ed. (Getty Research Institute, 2016), accessed June 23, 2021, https://www.getty.edu/publications/intrometadata/metadata-matters/.

or by the public through user-generated tags.[531]

Images can only be found by keywords included in the metadata. If keywords are drawn solely from specialized art-historical vocabularies, it becomes difficult to search for specific objects depicted in an artwork. To address this limitation, metadata can be enriched through crowdsourcing, allowing volunteers to contribute additional tags. Depending on the complexity of a project and the nature of its tasks, volunteers can participate without requiring specialized knowledge or expertise. The social tagging project *ARTigo*[532] was created as a crowdsourcing platform for the annotation of digital images of artworks that are used by the departments of art history for teaching and publications. Its goal is to supplement existing metadata with everyday terms—those the general public would intuitively use when searching digital collections. Any interested user can participate by playing games to contribute tags that are validated when another user applies the same term to the same artwork. It is also possible to search for images in the database by relying on assigned tags and combinations of them, for example, a query such as "baum -haus" retrieves all artworks depicting trees but not houses.[533] Most user-generated tags describe visible elements such as figures, objects, attributes, and colors, while more advanced concepts and art-historical terminology appear less frequently.[534] Crowdsourcing makes a digital collection searchable with more intuitive terms by referencing an artwork's visible content that otherwise could not be found based on a title or artist name.

Apart from metadata assigned by curators or registrars, which is usually more helpful for experts, social tagging is a possibility for subject matter categorization and to broaden the vocabulary for more users. The use of social tags bridges the semantic gap that arises between the metadata an expert creates and the terms a layperson uses to search a digital collection.[535] Tags that users assign to images of artworks usually describe people and objects in the image and thus the observable content, which is usually not captured

531 Corinne Jörgensen, "Photos: Flickr, Facebook and Other Social Networking Sites," in *Managing Digital Cultural Objects: Analysis, Discovery and Retrieval*, ed. Allen Foster and Pauline Rafferty (Facet, 2014), https://doi.org/10.29085/9781783301539.008.

532 *ARTigo*, Ludwig-Maximilians-Universität München, accessed December 27, 2024, https://www.artigo.org.

533 François Bry and Christoph Wieser, "Squaring and Scripting the ESP Game: Trimming a GWAP to Deep Semantics," in *Serious Games Development and Applications*, ed. Minhua Ma et al. (Springer, 2012), 183–184, https://doi.org/10.1007/978-3-642-33687-4_16.

534 Bry and Wieser, "Squaring and Scripting," 183–184.

535 Judith L. Klavans et al., "Subject Matter Categorization of Tags Applied to Digital Images from Art Museums," *Journal of the Association for Information Science and Technology* 65, no. 1 (2014): 3, https://doi.org/10.1002/asi.22950.

in the metadata.[536] User-generated tags can also add other languages and culture-specific context that may exist in another language, which increases accessibility.[537] Tags assigned by users rarely identify specific people, events, or places, and abstract concepts, aside from naming emotions, opinions, or philosophical frameworks.[538] The richest metadata results when both professionals and the public contribute terms from different perspectives of the content. Finally, the more keywords associated with a dataset, the more sophisticated searches become for all users.

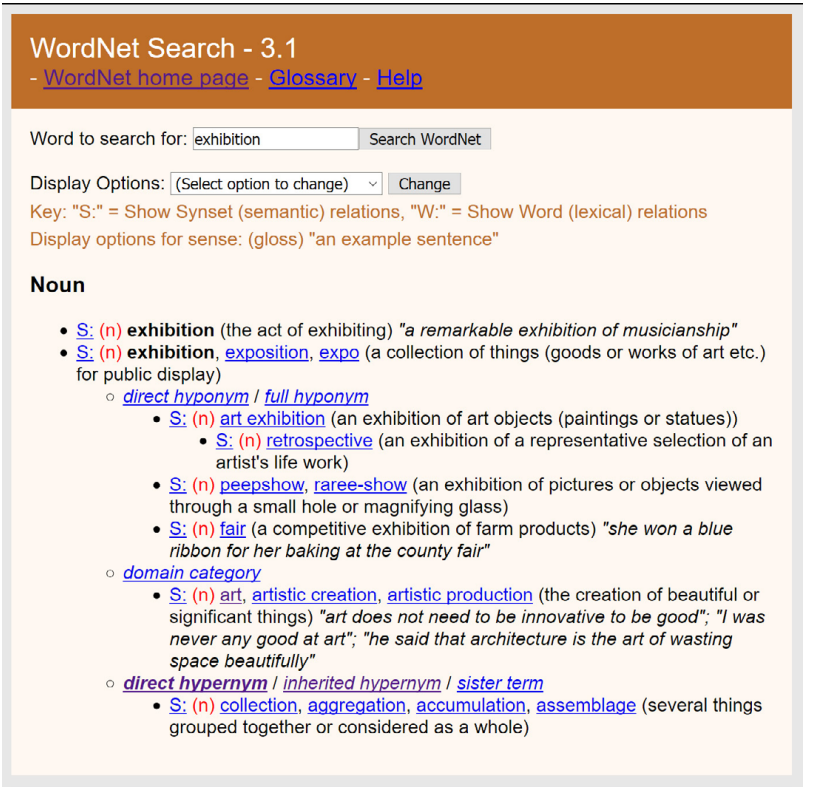


Figure 19. *Search results for "exhibition" and expanded branches with related words at* WordNet Search*, accessed December 31, 2018, http://wordnetweb.princeton.edu/perl/webwn*

536 Klavans et al., "Subject Matter Categorization," 3.

537 Klavans et al., "Subject Matter Categorization," 5.

538 Klavans et al., "Subject Matter Categorization," 10.

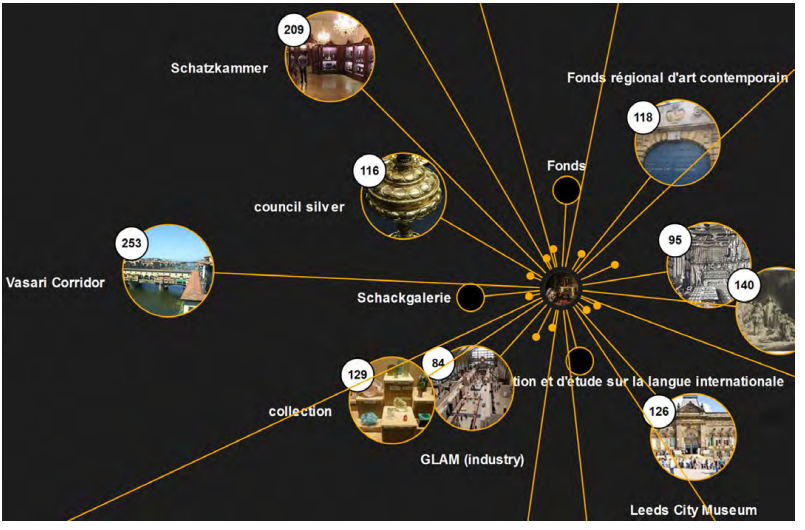


Figure 20. *Knowledge graph visualization. Semantically related terms for "digital collection" at* BabelNet*, accessed February 9, 2021, https://babelnet.org/synset?id=bn%3A00005931n&orig=digital%20collection&lang=EN*

A search engine does not necessarily use only the keywords directly associated with a digital object. For an enhanced search, semantic relationships between words from lexical databases such as *WordNet* or *BabelNet* are also considered. *WordNet* is a lexical database for English, but there are also WordNets for other languages.[539] "Nouns, verbs, adjectives and adverbs are grouped into sets of cognitive synonyms (synsets), each expressing a distinct concept. Synsets are interlinked by means of conceptual-semantic and lexical relations. The resulting network of meaningfully related words and concepts can be navigated with the browser."[540] Unlike a thesaurus, *WordNet* interlinks specific senses of words, which leads to semantic disambiguation, and also labels the semantic relations between words.[541] *WordNet* users can explore hierarchies and navigate the semantic structure by clicking on the links (fig. 19), *BabelNet* also visualizes and explores the semantic relationships

539 "What is WordNet?," WordNet, Princeton University, accessed December 31, 2018, https://wordnet.princeton.edu/. For other languages and multilingual WordNets see: "Wordnets in the World," Global WordNet Association, accessed December 28, 2018, https://globalwordnet.org/wordnets-in-the-world/.

540 "About WordNet," WordNet, https://wordnet.princeton.edu/.

541 "About WordNet," WordNet, https://wordnet.princeton.edu/.

for a term in a knowledge graph (fig. 20). In the humanities, applying digital technology to data requires confronting ambiguity in language and the fuzzy delineations of cultural subjects.

Intelligent use of technology can improve sources. For example, a database record for an artwork in a museum's digital collection can contain an error such as a wrong year or a typo in the artist's name. Moreover, the datasets of different artists may be incomplete. At first, all these issues might suggest that such a repository is inadequate as a source for doing research in the humanities. However, heuristics of computer science and technology help to overcome such a blurriness. Analysis of a large amount of data makes inaccuracy, on an individual scale, irrelevant. Filtering and the use of word lists in database searches permit minor spelling variations and can still retrieve relevant records for an artist even when the name is misspelled. By accepting a certain degree of content-related inaccuracy in data on the one hand and extreme numerical precision on the other—and recognizing both as inherent and unalterable—one reaches an interesting starting point for developing promising approaches to effectively engage with digitally available cultural data.

The deliberate acceptance of some fuzziness can help users discover the unexpected, based on concepts that enhance and enable browsing. Serendipity allows getting from one artwork to another to find unexpected content. Works can be connected through similarities. Algorithms play an important role in serendipity and similarity and are widely used in e-commerce to recommend products.

Similarity allows for the automatic detection of relationships between objects in a database by computing. Connecting related objects by similarity can be a tool for navigating or for clustering objects. In digital collections, this enables exploration and discovery of artworks. Additionally, similarity between items is the underlying principle for information access based on recommender systems, for personalization and automatic tour generation.[542] Identifying semantic similarity between texts consists of two main approaches: knowledge-based methods and corpus-based methods. Knowledge-based methods rely on algorithms based on structured resources such as thesauri, dictionaries, and semantic networks to measure similarity. Corpus-based methods use occurrences of words in a collection of documents or in a corpus.[543] Algorithms in knowledge-based methods often rely on

542 Nikolaos Aletras et al., "Computing Similarity Between Items in a Digital Library of Cultural Heritage," *Journal on Computing and Cultural Heritage* 5, no. 4 (2012): 2, https://doi.org/10.1145/2399180.2399184.

543 Aletras et al., "Computing Similarity Between Items," 5.

WordNet,[544] aggregated content from *Wikipedia*[545] available through *DBpedia,*[546] or *Wikidata*'s[547] structured knowledge.[548] As a lexical resource, *WordNet* organizes words in a hierarchical structure. *WordNet* includes *synsets*, "sets of word senses with nearly identical meanings," and "can be viewed as a large semantic network of synsets denoting the connections between words."[549] Semantic relationships in language can improve upon the search experience. This is especially useful for retrieving artworks, where textual information always serves as a substitute for the visual object. Allowing for fuzziness in search or browsing helps avoid the expectation of identical wording and instead accommodate expressions with similar meanings.

3.4 Content-Based Image Retrieval (CBIR)

Finding artworks in a digital collection works if the query includes stored information like artist name, title, or date. It is usually impossible to find artworks via content within an image because components of the motif are only partially indexed in the metadata or not at all. Image search engines require specialized search methods to recognize visual content if images are to be retrieved without keywords that are assigned to an image or text that exists next to an image. Apart from text-based image retrieval, automated identification of objects in an image are possible using computer vision algorithms based on low-level features like color and shape, and mapping it to linguistic concepts for generating tags.[550] In this way, it becomes possible, for example, to set up an image search based on a sketch as search input.[551] Content-based image retrieval (CBIR) is a promising technique that exploits the properties of pixel images for computational analysis. Searching for digital images based on the distribution of brightness or pixel colors is possible across a large image collection without the time-consuming task of adding tags to the metadata. A visual search for motifs is more demanding and usually requires the extraction of specific features from an image, as in face recognition.[552] CBIR illustrates the possibilities for other approaches opened up by the difference between digital and analog images. It is therefore an area of

544 *WordNet*, https://wordnet.princeton.edu.

545 *Wikipedia*, accessed December 27, 2024, https://www.wikipedia.org.

546 *DBpedia*, accessed December 27, 2024, https://www.dbpedia.org.

547 *Wikidata*, accessed December 27, 2024, https://www.wikidata.org.

548 Aletras et al., "Computing Similarity Between Items," 5.

549 Aletras et al., "Computing Similarity Between Items," 5.

550 Petrelli and Clough, "Analysing User's Queries," 199.

551 Petrelli and Clough, "Analysing User's Queries," 199.

552 Manmatha, "Bildsuche," 72–74.

research worth pursuing in the context of digital collections and art history and offers these fields potential for future development. Visual approaches to image retrieval supplement a text-dependent retrieval because tags and other metadata are often limited and inconsistent over large image datasets from disparate collections. Automatically analyzing image datasets based on the information contained in an image allows for bypassing laborious tasks such as manual expansion of keywording.

Out of this interest, Peter Bell and Björn Ommer took computer vision methods from computer science and applied them to art historical images for the recognition of scenes and objects in digital images.[553] To find a certain object or motif, a large set of images can be searched for recurring patterns.[554] Using algorithms for automatic search and image analysis can address problems relevant to both computer science and art history: visual search for the content of the images, image comparison, and the understanding of scenes and objects in an image.[555] They emphasize that the computer complements the experts and does not replace them, on the contrary, the machine is used for fast image processing of large data volumes.[556] In the context of digital collections, this allows for marking specific visual features in an artwork, enabling the discovery of other artworks with similar features in the motif. The challenge in using computer vision in art history is that the algorithms are trained with recent photographs and videos. Images of artworks include various styles, degrees of realism, abstractions, and therefore significantly differ from photographs.[557] In computer vision, low-level vision (image processing approaches to determine the authorship of artworks by the texture of brush strokes, for example) can be distinguished from high-level vision (semantic image understanding by recognizing objects and scenes).[558] Searches based on direct analysis of images offers new ways to find and make connections between artworks in digital collections.

Data analysis can be performed not only on individual image files but also on large sets of images. The analysis results must be made visible in a way that is comprehensible to humans. Large image sets can be visualized based on similarity through a system that combines a distance function, clustering, and projection methods, dynamically computing new results as the

553 Peter Bell and Björn Ommer, "Training Argus: Ansätze zum automatischen Sehen in der Kunstgeschichte," *Kunstchronik* 68, no. 8 (2015): 414–420.

554 Bell and Ommer, "Training Argus," 414.

555 Bell and Ommer, "Training Argus," 414.

556 Bell and Ommer, "Training Argus," 414.

557 Bell and Ommer, "Training Argus," 414–415.

558 Bell and Ommer, "Training Argus," 416.

user interacts.[559] Data preparation by analyzing large numbers of images involves several steps. Features are defined in the images, each of which forms a dimension and maps the data within a feature space.[560] Feature values are considered identical or similar, and weighting is applied by calculating the similarity distance between two images.[561] On one hand, identical or similar images, as well as images with specific features, can be searched.[562] On the other hand, images can be clustered, relationships between features can be analyzed, and image sets can be visualized as point clouds, revealing patterns within the dataset.[563] Visual similarity features can also be combined with metadata consisting of image annotations or obtained from the image files.[564] Algorithms that determine characteristic areas, such as salient regions, and descriptors for these areas, e.g., local histograms, compare only image details and similarity is calculated theoretically.[565] The distance function calculates the similarity between images based on several features, among them fixation points, color scheme, granularity, and complexity.[566] The features consider various dimensions of similarity. For comparing images, high-level objects like eyes, mouth, ears, as well as mid-level objects, such as horizon line, simple geometric objects can be identified, which means that both, high- and mid-level objects are characterized by individual patterns.[567] By recognizing structural features and motif details, artworks can be related to each other with a certain probability, making it possible to identify works with commonalities. This leads to the possibility of finding interesting works within a large, non-keyworded set of images or, thanks to this principle, suggesting to the user other works of art that might be of interest. Computer science and digital technology help to retrieve images from large collections and make them analyzable and manageable by context-dependent clustering through the calculation of similarity.[568] These techniques are promising for research using digital images in digital art history, but also for museum digital collections. Nevertheless, image search often still falls short of visual expectations.

559 Hermann Pflüger and Thomas Ertl, "Sifting Through Visual Arts Collections," *Computers & Graphics* 57 (2016): 127–138, https://doi.org/10.1016/j.cag.2016.03.009.

560 Pflüger and Ertl, "Sifting Through Visual Arts Collections," 128.

561 Pflüger and Ertl, "Sifting Through Visual Arts Collections," 128.

562 Pflüger and Ertl, "Sifting Through Visual Arts Collections," 128.

563 Pflüger and Ertl, "Sifting Through Visual Arts Collections," 128.

564 Pflüger and Ertl, "Sifting Through Visual Arts Collections," 129.

565 Pflüger and Ertl, "Sifting Through Visual Arts Collections," 129.

566 Pflüger and Ertl, "Sifting Through Visual Arts Collections," 129.

567 Pflüger and Ertl, "Sifting Through Visual Arts Collections," 129.

568 Pflüger and Ertl, "Sifting Through Visual Arts Collections," 137.

Image searches, dominated by standards and technologies that focus on processing text rather than images and therefore rely largely on words that describe the visual, often fall short for finding artworks or other visual digital material.[569] CBIR, in contrast, detects machine-readable information such as shapes, colors, or tonal values in the digital image itself.[570] For bitmap graphics, pattern recognition, signal processing, and statistical analysis can be used to retrieve information from the pixels.[571] With vector graphics, precise positions in 2D or 3D space can be displayed.[572] CBIR bypasses the almost infinite amount of text that would need to be added to an artwork's data record to cover all conceivable search queries with text-based image retrieval.[573] What is considered significant in an artwork may differ depending on the question being asked and the perception of the user, which is why one and the same work should be discoverable in a variety of contexts.[574] From this perspective, it is refreshing to combine art history with technology, in contrast to traditionally manual and text-focused approaches in the humanities.

Peter Bell and Björn Ommer embrace the promise of an art history–technology collaboration, perceiving computer vision and art history not as opposing but as complementary fields.[575] Machine vision arose from digitization and artificial intelligence and can assist in making image databases accessible.[576] If artworks in digital collections can be located not only via recorded artwork information and keywords, but also via the images, this improves findability. Computer vision methods include duplicate search, object detection, image comparison, and style analysis, all of which enhance search flexibility.[577] When applying computer vision methods, it is required to define what should be searched or analyzed and in what quantity, form, and variance this phenomenon occurs in the image dataset.[578] Machine learning enables training and refinement of algorithms through human-computer interaction, improving their performance for the intended task. Bell

569 Mike Pringle, "Do a Thousand Words Paint a Picture?" in *Revisualizing Visual Culture*, ed. Chris Bailey and Hazel Gardiner (Ashgate, 2010), 12.

570 Pringle, "Thousand Words," 16.

571 Pringle, "Thousand Words," 16.

572 Pringle, "Thousand Words," 16.

573 Pringle, "Thousand Words," 21.

574 Pringle, "Thousand Words," 23.

575 Peter Bell and Björn Ommer, "Computer Vision und Kunstgeschichte: Dialog zweier Bildwissenschaften," in *Computing Art Reader: Einführung in die digitale Kunstgeschichte*, ed. Piotr Kuroczyński et al. (arthistoricum.net, 2018).

576 Bell and Ommer, "Computer Vision und Kunstgeschichte," 61.

577 Bell and Ommer, "Computer Vision und Kunstgeschichte," 64.

578 Bell and Ommer, "Computer Vision und Kunstgeschichte," 62.

and Ommer stress that algorithms might not be suitable for certain tasks or answer questions outside of art history's purview, which is why it is important that the human being is well informed about the characteristics of the algorithms and can understand the application's internal processes.[579] Algorithms applied in computer vision to artworks include multiple considerations: comparison of whole images (for finding duplicates, copies, or successors, or for linking images with information); semantical comparison of scenes, objects, or details; difference analysis; comparison of technical features (like brush strokes), textures, and colors (low-level vision); as well as indexing a large amount of image data to find structural similarities.[580] What defines a search can be studied further beginning with image-based methods.

Applications that rely on these technologies can benefit museums. A possible use case would be to implement a duplicate search in an app to allow visitors to take photographs of the artworks with their smartphone during a museum visit and to find corresponding information in the digital collection.[581] This works by comparing the photograph with images of the artworks in the collection, where strong similarities between the new image and existing ones ensure accurate results.[582] Small variations, a slightly different angle, or different illumination do not hinder the algorithms from producing correct matches.[583] Algorithms that take only parts of an image into account can be used to find different images that include the same detail but might have very different compositions.[584]

Computer-calculated visual similarity can yield surprising results or quantitatively confirm assumptions. Image search based on computer vision makes it possible to identify topics within images without the need to compile an extensive corpus or rely on indexing and keywords. This facilitates the analysis of large quantities of images and the study of contexts across broader geographic areas and longer time spans. Technology enables the transition from distant viewing to visually perceivable structures and manageable corpora, ultimately leading to individual objects that can be studied using traditional methods.[585] Computer vision, however, is only partly useful for a single museum collection, because a collection may consist of only a small number of visually comparable objects. It makes more sense to situate a single artwork within the context of broader cultural heritage rather than

579 Bell and Ommer, "Computer Vision und Kunstgeschichte," 63.

580 Bell and Ommer, "Computer Vision und Kunstgeschichte," 63–64.

581 Bell and Ommer, "Computer Vision und Kunstgeschichte," 66.

582 Bell and Ommer, "Computer Vision und Kunstgeschichte," 66.

583 Bell and Ommer, "Computer Vision und Kunstgeschichte," 66.

584 Bell and Ommer, "Computer Vision und Kunstgeschichte," 66.

585 Bell and Ommer, "Computer Vision und Kunstgeschichte," 71.

an individual collection.[586]

In the future, computer vision and machine learning could be invaluable tools for art historians by enabling the search and analysis of image collections, assisting in processing vast amounts of visual data. Peter Bell et al. explored computer-based object retrieval by analyzing illustrations in the Heidelberg Sachsenspiegel (University Library, MS Cod. Pal. Germ. 164) using an algorithm that identified and compared gestures and forms from the manuscript's drawings.[587] They found that their approach offered significant advantages for identifying repetitive or similar motifs in large image datasets.[588] Computer-aided algorithms can generate statistical visualizations for large numbers of similar motifs, offering new insights into the material and aiding in attribution. Additionally, objects and their positions within compositions can be detected, allowing for deeper analysis of relationships and stylistic changes across the dataset.[589] However, art historical expertise is still essential to vet and interpret these results.[590]

Computer vision technologies are not limited to analyzing still images, but also work for moving images, other multimedia files, and 3D models. This opens up the possibility of searching digital collections for video art content or 3D objects with specific characteristics. Paisarn Muneesawang et al. studied multimedia database retrieval, which utilizes computer vision and machine learning technologies. This approach is suitable for searching large-scale image and video databases and includes interactive search and recognition technologies, as well as gesture databases used in advanced motion training for virtual reality systems. Challenges in large-scale multimedia databases include automatic classification and retrieval with minimal human labeling, efficient indexing and storage, fast and accurate retrieval performance, and seamless integration with cross-platform applications.[591] Search engines with integrated computer vision and machine learning technologies support various functionalities, including the ability to search for multimedia objects using audio, photo, or video files. Landmark recognition enables the retrieval of additional information based on a photograph taken by the user. This technology can also identify specific sequences in movies and videos or detect motions—such as those of a dancer—to locate other clips

586 Bell and Ommer, "Computer Vision und Kunstgeschichte," 75.

587 Bell et al., "Nonverbal Communication," 26.

588 Bell et al., "Nonverbal Communication," 27.

589 Bell et al., "Nonverbal Communication," 27, 34.

590 Bell et al., "Nonverbal Communication," 34.

591 Paisarn Muneesawang et al., *Multimedia Database Retrieval: Technology and Applications* (Springer, 2014), 1–3, https://doi.org/10.1007/978-3-319-11782-9.

featuring similar motions.[592] The underlying principle involves extracting information from multimedia signals and then describing, comparing, and classifying multimedia data.[593] Retrieving 3D objects from databases in a ranked order based on similarity requires sophisticated techniques.[594] Specifically, using a part-based representation for 3D object retrieval requires partitioning both the 3D objects in the database in addition to the query object.[595] Techniques like 3D mesh segmentation, node features, edge features, part-to-part distance measurements, and graph matching are mobilized for these searches.[596] While most digital collections currently comprise static images of artworks and rely on text-based search, many also include three-dimensional objects and video art. As a result, AI-powered search functionalities offer promising advancements for future applications.

Artificial Intelligence (AI) and Algorithms

The ability to automatically analyze digital images enables different modes of searching. For image retrieval, algorithms detect visual sequences and relationships between neighboring elements.[597] Filters and invariant transformations, which are operators in image processing and pattern recognition, can be used to cluster images from a database.[598] This capability suggests the possibility of creating search tools that retrieve images based on hand-drawn sketches.[599] Sketch-based image retrieval calculates the smallest contour distance between a user's drawing and the best-matching shapes detected in the images within the collection.[600] Archival methods, which emphasize text-based data storage, contrast with algorithms that are better suited for image and sound databases, as these algorithms are not restricted to written language.[601] In the digital realm, an archive can be reimagined as a mathematically defined space, in which each pixel in a static image or film

592 Muneesawang et al., *Multimedia Database Retrieval*, 14.

593 Muneesawang et al., *Multimedia Database Retrieval*, 15.

594 Panagiotis Theologou et al., "A Review on 3D Object Retrieval Methodologies Using a Part-Based Representation," *Computer-Aided Design and Applications* 11, no. 6 (2014): 670–684, https://doi.org/10.1080/16864360.2014.914385.

595 Theologou et al., "3D Object Retrieval Methodologies," 679.

596 Theologou et al., "3D Object Retrieval Methodologies," 679.

597 Wolfgang Ernst, "Dis/continuities: Does the Archive Become Metaphorical in Multi-Media Space?" in *New Media, Old Media: A History and Theory Reader*, ed. Wendy Hui Kyong Chun and Thomas Keenan (Routledge, 2006), 117.

598 Ernst, "Dis/continuities," 117.

599 Ernst, "Dis/continuities," 117.

600 Hadar Averbuch-Elor et al., "Distilled Collections from Textual Image Queries," *Computer Graphics Forum* 34, no. 2 (2015): 140, https://doi.org/10.1111/cgf.12547.

601 Ernst, "Dis/continuities," 117.

frame is uniquely addressable.[602]

A digital collection of art can similarly be understood as a mathematically defined space to which algorithms can be applied. Isabella di Lenardo and Frédéric Kaplan, for example, use pattern recognition algorithms to identify small details within large image collections, allowing for the identification of motifs across artworks from different time periods and geographies.[603] Three visual characteristics can be evaluated for similarity between images: general composition, specific figures or groups of figures, or individual objects. By examining variables such as color, texture, and light, researchers can infer shapes and structures within an image that are most perceptibly significant.[604] Advances in deep learning have substantially improved machine vision. "A neural network, made up of several layers bound together by various mathematical functions," consists of a large number of parameters to "produce an internal representation that allows different objects to be easily distinguished."[605] A neural network generates a vector-based projection of an artwork, shaped by a learning algorithm that processes billions of parameters.[606] To train an algorithm to classify works by distinguishing between different categories of objects, a sizable number of examples is necessary.[607] Convolutional neural networks (CNNs) achieve this by employing multiple layers that define the network's depth in deep learning approaches.[608] A neural network designed to assign descriptors to objects in photographs can also effectively classify images of paintings without additional algorithm training.[609] This method works particularly well for realistically executed paintings with realistic representations, but as abstraction increases, the result becomes less meaningful.

As established in previous chapters, successful deployment of digital technology for data analysis requires careful data preparation involving normalization, segmentation, and analysis of images well before investigation, evaluation, and knowledge acquisition can take place.[610] These procedures can be separated into low-level and high-level processing. Low-level process-

602 Ernst, "Dis/continuities," 117.

603 Isabella di Lenardo and Frédéric Kaplan, "The Large-Scale Search for Small Details: Redefining Patterns in Art History," in *The Museum in the Digital Age: New Media and Novel Methods of Mediation*, ed. Régine Bonnefoit and Melissa Rérat (Cambridge Scholars Publishing, 2017), 57.

604 di Lenardo and Kaplan, "Large-Scale Search," 59.

605 di Lenardo and Kaplan, "Large-Scale Search," 60.

606 di Lenardo and Kaplan, "Large-Scale Search," 60.

607 di Lenardo and Kaplan, "Large-Scale Search," 60.

608 di Lenardo and Kaplan, "Large-Scale Search," 60.

609 di Lenardo and Kaplan, "Large-Scale Search," 61.

610 Sara Colantonio et al., "An Ontological Framework for Media Analysis and Mining," *Pattern Recognition and Image Analysis* 19, no. 2 (2009): 221, https://doi.org/10.1134/S1054661809020023.

ing entails direct manipulations of the image file, such as contrast enhancement, normalization of variations, segmentation, and edge detection.[611] In contrast, high-level processing enriches data extracted during low-level processing using machine learning techniques, like neural networks, to derive semantic annotations and reveal patterns.[612] Additional algorithm-based techniques can adjust an image's size or convert its format in later stages.[613] The goal of these procedures is to extract implicit, semantically significant information from image data by identifying patterns and relationships not explicitly stored in a database.[614] Media mining "relies on rather assessed disciplines such as computer vision, media processing and retrieval, data mining, machine learning, databases, and artificial intelligence."[615] The challenge lies in transforming low-level representations into high-level information, aiding in the discovery of novel relationships within the data.[616]

3.5 Semantic Searches

A database with a semantic structure stores digital objects along with corresponding metadata and is searchable using a semantically powered search engine.[617] This metadata is organized as triples—consisting of a subject, predicate, and object—expressed in Resource Description Framework (RDF) syntax.[618] Each RDF record includes a Uniform Resource Identifier (URI), which uniquely identifies concepts and entities such as topics, people, corporate bodies, or geographic locations, and is accompanied by a human-readable label.[619] URIs ensure that metadata associated with the same entity across different databases—linked through controlled vocabularies and authority files—can be uniquely identified.[620] With semantic data organized as a triple store and accessed through graph-based retrieval, digital repositories become more flexible, interoperable, and interconnected. Semantic

611 Colantonio et al., "Ontological Framework," 221.

612 Colantonio et al., "Ontological Framework," 221.

613 Colantonio et al., "Ontological Framework," 221.

614 Colantonio et al., "Ontological Framework," 221.

615 Colantonio et al., "Ontological Framework," 221–222.

616 Colantonio et al., "Ontological Framework," 222.

617 Sebastian Ryszard Kruk and Bill McDaniel, "Introduction," in *Semantic Digital Libraries*, ed. Sebastian Ryszard Kruk and Bill McDaniel (Springer, 2009), 3.

618 Kruk and McDaniel, "Introduction," 3.

619 Ricardo Eito-Brun, "Context-Based Aggregation of Archival Data: The Role of Authority Records in the Semantic Landscape," *Archival Science* 15, no. 3 (2015): 228, https://doi.org/10.1007/s10502-014-9215-3.

620 Eito-Brun, "Context-Based Aggregation," 228.

structures add relational context to unstructured data, such as documents and images, enabling search algorithms to interpret unstructured data and metadata. This process relies on ontologies, which provide a standardized vocabulary and formalized set of relationships.[621]

Unlike relational databases, which limit keyword searches to a few metadata fields, semantic databases support dynamic and networked knowledge discovery.[622] For example, implicit networks of information allow queries such as:[623] "show all artworks by painters born in Europe between 1830 and 1910." Semantic search extends full-text and field-qualified searches by making records discoverable through cross-referencing between finding aids, authority records, and controlled vocabularies, thereby unlocking new possibilities.[624]

Cultural collections are semantically rich, situating objects within historical and social contexts while linking them to other items within the same collection or entirely different collections. To fully harness this richness, digital collections of cultural heritage should be made accessible through semantic portals. These portals use search engines that rely on semantic relationships modeled in an underlying knowledge base. Semantic Web technology offers notable advantages for digital collections in museums, enabling diverse collections to become interoperable through web languages, standards, and ontologies. Furthermore, applications built on the semantics of the collections can be versatile, user-friendly, and highly functional.[625] Ontologies play a crucial role in expanding user queries by providing semantics-based search capabilities.[626] Digital collections of cultural heritage often utilize *CIDOC CRM*, an extendable ontology flexible enough to accommodate diverse information sources.[627] Semantic Web-based portals can support ontology-based, content-based visual, or hybrid ontology-visual searches, connecting the collections of multiple museums. A view-based search engine allows users to form queries based on ontology concepts rather than relying solely on simple keywords.[628] Semantic recommender systems

621 Kruk and McDaniel, "Introduction," 4.

622 Sebastian Ryszard Kruk and Bill McDaniel, "Conclusions: The Future of Semantic Digital Libraries," in *Semantic Digital Libraries*, ed. Sebastian Ryszard Kruk and Bill McDaniel (Springer, 2009), 220.

623 Kruk and McDaniel, "Conclusions," 220.

624 Eito-Brun, "Context-Based Aggregation," 220.

625 Maria Nisheva-Pavlova et al., "Museum Collections and the Semantic Web," *Digital Presentation and Preservation of Cultural and Scientific Heritage*, no. 4 (2014): 33, accessed May 7, 2016, https://www.ceeol.com/search/article-detail?id=268995.

626 Nisheva-Pavlova et al., "Museum Collections," 34.

627 Nisheva-Pavlova et al., "Museum Collections," 35.

628 Nisheva-Pavlova et al., "Museum Collections," 35.

leverage explicit and implicit associations for browsing collections, while personalization features align search results with individual user interests.[629] For example, museums can use semantic data to develop mobile applications that provide tailored content based on user context—far surpassing the capabilities of conventional audio guides.[630] The systems must remain flexible, adapting to the tasks, interests, and goals of individual users.[631]

A semantic data model transforms a database into a holistic platform that integrates Knowledge Organization Systems (KOS).[632] This approach provides not only access to the images and metadata but also tools for manipulating them.[633] Such platforms enable users to create an information space where digital content from different museums, archives, and libraries can be selected, annotated, and enriched collaboratively, ultimately acting as a presentation, publication, and communication platform.[634] Semantically enhanced multimedia search and retrieval makes possible free text and image queries across multiple languages and systems resulting in answers, reasoning, and inference.[635] In such an environment, users can seamlessly access various information formats and systems, utilize task-specific tools, and work with digital collections—presenting works, analyzing data, and produce documents within a unified, adaptable platform.[636]

The Semantic Web, along with standards developed for it like the Resource Description Language (RDF) and the Web Ontology Language (OWL), offers great promise for knowledge representation in the humanities and museums by linking semantic markup with web content.[637] Not only are sophisticated searches possible, but the centralization and processing of information from various web sources presents new interpretive possibilities.[638] Semantic Web technologies make possible complex search tasks that surpass the capabilities of simple keyword queries. A challenge unique to developing ontologies for cultural heritage is the need to model not only the present-day relationships of an object but also legacy information from the

629 Nisheva-Pavlova et al., "Museum Collections," 35, 37.

630 Kruk and McDaniel, "Conclusions," 215–216.

631 Nisheva-Pavlova et al., "Museum Collections," 38.

632 Dagobert Soergel, "Digital Libraries and Knowledge Organization," in *Semantic Digital Libraries*, ed. Sebastian Ryszard Kruk and Bill McDaniel (Springer, 2009), 9.

633 Soergel, "Digital Libraries," 10.

634 Soergel, "Digital Libraries," 10–12.

635 Soergel, "Digital Libraries," 12.

636 Soergel, "Digital Libraries," 12.

637 AnHai Doan et al., *Principles of Data Integration* (Morgan Kaufmann, 2012), 325.

638 Doan et al., *Principles of Data Integration*, 325.

past—such as an artwork's provenance and locations over time.[639] Creating an ontology for digital cultural objects, enriched with contextual background information, can yield valuable and often unexpected connections.[640] The process involves building a knowledge base containing relationship graphs that link terminology and named entities associated with an artwork—like the artist, creation date, technique, relationships to other artists or artworks. A knowledge base such as this allows users to retrieve information beyond the metadata in a database.[641] Ontologies also uncover new possibilities in the search interface design. For example, Daniel Isemann and Khurshid Ahmad proposed a dynamic search interface that employs ontologies and knowledge bases: "input panels with the look and feel of advanced search templates are dynamically generated from an ontology and knowledge base and facilitate the construction of logically complex queries."[642] The dynamic adaptation of layouts and functionalities that align with a user's context-specific activities enables intuitive engagement with complex knowledge stored in databases.

Even the most sophisticated interface will never fully replace advanced search skills. This is because search options range in complexity from simple queries to highly specialized techniques requiring expert knowledge. While keyword searches provide a straightforward way to retrieve information from a knowledge base, understanding how objects are interconnected through semantic annotations is equally essential.[643] Tree diagrams and semantic networks with labeled nodes and edges allow users to explore the knowledge base visually or navigate concept and relationship hierarchies.[644] To fully exploit the potential of RDF-based systems, users must be able to act on, manipulate, and interpret the subject-predicate-object triples.[645] Query languages like SPARQL provide this capability by enabling users to retrieve information implicitly contained in the knowledge base through the application of a specific representation language and logic.[646]

Searches can become highly complex when addressing sophisticated research questions, often surpassing the standard search capabilities available to art historians in digital collections. Advanced queries may require defining search parameters through code, as is common in computer science

639 Daniel Isemann and Khurshid Ahmad, "Ontological Access to Images of Fine Art," *Journal on Computing and Cultural Heritage* 7, no. 1 (2014): 2, https://doi.org/10.1145/2538030.

640 Isemann and Ahmad, "Ontological Access to Images," 2.

641 Isemann and Ahmad, "Ontological Access to Images," 2.

642 Isemann and Ahmad, "Ontological Access to Images," 3.

643 Isemann and Ahmad, "Ontological Access to Images," 11.

644 Isemann and Ahmad, "Ontological Access to Images," 11.

645 Isemann and Ahmad, "Ontological Access to Images," 11.

646 Isemann and Ahmad, "Ontological Access to Images," 11.

and the digital humanities, to tailor searches to specific and unique inquiries. To enhance usability, digital collections should include broad search categories supplemented by multiple filtering options and facets. Additionally, direct data access should be available for users with programming skills, enabling more flexible and in-depth research.

For digital collections of museums containing large, diverse datasets and semantically rich, interconnected metadata, Semantic Web technologies have considerable promise.[647] Potentially, these technologies offer personalized access to digital collections by defining ontologies that integrate metadata and map a range of representation schemas across vocabularies.[648] Recommender systems leveraging extensive metadata and complex semantic structures provide users with serendipitous references to related items that might otherwise remain undiscovered through traditional query-based searches.[649] These systems incorporate various relationship types and employ strategies such as collaborative filtering, content-based recommendation, and event-based recommendation to address semantic complexity.[650] Unlike general information retrieval systems, ontology-based systems are structured within specific knowledge domains, facilitating precise retrieval and the execution of complex queries.[651] For instance, users can search for: "all paintings by artists from a specific area and period featuring a particular motif," which illustrates the promise of Semantic Web technologies for humanities research.

Interactive user modeling further enhances exploratory tasks by combining recommender systems with reinforcement learning and interactive visualization.[652] These systems adapt through model-based feedback loops that respond to user interactions.[653] Based on the initial keyword for the search, a set of documents from the collection with other relevant keywords is presented to the user on an interface.[654] Using an interactive interface, users can refine their search by selecting new keywords through a drag-and-drop function.[655] This generates feedback for the underlying user model updating

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647 Yiwen Wang et al., "Semantically Enriched Museum Collections," *Web Semantics: Science, Services and Agents on the World Wide Web* 6, no. 4 (2008): 283, https://doi.org/10.1016/j.websem.2008.09.002.

648 Wang et al., "Semantically Enriched Museum Collections," 283, 289.

649 Wang et al., "Semantically Enriched Museum Collections," 283.

650 Wang et al., "Semantically Enriched Museum Collections," 284.

651 Kohle, *Digitale Bildwissenschaft*, 27–28.

652 Ruotsalo et al., "Supporting Exploratory Search Tasks," 1.

653 Ruotsalo et al., "Supporting Exploratory Search Tasks," 1.

654 Ruotsalo et al., "Supporting Exploratory Search Tasks," 1–2.

655 Ruotsalo et al., "Supporting Exploratory Search Tasks," 2.

the interface and refining results in real time.[656] The iterative nature of this interaction allows users to adjust their searches continuously, resulting in outcomes that more closely align with their intentions than the initial keyword search alone.[657] Interactive user modeling differs from approaches like exploratory searches, personalized information retrieval, faceted search, result categorization, clustering, and mixed-initiative interaction.[658] While other techniques typically narrow the search query, interactive user modeling enhances navigation by offering additional options tied to the search results.[659] Users can refocus, expand, or broaden the query's scope, moving beyond narrowly defined content.[660] Furthermore, relevant features are displayed in a manipulable visualization, allowing users to provide direct feedback and engage in continuous dialogue with the system to reduce uncertainty inherent in the search query.[661] Ultimately, a search always remains an approximation of the desired result, with success depending on how effectively uncertainty is addressed and mitigated.

Uncertainty in database searches arises for several reasons. While database systems use precise data, real-world knowledge often contains ambiguities that must be modeled in the database.[662] Uncertainty may exist in the data itself, such as inaccuracies in data extracted from unstructured sources, inconsistencies across multiple sources, or outdated information.[663] It may also occur in schema mappings generated through semiautomatic techniques, as the exact mapping may be ambiguous or unknown.[664] Keyword-based queries introduce uncertainty when users unfamiliar with the database schema rely on simple search terms, which the system must translate into a structured form.[665] Additionally, mediated schemas lead to vaguer terms due to overlaps between disciplines and attempts to model broader domains.[666] To provide transparency for users, systems designed to handle uncertainty in data, schema mappings, and queries should assign probabilities to search results.[667]

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656 Ruotsalo et al., "Supporting Exploratory Search Tasks," 2.

657 Ruotsalo et al., "Supporting Exploratory Search Tasks," 1–2.

658 Ruotsalo et al., "Supporting Exploratory Search Tasks," 2–3.

659 Ruotsalo et al., "Supporting Exploratory Search Tasks," 3.

660 Ruotsalo et al., "Supporting Exploratory Search Tasks," 3–4.

661 Ruotsalo et al., "Supporting Exploratory Search Tasks," 4.

662 Doan et al., *Principles of Data Integration*, 345.

663 Doan et al., *Principles of Data Integration*, 345.

664 Doan et al., *Principles of Data Integration*, 345.

665 Doan et al., *Principles of Data Integration*, 346.

666 Doan et al., *Principles of Data Integration*, 346.

667 Doan et al., *Principles of Data Integration*, 346.

3.6 Search Result Display

In addition to the search functionalities, the presentation of search results is key, as it shapes the user's ability to interpret and create meaning. This section compares the functionality of traditional with more experimental interfaces. Traditional interfaces for digital collections often display results as lists with basic information—such as an image accompanied by basic metadata—or ordered lists organized by artist names, techniques, or keywords, offering a structured overview. Visual and intuitive access to database contents can be achieved by presenting images directly to users, either randomly or associated with specific categories.[668] Ideally, interfaces should allow the viewing of multiple images simultaneously, browse and filter results, and reorganize images using automated feature analysis based on attributes like color, composition, or texture.[669] Rather than static displays, dynamically organized and adjustable layouts improve usability by aligning results more closely with the user's intent.

The design of advanced search result displays requires thoughtful consideration of interface organization and the different phases of the search process. Several visualization techniques can be mobilized to support the search process in digital collections.[670] The search process typically involves three stages: formulating and refining a query, browsing result lists, and examining individual objects.[671] Each stage benefits from customized visualization techniques to support the user's experience.[672] Valuable search interfaces must also account for the specific type of objects in a digital collection.[673] Visualizations are useful for providing a data overview, connections, and additional information.[674] Wilko van Hoek and Philipp Mayr question whether presenting search results from a document collection as a simple list with brief previews of each document's author, title, and date is the best strategy, and instead, they advocate for using visualization techniques.[675] Visualizations take the form of query highlighting, which marks query terms in the document preview to indicate the metadata fields containing the terms, as well as two- and three-dimensional result views.[676]

668 Blome and Denzinger, "netzspannung.org," 202.

669 Layne, "Subject Access," 17.

670 van Hoek and Mayr, "Assessing Visualization Techniques," 70.

671 van Hoek and Mayr, "Assessing Visualization Techniques," 63.

672 van Hoek and Mayr, "Assessing Visualization Techniques," 64.

673 van Hoek and Mayr, "Assessing Visualization Techniques," 64.

674 van Hoek and Mayr, "Assessing Visualization Techniques," 65.

675 van Hoek and Mayr, "Assessing Visualization Techniques," 70.

676 van Hoek and Mayr, "Assessing Visualization Techniques," 70–71.

Two-dimensional visualizations, such as map- or cluster-based layouts and grid or table views, can show relationships between documents, with their relative positions indicating the degree of relatedness.[677]

> The relatedness is based on clustering where the multidimensionality of documents and their metadata is reduced to a 2-dimensional value. Due to the large amount of documents that are displayed in such a way they are represented by points or icons to reduce the complexity of the interface. Detailed information can be accessed upon zooming in on certain clusters or documents.[678]

Three-dimensional visualizations add an additional layer of information, making them particularly effective for presenting clusters or complex relationships within data spatially.[679] Additional techniques, such as document thumbnails or visual representations of the frequency and distribution of query terms, offer users a closer examination of individual documents.[680]

Visualizations serve not only as search interfaces but also as tools for providing an overview of the data and displaying the results. Unlike traditional interfaces designed for targeted searches, visualization-based interfaces promote serendipitous discoveries that may lead to unexpected insights.[681] The combination of multiple interlinked visualizations allows users experience different perspectives on the data.[682] Interfaces designed with interconnected visualizations provide multiple access points to the data, reveal connections between artworks, spark curiosity through abstract representations, and foster playful exploration of collections.[683] Other related visualization approaches include providing an overview of an entire collection using tools that offer analytical views, such as pie charts, tree diagrams, or scatter plots; interlinked visualizations for document exploration; and public information displays to facilitate discoveries.[684] When visualizations incorporate these features, more of a collection's content becomes accessible and interpretable. However, it is important to remember that the effectiveness of any

677 van Hoek and Mayr, "Assessing Visualization Techniques," 71.

678 van Hoek and Mayr, "Assessing Visualization Techniques," 71.

679 van Hoek and Mayr, "Assessing Visualization Techniques," 75–78.

680 van Hoek and Mayr, "Assessing Visualization Techniques," 78–80.

681 Alice Thudt et al., "The Bohemian Bookshelf: Supporting Serendipitous Book Discoveries Through Information Visualization," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ed. Joseph A. Konstan et al. (ACM Press, 2012), 1461, https://doi.org/10.1145/2207676.2208607.

682 Thudt et al., "The Bohemian Bookshelf," 1461.

683 Thudt et al., "The Bohemian Bookshelf," 1461.

684 Thudt et al., "The Bohemian Bookshelf," 1463–1464.

visualization depends on the categories and the quality of the available metadata.

Data visualization complements searching and browsing digital collections of art, and the next several paragraphs will highlight a few exceptional advanced interfaces. While retrieving information about artworks through a simple keyword search is convenient and easy, digital technology offers numerous advanced ways to utilize data from digital collections, going far beyond basic functionalities. Taking different approaches to the presentation of content in digital collections communicates cultural content to a broader audience. This is precisely what characterizes the purpose of art museums. The *ICOM Code of Ethics for Museums* states, "Museums preserve, interpret and promote the natural and cultural inheritance of humanity."[685] These principles ideally apply to digital collections as well. In a digitally connected world, museums that serve the public should embrace the expanded potential of digital cultural heritage for professional and public engagement. As the following examples illustrate, leveraging digital collections as valuable resources can open new possibilities for innovative applications.

Browse by Metadata with *MoMA Spelunker*

Digitally available cultural content makes possible collection visualizations based on existing metadata. The amount of information in a database is overwhelming and difficult to navigate for users, which can reduce motivation to engage with material. Visualizations can address this challenge by highlighting key aspects and revealing structures inherent in the data, making the information more appealing and comprehensible for users. Interactive visualizations are effective tools for organizing and integrating data from multiple sources, thereby making visible multiple connections. A data visualization is particularly absorbing when collections from different scholarly areas of a museum are digitized. The *MoMA Exhibition Spelunker*[686] is one of the applications that make use of MoMA's extensive online data pool. In 2016, they announced that digitized installation views of all exhibitions since the museum's founding in 1929 were accessible in the "exhibition history" section on MoMA's website.[687] In addition to the art collection, MoMA also digitized archival documents and information on exhibitions—including installation photography. *MoMA Exhibition Spelunker* makes use

685 International Council of Museums, *ICOM Code of Ethics for Museums* (ICOM, 2013), 1.

686 *MoMA Exhibition Spelunker*, MoMA, accessed December 27, 2024, http://spelunker.moma.org.

687 MoMA, "The Museum of Modern Art Launches Comprehensive Online Exhibition History," press release, published September 14, 2016, archived March 14, 2017, at https://web.archive.org/web/20170314164024/press.moma.org/2016/09/exhibition-history-digital-archive/.

of these resources to demonstrate relationships between different entities, and thus, provide insights on MoMA's exhibition history (fig. 21).

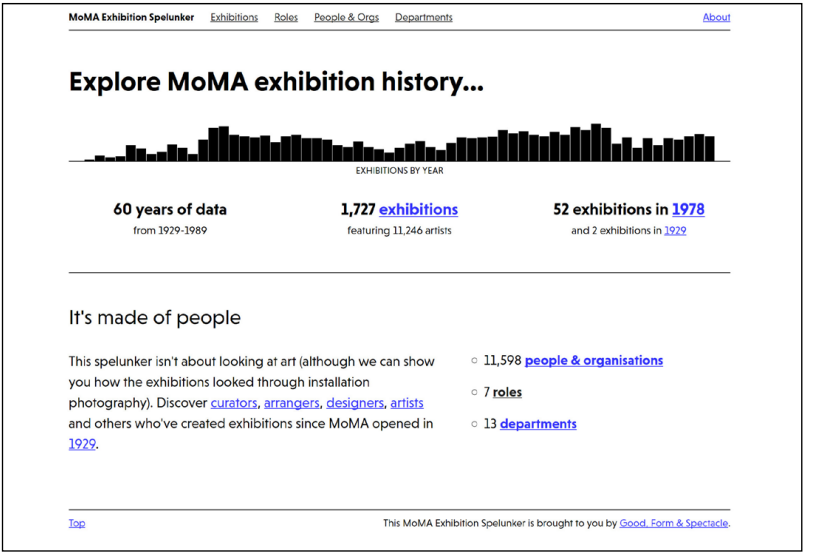


Figure 21. MoMA Exhibition Spelunker, *MoMA, accessed November 21, 2017, http://spelunker.moma.org*

In interfaces, graphic elements help consolidate information and support navigation by seamlessly linking different content and views. For instance, a bar chart in the application shows the number of exhibitions from 1929 to 1989 and serves as a navigation tool. Clicking on one of the bars leads to a page that displays all exhibitions for that year. The combination of information from different categories not only creates content-related connections but also opens multiple navigation paths through linked keywords. Individual exhibition pages feature installation photography, the exhibition title, dates, responsible MoMA staff, and participating artists. Artists' names are linked and lead to an overview that includes the most important biographical information, a portrait image—if available, and the MoMA exhibitions in which the artist participated. Available metadata is used to illustrate quantitative relationships, establish connections between different units of information, and provide users with the option to explore based on their interests. At the same time, the application also serves as an access point for specific types of sources.

The application provides comprehensive information by offering specifically designed pages for detailed exploration. Each page is interconnected, allowing users to navigate seamlessly between exhibitions, artists, curators, and departments. For example, users can explore an exhibition, view related artists, and then navigate to other exhibitions or curators associated with the same artist. A dedicated page for curators provides bar charts visualizing their activity over time and the number of exhibitions they curated. Similarly, a further overview illustrates when departments were established or merged, providing a chronological context. These interconnected access points—through departments, exhibitions, individuals, and roles—enable users to browse the data based on their interests, unearthing relationships and contexts rarely available in other digital collections or museum websites, where exhibition-related data is often limited or absent.

Individuals represented in collection metadata often appear in other databases, making unique identifiers essential for linking data across sources. *MoMA Exhibition Spelunker* references external resources such as *Wikidata*, *VIAF*, and *ULAN* on individual artist and staff pages. These authority records reach beyond the metadata stored in a single database, aiding in more robust searches, such as finding an artist's name across language variants. Unique IDs help merge identical individuals across databases, distinguishing namesakes and consolidating different spellings, thus ensuring that meta-searches retrieve all relevant results, not just exact matches. Applications with thematically self-contained data should always consider their potential for integration with other databases to boost connectivity and the utility of their information.

Browse by Image and Metadata Visualizations with *Past Visions*

Images are a central component of digital collections, serving both as standalone elements and as integral components of data visualizations that provide a broader perspective on a collection. *Past Visions*—developed by the Urban Complexity Lab under Professor Marian Dörk at the University of Applied Sciences Potsdam—combines images and metadata in innovative visualizations (fig. 22). Katrin Glinka et al. authored a 2017 article about the project discussing their goal of creating interfaces that appeal to researchers and educators, along with the general public.[688] According to the success of *Past Visions*, interfaces should be designed to be both inviting and rich in information.

Past Visions contains a zoomable visualization that combines distant

688 Katrin Glinka et al., "Past Visions and Reconciling Views: Visualizing Time, Texture and Themes in Cultural Collections," *Digital Humanities Quarterly* 11, no. 2 (2017), accessed August 27, 2017, https://www.digitalhumanities.org/dhq/vol/11/2/000290/000290.html.

viewing (bird's-eye view) with close viewing (close-up inspection), allowing users to explore a digital collection's quantitative structure from a broader perspective while also delving into the qualitative texture of individual objects.[689] As the researchers noted, "Our research aims to contribute to this line of work on generous and rich-prospect interfaces for cultural collections in particular by supporting the shift between abstract, distanced explorations and highly detailed close-up views."[690] This dual perspective allows users to shift seamlessly between abstract overviews and detailed examinations, revealing data connections and patterns that might otherwise remain hidden and fostering deeper engagement with a collection.

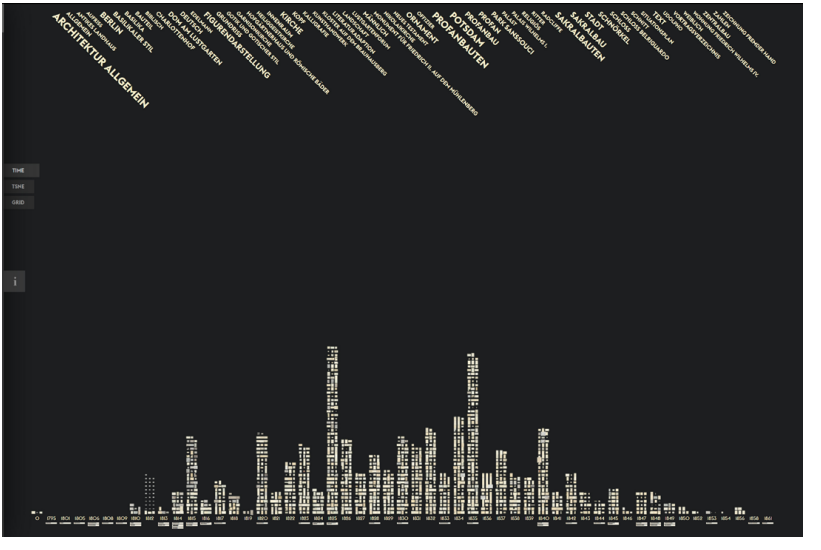


Figure 22. Past Visions*, Urban Complexity Lab, University of Applied Sciences Potsdam, accessed November 21, 2017, https://uclab.fh-potsdam.de/fw4/en/vis/*

689 Glinka et al., "Past Visions," 2.

690 Glinka et al., "Past Visions," 5.

Thematically and structurally coherent collections are particularly well-suited for data visualization. The source used for the application seen in figure 22 is a collection of drawings by Frederick William IV of Prussia (1795–1861) from the prints and drawings collection of the Prussian Palaces and Gardens Foundation Berlin-Brandenburg. The developers' goal was to find alternative forms of presentation and user interaction that departed from simple online inventory catalogs.[691] The visualization is based on data within the digital inventory of drawings by Frederick William IV. The visualization features excerpts from the exhibition catalog for the historical and biographical information at the bottom of the timeline.[692] The curation of such information units helps users to grasp the content and to navigate effectively.

When an interface is designed with specific requirements and tailored to a particular collection, it allows for approaches that are otherwise impossible. By combining various structural, content-related, and functional elements, a unique interface can be created for presenting and browsing a digital collection. The interface for *Past Visions* consists of a zoomable canvas with a timeline that features small images of about 1,500 collection drawings arranged in columns. At the top, a list of keywords in varying sizes is organized alphabetically, with the size of each keyword correlating to its frequency withing the artwork records. As users select keywords—acting as filters—the column configurations on the timeline adjust accordingly. The timeline itself displays drawings stacked in a grid, forming bars organized by year, to show how many drawings were made each year. Users can zoom in on the canvas or select an image, which leads to a high-resolution view of the artwork and opens an information panel on the right that includes detailed information about the artwork. Developing such a conceptually and technologically complex application requires collaboration from a diverse team, as demonstrated by the interdisciplinary group behind the project, which included a cultural heritage foundation, art historians, interface designers, computer scientists, and data visualization experts.[693]

Each element of *Past Visions'* functions as a navigation tool for refining results. Clicking on a keyword filters the timeline, displaying only those works indexed with that keyword, while greying out and repositioning

691 The Prussian Palaces and Gardens Foundation Berlin-Brandenburg (SPSG) published their online inventory catalog *Bestandskataloge der Kunstsammlungen. Zeichnungen König Friedrich Wilhelms IV. von Preußen (1795–1861)* in 2013, accessed November 21, 2017, https://bestandskataloge.spsg.de/.

692 Glinka et al., "Past Visions," 16–17.; Jörg Meiner, ed.,*"Unglaublich ist sein Genie fürs Zeichnen" Friedrich Wilhelm IV. von Preußen (1795–1861) zum 150. Todestag,* exh. cat. (Prussian Palaces and Gardens Foundation Berlin-Brandenburg, 2011).

693 Glinka et al., "Past Visions," 37.

unrelated works underneath the timeline. The keyword list dynamically rearranges to display shared keywords within the selection, adjusting their occurrences accordingly. The selection can be further refined by selecting multiple keywords simultaneously. Hovering over a keyword previews which works will remain or be excluded upon selection. The design offers multiple navigation options and access points for the collection's contents.

The entire interface is fully zoomable, allowing users to focus on specific parts of the timeline or inspect images in greater detail without clicking. By zooming in, short historical or biographical texts become readable. Selecting an artwork either by clicking or by zooming opens an enlarged view alongside a short description, commentary, and identifying details, such as date, dimensions, inventory number, and assigned keywords. Clicking the artwork again returns users to the timeline interface. Beyond the timeline, two additional viewing modes encourage further exploration. One mode uses an algorithm to group works by similarity rather than chronology, forming clusters similar to a word cloud. Works with more statistical similarities are closer together, while those with fewer are spaced further apart. The third mode displays works in a grid, positioning those with shared keywords nearer to one another. Hovering over a keyword highlights relevant clusters in the visualization.

The more possibilities for interaction within an application, the more engaging the digital collection. *Past Visions* presents the drawings both thematically and chronologically allowing for interactive exploration of the collection. This interface enables users to delve deeper from a general overview to extensive details as needed. The multiple interaction options, coupled with alternative perspectives, enhance the user experience and encourage a deeper understanding of the collection as an interconnected whole rather than as isolated artworks.

Despite beeing deemed protoype,[694] *Past Visions* is already well-advanced in layout, interaction, and navigation design. It was built using state-of-the-art open-source web technologies, including HTML5, CSS3, *Canvas/WebGL*, *d3.js*, and *pixi.js*.[695] The latter two are JavaScript libraries that allow for direct interaction with objects in the browser without loading new HTML pages. *D3* makes possible the application's interactive, data-driven charts. *Past Visions* is an exemplary case study in how to best expand and capitalize on digital collections.

694 See the project website "Past Visions. Penned by Frederick William IV," Urban Complexity Lab, University of Applied Sciences Potsdam, accessed November 22, 2017, https://uclab.fh-potsdam.de/fw4/en/. "The following visualisation is a research prototype."

695 See project website "Past Visions," https://uclab.fh-potsdam.de/fw4/en/.

Browse by Serendipity in *X Degrees of Separation*

The organization of images in interactive data visualizations does not need to rely solely on manually added metadata. Images can also be technically analyzed and arranged based on visual similarity, which can lead to serendipitous discoveries and reveal unexpected connections. *Google Arts & Culture Experiments*[696] explores similar innovations, showcasing potential solutions—created by artists and coders using images from *Google Arts & Culture*—for enhancing the search and browse experience for digital collections through technologies such as machine learning, serendipity, and image similarity.

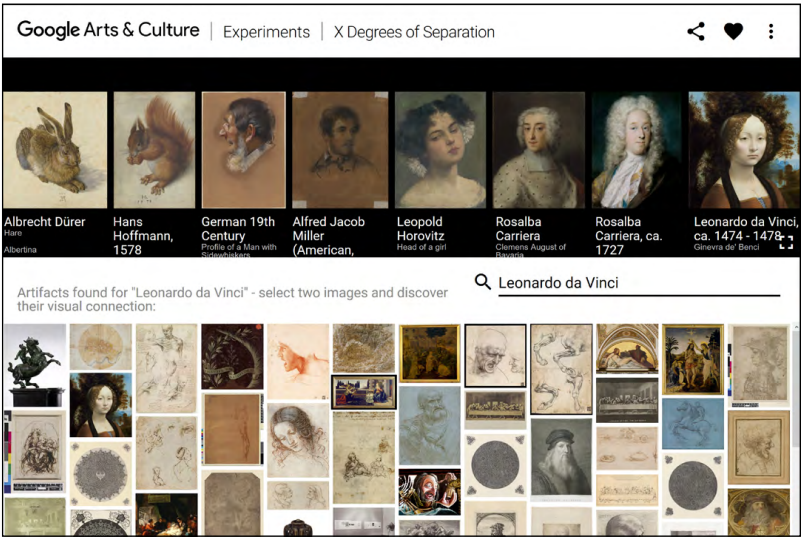


Figure 23. X Degrees of Separation *by Mario Klingemann and Simon Doury, Experiments, Google, accessed December 17, 2016, https://artsexperiments.withgoogle.com/xdegrees*

One such tool, *X Degrees of Separation* by Mario Klingemann and Simon Doury, connects any two artworks through a progression of visually similar images (fig. 23). For instance, Albrecht Dürer's drawing *Hare* (1502) and Leonardo da Vinci's painting *Ginevra de' Benci* (1474–1478) are linked through six intermediate artworks. This sequence, at first glance, appears to progress from small animals to portraits, with color seeming to guide the arrangement. The intermediate works span centuries with no works from the same

696 *Experiments*, Google, accessed February 22, 2017, https://artsexperiments.withgoogle.com/#/introduction.

period as Dürer and da Vinci. The inclusion of Hans Hoffmann, who was a copyist of Dürer, highlights interesting art historical connections, while other links, such as those between Rosalba Carriera's *A Gentleman in a Gold Patterned Coat and Violet-Brown Cape* and da Vinci's *Ginevra de' Benci* seems arbitrary.

While this tool can yield thought-provoking results for art historians, like showing Dürer's influence on later artists or uncovering connections across time, its randomness may limit its utility for studying specific periods or movements. To enhance its value for art historical research, users need the ability to define selection criteria based on parameters like time, style, or material.

Nevertheless, *X Degrees of Separation* is an engaging tool for both academic and general audiences. Researchers can discover related artworks that might otherwise go unnoticed, while casual users can explore images in a visually captivating and serendipitous manner. Clicking on any of the resulting images directs users to the *Google Arts & Culture* database, where they can access more information about the artwork.

Ultimately, *X Degrees of Separation* underscores the importance of involving cultural and art historians in developing digital tools tailored to their needs. Leaving the creation of digital collection tools solely to large technology companies risks producing solutions that do not align with academic or institutional priorities.

3.7 Conclusion

The display and arrangement of results on an interface are just as important as data retrieval itself, as they impact and can influence a user's insights. As seen throughout this chapter, searching is not merely a goal-oriented process of finding specific information but also raises questions about visibility—what is brought to light and what remains hidden within a database. Moreover, search functionalities must address the range of needs among art historians and the general public, who often seek and interact with collections in distinct ways.

Image search presents unique challenges while sharing similarities with text-based search; indeed, image search often involves text-based queries. Searching, browsing, and filtering are the primary methods employed for both keyword and image searches. The quality of the search results depends on the richness and diversity of metadata, which should incorporate controlled vocabularies, thesauri, and authority files. Comprehensive metadata anticipates diverse queries from users with different backgrounds and interests, ensuring more accurate and relevant results.

A fundamentally different approach to searching involves using images to

find other images, a process that relies on algorithms. Artificial intelligence technologies—such as data mining, machine learning, and especially deep learning with neural networks and computer vision—are poised to play a significant role in extracting knowledge from data. While keyword-based and image-based searches have inherent limitations, when used in tandem and utilizing fuzziness, similarity, and network models, they lead to more effective and nuanced results.

Despite advancements in search technologies, user interaction with digital collections remains relatively static when limited to retrieving individual artwork records. To engage broader audiences beyond experts, museums must actively mediate their collections in digital environments. Digitally available datasets of art hold immense potential for creating cutting-edge applications. By harnessing metadata and digital technologies, institutions can design interfaces that go beyond simple search fields to offer dynamic and engaging presentations of art and its data. Data visualization, as discussed in this chapter, is a compelling interface approach that encourages interactive and meaningful exploration of database content.

Beyond static keyword searches or basic filtering and browsing, digital technologies can provide numerous access points that facilitate user discovery. Effective presentation and mediation tools enable the general public to intuitively access relevant information. Interactive graphical presentations, for example, can reveal the scope of a database by visualizing included artists, their relationships, or the distribution of artworks across creators. These layered visualizations bring latent connections within the data to the forefront, increasing the value of digital collections for users.

Particularly significant for art historical research is the potential to link data sources across institutions. Open data initiatives enable the integration of decentralized datasets, fostering new insight and groundbreaking research opportunities. Such tools not only enrich academic inquiries but also make collections more accessible and engaging to wider audiences.

The process of navigating a digital collection entails more than just locating specific records; it represents active engagement with content. The technological structure of a database, along with its search and interface design, shapes the user experience. Interfaces do more than display results—they create meaning through their presentation and functionality, transforming how users interact with and perceive a collection.

This chapter underscores the importance of human-machine interaction in the design of digital collection interfaces. The next chapter explores the spatial and narrative dimensions of digital environments, examining how these factors influence the perception of art and the conveyance of knowledge.

4 User, Space, Narration

4.1 Introduction

Searching and browsing are the primary methods of accessing data in digital collections. However, alternative approaches can improve interaction by focusing on the user's experience, and incorporating spatial dimensions in the digital environment, or creating narratives. These conceptual considerations pave the way for digital applications that go beyond mere information retrieval to convey meaning and content. Images and metadata from digital collections are not standalone entities but dynamic elements that carry and can communicate multiple meanings when interconnected. When integrated into applications that treat the digital environment as both a representational space for art and a narrative medium, these elements cultivate possibilities for interaction and engagement.

Regardless of the access method, efficient interaction between user and system is essential. The interface, as the intermediary, facilitates communication by translating system code into forms understandable by humans and vice versa. A well-designed interface determines how users perceive the digital space, interact with the system, engage with the content, and spend time using it. Successful applications prioritize usability, ensuring that users can intuitively navigate and interact with the system. For museums, achieving user-friendly interfaces is critical to making digital collections accessible and engaging.

Digital environments differ fundamentally from physical museum spaces in the curation, presentation, and mediation of art. Curating in the digital realm involves adapting curatorial and museum expertise to the unique characteristics of digital space. This includes understanding digital space as distinct from physical space, acknowledging its potential to create new forms of art presentation and audience engagement. When used here, curator refers to a museological context, rather than a data management one. While traditional museum curating is centered around selecting, researching, and sharing content, digital curating also requires facilitating interactions that meet the needs of users different from traditional museum visitors, broader audiences that are more diverse and location-independent.

Engaging with art in a digital environment requires rethinking the roles of both the audience and the presentation medium. In the digital realm, users—different from visitors to physical museums—interact with art in new ways. Curating digital collections involves creating narratives that impart knowledge, often through multimedia content. These narratives emerge differently than in physical exhibitions or printed catalogs,

demanding original modes of mediating and learning.

Museums' digital transformation is not merely a matter of digitizing collections and making them accessible. Instead, it introduces new dimensions to museum work and enriches art historical research. Digital objects have unique characteristics, and the technological environment operates under principles distinct from those of physical spaces. As such, curating with digital images is a fundamentally independent task. Like physical artworks, digital images must be actively used and made visible to achieve full potential. As is the case also for digital curating, this visibility is for a wider-ranging audience with needs outside of those of traditional museum visitors and art historians.

Space in the digital realm must be reconceptualized, not as a direct transfer of physical space into virtual form, but as a unique environment with its own principles and behaviors. The designed environment for digital collections shapes how users engage with art. Narratives, strategies for contextualizing and conveying art, are constructed differently in the digital space giving curating in this context a unique quality. While curating digital collections and curating physical exhibitions share similar goals—generating and imparting knowledge—digital curation opens up new avenues for presenting art and advancing art historical research. In this way, the digital realm becomes a "knowledge space" that transforms how art is experienced, understood, and studied.

4.2 User Interaction with Digital Applications

Opening up the knowledge space contained in digital collection data depends on interaction opportunities and interface design. User engagement is essential to make digital collections comprehensible, perceivable, and explorable. Interaction methods vary by device and interface type—whether a website, a 3D model, or a virtual or augmented reality environment—each offering options for user engagement. Understanding the technological and psychological aspects of user interaction is crucial for developing effective interfaces and system architectures.

Successful communication occurs when the system correctly interprets the user's input and presents machine calculations in an understandable manner. The user interface bridges human and machine logic, playing a central role in human–computer interaction (HCI).[697] In 1960, J. C. R. Licklider envisioned a symbiotic relationship between humans and computers:

697 Andreas Butz and Antonio Krüger, *Mensch-Maschine-Interaktion* (De Gruyter Oldenbourg, 2014).

> In the anticipated symbiotic partnership, men will set the goals, formulate the hypotheses, determine the criteria, and perform the evaluations. Computing machines will do the routinizable work that must be done to prepare the way for insights and decisions in technical and scientific thinking.[698]

This underscores that computers support humans by automating formalizable tasks enabling a focus on knowledge acquisition—a concept foundational to the digital humanities and museum digital collections.

Designing systems to facilitate seamless communication between humans and machines ensures users can perform intended tasks effectively. Beyond HCI, theories of user experience (UX), participation, interaction, and immersion—especially in virtual reality (VR)—are relevant. While most applications use flat graphical interfaces, three-dimensional representations, such as VR and augmented reality (AR), hold promise for exhibitions and cultural heritage. An interface like this requires a computer system that recognizes a user's actions, simulates a virtual world accordingly, and generates stimuli that let the user perceive the virtual world.[699] These systems use input and output devices and computational simulations to create perceptual objects mediated visually, auditorily, and haptically.[700] Sensors track user actions (like viewing direction and device position).[701] Human-computer systems combine cognitive, perceptual, and motor properties.[702] User interaction in VR involves of selecting and manipulating virtual objects, navigating environments, and controlling systems.[703] Whether users engage with immersive environments or screen-based applications, the design of interaction opportunities determines what users can do or not do. The user interface—typically a graphical user interface (GUI)—is key to enabling interaction. Thoughtful interface design maximizes the utility of available data and its structure.

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698 Joseph Carl Robnett Licklider, "Man-Computer Symbiosis," *IRE Transactions on Human Factors in Electronics*, no. 1 (1960): 4, https://doi.org/10.1109/THFE2.1960.4503259.

699 Ralf Dörner et al., "Einleitung," in *Virtual und Augmented Reality (VR / AR): Grundlagen und Methoden der Virtuellen und Augmentierten Realität*, ed. Ralf Dörner et al. (Springer Vieweg, 2013), 21.

700 Butz and Krüger, *Mensch-Maschine-Interaktion*, 8.

701 Dörner et al., "Einleitung," 21.

702 Butz and Krüger, *Mensch-Maschine-Interaktion*, 8.

703 Ralf Dörner et al., "Interaktionen in Virtuellen Welten," in *Virtual und Augmented Reality (VR / AR): Grundlagen und Methoden der Virtuellen und Augmentierten Realität*, ed. Ralf Dörner et al. (Springer Vieweg, 2013), 190, https://doi.org/10.1007/978-3-642-28903-3_6.

Interface

The GUI bridges machine logic and human logic, transforming abstract data into perceptible, user-friendly formats. Effective GUIs align the design model with user's mental models, simplifying interaction.[704] While command-line interfaces require advanced computer skills, GUIs make systems accessible to general users, driving use.[705] Museums primarily use GUIs to provide access to digital collections, balancing simplicity with depth to avoid overwhelming users while preserving information richness. For advanced users, interfaces like application programming interfaces (APIs), offer greater flexibility. Museums must cater to diverse audiences, offering GUIs for general users and APIs for experts. Amsterdam's Rijksmuseum, discussed in the "Advanced Collection Interface" section (p. 200), exemplifies this approach, providing both a well-designed GUI and an API.

Search interfaces highlight the balance between simplicity and functionality. Those for the general public need to be simple enough to understand and use.[706] A basic keyword search suffices for general users when paired with robust filters (like time period or public domain status). However, simplistic interfaces can frustrate experts if the interface design is too restrictive. Layered tools, such as contextual navigation or separate "advanced search" options, can address this. The easier it is to find and use digital sources, the greater the chance that they will be used and, therefore, become valuable sources of information. Access to digital resources is crucial for the institution's digitization efforts to be fruitful for further research.

For general users, a GUI offering search capabilities and artwork details may suffice. Experts, however, may require features like image and metadata downloads, CSV exports, or API access. While APIs may not be prominently featured, experienced users are able to locate them. The Rijksmuseum demonstrates how careful interface design can meet the needs of both general (GUI) and expert audiences (API).[707] Beyond search interfaces, alternative applications can invite deeper engagement with digital collections.

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704 Butz and Krüger, *Mensch-Maschine-Interaktion*, 51–52.

705 Margarete Pratschke, "Geschichte und Kritik digitaler Kunst- und Bildgeschichte," in *Computing Art Reader: Einführung in die digitale Kunstgeschichte*, ed. Piotr Kuroczyński et al. (arthistoricum.net, 2018), 68–69.

706 Joachim Sauter, "Interfaces in Public and Semi-Public Space," in *The Art and Science of Interface and Interaction Design*, ed. Christa Sommerer et al. (Springer-Verlag, 2008), 63.

707 "Rijksmuseum Data Services," Rijksmuseum Amsterdam, accessed December 27, 2024, https://data.rijksmuseum.nl.

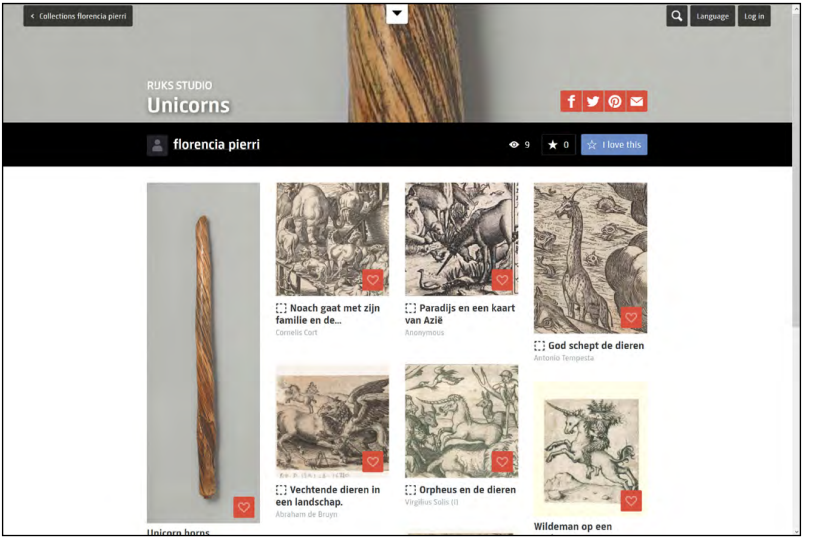


Figure 24. *Curated set "Unicorns" by user Florencia Pierri at* Rijksstudio, *Rijksmuseum Amsterdam, accessed April 18, 2016, https://www.rijksmuseum.nl/en/rijksstudio*

Advanced Collection Interface

The Rijksmuseum exemplifies how a museum can foster interaction with artworks and its digital collection. Through its digital platform, launched in 2012 as *Rijksstudio* and relaunched as *Collection* in 2024,[708] users can create personal accounts, curate their own online exhibitions, and make image sets public. For example, one user has curated a collection about unicorns (fig. 24),[709] revealing the legendary creature's surprising prevalence in the collection—from paintings and prints to objects like a narwhal tusk. Clicking on any image in a collection like this leads to the corresponding object record complete with detailed metadata. In some cases, the unicorn is not the main motif but a minor element in the artwork's composition. Users who assemble a set can highlight details of specific works to emphasize special features of

708 *Rijksstudio*, Rijksmuseum Amsterdam, accessed November 21, 2017, https://www.rijksmuseum.nl/en/rijksstudio (site discontinued). New site: *Collection*, Rijksmuseum, accessed December 27, 2024, https://www.rijksmuseum.nl/en/collection.

709 Florencia Pierri "Unicorns," in *Rijksstudio*, Rijksmuseum Amsterdam, accessed November 21, 2017, https://www.rijksmuseum.nl/en/rijksstudio/208581--florencia-pierri/collections/unicorns?ii=0&p=0.

an artwork, enriching the experience for others.

This functionality lets Rijksmuseum's *Collection* users enhance existing metadata by marking details and titling their curated groups. For instance, user's contributions ensure that unicorns can be found even if the term does not appear in an artwork's title or description. While primarily serving entertainment purposes, these user-generated collections also add value by improving searchability and establishing connections between artworks. This is further complemented by free high-resolution image download and developer access to the data via an API.[710]

Rijksmuseum intentionally publishes collection records with high-resolution images and no copyright restrictions for those in the public domain.[711] Anyone is permitted to share and use these images for any purpose. In 2014, the Rijksmuseum launched the Rijksstudio Award, a competition that rewarded the most creative use of its collection images,[712] significantly boosting visibility and inspiring innovative products. Although the competition ended in 2020, its impact is evident.

Rijksmuseum's participatory approach to user interaction is commendable, but not without criticism. In 2017, Viola Rühse pointed to the uncritical reception of *Rijksstudio*.[713] While *Rijksstudio* enables users to create, title, and share collections, it only offers basic functionality.[714] User's creative freedom on the platform is restricted to a predefined, narrow framework.[715] The available tools are limited resulting in a superficial engagement with art without an educational foundation.[716] Rühse advocates instead for online presentations that embrace a hybrid educational and entertaining mission,[717] as are seen in the examples in the subsequent paragraphs. It is always a balancing act to decide how comprehensive a digital application should be, who its target audience is, how much time users will need to spend on it, and what priorities should be set. Nevertheless, digital applications can effectively

710 See: "Our Data in a Nutshell," Rijksmuseum Amsterdam, accessed June 10, 2022, https://www.rijksmuseum.nl/en/research/conduct-research/data/overview.

711 Joris Pekel, *Democratising the Rijksmuseum: Why Did the Rijksmuseum Make Available Their Highest Quality Material Without Restrictions, and What Are the Results?*, November 14, 2014, accessed December 27, 2021, https://pro.europeana.eu/files/Europeana_Professional/Publications/Democratising%20the%20Rijksmuseum.pdf.

712 Viola Rühse, "The Digital Collection of the Rijksmuseum: Open Content and the Commercialization of a National Museum," in *Museum and Archive on the Move: Changing Cultural Institutions in the Digital Era*, ed. Oliver Grau (De Gruyter, 2017), 37.

713 Rühse, "Digital Collection," 37–38.

714 Rühse, "Digital Collection," 45.

715 Rühse, "Digital Collection," 46–47.

716 Rühse, "Digital Collection," 37–39, 45–47.

717 Rühse, "Digital Collection," 39.

combine education and entertainment as other examples show.

Other institutions have taken steps in this direction. The Kunsthalle Karlsruhe's *Art of* initiative,[718] for example, offers playful applications that invite thematic, creative, and dialogical interactions with artworks while linking users directly to detailed records in the digital collection.

Similarly, the Metropolitan Museum of Art's *Heilbrunn Timeline of Art History*[719] combines artworks, chronologies, and essays to narrate the story of art and global culture. By contextualizing artworks within their historical and geographical contexts, the timeline enhances learning and accessibility. However, unlike *Rijksstudio*, it does not allow users to exercise creative freedom in curating collections, as all content is predetermined.

These examples illustrate the inherent trade-offs in digital applications. Each reflects the priorities established during its development, underscoring the need for flexibility in digital collections. Museums must continuously adapt, creating new applications that utilize digital images and metadata to establish fresh contexts. This adaptability applies to both museum-led initiatives and third-party projects, such as those in research contexts, where customized applications address specific needs.

The advantage of digital collections lies in their capacity to support multiple interfaces, serving diverse purposes and communities.[720] Ideally, reciprocal links between applications—such as the Rijksmuseum's and the Metropolitan Museum of Art's offerings—create an expansive knowledge network where a range of information units remain discoverable. This interconnectedness fosters meaningful engagement and exploration across platforms.

Flexible User Interfaces

The richest access to a digital collection is achieved by making the interface and the selection of data displayed more flexible. This flexibility can take the form of multiple applications with tailored interfaces designed to meet the diverse needs of varying user groups. Alternatively, it can be realized through an adaptive interface that dynamically adjusts the presentation of data to meet situational requirements. In large digital collections, this adaptability can be implemented using algorithmically-generated assemblies that respond flexibly to user input. By determining the content displayed through algorithms, the interface becomes dynamic, thereby opening up

718 *Art of*, Staatliche Kunsthalle Karlsruhe, accessed December 27, 2024, https://www.mood-for.art.

719 *Heilbrunn Timeline of Art History*, Metropolitan Museum of Art, accessed December 27, 2024, https://www.metmuseum.org/toah.

720 N. Katherine Hayles, "How We Think: Transforming Power and Digital Technologies," in *Understanding Digital Humanities*, ed. David M. Berry (Palgrave Macmillan, 2012), 54.

opportunities for the user to explore and acquire knowledge. The GUI thus serves as a consciously designed structure that bridges algorithms and aesthetics, creating a framework for the advancement of academic knowledge.[721] If a GUI can generate academic insights, then it is equally capable of providing meaningful knowledge to general users.

The effectiveness of creating multiple applications with shared data lies in conceiving the database, data modeling, and interface as a layered model. Kathrin Friedrich proposes distinguishing between the surface, undersurface, and intermediate surface, which interact in complex ways without forming self-contained structures.[722] The surface ensures visibility, representing database content in a comprehensible format based on a designer's decisions.[723] The undersurface handles computability, incorporating data and machine processes that generate outputs according to standardized rules.[724] The intermediate surface facilitates configurability, linking the undersurface and surface by defining how users interact with the data.[725] Successful software development and interface design depend on the smooth integration of these layers to create applications.

Web-based applications follow conventions in structure and interaction, but some may adopt experimental designs, which can pose challenges for users unfamiliar with an application's functionality. To address such difficulties, user testing is critical during application development.[726] Testing helps identify user goals, preferences, and potential hurdles, allowing developers to refine interactions and improve usability. Technical or academic experts who create a digital resource cannot assume that users will use it in the same way, which is why user testing is vital.[727] User-centered design is fundamental to application development, encompassing both usability and

721 Kathrin Friedrich, "Hello Again!? Beziehungsweisen digitaler Bildgebung," in *Long Lost Friends: Wechselbeziehungen zwischen Design-, Medien- und Wissenschaftsforschung*, ed. Claudia Mareis and Christof Windgätter (Diaphanes, 2013), 79.

722 Friedrich, "Hello Again!?" 81.

723 Friedrich, "Hello Again!?" 81.

724 Friedrich, "Hello Again!?" 81.

725 Friedrich, "Hello Again!?" 81.

726 Dörner et al., "Interaktionen in Virtuellen Welten," 190; Lars Wieneke et al., "Building the Social Graph of the History of European Integration: A Pipeline for Humanist-Machine Interaction in the Digital Humanities," in *Social Informatics: SocInfo 2013 International Workshops, QMC and HISTOINFORMATICS, Kyoto, Japan, November 25, 2013, Revised Selected Papers*, ed. Akiyo Nadamoto et al. (Springer, 2014), 97; Claire Warwick, "Studying Users in Digital Humanities," in *Digital Humanities in Practice*, ed. Claire Warwick et al. (Facet, 2012), https://doi.org/10.29085/9781856049054.002.

727 Warwick, "Studying Users," 9.

storytelling, for example.[728] User interface (UI) design focuses on creating visual elements that facilitate efficient communication between users and the system, enabling them to perform tasks.[729] Meanwhile, user experience (UX) design emphasizes how users think, feel, and behave when using a system.[730] Together, UI and UX ensure that the interface provides orientation, supports interaction, and presents content in a clear, meaningful way. A well-designed interface enables smooth navigation, cultivating connections between pieces of content that coalesce into cohesive narratives, bettering the user's overall experience.

Extension and Limits of Interfaces

User interfaces are often perceived as flat surfaces confined to the size of a device's screen. However, interfaces can extend beyond this constraint, employing strategies to condense vast amounts of information into manageable, displayable sections. Accordingly, spatial representations of three-dimensional digital objects in virtual environments, for instance, constitute a specialized interface type with unique forms of interaction.

Augmented reality (AR) overlays real-world spaces with static or time-based dynamic virtual objects that adapt to the viewer's perspective, making them visible on mobile devices.[731] By contrast, virtual reality (VR) immerses users in entirely digital environments, isolating them from the physical world.[732] *WDR 360 VR* for instance,[733] offers an immersive experience of Cologne Cathedral, allowing users to journey through time from the Romans to the present day, hear stories from stonemasons working on

728 Harald Reiterer, "Einleitung: Benutzerzentrierung als gemeinsames Paradigma," in *Knowledge Media Design: Theorie, Methodik, Praxis*, ed. Maximilian Eibl et al., 2nd ed. (Oldenbourg, 2006).

729 Jinwoo Kim, *Design for Experience: Where Technology Meets Design and Strategy*, Human-Computer Interaction Series (Springer, 2015), 6–7.

730 Kim, *Design for Experience*, 11.

731 Wolfgang Broll, "Augmentierte Realität," in *Virtual und Augmented Reality (VR / AR): Grundlagen und Methoden der Virtuellen und Augmentierten Realität*, ed. Ralf Dörner et al. (Springer Vieweg, 2013), 241–242, https://doi.org/10.1007/978-3-642-28903-3_8.

732 Clara Boj and Diego Díaz, "The Hybrid City: Augmented Reality for Interactive Artworks in the Public Space," in *The Art and Science of Interface and Interaction Design*, ed. Christa Sommerer et al. (Springer-Verlag, 2008), 143.

733 *Weltkulturerbe Kölner Dom,* WDR, accessed December 27, 2024, https://koelnerdomlive.wdr.de; *WDR 360 VR,* Meta, accessed April 6, 2025, https://www.meta.com/de-de/experiences/wdr-360-vr/1268267383280759/; "WDR 360 VR," Google Play, accessed April 29, 2022, https://play.google.com/store/apps/details?id=de.WDR.VR. The report "Der Kölner Dom in 360°," WDR, accessed December 27, 2024, https://reportage.wdr.de/den-kolner-dom-in-360-grad-erleben documents the app with embedded 3D videos.

restoration, or stand amidst a singing choir—perspectives that would be impossible to access during an actual visit to the heritage site. While VR enables such remote explorations, AR is particularly promising for exhibition spaces because it allows additional information without diverting attention from the artworks. AR applications, as offered by *Google Arts & Culture*,[734] also enable users to project artworks into their homes.

In digital spaces, the GUI serves as the curatorial layer—just as exhibition curation shapes the walls and space in a physical setting. Rather than curating virtual walls, the focus is on the interface, which can take many forms beyond a virtual room and must accommodate the distinct needs of digital application users compared to visitors of physical exhibitions.

Virtual worlds offer humanities scholars tools for narratives construction, annotation, and immersive dissemination.[735] For these tools to be effective, scholars must define interface requirements according to their needs, rather than relying on predefined parameters.[736] Virtual environments are most rewarding when they function as laboratories for inquiry, interactive collaborations, or platforms for multivocal authorship and interpretation.[737] Designing software for cultural content requires flexibility and the involvement of experts to reflect the nuances of art and heritage.[738] Art historians and museum professionals, deeply familiar with their cultural content, should actively engage in developing digital tools and applications that meet their needs.

Effective interface design requires balancing user orientation, navigation clarity, and simplicity to avoid overwhelming users. This applies to VR applications, data visualizations, interactive storytelling, and digital collections. Interfaces should display only relevant options for the specific dataset being analyzed.[739] For example, zooming functionality can reveal detailed views,[740] while context-sensitive displays present options only when applicable, reducing cognitive load.

Context-aware systems further enhance user interaction by presenting

734 "Reality Check," *Google Arts & Culture*, accessed December 27, 2024, https://artsandculture.google.com/project/ar.

735 Christopher Johanson, "Making Virtual Worlds," in *A New Companion to Digital Humanities*, ed. Susan Schreibman et al. (Wiley Blackwell, 2016), 110.

736 Johanson, "Making Virtual Worlds," 110.

737 Johanson, "Making Virtual Worlds," 110.

738 Craig Dietrich and John Bell, "Representing Culture via Agile Collaboration," in *Handbook of Research on Technologies and Cultural Heritage: Applications and Environments*, ed. Georgios Styliaras et al. (Information Science Reference, 2011), 208, https://doi.org/10.4018/978-1-60960-044-0.ch010.

739 Forrest W. Young et al., *Visual Statistics: Seeing Data with Dynamic Interactive Graphics* (Wiley-Interscience, 2006), 29.

740 Butz and Krüger, *Mensch-Maschine-Interaktion*, 95–96.

tailored information, as seen in interactive storytelling applications.[741] While command-line interfaces offer efficient interaction for experts in statistical analysis, graphical user interfaces provide structured environments for dynamic data analysis.[742] Similar principles apply to digital exhibitions and cultural heritage applications, where interaction relies on features such as animation, stereo rendering, and natural interaction.[743]

A well-designed interface is highly dynamic, adapting to user interactions and modulating the visibility of content. This adaptability reflects the fundamental difference between digital applications and physical exhibitions: the nature of the space. Digital environments require interfaces that accommodate diverse user behaviors and foster meaningful engagement with cultural and academic content.

4.3 Space in the Digital Environment

Space in a digital environment differs entirely from space in a museum. While museums exist to present art in physical spaces, the digital realm requires a new approach, particularly when using data from collection databases. These databases mostly describe physical artworks rather than digital art forms, raising questions about art's representation and reception in virtual or hybrid spaces, such as augmented reality. The ways in which art is presented and experienced differ significantly between the reception of art, which can differ between physical and digital spaces.

Scholarly discourse on the use of museum space for art presentation has a rich history, grounded in museology, art history, and studies on contemporary and media art. Kai-Uwe Hemken's anthology explores the evolution of art exhibitions in the 21st century, tracing their development since the 1970s.[744] The focus then turns to curatorial practices and exhibition trends through the 1990s.[745] More recent discussions address topics such as digital

741 Fabio Pittarello, "A Simple Story: Using an Agents' Based Context-Aware Architecture for Storytelling," in *Technologies for Interactive Digital Storytelling and Entertainment: Third International Conference, TIDSE 2006, Darmstadt, Germany, December 4–6, 2006: Proceedings*, ed. Stefan Göbel et al. (Springer, 2006), 25.

742 Young et al., *Visual Statistics*, 29.

743 Dongming Lu and Yunhe Pan, *Digital Preservation for Heritages: Technologies and Applications* (Springer, 2010), 25.

744 Kai-Uwe Hemken, ed., *Kritische Szenografie: Die Kunstausstellung im 21. Jahrhundert*, Image 64 (transcript, 2015).

745 Hemken, *Kritische Szenografie*, 15–16.

representation,[746] media-driven spaces,[747] and the role of the museums within the art world and more broadly.[748] These considerations also extend to site-specificity, traditionally tied to specific, physical locations like a museum or public space,[749] but increasingly relevant to digital spaces. Digital environments, like physical spaces, operate within specific contexts and public spheres, shaping the framework for the digital representation of art.

The evolution of the museum as an institution underscores its responsiveness to societal changes. Beat Wyss distinguishes between the traditional museum and its 21st-century counterpart.[750] The traditional museum pre-

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746 Fiona Cameron and Sarah Mengler, "Activating the Networked Object for a Complex World," in *Handbook of Research on Technologies and Cultural Heritage: Applications and Environments*, ed. Georgios Styliaras et al. (Information Science Reference, 2011), https://doi.org/10.4018/978-1-60960-044-0.ch008; Sarah Cook and Aneta Krzemień Barkley, "The Digital Arts In and Out of the Institution: Where to Now?" in *A Companion to Digital Art*, ed. Christiane Paul (Wiley Blackwell, 2016); Stuart Dunn et al., "Spatial Narratives in Museums and Online: The Birth of the Digital Object Itinerary," in *Museums and Digital Culture: New Perspectives and Research*, ed. Tula Giannini and Jonathan P. Bowen (Springer, 2019), https://doi.org/10.1007/978-3-319-97457-6_12; Marisa Enhuber, "Art, Space and Technology: How the Digitisation and Digitalisation of Art Space Affect the Consumption of Art—A Critical Approach," *Digital Creativity* 26, no. 2 (2015): 121–137, https://doi.org/10.1080/14626268.2015.1035448; Annette Hünnekens, *Expanded Museum: Kulturelle Erinnerung und virtuelle Realitäten* (transcript, 2002); Iryna Kuksa and Mark Childs, *Making Sense of Space: The Design and Experience of Virtual Spaces as a Tool for Communication*, (Chandos, 2014); Ross Parry, ed., *Museums in a Digital Age* (Routledge, 2010).

747 Hendrikje Carius and Guido Fackler, eds., *Exponat – Raum – Interaktion: Perspektiven für das Kuratieren digitaler Ausstellungen* (V & R Unipress, 2022); Beryl Graham and Sarah Cook, *Rethinking Curating: Art After New Media*, (MIT Press, 2010); Sarah Kenderdine et al., "Cultural Data Sculpting: Omnidirectional Visualization for Cultural Datasets," in *Knowledge Visualization Currents: From Text to Art to Culture*, ed. Francis T. Marchese and Ebad Banissi (Springer, 2013), https://doi.org/10.1007/978-1-4471-4303-1_11; Arjun Sabharwal, *Digital Curation in the Digital Humanities: Preserving and Promoting Archival and Special Collections* (Chandos, 2015), https://doi.org/10.1016/B978-0-08-100143-1.00002-7.

748 Howard Besser, "The Future of Museums: How Will They Evolve Due to Digital Changes and in Relation to Time-Based Media," in *Digital Art Through the Looking Glass: New Strategies for Archiving, Collecting and Preserving in Digital Humanities*, ed. Oliver Grau et al. (Edition Donau-Universität, 2019), https://doi.org/10.25969/mediarep/131874; Tula Giannini and Jonathan P. Bowen, eds., *Museums and Digital Culture: New Perspectives and Research* (Springer, 2019), https://doi.org/10.1007/978-3-319-97457-6.

749 Knut Ebeling, "'In situ': von der Philosophie des Raums zur ortsspezifischen Theorie," in *Topologie: Zur Raumbeschreibung in den Kultur- und Medienwissenschaften*, ed. Stephan Günzel (transcript, 2007); Petra Hornig, *Kunst im Museum und Kunst im öffentlichen Raum: Elitär versus demokratisch?* (VS Verlag für Sozialwissenschaften, 2011); Miwon Kwon, *One Place After Another: Site-Specific Art and Locational Identity* (MIT Press, 2002).

750 Beat Wyss, "Kritische Szenografie: Das postmuseale Zeitalter," in *Kritische Szenografie: Die Kunstausstellung im 21. Jahrhundert*, ed. Kai-Uwe Hemken (transcript, 2015), 24.

serves cultural heritage for a regional audience, focusing on ancient art and conservation.[751] In contrast, 21st-century museums serve as "event machines" for mass audiences, emphasizing modern and contemporary art and entertainment.[752] The 1977 inauguration of Paris' Centre Georges Pompidou marked a shift from traditional museums to the "post-museum age."[753] The spectacular postmodern museum architecture and the construction boom since the 1980s reflect a crisis in the museum as an educated middle-class institution rooted in the 19th century.[754]

If the distinction between traditional museums and the so-called "post-museum age" holds merit, then a further conceptual evolution is necessary to envision a "post-post-museum," adapted to the digital era. Such an institution would embrace participatory and interactive applications, digital art, and remote accessibility, allowing visitors to engage with collections from any location. This raises critical questions about whether investment should prioritize new or expanded physical buildings designed by renowned architects, or rather focus on the digital environment. Thus, the museum finds itself in crisis once again, this time driven by technological transformation.

Hubert Locher asserts that art museums in crisis must redefine their societal role.[755] On one hand, museums grapple with the intellectual challenges of exhibiting art; on the other, they face pressure to cater to public demand for entertainment and attractive exhibitions, thereby becoming sites of event culture.[756] To address these competing demands, future museums must reconceptualize their roles as both exhibition spaces and archives.[757] New media play a pivotal role in this evolution, not only by making stored artworks more visible but also by enabling innovative curatorial practices and addressing the temporality and transience of art.[758]

Traditionally, museums have been physical institutions bound by location and space, focused on collecting and exhibiting art within their walls. However, in the digital age, such restrictions seem increasingly unnatural. Digital technology offers opportunities to connect collections from various

751 Wyss, "Kritische Szenografie," 24.

752 Wyss, "Kritische Szenografie," 24.

753 Wyss, "Kritische Szenografie," 24.

754 Wyss, "Kritische Szenografie," 35–36.

755 Hubert Locher, "Die Kunst des Ausstellens: Anmerkungen zu einem unübersichtlichen Diskurs," in *Kritische Szenografie: Die Kunstausstellung im 21. Jahrhundert*, ed. Kai-Uwe Hemken (transcript, 2015), 61.

756 Locher, "Die Kunst des Ausstellens," 61.

757 Locher, "Die Kunst des Ausstellens," 61–62.

758 Locher, "Die Kunst des Ausstellens," 62.

institutions across the globe, enabling entirely new forms of analysis and presentation. For instance, curating digital collections of specific artists' works from multiple museums can provide novel insights and perspectives. Investment in digital applications becomes justified when these tools offer unique ways to present art, engage the public, and provide access to information that surpasses traditional on-site exhibitions, art education, catalogs, or the museum website.

The concept of public versus private space in art presentation offers another compelling argument for digital transformation. Typically, museum and gallery spaces are considered private while urban spaces are public, and from this a dichotomy emerges that is relevant also to the digital space.[759] The digital realm, particularly, the Internet, functions as a new form of public space.[760] Consequently, artworks represented digitally enter this public space, sparking calls for the free use of digital images and metadata of artworks. This fusion of private and public spheres, driven by the fluidity of digital space, highlights the importance of reconsidering spatial concepts in the representation of art.

The meaning of space, both physical and virtual, is complex and multifaceted. Space can be interpreted as geopolitical territory or as the immaterial experience of communication.[761] Nevertheless, both physical and virtual space are real.[762] Other terms that are closely related but differ in meaning are those of the dichotomies of "room" vs. "space" and "place" vs. "site."[763] These notions of spatial location, combined with digital technology, shift scenography to media design, which must adapt to the unique characteristics of digital objects and environments.

Museum spaces are not the only place where art requires mediation. With the Internet, a new web-based social platform has emerged that forms a public space where people can be reached. This is not a revolutionary change, however, because from a historical perspective, the encounter with art is not tied necessarily to museum space. As André Malraux states, our notion of a museum as an art mediator did not exist before the 19th century and only existed in areas where modern European culture was celebrated.

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759 Rosalyn Deutsche, "The Art of Non-Indifference," in *The Artist as Public Intellectual?*, ed. Stephan Schmidt-Wulffen (Schlebrügge, 2008), 19.

760 Tula Giannini and Jonathan P. Bowen, "Museums, Art, Identity, and the Digital Ecosystem: A Paradigm Shift," in *Museums and Digital Culture: New Perspectives and Research*, ed. Tula Giannini and Jonathan P. Bowen (Springer, 2019), 64, https://doi.org/10.1007/978-3-319-97457-6_4.

761 Stephan Günzel, *Raum: Eine kulturwissenschaftliche Einführung* (transcript, 2017), 23.

762 Günzel, *Raum*, 23.

763 Günzel, *Raum*, 52–53.

He noted also that the relationship between the viewer and artwork had changed.[764]

Exhibitions shown in museums are a 19th-century concept that emerged when collections first became accessible to the public (early pioneers were the Ashmolean, founded in 1683, and the British Museum, which opened its doors in 1759). For centuries, art stood in a certain functional context, like a church altarpiece or a ceiling fresco in a ballroom. Art placed in a museum away from its original context and public access changes its reception. At a museum, the artwork has lost its status as a mere interior decoration, and the artwork becomes more an image of something that can be compared with other artworks and put together with artworks from different genres, periods, regions, and styles.

André Malraux called the idea of putting together various artworks "musée imaginaire," which translates to "imaginary museum" or sometimes "museum without walls."[765] He does not assume that the originals need to be observed. Instead, he argues that knowledge, paired with images of artworks, enables everyone to create their own imaginary museum composed of all objects they know or find intriguing. This stresses the validity of digital virtual spaces as legitimate venues for art representation.

The interplay between physical museum spaces and virtual realms hinges on questions of positioning and arranging physical or digital objects. Three-dimensional representation of art in virtual spaces generally occurs in three different ways: (1) through the spatial visualization of complex relational networks using large 2D image sets arranged on three axes; (2) as a virtual 3D model of art objects and architecture; and (3) through the active creation of virtual spaces that simulate and analyze the three-dimensional visual culture "timespace" beyond the constraints of static images.[766] To this must be added the question of fourth dimensionality. A fourth way deserves inclusion—the fourth dimension—which includes interactive, user-generated changes in generative visualizations, temporal modifications in 3D models simulating architecture or art installations, or the incorporation of changing components in time-based artworks.

The boundary of a museum or gallery calls attention to the importance of originals or artists-authorized works, as opposed to reproductions.[767]

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764 André Malraux, *Das imaginäre Museum: Mit einem Nachwort von Ernesto Grassi. Le musée imaginaire* (Campus, 1987), 7, 9–19.

765 Malraux, *Das imaginäre Museum*.

766 Harald Klinke et al., eds., *International Journal for Digital Art History: Digital Space and Architecture* (Graphentis, 2018), 11, accessed May 7, 2023, https://journals.ub.uni-heidelberg.de/index.php/dah/issue/view/3471/806.

767 Clemens-Carl Härle, "Heterotopie des Museums," *Paragrana* 26, no. 1 (2017): 42, https://

This principle is also relevant to digital spaces, especially when dealing with born-digital artworks. However, representing artworks from a collection database inherently involves reproductions. Digital space, therefore, is most productive when used for establishing contexts between reproductions. It need not be limited to a narrow selection of artworks—as would be the case if only digital art were considered—while excluding the rest of art history simply because original works are physical objects. Instead, digital spaces prioritize information and context. In physical galleries or museums, the uniqueness of an artwork is paramount. Conversely, in digital spaces, uniqueness holds less significance. Digital environments are spaces where various media converge, and reproductions effectively convey meaning and context of artworks housed elsewhere, such as museum collections.

When originals are curated for an exhibition, each becomes a vocal object, as presentation always communicates a message.[768] The interpretation of an object evolves with each exhibition and in new constellations with other objects.[769] The advantage of such interactions lies in dialogue created among artworks; for instance, a sequence of paintings on a wall can form a coherent statement, especially when complemented by architecture, light, and sound.[770] This is also pertinent for digital objects.

The *Digital Curator*[771] directly adapts the concept of lining up artworks on exhibition walls into a digital application. This application can be described as an exhibition generator. Artworks from the digital collections of 91 museums across Austria, Bavaria, the Czech Republic, and Slovakia are arranged based on objects identified within the motifs, which are automatically recognized through computer vision using artificial intelligence.[772] This results in a sequence of thematically-related works, introducing a technical component to the presentation of art. Thanks to the statistical analysis of the recognized motifs, the temporal occurrence of these motifs over the years is shown in relation to the entire dataset. Images are displayed alongside standard artwork information, while identified objects are highlighted, with their recognition probabilities displayed for users. Here, digital objects may be images of artworks or datasets containing related information.

Even when digital objects are reproductions, they remain important. Understanding the range of ways an artwork or its corresponding information can appear is crucial. The role of objects and their relationships—

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doi.org/10.1515/para-2017-0003.

768 Locher, "Die Kunst des Ausstellens," 45.

769 Locher, "Die Kunst des Ausstellens," 45.

770 Locher, "Die Kunst des Ausstellens," 49.

771 *Digital Curator*, accessed May 11, 2022, https://digitalcurator.art.

772 See *Digital Curator*, accessed May 11, 2022, https://digitalcurator.art.

whether in museums or digital spaces—influences how art representation works in these environments.

In physical spaces, exhibition designers work within architectural constraints to craft compelling presentations. Uwe R. Brückner identifies four essential parameters for creating effective spaces: physical-substantive, atmospheric-adjective, narrative-verbal, and dramatized space.[773] The physical parameter involves boundaries that define actionable space.[774] Atmosphere allows intuitive engagement with the intangible.[775] Narrative relies on text, graphics, and sound to guide visitors through an experiential story dependent on their decisions and movements.[776] Finally, dramatized space choreographs movement through themes creating an absorbing journey for the visitor.[777] In the digital realm, these must be adapted. Media designers, rather than exhibition designers or architects, apply digital design parameters particular to represent digital objects in their native environment.

Digital spaces, especially virtual museums, virtual reality (VR), and augmented reality (AR), require reconceptualizing space. Gertraud Koch argues for interpreting AR as "augmented realities" (plural), emphasizing their social and cultural contexts rather than technological constructs.[778] In AR, physical and virtual space overlap allowing interactions between real and digital objects. This hybrid environment can be characterized as a space in which virtual and physical reality merge and is fully media-generated,[779] providing visitors with intuitive interactions with exhibited objects.[780] While AR applications can enhance museum navigation and object engagement, they also present challenges due to the contextual complexity of museum interiors, making AR experimentation attractive to AR developers.[781]

Digital infrastructure demands social, organizational, and technical awareness.[782] For an effective cultural analysis of digital spaces, a relational

773 "Dabei liegen allen künstlerisch schlüssig initiierten Räumen die gleichen vier Raumparameter zu Grunde: der physisch-substantivische, der narrativ-verbale, der atmosphärisch-adjektivische und der dramatisierte Raum." Uwe R. Brückner, "Raum als Gesamtkunstwerk – Ästhetik des Erlebens," in *Kritische Szenografie: Die Kunstausstellung im 21. Jahrhundert*, ed. Kai-Uwe Hemken (transcript, 2015), 283.

774 Brückner, "Raum als Gesamtkunstwerk," 284.

775 Brückner, "Raum als Gesamtkunstwerk," 286.

776 Brückner, "Raum als Gesamtkunstwerk," 287.

777 Brückner, "Raum als Gesamtkunstwerk," 290.

778 Gertraud Koch, "Augmented Realities," in *Digitalisierung: Theorien und Konzepte für die empirische Kulturforschung*, ed. Gertraud Koch (Herbert von Halem Verlag, 2017), 310–311.

779 Koch, "Augmented Realities," 312.

780 Koch, "Augmented Realities," 321.

781 Koch, "Augmented Realities," 321.

782 Gertraud Koch, "Ethnografie digitaler Infrastrukturen," in *Digitalisierung: Theorien und Konzepte*

view of that addresses spatio-temporal and socio-technical dynamics is essential.[783] Infrastructure evolves continuously, adapting to user needs as much as possible.[784] Thus, curating digital spaces requires specialized skills in digital technology, but also new organizational structures, and a cohesive digital strategy.

A museum exhibition is an organizational construct involving a large network of stakeholders. Different groups bring their interests to an exhibition, and thus varying foci, vocabularies, and practices of discourse come together.[785] Not only do interests in art, economics, exhibition design, politics, and technology collide, but academic disciplines do as well.[786] As is seen for physical exhibitions, in digital applications art historians, artists, computer scientists, curators, designers, and users similarly converge. Coordinating different stakeholder interactions is a prerequisite for the success of digital applications.

In the early 1990s, Paolo Bianchi criticized curatorial practices for prioritizing attendance numbers over intellectual rigor, resulting in increased quantity at the expense of quality.[787] This criticism may reflect the professionalization of exhibition practices where specialized workflows and staff ensure efficient work but risk uniformity.

This challenge extends to online art collections, where quantity often outweighs quality. While many museums focus on maximizing content availability, they often neglect user-friendly and intellectually robust presentations. The vastness of online databases, coupled with limited interactive features, can overwhelm users. Unlike exhibitions, this imbalance stems from a lack of specialized personnel. Sustainable digital engagement requires dedicated staff who understand technology and its potential to communicate art. By fostering connections within digital databases, museums can deliver evocative and content-rich online experiences.

Museum Space as Place for Exhibiting Art

Before examining how digital objects are represented in virtual environments, it is essential to consider the concept of space in the presentation of art. Museum spaces are architectural and institutional constructs designed

für die empirische Kulturforschung, ed. Gertraud Koch (Herbert von Halem Verlag, 2017), 109.

783 Koch, "Ethnografie digitaler Infrastrukturen," 109.

784 Koch, "Ethnografie digitaler Infrastrukturen," 113.

785 Hemken, *Kritische Szenografie*, 14.

786 Hemken, *Kritische Szenografie*, 14.

787 Paolo Bianchi, "Die Kunst der Ausstellung (I): Ansätze für eine neue Kunst der Ausstellung und der Museographie – im Allgemeinen (I) und vor allem im interkulturellen Bereich (II)," *Artis* 45 (1993): 36.

for social interaction and curatorial practice, specifically tailored to focus on artworks. As Brian O'Doherty explains in *Inside the White Cube* (first published in 1976 as a series of essays in *Artforum*), what we know as the ideal gallery space is primarily white, closely linked to Modernism,[788] and "the work is isolated from everything that would detract from its own evaluation of itself."[789] This distraction-free, windowless space, isolated from the external world—illuminated from above—minimizes architectural presence to ensure the art remains the central focus.[790]

These same characteristics of physical exhibition space apply to virtual spaces as well, though with unique considerations. Virtual space should prioritize the artwork, avoiding technological distractions, or mimicking physical museum spaces unnecessarily. Instead of replicating the "ideal space" described by O'Doherty, the challenge lies in defining the characteristics of virtual space distinct from its physical counterpart.

Analog spaces and virtual spaces are both constructs designed to provide neutral frameworks for art. O'Doherty characterizes gallery spaces:

> Unshadowed, white, clean, artificial—the space is devoted to the technology of aesthetics. Artworks are mounted, hung, scattered for study. Their ungrubby surfaces are untouched by time and its vicissitudes. Art exists in a kind of eternity of display, and though there is lots of "period" (late modern), there is no time.[791]

Virtual space creates an equally artificial environment for the representation of artworks, in which art exists in a certain timelessness. Yet, unlike physical spaces, virtual spaces can expand infinitely, offering an endless space for digital objects. However, limiting and organizing this space is crucial for usability. Users should be able to tailor their experience, selecting content of interest and navigating various paths of interrelated objects, all of which necessitates thoughtful data modeling.

In some respects, the tiled display of image search results in a collection database mirrors the St. Petersburg hanging or salon style, where framed artworks are densely arranged. O'Doherty described this installation style in relation to 19th-century salon paintings as one that "makes it possible for pictures to hang like sardines."[792] While salon-style exhibitions curate works based on form and content, search results in digital collections often lack

788 Brian O'Doherty, *Inside the White Cube: The Ideology of the Gallery Space* (University of California Press, 1999).

789 O'Doherty, *Inside the White Cube*, 14.

790 O'Doherty, *Inside the White Cube*, 15.

791 O'Doherty, *Inside the White Cube*, 15.

792 O'Doherty, *Inside the White Cube*, 19.

connections between artworks, relying instead on ranking images by relevance. Contextualization remains integral to creating meaning, whether in physical galleries or digital environments.

O'Doherty noted that, "Abstract Expressionist paintings followed the route of lateral expansion, dropped off the frame, and gradually began to conceive the edge as a structural unit through which the painting entered into a dialogue with the wall beyond it."[793] The relationship between painting and wall, questioned throughout the 1950s and 1960s, is key to the evolution of framed paintings to the painting without a frame, as first established with photography, to Abstract Expressionist paintings, and to Kurt Schwitters' *Merzbau*.[794] This evolution parallels the transition from physical artworks to digital representations in virtual spaces. In this shift, artworks exist without physical manifestations and exist purely as images in digital environments.

The digitization of artworks introduces a new kind of space shaped by media technologies, distinct from the white cube. Digital reproductions and digital art, such as Net.art that emerged in the 1990s, redefine the idea of space and interaction.[795] Since the 1960s, conceptual, performance, installation, and digital art have shifted the definition of art from being object-based to one that emphasizes participation and interactivity,[796] transforming the creation, presentation, and reception of art. The Internet is simultaneously a platform, tool, and environment, enabling aesthetic experiences that are situational and device-dependent.[797] Jean Paul Fourmentraux's analysis of Net.art stresses central elements of digital spaces, including media, code, programs, linkages, navigation, communication structures, and content generation, that, when combined, challenge predefined roles for users.[798] A device—such as a computer, smartphone, or virtual reality headset—serves as the interface, making digital spaces accessible, content visible, and interaction possible.[799]

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793 O'Doherty, *Inside the White Cube*, 27.

794 O'Doherty, *Inside the White Cube*, 19–20, 27, 47–49.

795 Jean-Paul Fourmentraux, "Preserving Digital and Interactive Art: Museums and the Variability of Online Media Artworks," in *The Museum in the Digital Age: New Media and Novel Methods of Mediation*, ed. Régine Bonnefoit and Melissa Rérat (Cambridge Scholars Publishing, 2017), 45–46.

796 Fourmentraux, "Preserving Digital and Interactive Art," 45.

797 Fourmentraux, "Preserving Digital and Interactive Art," 45–47.

798 Fourmentraux, "Preserving Digital and Interactive Art," 47–53.

799 Fourmentraux, "Preserving Digital and Interactive Art," 47.

Virtual Representation of Art

Virtualization makes it possible to create an approximate and modifiable digital model based on the object's mathematically formalizable structures, like its dimensions.[800] Detached from the physical world, the simulated object can be displayed across numerous devices.[801] This also applies to the virtual space, which provides the foundational structure for integrating digital objects.[802] Data from art collections form a pool of objects that can be presented in virtual space.

While virtual space can replicate real-world environments, it offers a unique opportunity to explore experimental methods of presenting art beyond the limitations of physical museums. Instead of merely duplicating real-world settings, virtual environments encourage novel designs that diverge from traditional museum presentation.[803]

A notable example of a museum translated into a virtual one was the *Dresden Gallery* reproduced in Second Life (2007–2011).[804] This platform allowed users to navigate an avatar through the 3D model of the museum and to view artworks, access additional information, or take an audio tour. However, the experience was constrained by the closed platform, requiring software installation, user registration, and contending with low-quality graphics and rendering glitches.

More recent virtual tours, like *Gemäldegalerie Alte Meister und Skulpturensammlung bis 1800*,[805] are far more accessible. These tours can be accessed directly through museum websites via a web browser, eliminating the need for additional software or user accounts. Typically based on high-resolution panoramic photographs, they replicate exhibition spaces with a reasonable level of quality. Yet, challenges remain: pixelated artwork images prohibit close looking, and wall labels are too blurry to decipher.

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800 Jens Schröter, "Die Ästhetik der virtuellen Welt: Überlegungen mit Niklas Luhmann und Jeffrey Shaw," in *Virtuelle Welten als Basistechnologie für Kunst und Kultur? Eine Bestandsaufnahme*, ed. Manfred Bogen et al. (transcript, 2009), 26.

801 Schröter, "Die Ästhetik," 26.

802 Schröter, "Die Ästhetik," 26.

803 Schröter, "Die Ästhetik," 34.

804 "Die Gemäldegalerie Alte Meister @ Second Life," Staatliche Kunstsammlungen Dresden, accessed September 11, 2019, https://forschung.skd.museum/projekte/details/c/pC/a/show/project/107-die-gemaeldegalerie-alte-meister-second-lifer/. In Second Life, the *Dresden Gallery* existed as the virtual counterpart to the Staatliche Kunstsammlungen Dresden's Gemäldegalerie Alte Meister (Old Masters Gallery).

805 *Gemäldegalerie Alte Meister und Skulpturensammlung bis 1800*, Staatliche Kunstsammlungen Dresden, accessed December 27, 2024, https://gemaeldegalerie.skd.museum/fileadmin/userfiles/SKD_Panorama_Tour/Alte_Meister_20200630.

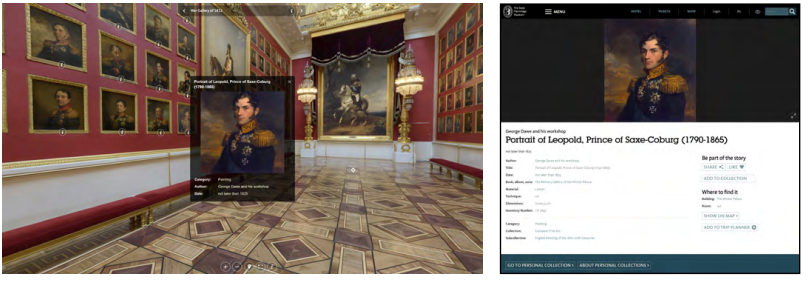


Figure 25. Left: Virtual Visit*, State Hermitage Museum, accessed November 26, 2021, https://pano.hermitagemuseum.org/3d/html/pwoaen/main/#node11*. Right: Collection Online*, State Hermitage Museum, accessed November 26, 2021, https://www.hermitagemuseum.org/digital-collection/39280*

The State Hermitage in St. Petersburg offers an extraordinary virtual experience of its permanent collection. Over 700 panoramas of the galleries in the museum's main complex are accessible via an interactive floor plan[806] or through the *Collection Online*,[807] where artworks included in one of these virtual tours directly linked to their corresponding 360° panoramas, allowing them to be explored in their exhibition context (fig. 25). The virtual tour provides the possibility to display the artwork information and to open high-resolution images. Making the entire museum virtually accessible is captivating for an encyclopedic museum, helping visitors revisit or discover works they may have missed in person.

While virtual tours attempt to replicate the museum experience, the experience is a significant departure from viewing original artworks in person.[808] Virtual museums are most meaningful when they do not replace physical visits but provide otherwise impossible experiences, such as reconstructing historical exhibitions or creating virtual models of museum spaces or artworks enriched with contextual information. The Louvre's *Petite Galerie* keeps virtual tours of temporary exhibitions digitally accessible, serving as archives documenting exhibition history in 3D.[809]

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806 "The Main Museum Complex," State Hermitage, accessed December 27, 2024, https://www.hermitagemuseum.org/panorama/pano_1.

807 *Collection Online*, State Hermitage, accessed December 27, 2024, https://www.hermitagemuseum.org/explore/artworks/?lng=en.

808 Michael Bockemühl, "Zu Grundfragen der Betrachtung, der Kunstvermittlung und zur Zukunft der Museen," in *Zum Bedeutungswandel der Kunstmuseen: Positionen und Visionen zu Inszenierung, Dokumentation, Vermittlung*, ed. Harald Krämer and Hartmut John (Verlag für Moderne Kunst, 1998), 105–107.

809 *Petite Galerie*, Louvre, accessed December 27, 2024, https://www.louvre.fr/en/online-tours.

Ideally, applications are designed to provide a distinct experience, separate from traditional museum visits. These applications require unique concepts that embrace digital technologies and prevent any confusion. Mediation through media produces a different experience and conveys new content.[810] This should be driven by a desire to develop new forms of art mediation, education, and communication. One example, *Kunsthalle Revisited*,[811] explores the history of the Staatliche Kunsthalle Baden-Baden through individually designed applications for selected past exhibitions. Employing diverse modeling techniques and interactive formats, it provides exciting ways to explore the museum's exhibitions and their historical evolution.

Rijksmuseum Masterpieces up Close offers a virtual tour that incorporates a scavenger hunt,[812] encouraging users to uncover hidden keys that unlock quiz questions tied to specific artworks. Rembrandt van Rijn's *The Night Watch* (1642) is enriched with interactive multimedia content, including hotspots with audio narratives that highlight specific areas of the painting. By incorporating gamification and storytelling, this application expands the scope of virtual tours can be thought of far more broadly than has been the case in the majority of cases to date, transforming them into standalone digital experiences.

Successful digital applications must align with museums' broader missions while acknowledging their distinct requirements. As Hildegard Vieregg states, a virtual museum is successful if it adheres to the Museum Definition by the International Council of Museums (ICOM).[813] According to ICOM Statutes:

> **A museum is a non-profit, permanent institution in the service of society and its development, open to the public, which acquires, conserves, researches, communicates and exhibits the tangible and intangible heritage of humanity and its environment for the purposes of education, study and enjoyment.[814]**

This definition, adopted in 2007, was revised in 2019 and again in 2022, after a controversial debate, to read:

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810 "Im medialen Vermittlungsprozess wird aus dem, was vermittelt wird, eine andere Erfahrung und damit ein neuer Inhalt." Bockemühl, "Zu Grundfragen der Betrachtung," 107.

811 *Kunsthalle Revisited*, Staatliche Kunsthalle Baden-Baden, accessed December 27, 2024, http://kunsthallerevisited.com.

812 *Rijksmuseum Masterpieces up Close*, Rijksmuseum, accessed December 27, 2024, https://www.rijksmuseum.nl/en/masterpieces-up-close.

813 Hildegard Katharina Vieregg, *Museumswissenschaften: Eine Einführung* (Wilhelm Fink, 2006), 20.

814 International Council of Museums, *International Council of Museums: Statutes*, amended and adopted by the Extraordinary General Assembly on June 9, 2017 (Paris, France), 2017, 3.

> A museum is a not-for-profit, permanent institution in the service of society that researches, collects, conserves, interprets and exhibits tangible and intangible heritage. Open to the public, accessible and inclusive, museums foster diversity and sustainability. They operate and communicate ethically, professionally and with the participation of communities, offering varied experiences for education, enjoyment, reflection and knowledge sharing.[815]

This further-refined definition emphasizes accessibility, inclusivity, and community engagement, widening the museums' scope and aligning well with digital initiatives. Virtual museums are not independent entities but extensions of physical institutions encouraging dialog and accessibility without physical limitations.[816]

In physical museums, the scarcity of artworks and logistical challenges of transportation limit access to originals. Artworks must be owned by, or loaned to, institutions to appear in exhibitions, and only organizing curators determine their presentation. While catalogs and publications provide additional access, digital collections and applications bridge the gap, allowing users to study artworks regardless of location.

815 *Museum Definition*, ICOM, accessed August 6, 2023 https://icom.museum/en/resources/standards-guidelines/museum-definition/.

816 Vieregg, *Museumswissenschaften*, 20.



Figure 26. Van Gogh Sunflowers Live*, Atavist, archived May 22, 2019, at https://web.archive.org/web/20190522023814/https://nationalgallery.atavist.com/vangoghsunflowers*

Exploring new ways of presenting art through institutional collaborations reveals promising opportunities for cultural heritage initiatives. A noteworthy example is *Van Gogh Sunflowers Live* from 2017, in which five museums collaborated to virtually bring together five versions of Vincent van Gogh's sunflower paintings in a groundbreaking digital effort (fig. 26).[817] This decentralized project underscored the importance of ensuring public accessibility at a specific virtual location. The hashtag #SunflowersLive directed users to information about the project across social media and other digital platforms, while a joint website served as the project's central access point. The website had information about the participating institutions, announced the Facebook live broadcast, and provided details about Van Gogh's historical context, in addition to reproductions of the sunflower paintings.

However, the limited lifespan of project-specific websites is a common criticism of such initiatives. Often, these sites are not maintained long-term,

817 *Van Gogh Sunflowers Live,* Atavist, archived May 22, 2019, at https://web.archive.org/web/20190522023814/https://nationalgallery.atavist.com/vangoghsunflowers. This was the joint project website.

leading to the eventual disappearance of centralized content. Consequently, only scattered parts of the project are accessible, archived across various social media platforms. This draws attention to the challenge of selecting technologies that accommodate both reach and longevity.

On August 14, 2017, from 6:50 to 8:05 p.m. CET, the event broadcast five consecutive 15-minute live video streams on Facebook. The platform was selected due to its widespread user base among art enthusiasts and its built-in live-streaming technology, *Facebook Live*.[818] Representatives from each museum—the National Gallery in London, the Van Gogh Museum in Amsterdam, the Neue Pinakothek in Munich, the Philadelphia Museum of Art, and the Seiji Togo Memorial Sompo Japan Nipponkoa Museum of Art in Tokyo—stood in front of their respective sunflower painting to share stories about each work's history and content. This approach to storytelling emphasized the individuality of each painting and its unique narrative. The project's viral reach illustrated its success: by September 8, 2017, the Neue Pinakothek's video had about 750,000 views, while the Van Gogh Museum's video had about 2.7 million views.[819] Such impressive numbers point to the potential for digital museum initiatives to reach a global scale when thoughtfully conceived. The event brought to audiences an unprecedented cross-institutional "guided tour," a concept that would be impossible in a physical setting due to the value and condition of the delicate originals.

Ahead of the live event, the Van Gogh Museum uploaded the *Sunflowers Virtual 360° Gallery* to Facebook on August 10 as a complementary feature.[820] The video presented the five works in a simulated, three-dimensional space, with commentary from Willem van Gogh, the great-grandson of Vincent's brother Theo. While optimized for 3D glasses or mobile devices, the low resolution of the image material hindered examining the artwork's details. Nonetheless, the initiative demonstrated the value of experimenting with digital technologies.

The *Van Gogh Sunflowers Live* project succeeded in raising awareness about multiple versions of Vincent Van Gogh's sunflower paintings and their respective histories, aiding in comparisons that would otherwise be impossible. However, the transfer of the traditional guided tour format to the digital realm raised questions about user engagement. Interactivity could have been introduced by integrating the five presentation videos into the 3D

818 "Best Practices for Major Broadcasts on Facebook Live," Meta, accessed May 7, 2022, https://www.facebook.com/business/help/626637251511853.

819 "Top #sunflowerslive Videos," Facebook, accessed May 7, 2022, https://www.facebook.com/watch/search/?q=%23sunflowerslive.

820 *Sunflowers Virtual 360° Gallery*, Facebook, accessed May 7, 2022, https://de-de.facebook.com/VanGoghMuseum/videos/sunflowers-virtual-360-gallery/10159187334010597/.

simulation. Still, the initiative effectively engaged audiences on social media, showcasing digital platform's capacity to foster art education and increase access to cultural heritage.

Van Gogh Sunflowers Live and other previous examples confirm that: the digital representation of artworks is most compelling when it transcends the mere simulation of real-world-exhibition spaces or architectural environments. Digital technology offers opportunities to reimagine the organization of time and space, providing conditions distinct from those of physical galleries. These differences call for specialized strategies to curating art in the virtual realm, with an emphasis on how audiences view and interact with artworks in digital settings.

4.4 Users of Digital Contents

The role of museum visitors changes in the context of viewing art via digital collections and applications. As art becomes more digitally accessible, visitors transform into users, engaging intentionally with art through applications and immersive virtual environments. This shift redefines art perception, moving from passive observation to active interaction. Art history has long examined the relationship between viewers and artworks,[821] while museology considers the visitor as a research subject.[822] Meanwhile, the term "user," originating in computer science, refers to individuals who

821 Hans Belting, *Bild-Anthropologie: Entwürfe für eine Bildwissenschaft*, 4th ed. (Wilhelm Fink, 2011), 13–14 and 20; Lars Blunck, ed., *Werke im Wandel? Zeitgenössische Kunst zwischen Werk und Wirkung* (S. Schreiber, 2005), 8–10; Gottfried Boehm, "Hat das Sehen eine Geschichte?" in *Werk und Diskurs: Karlheinz Stierle zum 60. Geburtstag*, ed. Dieter Ingenschay and Karlheinz Stierle (Wilhelm Fink, 1999); Wolfgang Kemp, ed., *Der Betrachter ist im Bild: Kunstwissenschaft und Rezeptionsästhetik* (Reimer, 1992); Paul J. Locher, "The Aesthetic Experience with Visual Art 'At First Glance'," in *Investigations into the Phenomenology and the Ontology of the Work of Art: What Are Artworks and How Do We Experience Them?*, ed. Peer F. Bundgaard and Frederik Stjernfelt (SpringerOpen, 2015), https://doi.org/10.1007/978-3-319-14090-2_5.

822 Sigrid Bekmeier-Feuerhahn et al., eds., *Zukunft Publikum: Jahrbuch für Kulturmanagement 2012* (transcript, 2012); Jennifer Eickelmann, "Wenn Kunst zum Ereignis wird: Eine Kritik der ästhetischen Praxis erlebnisorientierter Museen," in *Ästhetische Praxis*, ed. Michael Kauppert and Heidrun Eberl (Springer VS, 2016); Hornig, *Kunst im Museum*; Nina Simon, *The Participatory Museum* (Museum 2.0, 2010).

use software.[823] These categories—viewer, visitor, and user—overlap but each corresponds to distinct contexts and characteristics of art perception. Digital collections alter the dynamic between viewer, artwork, and information. In a physical exhibition, a visitor becomes a viewer when engaging with an artwork. In a digital context, however, an individual is simultaneously a visitor to a website, a viewer of an artwork, and a user navigating a system. These roles often merge, necessitating clarity about which interaction or relationship is being analyzed. Perception, as a philosophical concept, takes on different meanings depending on whether it pertains to engagement in physical or digital environments.

In digital spaces, computer technology establishes new relationships between individuals, objects, and information, reshaping traditional access points to the world.[824] This creates new modes of perception blending physical and virtual realities.[825] These fluid transitions between analog and digital experiences often go unnoticed, but fundamentally impact art and culture.[826]

A viewer's perception of art depends on their actions and the environment—physical or virtual space. The relationship between viewer and artwork not only changes between an analog and digital environment, but is already variable within traditional art viewing, evolving significantly with conceptual art. While the artist defines certain parameters, an artwork's meaning remains open and is completed through the viewer's participation—transforming them into an active participant.[827] Similarly, digital collections and applications are designed with parameters that invite users to investigate multilayered contexts, making participation an integral part of the experience. Although viewing art in museums and engaging with digital

823 Michael Bender, *Forschungsumgebungen in den Digital Humanities: Nutzerbedarf, Wissenstransfer, Textualität* (De Gruyter, 2016), 127–133; Butz and Krüger, *Mensch-Maschine-Interaktion*, 7–8, 51–53; Giuseppe Conti et al., "User Centered Technologies, Serious Games and Learning: A Critical, Speculative Perspective," in *Handbook of Research on Technologies and Cultural Heritage: Applications and Environments*, ed. Georgios Styliaras et al. (Information Science Reference, 2011), 412–414, https://doi.org/10.4018/978-1-60960-044-0.ch020; Christian Moser, *User Experience Design: Mit erlebniszentrierter Softwareentwicklung zu Produkten, die begeistern* (Springer, 2012), https://doi.org/10.1007/978-3-642-13363-3; Wibke Weber and Alexandra Wenzel, "Interaktive Infografiken: Standortbestimmung und Definition," in *Interaktive Infografiken*, ed. Wibke Weber et al. (Springer Vieweg, 2013), 8–14, https://doi.org/10.1007/978-3-642-15453-9_1.

824 Gertraud Koch, "Einleitung: Digitalisierung als Herausforderung der empirischen Kulturanalyse," in *Digitalisierung: Theorien und Konzepte für die empirische Kulturforschung*, ed. Gertraud Koch (Herbert von Halem Verlag, 2017), 14.

825 Koch, "Einleitung," 14.

826 Koch, "Einleitung," 14.

827 Hélio Oiticica, "Position and Program," in *Conceptual Art: A Critical Anthology*, ed. Alexander Alberro and Blake Stimson (MIT Press, 2000), 5.

representations share commonalities, each originates from different environments with unique demands.

The integration of digital media into physical exhibitions further blurs the boundaries between analog and virtual experiences. Digital tools enhance exhibitions by guiding visitors and enriching their visit. However, engaging diverse audiences in the digital realm requires distinct approaches compared to physical museum visits. Institutions must address how interaction, learning, participation, and mediation function with digital representations of art. Virtual reality, immersion, emotions, user experience design, usability, visitor research, gamification, HCI, and personalization are all subject to this.

Digital collections provide an opportunity for the public to immerse themselves in museum content online, making collections more visible and welcoming, which enables user participation. For example, London's National Portrait Gallery includes a "tell us more" form in its digital collection, inviting users to share their knowledge.[828] This simple participatory option strengthens the relationship between an institution and its audience, valuing users' contributions.

Other institutions empower users to personalize their experiences. The Rijksmuseum *Visitor's Routes*[829] feature lets users create custom tours based on their interests, which can be shared and accessed via an app during museum visits. Similarly, the Art Institute of Chicago's *JourneyMaker*[830] app allows families to design thematic tours from the collection and download personalized booklets with quizzes to enhance their museum experience. These examples bridge digital and physical engagement, offering intuitive, user-friendly tools that require no advanced technical skills.

Model applications extend the value of digital collections beyond information storage to provide innovative services. However, their design and purpose must align with their target audience. As has been discussed, scholars and professionals often have different needs from the general public, requiring institutions to be mindful of their audience when developing digital tools. Ideally, applications meet the needs of both groups, though targeted solutions may be necessary in some cases.

828 *Explore Our Collection*, National Portrait Gallery, accessed December 14, 2021, https://www.npg.org.uk/collections/search/portrait/mw05203/.

829 *Visitor's Routes*, Rijksmuseum, accessed December 14, 2021 https://www.rijksmuseum.nl/en/tours.

830 *JourneyMaker*, Art Institute of Chicago, accessed December 27, 2024, http://journeymaker.artic.edu.

4.5 Digital Narratives

The availability of images and metadata from digital collections has transformed how narratives are created and knowledge disseminated. It is vital to examine how data and art perception can be organized in a digital environment to aid in knowledge generation. Digital visualization and mediation involve establishing connections between artworks or supplementing them with additional information such as archival documents. Through the Semantic Web, vast data collections from various sources can be integrated and visualized using web technologies, including HTML5 and JavaScript libraries (like *D3.js*, *p5.js*, or *WebGL*). These technologies enable fruitful data connections and dynamic, adaptable layouts.

Storytelling plays a central role in creating content-related connections, allowing knowledge to be communicated. In the context of digital representations based on data, interactive storytelling is particularly valuable. Narratives are foundational across disciplines: art history and visual studies examine narratives of and within images;[831] museology focuses on exhibition narratives;[832] design theory explores visual communication as a medium for conveying information;[833] and media and communication studies address

831 Silke Betscher, "Bildsprache: Möglichkeiten und Grenzen einer Visuellen Diskursanalyse," in *Bilder in historischen Diskursen*, ed. Franz X. Eder et al. (Springer VS, 2014), https://doi.org/10.1007/978-3-658-05398-7_3; Matthias Bruhn, *Das Bild: Theorie, Geschichte, Praxis* (Akademie Verlag, 2009); Kathrin Popp, *Das Bild zum Sprechen bringen: Eine Soziologie des Audioguides in Kunstausstellungen* (transcript, 2013).

832 Felix Ackermann et al., eds., *Partizipative Erinnerungsräume: Dialogische Wissensbildung in Museen und Ausstellungen* (transcript, 2013), 9–18; Eickelmann, "Wenn Kunst zum Ereignis wird"; Gregor H. Lersch, "Museum und Ausstellung: Partizipative Erinnerungsräume?" in *Partizipative Erinnerungsräume: Dialogische Wissensbildung in Museen und Ausstellungen*, ed. Felix Ackermann et al. (transcript, 2013); Charlotte Martinz-Turek and Monika Sommer-Sieghart, eds., *Storyline: Narrationen im Museum* (Turia & Kant, 2009), 7–8; Monika Sommer-Sieghart, "(Kultur-)historische Museen als gegenwartsrelevante Diskursräume," in *Storyline: Narrationen im Museum*, ed. Charlotte Martinz-Turek and Monika Sommer-Sieghart (Turia & Kant, 2009), 74–77.

833 Anne Burdick et al., *Digital Humanities* (MIT Press, 2012), 11–15; Wibke Weber et al., eds., *Interaktive Infografiken* (Springer Vieweg, 2013), https://doi.org/10.1007/978-3-642-15453-9; Julie Steele and Noah Iliinsky, eds., *Beautiful Visualization: Looking at Data Through the Eyes of Experts* (O'Reilly, 2010); Angela M. Zoss, "Designing Public Visualizations of Library Data," in *Data Visualization: A Guide to Visual Storytelling for Libraries*, ed. Lauren Magnuson (Rowman & Littlefield, 2016).

storytelling's social impact, particularly in mass media.[834] Furthermore, the ability to reach audiences depends on educational philosophies and learning styles.[835] Together, these theoretical frameworks guide the creation of digital narratives that utilize images and metadata from collections to support learning and knowledge acquisition.

Interactive systems like chatbots are a novel way to deliver information.[836] Chatbots such as *Europeana*'s *Culturebot*[837] or Fondation Cartier's *bot*[838] integrate user interaction into a conversational narrative. By using artificial intelligence to semantically parse user input, these systems provide accurate responses based on the digital collection's metadata. Chatbot interactions can take multiple forms.[839] *Message Máximo*,[840] the Field Museum of Natural History in Chicago's chatbot—who also happens to be a titanosaur in the collection—engages users in an entertaining and educational dialogue.

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834 Stefan Göbel et al., eds., *Technologies for Interactive Digital Storytelling and Entertainment: Third International Conference, TIDSE 2006, Darmstadt, Germany, December 4–6, 2006: Proceedings* (Springer, 2006); Frank Hartmann, *Medienphilosophie* (WUV-Universitätsverlag, 2000); Niklas Luhmann, *Die Realität der Massenmedien*, 5th ed. (Springer VS, 2017); Carolyn Handler Miller, *Digital Storytelling: A Creator's Guide to Interactive Entertainment*, 4th ed. (CRC Press, 2020), https://doi.org/10.1201/9780429440045; Christina Schachtner, *Das narrative Subjekt: Erzählen im Zeitalter des Internets* (transcript, 2016).

835 Georgina Barton, ed., *Literacy in the Arts: Retheorising Learning and Teaching* (Springer, 2014), https://doi.org/10.1007/978-3-319-04846-8; Anna Boroffka, "Kulturelle Bildung und besucherorientierte Vermittlung: Theoretische Diskursfelder und die Praxis in Museen und Ausstellungen," in *Partizipative Erinnerungsräume: Dialogische Wissensbildung in Museen und Ausstellungen*, ed. Felix Ackermann et al. (transcript, 2013); Peter Faulstich, *Menschliches Lernen: Eine kritisch-pragmatistische Lerntheorie* (transcript, 2013); Norbert M. Seel and Dirk Ifenthaler, *Online lernen und lehren* (Reinhardt, 2009); Richard Stang, "Multifunktionalität als Option: Gestaltung von Lern- und Informationsräumen," in *Formierungen von Wissensräumen: Optionen des Zugangs zu Information und Bildung*, ed. Olaf Eigenbrodt and Richard Stang (De Gruyter Saur, 2014).

836 Savvas Varitimiadis et al., "Graph-Based Conversational AI: Towards a Distributed and Collaborative Multi-Chatbot Approach for Museums," *Applied Sciences* 11, no. 19 (2021): 9160, https://doi.org/10.3390/app11199160. The authors provide an overview of museum chatbots and the underlying technologies.

837 *Culturebot*, Europeana, accessed May 6, 2022, https://culturebot.eu.

838 *bot*, Fondation Cartier, accessed May 6, 2022, https://www.fondationcartier.com. The bot can be started via the blue rectangle that looks like an abstract face.

839 Varitimiadis et al., "Graph-Based Conversational AI," 10. Varitimiadis et al. distinguish five types of museum chatbots: simple QA informational chatbots (infobots), chatbots with predefined routes of conversation, gamification and reward chatbots, provoking conversational chatbots, and fully human-like conversational chatbots.

840 *Message Máximo*, Field Museum of Natural History in Chicago, accessed May 6, 2022, https://www.fieldmuseum.org/exhibitions/maximo-titanosaur. The bot can be started by clicking on the blue circle button with the dinosaur head.

Similarly, art museum chatbots could impersonate artists or historical figures to answer questions about their artwork and contexts.

Kunsthalle Karlsruhe's *Art of Chit-Chatting*[841] bot complements engagement by providing information about artworks and prompting users to respond via predefined options. While this approach ensures successful communication, it also limits the conversation's scope. Designing chatbots that can sustain coherent and engaging dialog remains a major technical challenge.[842] Nonetheless, these systems offer an accessible, low barrier entry point for digital collection, sparking user interest and providing links to information with minimal effort.

Museums and Archives in Creating Cultural Memory

Artworks and objects derive their relevance from their association with archives and memory. Museums are integral repositories where cultural memory accumulates through objects.[843] By fostering connections between cultural artifacts, museums enable the formation of memory.[844] Museums, as places that house unique objects, serve as anchors of cultural memory in a rapidly changing global society.[845] They position art in a legitimate framework of existence, often decontextualizing, actualizing, and recontextualizing it.[846] Similarly, digital archives and collections are repositories for cultural content.

The value of a digital collection parallels that of a physical archive, in that both preserve information critical to cultural memory. However, instead of archiving physical objects, digital archives store data deemed important enough for inclusion. Digital cultural memory is inherently limited by the scope of the database, often reflecting the institution's priorities. Museums typically present less information online than they hold internally, as not all records are digitized or intended for public access. This limitation is intentional, as organizing and curating ensure meaning within the overwhelming volume of available data.

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841 *Art of Chit-Chatting*, Kunsthalle Karlsruhe, accessed May 31, 2022, https://www.moodfor.art/chit-chatting.

842 Varitimiadis et al., "Graph-Based Conversational AI," 1–2.

843 Bernhard Serexhe, "Neue Medien – kurzes Gedächtnis? Anmerkungen zum Systemwechsel des kulturellen Gedächtnisses," in *Neues Erbe: Aspekte, Perspektiven und Konsequenzen der digitalen Überlieferung*, ed. Robertson-von Trotha, Caroline Y. and Robert Hauser (KIT Scientific Publishing, 2011), 75.

844 Serexhe, "Neue Medien – kurzes Gedächtnis?" 75.

845 Härle, "Heterotopie des Museums," 37.

846 Härle, "Heterotopie des Museums," 37.

Curating an exhibition involves selecting artworks to highlight an aspect of general or art history and framing them within a coherent thematic framework. Likewise, digital archives and collections require careful selection to make their content meaningful. Digitization alone does not suffice; the data must be thoughtfully organized and supplemented to foster cultural memory. Digital collections can also benefit from linking datasets across institutions, much like physical exhibitions are enhanced by loans from other collections.

Reinterpretation and reevaluation are ongoing processes in museums and archives, as cultural memory is continuously reshaped to reflect present-day perspectives.[847] The digital age and information accessibility do not guarantee knowledge acquisition,[848] but they do offer new opportunities to create cultural memory through inventive methods and alternative interpretations of artifacts. Linking digital collections with external datasets makes possible the formation of even more connections and associations, enriching cultural memory in ways similar to physical exhibitions.

Narratives Through Images in the Context of other Images

The tradition of comparison in art history lies in deriving narrative threads from artworks and relating them to one another. This raises the question: How can the comparison of images be adapted in digital environments to produce narratives? Artworks in digital collections forge new pathways for humanities research. By utilizing database APIs, researchers can combine data from multiple sources, gaining fresh insights through tailored applications like visualizations. Unlike the direct comparison of two artworks—a method popularized by Heinrich Wölfflin and dominant in art history for decades—digital technology enables simultaneous analysis of large groupings of artworks and metadata.[849] Computer vision can automatically identify similarities and differences across large datasets. This approach redefines how researchers can evaluate visual sources, particularly within digital collections from museums and cultural institutions. It is, therefore, indispensable to examine how images create narratives and generate meaning.

Narratives emerge not only from what is depicted but also from the contexts in which images are related to one another. Felix Thürlemann

847 Serexhe, "Neue Medien – kurzes Gedächtnis?" 75–76.

848 Serexhe, "Neue Medien – kurzes Gedächtnis?" 77.

849 Lev Manovich, "Museum Without Walls, Art History Without Names: Methods and Concepts for Media Visualization," in *The Oxford Handbook of Sound and Image in Digital Media*, ed. Carol Vernallis et al. (Oxford University Press, 2013), 274, https://doi.org/10.1093/oxfordhb/9780199757640.013.005.

introduced the term "hyperimage" to describe constellations in which artworks appear, such as exhibitions, private collections, or artists' studios.[850] A hyperimage represents an intentional combination of image objects curated by collectors, art historians, or artists, creating meaning that extends beyond individual images and is temporary.[851] This idea prioritized contextual meaning over focusing solely on inherent qualities of artworks. Analog photography, as a precursor to digital collections, enabled flexible contextualization of artworks irrespective of their physical location.

In the early 20th century, photographs offered art historians new ways to organize and analyze artworks. German art historian Aby Warburg, for instance, arranged his photo library by geographic location and medium while also grouping them thematically.[852] With his tableaux, Warburg had other ways to combine and rearrange images according to other classifications.[853] The choice of which images to combine depends on research questions and interests. Archival structures should thus incorporate multiple pathways for exploration, a potential greatly enhanced by the Semantic Web, the technology that facilitates modeling complex connections between digital objects, catering to the multiplicity of research needs.

Narratives through Storytelling

Databases that allow multi-perspective linking of data support the creation of complex narratives. Recording vast amounts of data, tracking actions done with the data, and interlinking information has fundamentally transformed art historical research. In architectural history, for example, data-driven simulations are replacing causality-driven teleological narratives.[854] Instead of constructing a single, overarching narrative, researchers explore nuanced perspectives, representing intricate networks and multiple stories.[855] However, due to the overwhelming number of potential connections within a database, researchers often select and organize content into linear narratives for clarity. These narratives are presented through text, images, audiovisual media, or combinations thereof.

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850 Felix Thürlemann, *Mehr als ein Bild: Für eine Kunstgeschichte des hyperimage* (Wilhelm Fink, 2013).

851 Thürlemann, *Mehr als ein Bild*, 7.

852 Philippe Despoix, "*Translatio* and Remediation: Aby Warburg, Image Migration and Photographic Reproduction," *SubStance* 44, no. 2 (2015), https://doi.org/10.3368/ss.44.2.129.

853 Elli Doulkaridou, "Reframing Art History," *International Journal for Digital Art History*, no. 1 (2015): 71, https://doi.org/10.11588/dah.2015.1.21638.

854 Mario Carpo, "Big Data and the End of History," *International Journal for Digital Art History*, no. 3 (2018): 31–32, https://doi.org/10.11588/dah.2018.3.49913.

855 Carpo, "Big Data," 32.

Storytelling techniques are increasingly used to make challenging information intelligible and entertaining. Journalists, for instance, use storytelling to integrate complex information into a narrative in an attractive manner for the readers, listeners, viewers and users.[856] Storytelling is characterized by figurative language, vivid details, and scene description to emotionally and intellectually relate with audiences.[857] The story offers also background and context, which allows the audience to connect to a topic.[858] Especially for online media, it is crucial to attract a user's interest immediately, and storytelling ensures that the message is received straightaway.[859] Museums adopt similar methods to craft narratives, bringing attention to themes and interpretations within their collections.

Art exhibitions create stories by combining artifacts, exhibition design, lighting, sound, electronic media, and texts.[860] Authentic objects serve as focal points for these narratives, with their meaning shaped by both their exhibition context and their relationship to other objects.[861] Curators welcome visitors to engage with interpretative narratives, providing contemporary perspectives and challenging definitive historical constructions.[862] Temporary exhibitions encourage an open view of history, with digital applications providing complementary or entirely different narratives.

Interactive digital storytelling provides tools to manage parallel narrative threads.[863] In video games, for example, users shape the narrative through their decisions, blending storytelling with interactivity.[864] There are, of course, difficulties in reconciling a strong story against the user's autonomous narrative influence.[865] Due to this complexity, museum applications often adopt linear structures to guide users while incorporating limited interactivity. This promises accessibility and user orientation, as seen in the Städel Museum's 2015 Digitorial *Monet and the Birth of Impressionism*,[866] which

856 Marie Lampert and Rolf Wespe, *Storytelling für Journalisten*, 2nd ed. (UVK, 2012), 11.

857 Lampert and Wespe, *Storytelling für Journalisten*, 13–34, 41.

858 Lampert and Wespe, *Storytelling für Journalisten*, 43.

859 Lampert and Wespe, *Storytelling für Journalisten*, 187.

860 Martinz-Turek and Sommer-Sieghart, *Storyline*, 7.

861 Martinz-Turek and Sommer-Sieghart, *Storyline*, 7.

862 Martinz-Turek and Sommer-Sieghart, *Storyline*, 7–8.

863 Göbel et al., *Interactive Digital Storytelling*.

864 Mark O. Riedl and Andrew Stern, "Believable Agents and Intelligent Story Adaptation for Interactive Storytelling," in *Technologies for Interactive Digital Storytelling and Entertainment: Third International Conference, TIDSE 2006, Darmstadt, Germany, December 4–6, 2006: Proceedings*, ed. Stefan Göbel et al. (Springer, 2006), 2.

865 Riedl and Stern, "Believable Agents," 11.

866 *Monet and the Birth of Impressionism*, Städel Museum, launched in 2015, accessed December 27, 2024, https://monet.staedelmuseum.de/en.

attracted 200,000 digital visitors alongside 430,000 exhibition visitors. The Digitorial won the Grimme Online Award that year.[867] This example underscores the potential of digital formats to appeal to a wide range of audiences.

Table 17. *Select Digitorials and other visual storytelling initiatives*

Institution	Type	URL	Title	Published
Art Institute of Chicago	Interactive Features	https://www.artic.edu/interactive-features	Interactive Features (Overview)	since 2020
digitorials.ch	digitorials.ch	https://www.digitorials.ch/#projekt	Projekt (Overview)	since 2019
Gemäldegalerie Alte Meister	Weborello	https://vermeer.skd.museum/en/	Vermeer. On Reflection	08/24/2021
Getty Museum	Digital Experience	https://mesopotamia.getty.edu/	Mesopotamia	12/07/2021
Google Arts & Culture	Stories	https://artsandculture.google.com/search/exhibit?q=story	Stories (Overview)	since 2021
Liebighaus	Digitorial®	https://www.liebieghaus.de/en/digitaloffers	Digitorial® (Overview)	since 2016
LWL-Museum für Kunst und Kultur	Digitorial®	https://www.lwl-museum-kunst-kultur.de/de/digitales/digitorials/	Digitorials® (Overview)	since 2019
MoMA	Interactive Feature	https://www.moma.org/interactives/moma_through_time/	MoMA Through Time	06/17/2019
Rijksmuseum	Stories	https://www.rijksmuseum.nl/en/stories	Stories (Overview)	since 2020
Schirn Kunsthalle	Digitorial®	https://www.schirn.de/en/program/offerings/digitorial/	All Digitorials® in an Overview (Overview)	since 2014
Städel Museum	Digitorial®	https://www.staedelmuseum.de/en/digitorial	Digitorials® (Overview)	since 2015
The Met	Primer	https://www.metmuseum.org/primer	Meet the Primers Overview)	since 2019
Van Gogh Museum	Stories	https://www.vangoghmuseum.nl/en/art-and-stories/stories/stories-overview	Stories Overview (Overview)	since 2014

867 Chantal Eschenfelder, "Die digitale Strategie des Städel Museums: Konzepte, Praxisbeispiele, Erfahrungen," in *Der digitale Kulturbetrieb: Strategien, Handlungsfelder und Best Practices des Digitalen Kulturmanagements*, ed. Lorenz Pöllmann and Clara Herrmann (Springer, 2019), 328, https://doi.org/10.1007/978-3-658-24030-1_15. See "Digitorial," Städel Museum, accessed May 8, 2022, https://www.staedelmuseum.de/de/angebote/digitorial.

Städel Museum creates Digitorials—classified as a visual form of storytelling—for major temporary exhibitions, allowing users to explore key themes before their visit.[868] Multimedia content is embedded in a dynamic layout, enabling users to learn at different levels.[869] Many museums have adopted this format to varying degrees, such as the digitorials.ch project,[870] which involved Swiss museums such as the Kunsthaus Zürich, Kunstmuseum Basel, Kunstmuseum Bern, Kunstmuseum Luzern, Migros Museum für Gegenwartskunst in Zurich, and Zentrum Paul Klee in Bern. Others call this format "Stories" (*Google Arts & Culture*, Rijksmuseum, and the Van Gogh Museum Amsterdam); "Interactive Feature" (the Art Institute of Chicago, MoMA, and SFMOMA); or "Weborello" (Gemäldegalerie Alte Meister, Dresden). Among the "Digitorials," LWL-Museum für Kunst und Kultur in Münster has also launched a "Kidditorial" dedicated to children. Links to various Digitorials are compiled in table 17. Vertical scrolling, complemented by horizontal interactions, creates a dynamic yet structured user experience. While navigation is linear, interactive elements encourage users to delve deeper into specific topics, making the content interesting for diverse audiences.

This format effectively presents short text alongside visual and audio-visual content, leveraging current web technologies like HTML 5, JavaScript, CSS, and responsive design. At the Art Institute of Chicago and Rijksmuseum, interactive features for works in the collection emerged as a direct response to the COVID-19 pandemic lockdown, demonstrating that such interactive stories function independently of exhibitions, serving as standalone digital offerings for cultural engagement.

Digitorials, like those of Städel Museum, Schirn Kunsthalle, and Liebighaus in Frankfurt, the Swiss project digitorials.ch, but also the Stories of the Van Gogh Museum or the Rijksmuseum, are one way to convey a narrative through an application.[871] Even *Google Arts & Culture* adopts this

868 Eschenfelder, "Die digitale Strategie," 326.

869 Eschenfelder, "Die digitale Strategie," 326.

870 digitorials.ch, Maze Pictures Swiss, accessed December 27, 2024, https://digitorials.ch.

871 "Digitorials," Städel Museum, accessed December 27, 2024, https://www.staedelmuseum.de/de/angebote/digitorial; "Digitorials," Schirn Kunsthalle, accessed December 27, 2024, https://www.schirn.de/angebote/digitorial; "Digitorial," Liebighaus, accessed December 27, 2024, https://www.liebieghaus.de/de/angebote/digitorial. Swiss Digitorials project: "Digitorials," digitorials.ch, accessed December 27, 2024, https://www.digitorials.ch/#digitorials. Stories from Amsterdam museums: "Longreads," Van Gogh Museum, accessed December 27, 2024, https://www.vangoghmuseum.nl/en/art-and-stories/stories/stories-overview#longreads; "Stories," Rijksmuseum, accessed December 27, 2024, https://www.rijksmuseum.nl/en/stories. Frankfurt museums created several digitorials.

concept to present stories and online exhibitions.[872] The format also lends itself to timeline-based storytelling, as seen in *MoMA Through Time*,[873] which allows users to scroll through MoMA and MoMA PS1's history by viewing selected artworks and archival objects. Similarly, the National Gallery of Art in Washington, DC, narrates its institutional history through a timeline,[874] by emphasizing diverse visual material like photographs, newspaper articles, installation views, but also collection artworks. Advanced features like 3D scans, or a 3D architectural model, and dynamic perspectives—exemplified by the Getty Museum's *Mesopotamia*[875] and *Persepolis Reimagined*[876]—further enhance the user experience.

These interactive story applications deepen a selected topic and are typically launched to accompany an exhibition. This provides museum visitors or other interested parties with a preview of the topic. As stand-alone applications, they remain valuable beyond the life of an exhibition. Usually, such applications are websites featuring abundant visual materials and short texts. These sites usually scroll vertically and are divided into thematic sections. They often include images of artworks, historical photos, archival documents, quotes, videos, audio streams, slideshows, artist interviews, and interactive elements like hotspots, object verso views, or a 3D object scan. The scrolling motion is interspersed with interactive options—like additional artwork details, browsing an image gallery, or enlarging a letter. Despite the structured navigation, these applications appeal to a broad audience and are user-friendly.

Storytelling in this format mirrors the dynamic of a storyteller and an audience. An application prescribing a narrative path works in the same way, presenting the museum or institution as an authority that conveys knowledge to the user. While these applications do not allow users to intervene, alter, or adapt the narrative, they excel at delivering knowledge in a clear, informative, and visually appealing manner, optimized for the digital medium. Unlike digital collections, which present each object independently, these curated applications use visual and linguistic means to provide art historical contexts.

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872 "Stories," *Google Arts & Culture*, accessed December 27, 2024, https://artsandculture.google.com/search/exhibit?q=story.

873 *MoMA Through Time*, MoMA, accessed May 15, 2022, https://www.moma.org/interactives/moma_through_time/.

874 *Highlights of the History of the National Gallery of Art*, National Gallery of Art, accessed August 17, 2021, https://www.nga.gov/research/gallery-archives/nga-history-timeline.html.

875 *Mesopotamia*, Getty, accessed May 14, 2022, https://mesopotamia.getty.edu. See also: "A New Way to Experience Art Online," Getty, May 14, 2022, https://www.getty.edu/news/get-closer-to-ancient-mesopotamia-than-ever-before/.

876 *Persepolis Reimagined*, Getty, accessed May 14, 2022, https://persepolis.getty.edu.

The primary navigation mechanism in Digitorials is vertical scrolling, occasionally interrupted by horizontal scrolling. Users interact by scrolling and clicking on media content to access additional information.[877] Vertical scrolling has a masking effect, revealing content step-by-step. Horizontal scrolling, while potentially distracting, can also break monotony.[878] The linear structure ensures users follow a predefined path without freely selecting content order. However, users can choose to view additional details at specific points. The guided approach minimizes the risk of users feeling overwhelmed by options, maintaining orientation and focus.[879] Unlike books or videos, these applications integrate interactive elements, such as clicking images for supplementary information.

Thematic applications leveraging linked networks and data visualization offer more branching paths of interaction, albeit at the cost of some clarity. One example, *Connect Vermeer*, was created as part of a major research and exhibition project about Johannes Vermeer and his contemporaries.[880] The 2017 touring exhibition *Vermeer and the Masters of Genre Painting: Inspiration and Rivalry* was shown in Paris, Dublin, and Washington, DC.[881] The application was both an independent digital counterpart to the exhibition and a medium to delve into its themes more deeply.

877 Paula Klinke et al., *Tool Support for Collaborative Creation of Interactive Storytelling Media* (Universitätsverlag Potsdam, 2022), 14, https://doi.org/10.25932/publishup-51857.

878 Robert Spence, *Information Visualization: An Introduction*, 3rd ed. (Springer, 2014), 118–119.

879 Spence, *Information Visualization*, 194.

880 *Connect Vermeer*, National Gallery of Ireland, accessed May 15, 2022, https://connectvermeer.ie/#about. This is the project website.

881 The venues were: Musée du Louvre, Paris, February 20 to May 22, 2017; National Gallery of Ireland, Dublin, June 17 to September 17, 2017; and National Gallery of Art, Washington, DC, October 22, 2017 to January 21, 2018.

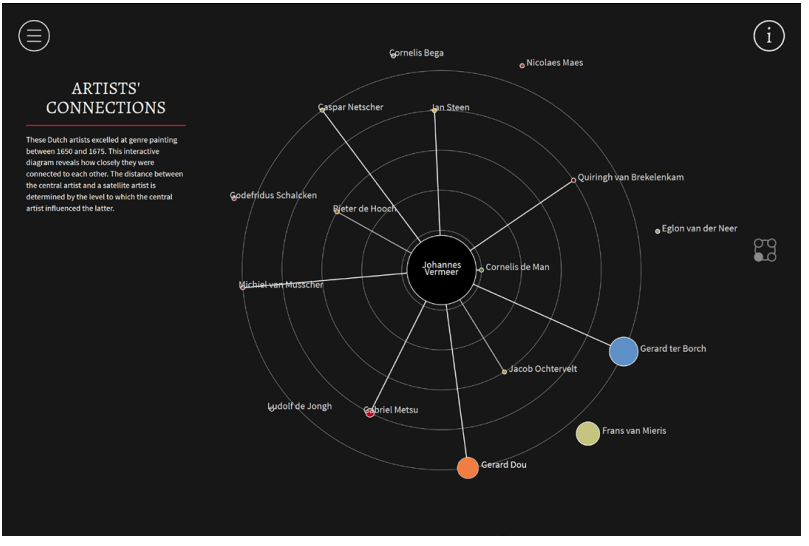


Figure 27. Connect Vermeer*, National Gallery of Ireland, Dublin, accessed May 15, 2022, https://connectvermeer.ie*

The application's interface visualizes connections between the painters using a dartboard-like diagram (fig. 27). Lines indicate whether an artist was inspired by the central figure, with proximity reflecting the strength of the connection. Node size (colored circles) represents the influence of a work on others. Clicking on an artist's name centers it, revealing connections from their perspective. This hyperbolic browser, an interactive radial tree diagram, allows navigation from any node's perspective.[882] Clicking an artist's name in the center opens their biography, while another click reveals their works in a grid layout. Additionally, users can view a timeline of the artist's creative phases, with bars indicating productivity. Every bar links to works, displaying basic details and relationships to other works—those inspiring and inspired by the selected piece. A comparative feature allows users to view and zoom in on two works side-by-side, facilitating stylistic analysis. Clicking the information icon provides additional contextual details, including the strength and similarity of relationships between works, explained through descriptive text.

This application demonstrates how stored data about artists and their works can generate meaningful relationships, offering information beyond individual collection objects. Users can explore intuitively without knowing

882 Spence, *Information Visualization*, 98.

their destination, aided by clear navigation and explanations accessible via the information icon. The project showcases collaboration among art historians, computer scientists, and research institutions, such as the Netherlands' RKD, ensuring technological sophistication (e.g., responsive design and linked data), and up-to-date practices. By integrating advanced technology and interdisciplinary expertise, *Connect Vermeer* is an exceptional example of how digital tools can enhance art historical research and engagement.

4.6 Conclusion

The usability of a system significantly impacts its acceptance by users. For digital collections and other interactive applications—often complex and multilayered—careful interface design is vital. Understanding the fundamental elements of user navigation and the technological possibilities is essential for developing a successful application. However, a compelling presentation of a digital collection requires far more than just allowing users to query the system through an interface. A meaningful digital representation of art demands the same meticulous consideration of content and context as a museum exhibition. Notable differences between the digital environment and the museum—such as spatial dynamics, the audience, and the relationship between objects—must be thoughtfully addressed.

In digital environments, space is redefined, and so is the experience of art. While a museum visitor physically moves through curated exhibitions, a digital user navigates art through virtual space, engaging in ways unique to the medium. This shift alters how users interact with and perceive art, leading to different interactions compared to physical spaces. Importantly, the focus extends beyond simple interaction with data to how cultural content and knowledge are communicated. Digital communication reaches audiences distinct from those already interested in museum activities, necessitating custom approaches to knowledge transfer.

To create richer representations of art in digital environments—outside of merely offering collections online—it is necessary to understand the best practices of effective communication, cultural mediation, and knowledge generation. Storytelling-based narrative approaches, such as those previously discussed, offer one method. Alternatively, data visualizations can be mobilized to reveal and communicate contextual relationships. To properly contextualize database records—whether images or metadata—using visualization, it is critical to know what types of visualizations are appropriate for specific data types.

The next chapter will explore visualizations in greater depth, examining their combination with graphic design principles. The discussion will demonstrate the complexity of content that visualizations are capable of communicating.

5 Methods of Data and Image Visualization

5.1 Introduction

Digital collections in museums and cultural institutions often comprise an overwhelming number of records that exceed the limits of human perception. Data visualization provides a means to present this information—whether digital images, metadata, or both—in a more comprehensible manner. This chapter explores the utility of data visualizations for accessing and analyzing digital collections, particularly for art historical research. By visualizing the visual and textual information related to artworks, these tools create alternate access points, assembling database content into meaningful constellations. Such approaches offer a broader understanding of the data surpassing what is possible with just simple keyword searches or browsing.

Examining how data translates into visual forms helps identify innovative ways to access and interpret digital collections. Different types of visualizations depend on the nature of the data being represented. By establishing a comprehensive overview of digital images and metadata, visualizations become a foundation for interpretation. These tools reveal information embedded in the data that remains inaccessible without appropriate visual representation.

Interactive visualizations, in particular, enhance understanding by making complex relationships perceptible, something static images cannot achieve. These tools enable users to freely explore artworks and their contexts in greater depth, shifting the focus from isolated artwork records to contextual interconnections. Consequently, data visualization in art historical research allows for meaningful analysis of extensive collections, giving scholars the opportunity to make informed statements based on data.

Several standard visualization formats, including diagrams, charts, timelines, and maps, are commonly used to represent data. This chapter outlines these forms and their application to different data types—images, text, temporal and geospatial data, and networks—to elucidate the principles of translating data into visual forms. While visualizing digital art collections might seem reductive, the process gains complexity when visualizations are interactive, generative, or interconnected. When integrated into application interfaces, visualizations allow users to customize and interact with the data dynamically. Examples include interactive maps, timelines, networks, and 3D reconstructions, often used in pioneering applications to visualize collection data.

Interactive visualizations offer distinct advantages by integrating multiple layers of information and accounting for more additional dimensions

within the data. For users, they serve as exploratory tools, adaptable to individual interests and preferences. Developing such applications requires careful consideration of their benefits, as well as limitations, for diverse audiences. This includes understanding when interactivity enhances digital collection representation and what design elements are essential for a range of user needs.

This discussion situates interactive visualizations within theories of visual communication and information design, emphasizing the principles of Mitchell Whitelaw's "generous interface."[883] Advanced applications make possible both exploratory and focused engagement with collections revealing relationships and structures that allow for multiple interpretations.[884] By optimizing large datasets into meaningful forms, patterns and connections become perceptible, paving the way for a more holistic grasp of collections.

For art historians, visualizations are valuable interpretive tools that complement qualitative methods with quantitative analysis. As visualizations structure data and make patterns visible, they provide insights that might otherwise go unnoticed. From a design perspective, visualizations function as interfaces and entry points for diverse audiences, presenting overviews of collections and their correlations. Previous research has examined data visualizations and advanced applications as a means of accessing digital collections, with a particular focus on archives and references to various examples.[885] Building on this foundation, this chapter shifts the focus to visualizations in the context of digital collections of art museums, exploring their design, data, and technical principles. Additionally, it considers the role of 3D visualizations as constructed representations based on data, examining concepts such as models, simulations, and reconstructions.

5.2 Visualization and Data Types

Visualizations are a favored approach to data because of the inherent properties of digital technology. The ability to manipulate, transfer, and transform data makes digital technology the defining visual medium of the 21st century.[886] If film was the medium of the 20th century, bound to linear narra-

883 Mitchell Whitelaw, "Generous Interfaces for Digital Cultural Collections," *Digital Humanities Quarterly* 9, no. 1 (2015): 3, accessed August 20, 2017, https://www.digitalhumanities.org/dhq/vol/9/1/000205/000205.html.

884 Whitelaw, "Generous Interfaces," 3.

885 Tobias Hodel et al., "Zugang zu Informationen in digitalen Sammlungen: Fokus Archive," *Informationswissenschaft: Theorie, Methode und Praxis* 7, no. 1 (2022): 27–91, https://doi.org/10.18755/iw.2022.5.

886 William Vaughan, "Preface," in *Revisualizing Visual Culture*, ed. Chris Bailey and Hazel Gardiner (Ashgate, 2010), xx.

tives, digital technology has amplified visual media's role in communication and storytelling.[887] The availability of large datasets through digitization has enabled computational methods for analyzing images and metadata, where quantitative techniques often complement qualitative examination. Statistics, diagrams, and interactive visualizations introduce new perspectives on data and connections between artworks, forming another basis for interpretation.

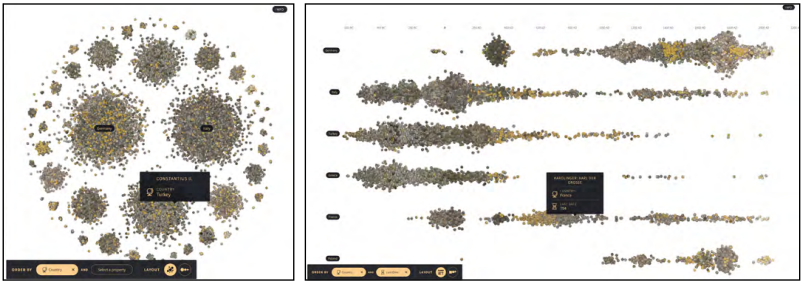


Figure 28. *Bubble diagram with coins arranged by country (*left*), scatter lines with coins arranged by country over time (*right*) at Coins:* A Journey Through a Rich Cultural Collection*, Urban Complexity Lab, University of Applied Sciences Potsdam, accessed May 17, 2022, https://uclab.fh-potsdam.de/coins/*

Different kinds of visualizations, such as graphs, timelines, or maps, focus on specific aspects of data. For example, the *Coins* application (fig. 28),[888] allows users to pair metadata (country, material, period, etc.) and switch between visualization types. Many applications visualizing digital collections utilize basic diagram types like those in figures 29–32. The choice of visualization depends on the data, which in the humanities often includes textual and categorical elements rather than purely numerical data. Timelines and maps are common, as they suit data like dates and geographic coordinates. Visualization design hinges on decisions about which data dimensions to include and how to present them, offering numerous possibilities for data analysis.

The digitization of texts and images has shifted scholarly work from studying and writing texts to analyzing cultural materials using computational methods.[889] Data visualization has become vital to the humanities and digital humanities, particularly as researchers gain control over selecting parameters and designing visualizations. Unlike static visualizations, interactive

887 Vaughan, "Preface," xx.

888 *Coins*, Urban Complexity Lab, University of Applied Sciences Potsdam, accessed May 17, 2022, https://uclab.fh-potsdam.de/coins/.

889 Suzanne Keene, "Imaging and Culture," in *Electronic Visualisation in Arts and Culture*, ed. Jonathan P. Bowen et al. (Springer, 2013), 7.

designs enable scholars to explore and interpret data dynamically. The foundations of data visualization lie in the analog domain, and many traditional types remain integral to digital data visualization practices.[890] This chapter examines differences between analog and digital implementations and sets the stage exploring notable digital collection visualization designs.

type	suitability	data
Bar Chart 	- comparison of values - read off numbers - explore patterns	- x-axis: discrete data (numerical) - y-axis: discrete data (categorical)
Histogram 	- frequency distribution - range of values - comparison of values - explore patterns	- x-axis: continuous data (numerical) - y-axis: discrete data (numerical)
Line Graph 	- connected data points - change over time - explore patterns	- x-axis: continuous data (numerical) - y-axis: discrete data (numerical)
Scatter Plot 	- display values from two variables - correlation of two variables - explore patterns - find clusters and outliers	- x-axis: discrete data (numerical) - y-axis: discrete data (numerical)

Figure 29. *Types of graphs and plots* Designed by Sonja Gasser, CC BY 4.0 (information source: Severino Ribecca, *The Data Visualisation Catalogue*, accessed May 3, 2021, https://datavizcatalogue.com)

Types of Visualizations

The most common types of visualization are graphs and plots (fig. 29), which display numerical data between two axes. Bar or column charts allow users to compare values and observe trends by representing data as bars whose lengths correspond to numerical values. Similar to column charts, histograms differ in that their bars represent continuous ranges of numerical data, making them ideal for illustrating frequency distributions. By connecting data points, line graphs reflect changes over time. Displaying pairs of

890 For an overview of the historical developments of statistical graphics and fundamental graphical designs, see Edward R. Tufte, *The Visual Display of Quantitative Information* (Graphics Press, 1983), 9–33.

numerical values as points, scatter plots reveal clusters, outliers, and correlations.[891] While most people are likely familiar with and can read graphs, there are other frequently used models that may be more challenging to comprehend.

type	suitability	data
Tree Diagram 	- hierarchical relationships	- hierarchical data (nodes and branches)
Tree Map 	- percentage of values	- hierarchical data
Network Diagram 	- relationships between entities	- relationships (nodes and edges)
Arc Diagram 	- relationship of two entities - explore patterns	- relationships (nodes on an axis and arcs)
Timeline 	- chronological order of events - distribution over time - explore patterns	- temporal data (dates and events)
Bubblelines 	- document/text comparison - distribution of terms	- one document per line - term frequency and position

Figure 30. *Types of diagrams* Designed by Sonja Gasser, CC BY 4.0 (information source: Severino Ribecca, *The Data Visualisation Catalogue*, accessed May 3, 2021, https://datavizcatalogue.com)

Diagrams are another kind of visualization, presented in figure 30, that illustrate relationships. Tree diagrams represent hierarchical structures, starting from a root node that branches into subordinate nodes. Tree maps visualize

891 Angela M. Zoss, "Designing Public Visualizations of Library Data," in *Data Visualization: A Guide to Visual Storytelling for Libraries*, ed. Lauren Magnuson (Rowman & Littlefield, 2016), 20–28.

hierarchical data as rectangles whose size reflect proportional values.[892] Spatially mapping nodes and connecting them with edges, network diagrams show relationships between entities.[893] Showing relationships through arcs connecting related values, arc diagrams arrange data along a line.[894] Useful for displaying chronological sequences, timelines mark events or time intervals.[895] Bubblelines visualize the frequency and distribution of terms in a document corpus, providing a comparative view.[896]

type	suitability	data
Pie Chart 	- comparison of values - percentage (part-to-whole) - proportions of categories	- discrete data (numerical) - discrete data (categorical)
Packed Circle Chart 	- proportions of categories	- variable (circle): discrete data (categorical) - variable (size): discrete data (numerical)
Word Cloud 	- relative word frequency - proportions	- text - variable (size): discrete data (numerical)

Figure 31. *Other visualization types* Designed by Sonja Gasser, CC BY 4.0 (information source: Severino Ribecca, *The Data Visualisation Catalogue*, accessed May 3, 2021, https://datavizcatalogue.com)

892 Johanna Drucker, "Graphical Approaches to the Digital Humanities," in *A New Companion to Digital Humanities*, ed. Susan Schreibman et al. (Wiley Blackwell, 2016), 239.

893 Snigdha Chaturvedi et al., "Group-in-a-Box Meta-Layouts for Topological Clusters and Attribute-Based Groups: Space-Efficient Visualizations of Network Communities and Their Ties," *Computer Graphics Forum* 33, no. 8 (2014): 52, https://doi.org/10.1111/cgf.12400.

894 Nan Cao and Weiwei Cui, *Introduction to Text Visualization* (Atlantis Press, 2016), 19–21.

895 Ben Shneiderman, "The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations," in *Proceedings 1996 IEEE Symposium on Visual Languages* (IEEE Comput. Soc. Press, 1996), 338, https://doi.org/10.1109/VL.1996.545307.

896 Stéfan Sinclair et al., "Information Visualization for Humanities Scholars," in *Literary Studies in the Digital Age: An Evolving Anthology*, ed. Kenneth M. Price and Ray Siemens (Modern Language Association, 2013), 5–6, https://doi.org/10.1632/lsda.2013.6.

The visualizations in figure 31 are best suited for percentage ratios. Pie charts divide a circle into segments, each representing a part of the whole based on categorical and numerical values. Packed circle charts compare categories proportionally by varying the sizes of circles according to a numerical value.[897] Word clouds represent the frequency of words in text, where font size correlates with word frequency.[898]

type	suitability	data
Map 	- explore spatial patterns - geographical distribution - localization	- spatial data (coordinates)
Choropleth Map 	- compare geographical areas - explore spatial patterns - localization	- location variable: geographical region - color variable: numerical or categorical
Symbol Map 	- proportions over regions - localization	- location variable: coordinates - size variable: numerical - color variable: numerical or categorical

Figure 32. *Types of maps* Designed by Sonja Gasser, CC BY 4.0 (information source: Severino Ribecca, *The Data Visualisation Catalogue*, accessed May 3, 2021, https://datavizcatalogue.com)

Used for geographic data visualization, maps (fig. 32) highlight spatial patterns through localization. Choropleth maps, for instance, fill regions with colors representing data values, while symbol maps use differently sized markers at specific locations to indicate numerical values.[899]

897 Zoss, "Designing Public Visualizations," 22–28.

898 Cao and Cui, *Introduction to Text Visualization*, 19.

899 Zoss, "Designing Public Visualizations," 29–33.

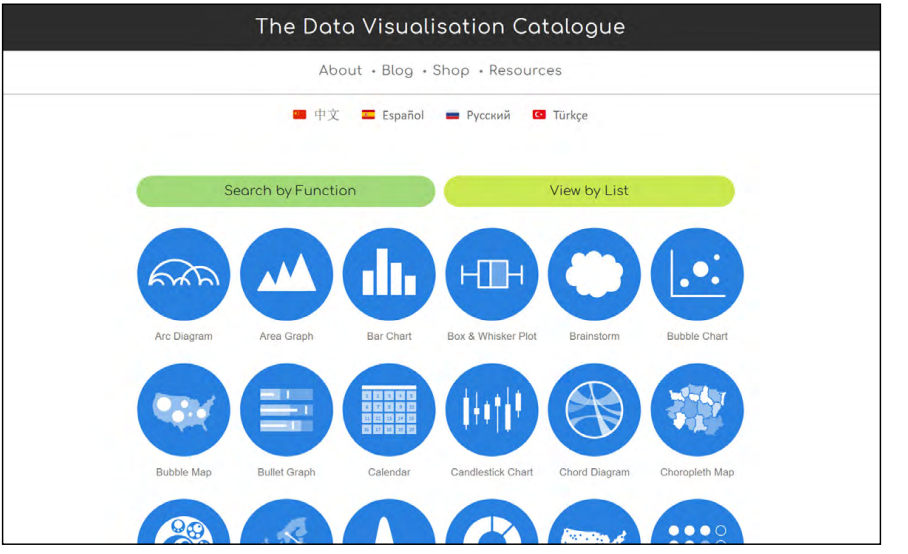


Figure 33. The Data Visualisation Catalogue *by Severino Ribecca, accessed May 18, 2022, https://datavizcatalogue.com*

While the above examples introduce foundational visualization types, modern tools and interactive platforms, such as the *Data Visualisation Catalogue* (fig. 33), provide comprehensive resources. These online catalogs offer exhaustive compilations, including descriptions, examples, variations, and code snippets.[900] Many also feature search and filter options to identify visualizations best suited to specific data types and functions.[901] Creating effective visualizations is a complex process, requiring thoughtful consideration of how to represent data, establish relationships, and guide users to accurate interpretations.

Conveying Content in Visualizations

To make visualizations readable, designers must carefully consider the use of color and text. Color often adds an additional layer of data in complex

900 See *Data Visualisation Catalogue*, accessed December 27, 2024, https://datavizcatalogue.com; Data Viz Project, accessed December 27, 2024, https://datavizproject.com; the R Graph Gallery, accessed December 27, 2024, https://www.r-graph-gallery.com; Chartopedia, accessed December 27, 2024, https://www.anychart.com/chartopedia/usage-type.

901 See the TimeViz Browser 2.0, Visual Analytics Group, University of Rostock, accessed December 27, 2024, https://browser.timeviz.net/; A Visual Bibliography of Tree Visualization, accessed December 27, 2024, https://treevis.net; Text Visualization Browser, ISOVIS group, accessed December 27, 2024, https://textvis.lnu.se.

visualizations, helping to differentiate categories or highlight trends. Text, in the form of annotations or labels, provides important context. Web-based visualizations enhance this functionality by incorporating interactive labels that appear when users hover over specific elements.[902]

Visualizations need not stand alone; they can be connected to convey richer narratives.[903] Linked visualizations work together to tell a more comprehensive story than any single chart could achieve. Data visualizations can thus function as storytelling tools, combining multiple visuals into cohesive narratives through sequences, slide shows, spatial arrangements, infographics, or online dashboards.[904] Presenting diverse perspectives on data reveals meanings that might otherwise remain obscured, particularly when designed to convey cultural knowledge with a targeted, audience-specific approach.

When creating narrative-driven visualizations, designers must reflect on the visualization type in relationship to the underlying data's structure.[905] Visualizations are excellent at illustrating trends in data, making them valuable for internal assessment and public outreach.[906] To maximize effectiveness, visualizations must be selected and customized for their intended audience and purpose.[907] Combining multiple visualizations provides the opportunity to create overarching narratives that appeal to a wider audience.[908]

The use of visualizations in cultural contexts differs from its application in scientific disciplines.[909] In the sciences, data is often numerical, and visualizations serve to make that information accessible and manipulable.[910] In the humanities, however, the data is frequently textual or graphic, and visualizations manipulate existing visual material to uncover patterns or observations not previously apparent.[911] While numerical visualizations relevance in the humanities, the most impactful formats often feature text and images, such as those found in digital collections.[912]

Data, whether drawn from images, metadata, or text-based documents

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902 Zoss, "Designing Public Visualizations," 38.

903 Hunter Whitney, *Data Insights: New Ways to Visualize and Make Sense of Data* (Morgan Kaufmann, 2013), 135.

904 Zoss, "Designing Public Visualizations," 38–39.

905 Zoss, "Designing Public Visualizations."

906 Zoss, "Designing Public Visualizations," 19.

907 Zoss, "Designing Public Visualizations," 19.

908 Zoss, "Designing Public Visualizations," 19.

909 Sinclair et al., "Information Visualization," 10.

910 Sinclair et al., "Information Visualization," 10.

911 Sinclair et al., "Information Visualization," 10.

912 Sinclair et al., "Information Visualization," 10.

follow common organizational principles. At a basic level, humanities data can be structured as variables, matrices, or tables and classified into categorical, numerical, and frequency metrics.[913] For example, images are matrices from a data perspective, enabling either visual display or pixel-level analysis. Artwork metadata is often organized in tabular form, with columns containing categorical and numerical metrics. Variables can be derived by measuring or counting features in image data and metadata, with the data type determining the range of possible analyses and visualizations.[914] Understanding these possibilities and limitations is essential for designing reliable representations of data from digital collections.

In digital humanities research, visualizations are powerful tools for accessing, analyzing, and interpreting data. Scholars Stéfan Sinclair et al. stress the importance of visualization systems that support interpretive activities, and ideally, such systems not only offer different ways to view data but also enable new ideas.[915] Interactive visualizations in particular outperform static formats by facilitating iterative exploration and revealing multiple perspectives.[916]

When humanities scholars create visualizations, they become producers of scholarly images—tools for analysis, presentation, and interpretation.[917] Museums can adopt similar approaches by using interactive visualizations to provide access to their digital collections. These visualizations, whether designed for scholarly inquiry or public engagement, enhance understanding and communication.

913 Forrest W. Young et al., *Visual Statistics: Seeing Data with Dynamic Interactive Graphics* (Wiley-Interscience, 2006), 32.

914 Young et al., *Visual Statistics*, 33.

915 Sinclair et al., "Information Visualization," 1.

916 Sinclair et al., "Information Visualization," 2.

917 Thorsten Stephan Beck, *Shaping Images: Scholarly Perspectives on Image Manipulation* (De Gruyter Saur, 2016), 1.

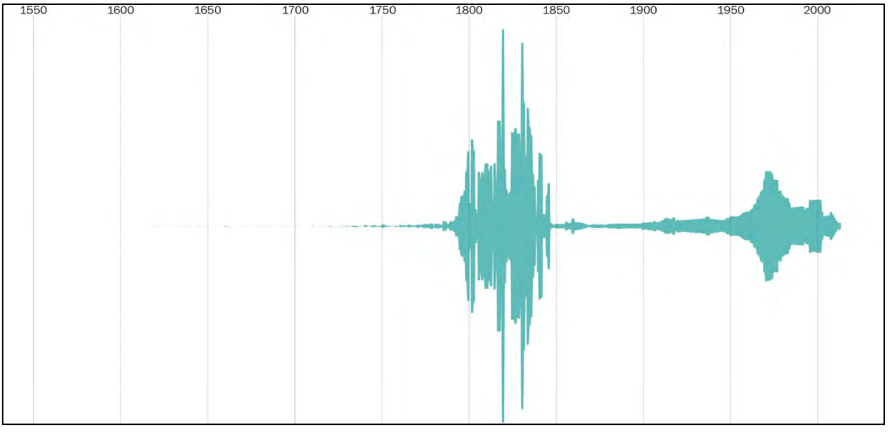


Figure 34. *Overview of the Tate collection at* Timeline Tools (TT) (reproduced by permission from: Kräutli, *Visualising Cultural Data*, 201, fig. 6.1)

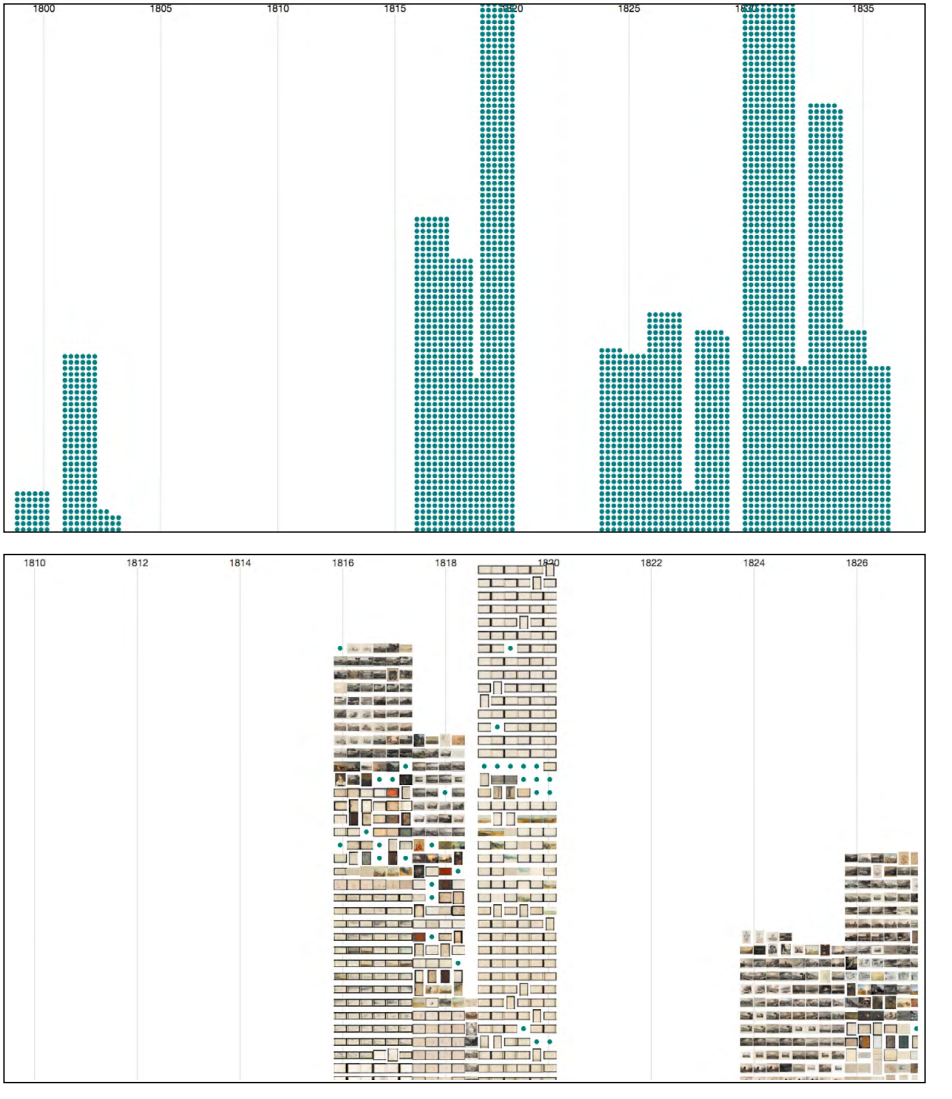


Figure 35. *Zoom view (*top*) and image view (*bottom*) of the Tate collection at* Timeline Tools (TT) (reproduced by permission from Kräutli, *Visualising Cultural Data*, 202, fig. 6.2)

Temporal Data in Timelines

Each type of visualization has unique complexities and variations, as demonstrated by monographs about individual visualization types. Scholars Florian Kräutli and Olivia Vane have explored the representation of cultural heritage collections in interactive timeline applications.[918] Both Kräutli and Vane have design backgrounds, but they position their work at the intersection of cultural heritage and the digital humanities, not just digital media design.

Kräutli's *Visualising Cultural Data* examines generative and interactive timelines for exploring digital collections.[919] With his prototypes, he aims to uncover knowledge from cultural datasets, analyzing curatorial decisions and institutional contexts through visualization tools.[920] *Timeline Tools (TT)* arranges data like that from the Tate collections on a timeline, drawing attention to trends and outliers (fig. 34).[921] Zooming into the visualization reveals detailed columns with preview images of artworks (fig. 35). For example, a dense cluster of artworks from between 1800 and 1850 highlights the William Turner sketchbooks in the Turner Bequest, as each page was cataloged individually.[922]

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918 Florian Kräutli, *Visualising Cultural Data: Exploring Digital Collections Through Timeline Visualisations* (Royal College of Art, 2016), accessed May 13, 2016, https://researchonline.rca.ac.uk/id/eprint/1774; Olivia Vane, *Timeline Design for Visualising Cultural Heritage Data* (Royal College of Art, 2019), accessed December 15, 2019, https://researchonline.rca.ac.uk/4325/1/TimelineDesignForVisualisingCulturalHeritageData_OliviaVane_redacted.pdf.

919 Kräutli, *Visualising Cultural Data*.

920 Projects, Florian Kräutli, accessed May 14, 2021, http://www.kraeutli.com/index.php/category/projects.

921 Kräutli's *Timeline Tools (TT)* visualization library is available here: "TT," GitHub, accessed December 27, 2024, https://github.com/fkraeutli/TT.

922 Kräutli, *Visualising Cultural Data*, 201–203.

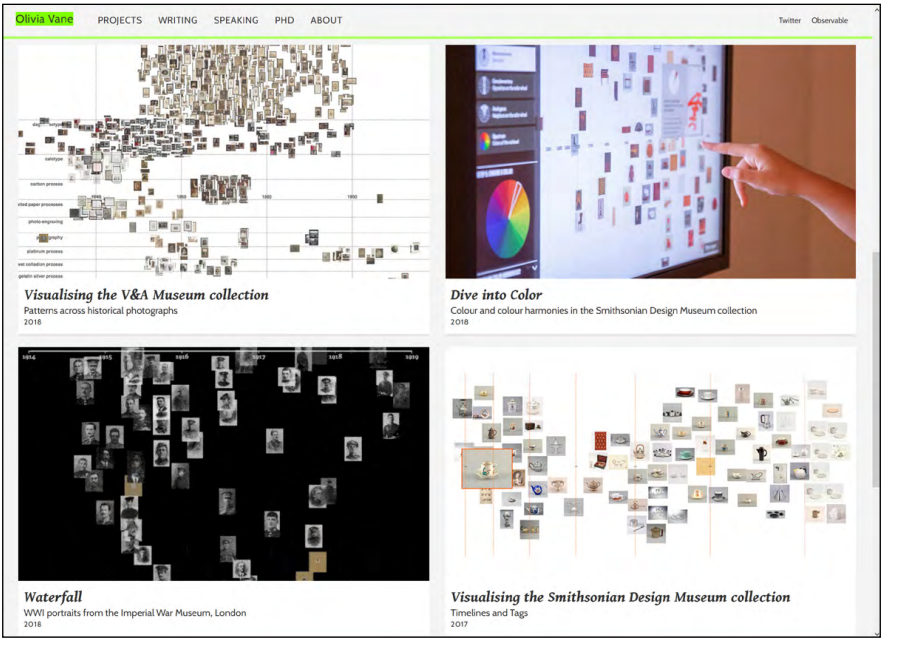


Figure 36. *Various interactive timeline visualization projects by Olivia Vane, accessed May 14, 2021, https://www.oliviavane.co.uk/projects*

By shifting focus from individual objects to datasets, timelines expose patterns, such as frequently occurring characteristics or aberrations. The capability allows for closer examination and interpretation of collection features. Similarly, Olivia Vane's book *Timeline Design for Visualising Cultural Heritage Data* investigates interactive timelines for digital collections,[923] developing prototypes that address overlapping images (fig. 36).[924] Using an image layout algorithm, Vane's timelines emphasize visual relationships rather than precise dates. One design example visualizes objects like coffee and tea sets tagged in metadata (fig. 36, *bottom right*),[925] while another organizes items based on color selection (fig. 36, *top right*).[926]

Interactive timelines are much better than static formats by offering dynamic exploration and greater contextualization. These projects highlight

923 Vane, *Timeline Design*.

924 Vane's, prototypes are well documented on her website: Olivia Vane, accessed May 14, 2021, https://www.oliviavane.co.uk/projects.

925 Vane, *Timeline Design*, 60–66.

926 Vane, *Timeline Design*, 88–96.

the challenges of visualizing data from digital art collections, requiring not only an understanding of the data but also thoughtful design to ensure clarity and usability.

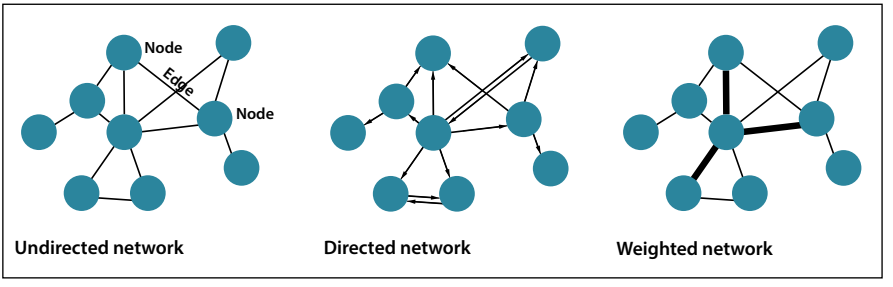


Figure 37. *Network graph types* Designed by Sonja Gasser, CC0 1.0

Relationships Between Data in Networks

Network graphs (figs. 37 and 38) represent a fundamentally different approach to visualization, relying on graph theory and visualization algorithms.[927] In these graphs, nodes represent entities (such as artworks, artists, places) while edges indicate the relationships between (like created by, born in, or associated with).[928] This approach is especially useful in the humanities, where visualizing connections can trace and establish relationships between objects or entities.[929]

In network visualizations, nodes and edges vary by type. An undirected network (fig. 37, *left*) simply shows that two nodes are connected, while a directed network (fig. 37, *center*) represents the direction of the relationship, often indicated with arrows. A weighted network (fig. 37, *right*) assigns numerical values to edges, reflecting the varying intensities of the connections. For example, in an exhibition dataset, edges might indicate the frequency of collaboration between artists.

927 Sander Münster, *Interdisziplinäre Kooperation bei der Erstellung geschichtswissenschaftlicher 3D-Modelle* (Springer VS, 2016), 164, https://doi.org/10.1007/978-3-658-13857-8.

928 Taylor Arnold and Lauren Tilton, *Humanities Data in R: Exploring Networks, Geospatial Data, Images, and Text* (Springer, 2015), 81.

929 Arnold and Tilton, *Humanities Data in R*, 81.

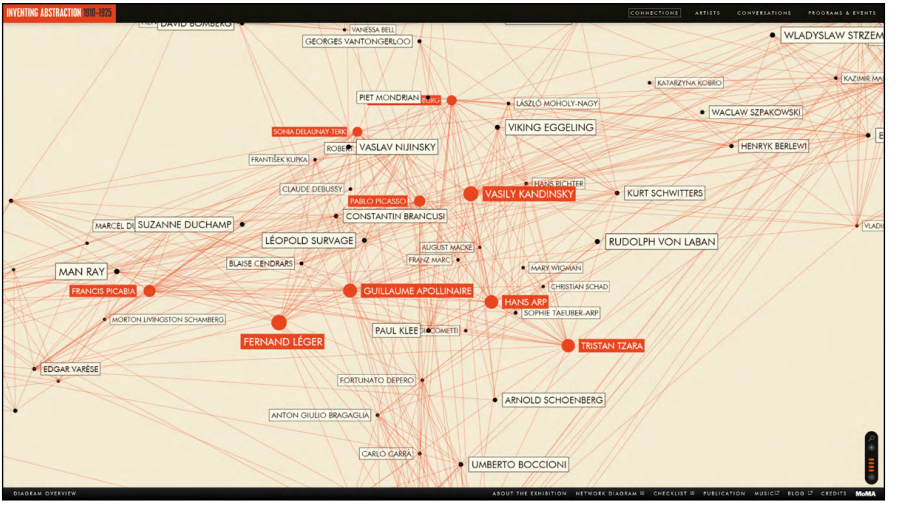


Figure 38. *Network visualization at* Inventing Abstraction. 1910–1925, *MoMA, 2012, accessed May 15, 2022, https://www.moma.org/interactives/exhibitions/2012/inventingabstraction/?page=connections*

One notable application is MoMA's *Inventing Abstraction*, where nodes in the interactive network visualization represent individuals in a group exhibition, and edges reveal connections among artists, composers, dancers, and poets (fig. 38). Nodes with the most connections are highlighted in red. Similarly, Matthew Lincoln's analysis of the Low Countries' printmaking industry (1550–1750) uses network graphs to explore centralization over time.[930] This method confirms established research while identifying lesser-known but potentially significant contributors.

Dense networks pose interpretive challenges, often mitigated by clustering algorithms that group related nodes. Clustering can be topological, based on node connections, or attribute-based, such as geographic location, or both methods can be combined.[931] These techniques clarify relationships within large datasets. Metrics like node degree (number of connections), centrality (relationship quality), and clustering coefficient (network structure) further aid analysis.[932]

930 Matthew Lincoln, "Social Network Centralization Dynamics in Print Production in the Low Countries, 1550–1750," *International Journal for Digital Art History*, no. 2 (2016): 135–157, https://doi.org/10.11588/dah.2016.2.25337.

931 Chaturvedi et al., "Group-in-a-Box Meta-Layouts," 52–53.

932 Münster, *Interdisziplinäre Kooperation*, 164–165.

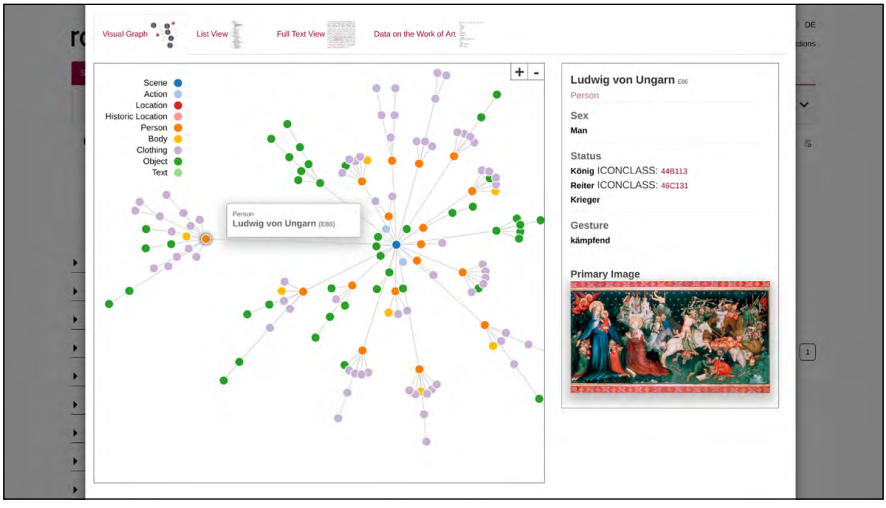


Figure 39. *Visual graph of* Equestrian Battle of Louis of Hungary *(1425–1435) by Master of the St. Lambrecht Votive Panel at* REALonline*, Institute for Medieval and Early Modern Material Culture (IMAREAL), University of Salzburg, accessed May 14, 2021, https://realonline.imareal.sbg.ac.at/en/detail/nr-000647*

Networks are not limited to human relationships; they can also represent semantic connections. For instance, the Institute for Medieval and Early Modern Material Culture (IMAREAL) at the University of Salzburg's *REALonline* database models medieval artworks as graphs.[933] Each image is indexed with detailed semantic data (labeling people, gestures, objects, animals, plants, and techniques) based on *Iconclass* and other thesauri, allowing relationships between elements to be studied.

Figure 39 shows a visual graph for the painting *Equestrian Battle of Louis of Hungary* (1425–1435). A central node labeled "Scene" connects to a node representing Louis of Hungary via the edge labeled "contains person." From this node labeled "Person" additional edges labeled "wears" link to nodes representing individual garments. Networks and the use of authority files with unique identifiers potentially allow to connect datasets across collections, making visible linkages otherwise impossible to identify.

933 *REALonline*, Institute for Medieval and Early Modern Material Culture (IMAREAL), University of Salzburg, accessed May 14, 2021, https://realonline.imareal.sbg.ac.at.

Geographical Data on Maps

While networks effectively connect art historical documents and data through various relationships, maps are particularly suited for exploring geographical topics. In geography, Geographic Information Systems (GIS) are advanced systems to model large quantities of complex and multilayered information. GIS refers to computational tools and software for producing maps and analyzing geographic data.[934] These systems rely on Global Positioning System (GPS) data to calculate and target any point on Earth using latitude, longitude, altitude, and time.[935] GIS, when combined with web-based applications, enables users to manipulate large datasets and customize map visualizations to suit their purposes, effectively transforming users into map makers.[936]

GIS is a powerful tool requiring specialized knowledge, typically used by professional geographers to process extensive and intricate data. However, in museum applications and digital humanities projects, simpler cartographic tools are usually sufficient for visualizing comparatively sparse data on the web, favoring less complex open-source alternatives. Tools like GoogleMaps,[937] OpenStreetMap,[938] Leaflet,[939] or Mapbox,[940] are preferred for their accessibility and ease of use, offering functionality tailored to web-based cultural projects. These lightweight tools simplify the visualization of digital collections without requiring the expertise needed for full GIS applications. Web-based mapping applications have made GIS's analytic tools widely available, changing the way geographic information is handled, created, visualized, interpreted, and accessed.[941]

Maps serve three primary purposes in research: collecting, exploring, and displaying data.[942] Within the GLAM (Galleries, Libraries, Archives, and Museums) sector, maps are valuable for presenting collected data to broad

934 Among the GIS softwares are the open source QGIS, accessed December 27, 2024, https://www.qgis.org; GRASS GIS, accessed December 27, 2024, https://grass.osgeo.org; or the proprietary ArcGIS, Esri, accessed December 27, 2024, https://www.esri.com/en-us/arcgis; Todd Presner and David Shepard, "Mapping the Geospatial Turn," in *A New Companion to Digital Humanities*, ed. Susan Schreibman et al. (Wiley Blackwell, 2016), 203.

935 Presner and Shepard, "Mapping the Geospatial Turn," 203.

936 Innisfree McKinnon, "Expanding Cartographic Practices in the Social Sciences," in *The SAGE Handbook of Visual Research Methods*, ed. Eric Margolis and Luc Pauwels (SAGE Publications, 2011), 452–454.

937 GoogleMaps, accessed May 14, 2021, https://www.google.com/intl/en/maps/about/mymaps.

938 OpenStreetMap, accessed May 14, 2021, https://www.openstreetmap.org.

939 Leaflet, accessed May 14, 2021, https://leafletjs.com.

940 Mapbox, accessed May 14, 2021, https://www.mapbox.com.

941 Presner and Shepard, "Mapping the Geospatial Turn," 203.

942 McKinnon, "Expanding Cartographic Practices," 457.

audiences and for aiding in the exploration of collections. The proliferation of digital imagery, geographic datasets, web- and GPS-enabled devices, and simplified mapping software has positioned mapping as an important topic in the digital humanities.[943] With the release of the Google Maps API in 2005, customizable digital maps became widely accessible, allowing users to integrate them into individual websites with minimal programming skills.[944]

Interactive maps, animated maps, and three-dimensional maps offer varied ways to consider data. Interactive maps allow users to manipulate data layers, animated maps represent changes over time, and three-dimensional maps model space more realistically while accommodating additional variables.[945] These maps reveal the limitations of any single representation, as only a portion of the available information can be visualized at once. Maps should be understood as provisional representations, reflecting a current state of knowledge rather than a static reality.[946]

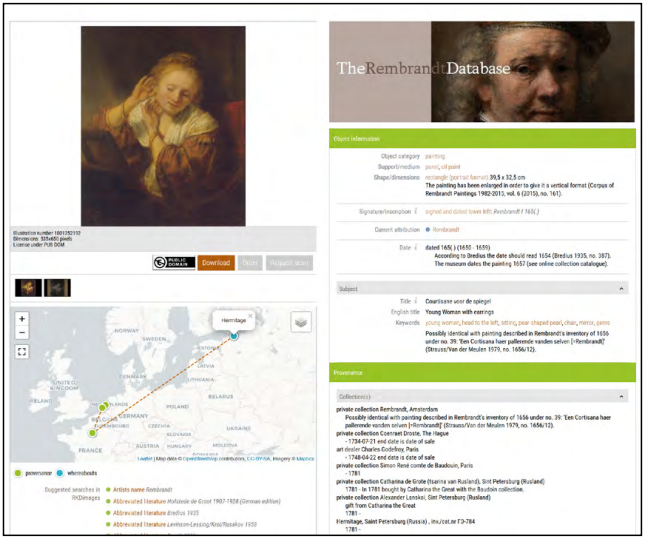


Figure 40. *Map illustrating the provenance of Rembrandt van Rijn's* Young Woman with Earrings *(1657) at* The Rembrandt Database*, Netherlands Institute for Art History (RKD), accessed May 14, 2021, https://rkd.nl/en/explore/images/40806*

943 Presner and Shepard, "Mapping the Geospatial Turn," 201.

944 Presner and Shepard, "Mapping the Geospatial Turn," 205.

945 McKinnon, "Expanding Cartographic Practices," 465–66.

946 Presner and Shepard, "Mapping the Geospatial Turn," 207.

For example, the *Rembrandt Database* developed by the Netherlands Institute for Art History (RKD) visualizes the provenance of artworks on maps (fig. 40).[947] This allows users to trace the movements of artworks, such as Rembrandt van Rijn's *Young Woman with Earrings* (1657), as seen in figure 40, which traveled through multiple locations before arriving at its current home at the State Hermitage Museum in Saint Petersburg. Users can interact with these maps by selecting an artwork and viewing detailed information about each node with a single click.

Visualizing provenance data on a map requires geographical information to be included in the dataset, formatted to derive coordinates. Incomplete or imprecise data, such as missing entries or vague location descriptions, present inevitable challenges. Visualizations must address these uncertainties, especially when mapping ambiguous or partial data.[948] One issue is the overall volume of data; another is the sheer number of individual items it comprises.

Perception of Data

Visualizing large datasets, such as text corpora, requires deliberate design to ensure user comprehension. Regardless of whether the cultural data consists of images, text, or metadata, effective visualizations depend on core design principles. Nan Cao and Weiwei Cui outline the process of visualizing text documents,[949] which begins with transforming unstructured text into a structured form. Visualizations based on this structured data can show document similarity, content, or sentiment.[950] Similarly cultural collections must structure their data—no matter its format—for successful visualization.

Computers aid data analysis by mining datasets for patterns and extracting information.[951] Visualization techniques make it possible to display and explore these patterns, enabling users to oversee and refine the process.[952] Well-executed visualizations minimize cognitive effort by compressing large amounts of data into accessible visual formats.[953] Abstraction helps users

947 *The Rembrandt Database*, accessed May 14, 2021, https://rembrandtdatabase.org.

948 McKinnon, "Expanding Cartographic Practices," 467.

949 Cao and Cui, *Introduction to Text Visualization*.; "Text Visualization Browser," ISOVIS group, accessed April 15, 2021, https://textvis.lnu.se. The authors created a visualization of the studies they analyzed in their text visualization survey.

950 Cao and Cui, *Introduction to Text Visualization*, 9.

951 Cao and Cui, *Introduction to Text Visualization*, 2.

952 Cao and Cui, *Introduction to Text Visualization*, 2.

953 Cao and Cui, *Introduction to Text Visualization*, 2; John B. Bender and Michael Marrinan, *Kultur des Diagramms* (Akademie Verlag, 2014), vii–viii.

discern trends, clusters, or outliers,[954] providing a clearer understanding of digital collections beyond individual objects.

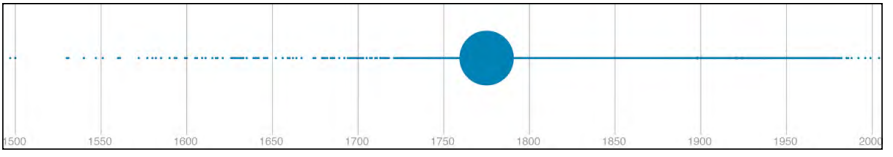


Figure 41. Timeline of Tate's Collection *with William Turner's works* (reproduced by permission from: Kräutli, *Visualising Cultural Data*, 147, fig. 4.12)

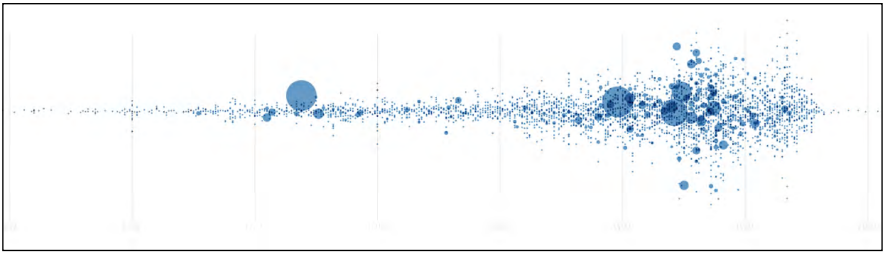


Figure 42. Timeline of Tate's Collection *omitting William Turner's works* (reproduced by permission from: Kräutli, *Visualising Cultural Data*, 146, fig. 4.11)

For example, Florian Kräutli used visualizations to provide an overview of the Tate's collection by plotting artists' birth years as bubbles with bubble size correlating to the number of artworks in the collection (figs. 41 and 42).[955] However, the initial timeline revealed an imbalance caused by the disproportionately large number of works by William Turner (1775–1851), whose sketchbooks were cataloged as individual entries (fig. 41). This outlier dominated the visualization, prompting the decision to omit Turner's works in favor of a more balanced representation of the rest of the collection (fig. 42).

This example underscores the importance of aligning visualizations with the nature of the data. Visualizations inevitably conceal decisions made during data preparation unless explicitly stated, and their accuracy depends on the quality and composition of the data. Nevertheless, visualizations remain powerful tools for unearthing fundamental trends and deepening understanding.

954 Shneiderman, "The Eyes Have It," 337.

955 "The Tate Collection," GitHub, accessed May 23, 2021, https://github.com/tategallery/collection. The Tate released artwork and artist metadata under a CC0 license.

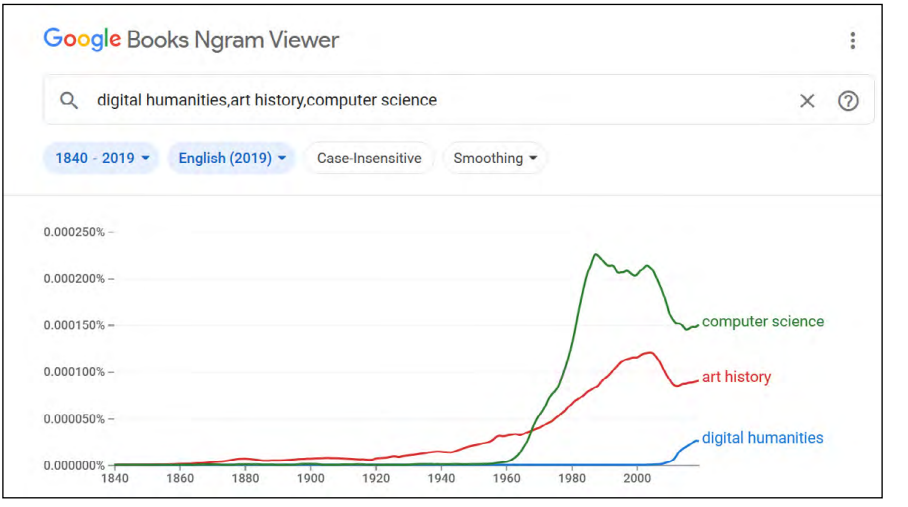


Figure 43. *Term frequencies for "digital humanities," "art history," and "computer science" in the English-language corpus from 1840 to 2019 at* Google Books Ngram Viewer, *Google, accessed March 4, 2021, https://books.google.com/ngrams/graph?content=digital+humanities%2Cart+history%2Ccomputer+science&year_start=1840&year_end=2019&corpus=26&smoothing=3#*

Quantitative Data in Graphs

Visualizations play a pivotal role in analyzing vast datasets, extracting information that would otherwise stay hidden. *Google Books Ngram Viewer*, for instance, provides a global perspective on large text corpora. Using the English corpus of *Google Books* from 1800 to 2019, the viewer highlights the emergence of terms like "art history," "computer science," and "digital humanities" (fig. 43). The data indicates that art history originated in the late 19th century, computer science surged in the 1960s, and digital humanities appeared around 2005.[956]

While these curves seem precise and the results plausible, it is crucial to consider the limitations of the underlying data. Questions arise about what has been digitized, in which languages, and with what gaps or biases. The quality of optical character recognition (OCR) is unclear, and users cannot create sub-corpora tailored to specific research questions.[957] *Ngram Viewer* allows analysis within a single-language corpus over a specified time range

956 Susan Schreibman et al., eds., *A Companion to Digital Humanities* (Blackwell, 2004), https://doi.org/10.1002/9780470999875. Schreibman et al.'s book is central to the dissemination of the term "digital humanities." See also: chapter 1, p. 36 in this book.

957 Tobias Hodel, "Das kleine Digitale: Ein Plädoyer für Kleinkorpora und gegen Grossprojekte wie Googles Ngram-Viewer," in *Digital Humanities*, ed. David Gugerli et al. (Diaphanes, 2013).

but does not clarify what lies beneath the curves. Despite these constraints, *Ngram Viewer* exemplifies how quantitative approaches can point to new discoveries using large datasets enriching metadata associated with artworks without requiring exhaustive reading.



Figure 44. Deutsche Digitale Bibliothek Visualized *(2014), Urban Complexity Lab, University of Applied Sciences Potsdam, accessed May 24, 2021, https://uclab.fh-potsdam.de/ddb/timeline*

Graphs summarize relationships between two values, but they lack additional contextual information about what is represented. To address this, interfaces can combine various visualizations to provide both overviews and filtering options. An example is *Deutsche Digitale Bibliothek Visualized*[958] (fig. 44), developed by the Urban Complexity Lab at the University of Applied Sciences Potsdam. The interface uses a series of diagrams to showcase the number of documents from various institutions over time. Each graph represents different types of institutions and their digital objects in *Deutsche Digitale Bibliothek*'s database.[959] Users can select time periods altering visualizations across the interface. Interactive elements such as word clouds and bar charts permit users to filter data, ultimately leading to specific search results. This model offers a dynamic alternative to traditional keyword-based searches, encouraging user curiosity through visual means.

958 *Deutsche Digitale Bibliothek Visualized*, Urban Complexity Lab, University of Applied Sciences Potsdam, accessed May 24, 2021, https://uclab.fh-potsdam.de/ddb.

959 *DeutscheDigitaleBibliothek*,accessedMay24,2021,https://www.deutsche-digitale-bibliothek.de.

Interaction with Data in Visualization Interfaces

Visualization interfaces aim to reveal either data distributions or relationships among objects and their attributes. Interactive visualizations allow users to manipulate analysis models, explore patterns, and identify anomalies.[960] Interfaces designed for these purposes provide tools that enable users to interact with data flexibly and intuitively, even without programming knowledge. Ben Shneiderman's widely cited mantra "overview first, zoom and filter, then details-on-demand,"[961] encapsulates the core principles of effective information visualization. An overview provides a general orientation, enabling users to identify relevant sections before delving into detailed information. Visualization interfaces prioritize context creation over direct access to individual objects, making for an overall inviting user experience.

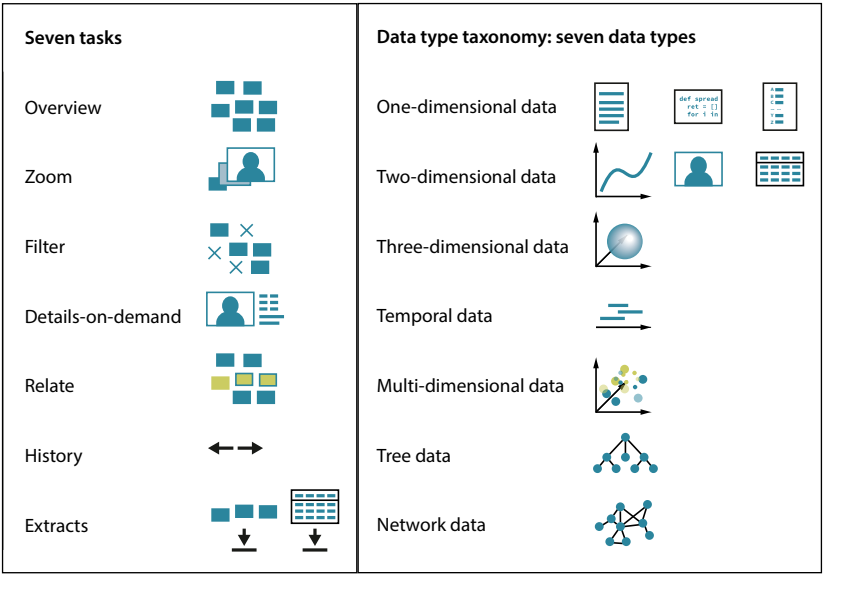


Figure 45. *Ben Shneiderman's seven tasks* (left) *and seven data types* (right) (information source: Shneiderman, "The Eyes Have It," 337–340)

960 Cao and Cui, *Introduction to Text Visualization*, 7.

961 Shneiderman, "The Eyes Have It," 337.

Shneiderman identifies seven tasks performed during interaction with visualizations: overview, zoom, filter, details-on-demand, relate, history, and extract (fig. 45, *left*).[962] These tasks collectively enhance user experience by providing an overview, narrowing focus through zoom and filters, and offering detailed inspections of selected data. Additional tools allow users to examine relationships among items, retrace actions, and extract a sub-set for further use.[963] When balanced, these tasks create seamless and varied interactions with collections.

The interface design also depends on the data types being visualized, which Shneiderman categorizes as: one-dimensional, two-dimensional, three-dimensional, temporal, multi-dimensional, tree, and network data (fig. 45, *right*). Each type has distinct characteristics and influences the appearance of visualizations. For instance, one-dimensional data includes linear structures like text, while two-dimensional data encompasses planar representations such as maps or images. Three-dimensional data represents the volume and complex relationships of items, and temporal data refer to and represent chronological time. Multi-dimensional data, commonly stored in relational databases, can reveal patterns or clusters through scattergrams. Tree structures and networks allow hierarchical or interconnected relationships to be evaluated. Shneiderman admits that the seven categories are a simplification of existing data types and that variations and combinations are inevitable.[964] By integrating data types with user tasks, visualization interfaces create dynamic, user-controlled examinations of digital collections.[965] For example, multi-dimensional data, makes image collections able to be displayed as clouds, allowing users to navigate, zoom, and retrieve detailed information interactively.

962 Shneiderman, "The Eyes Have It," 337.

963 Shneiderman, "The Eyes Have It," 339–340.

964 Shneiderman, "The Eyes Have It," 337–339.

965 Shneiderman, "The Eyes Have It," 341.

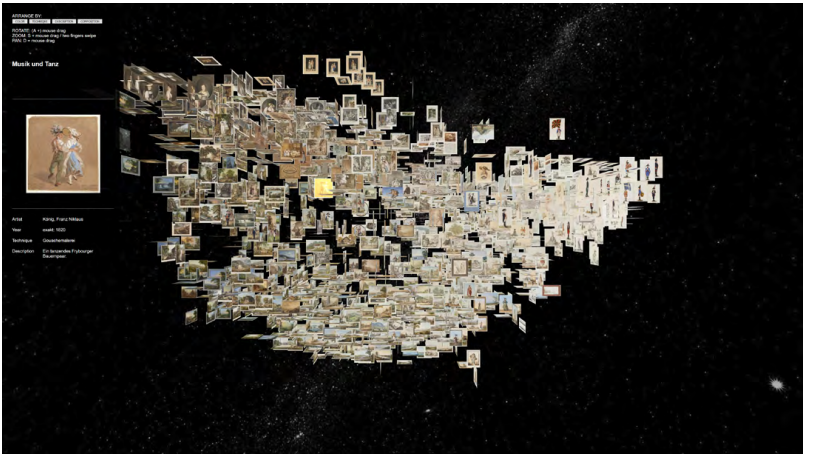


Figure 46. *Visualization of 2,300 Schweizer Kleinmeister images. Swiss National Library's Gugelmann Collection, arranged by color at Mathias Bernhard,* Gugelmann Galaxy *(2015), accessed February 27, 2021, https://www.mathiasbernhard.ch/gugelmann/*

The *Gugelmann Galaxy* application demonstrates the potential of interactive visualization interfaces. This image cloud arranges artworks from a collection in a three-dimensional space (fig. 46),[966] showing both a holistic view and detailed inspection.[967] Images can be organized by metadata-derived criteria, such as technique and descriptions or by visual attributes like color and composition, extracted through computer vision algorithms.[968] Hovering over an image prompts a preview with information about the artwork. This interface embodies Shneiderman's mantra: users get an overview of the collection, zoom into specific clusters, filter by criteria, and access detailed data for individual objects. Furthermore, the visualization relies on both explicit relations within metadata and inferred similarities based on visual attributes, making the user experience more absorbing.[969]

966 Mathias Bernhard, "Gugelmann Galaxy: An Unexpected Journey Through a Collection of Schweizer Kleinmeister," *International Journal for Digital Art History*, no. 2 (2016): 95–113, https://doi.org/10.11588/dah.2016.2.23250. The first version of this application entitled "Schweizer Kleinmeister: An Unexpected Journey" was developed by Mathias Bernhard, Jorge Orozco, Nikola Marincic, and Sonja Gasser at the First Swiss Open Cultural Data Hackathon in Bern in 2015, accessed February 27, 2021, https://make.opendata.ch/wiki/project:schweizer_kleinmeister:an_unexpected_journey.

967 Bernhard, "Gugelmann Galaxy," 95.

968 Bernhard, "Gugelmann Galaxy," 98.

969 Marian Dörk et al., "Visualizing Explicit and Implicit Relations of Complex Information Spaces,"

Combining Data Sources in Multimedia Applications

Multimedia applications can organize information in different ways while also providing users with an overview, content selection, and a closer examination of objects. By combining different datasets and visualization types, these applications connect and conceptualize data, permitting nonlinear exploration and narrative creativity around specific topics. For example, integrating maps with timelines can reveal data from multiple perspectives, facilitating serendipitous discovery and a more comprehensive understanding of the subject matter.

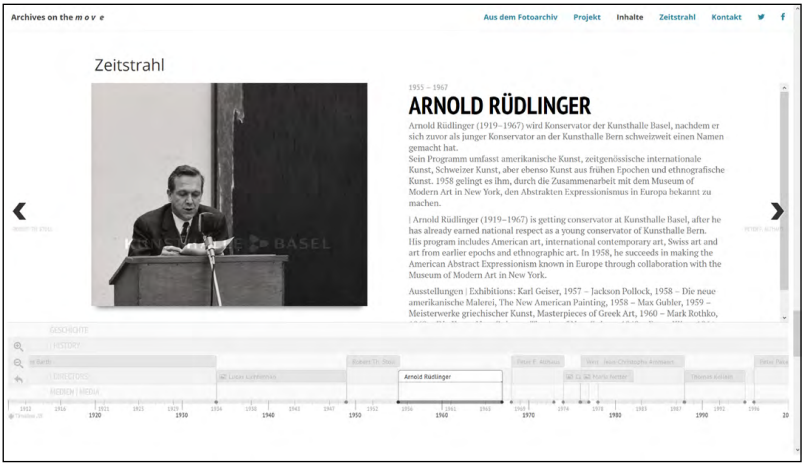


Figure 47. *Interactive timeline record for Arnold Rüdlinger at* Heads of Kunsthalle Basel*, Archives on the Move, accessed May 13, 2019, https://archivesonthemove.org/#zeitstrahl*

Museums' digital collections often focus on individual artworks. However, museums' archives and libraries house additional types of digitized documents such as manuscripts, photographs, audio recordings, videos, photographs, and digital applications, which can be of historical significance. A curated selection of these disparate materials under a specific theme can create fulfilling multimedia experiences. One such example is *Heads of Kunsthalle Basel*[970] (fig. 47), an interactive timeline built using the open-source tool

Information Visualization 11, no. 1 (2012): 5, https://doi.org/10.1177/1473871611425872.

970 *Heads of Kunsthalle Basel*, Archives on the Move, accessed December 9, 2018, https://archivesonthemove.org/#zeitstrahl.

TimelineJS[971] by the Northwestern University Knight Lab.[972] The application offers a historical overview of Kunsthalle Basel, centering conservators, directors, and key milestones. Digitized portraits from Kunsthalle Basel's photo archive are paired with brief biographical notes and associated exhibitions.[973] Additional multimedia content (such as Google Maps, YouTube videos, and social media posts) is smoothly integrated into the timeline. *TimelineJS* is a good example of how digital technologies can repurpose and combine existing materials into cohesive presentations.

971 *TimelineJS*, Knight Lab, Northwestern University, accessed December 9, 2018, https://timeline.knightlab.com.

972 The *Heads of Kunsthalle Basel* timeline was realized by Sonja Gasser using images from Kunsthalle Basel's *Photo Archive* as a part of her project *Archives on the Move*. From November 2015 to October 2018, the project Archives on the Move: Visualisierungs- und Vermittlungsstrategien für das digitalisierte Fotoarchiv der Kunsthalle Basel at the Digital Humanities Lab, University of Basel, was funded by the UBS Culture Foundation. Project leader: Prof. Dr. Lukas Rosenthaler, project manager: Sonja Gasser, in cooperation with: Kunsthalle Basel, accessed December 14, 2018, https://archivesonthemove.org. For the principal aims of the project, see Sören Schmeling and Sonja Gasser, "What's Left When the Show Is Over? Les archives photographiques de la Kunsthalle de Bâle," in *Photographie et exposition*, ed. Christian Joschke and Olivier Lugon, Transbordeur (Éditions Macula, 2018), 142.

973 *Photo Archive*, Kunsthalle Basel, accessed May 18, 2021, https://www.kunsthallebasel.ch/en/photo-archive/.



Figure 48. *Exhibition* The New American Painting *(1958) at* Timeline and Map*, International Program, MoMA, accessed May 13, 2019, https://www.moma.org/interactives/ip_timeline/index.html#*

Applications that incorporate maps with timelines represent geographical and temporal dimensions simultaneously. MoMA developed *Timeline and Map* (fig. 48),[974] an advanced example based on digitized archives. This interactive visualization showcases more than 300 touring exhibitions organized by MoMA's International Program between 1952 and 1980. The timeline features representative installation views for each exhibition while red dots on the map indicate exhibition locations and blue dots specify venues for a particular show, such as *The New American Painting*. Additional details, including venue lists, exhibition periods, and additional installation views, are provided below the primary visualization.

MoMA's *Timeline and Map* exemplifies how ongoing digitization transforms museum's digital offers as well as the material included in digital collections. Beyond artworks, archival materials—such as installation views, digitized catalogs, and press releases—are increasingly accessible. This comprehensive approach underscores the need for diverse metadata and the inclusion of documents outside of the core art collection to support more fruitful experiences.

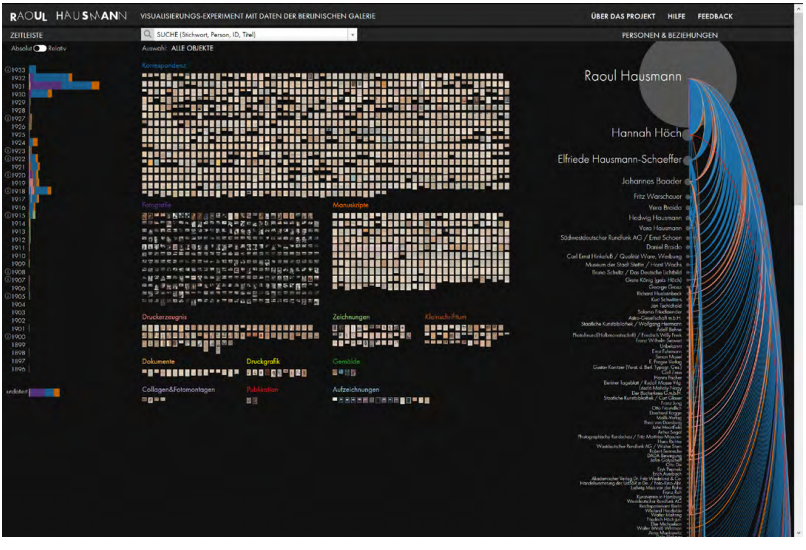


Figure 49. *Experimental visualization by Mark-Jan Bludau at* Raoul Hausmann*, Urban Complexity Lab, University of Applied Sciences Potsdam, accessed May 13, 2019, https://uclab.fh-potsdam.de/hausmann*

974 *Timeline and Map*, MoMA, International Program, accessed November 7, 2017, https://www.moma.org/interactives/ip_timeline.

The growing volume and variety of data present challenges in managing and interpreting content. To address these, Marian Dörk's team at the University of Applied Sciences Potsdam has developed advanced visualization prototypes over several years. These tools use diagrams to condense extensive datasets into intuitive visual representations,[975] allowing users to gain an overview before examining specific objects. One notable example is *Raoul Hausmann* (fig. 49), a master's thesis project by Mark-Jan Bludau, which uses data from the Berlinische Galerie.[976] The dashboard-style application integrates multiple visualization types to structure and present the estate of Raoul Hausmann from Berlinische Galerie's collection. A timeline on the left uses bars to show document counts by year, with colors distinguishing document types. In the center, documents are arranged in a grid by type. On the right, type size and dots represent the frequency of certain names, with lines indicating relationships among them, allowing users to filter and explore the collection interactively. The visualizations are generative and interconnected, letting users manipulate diagrams and dynamically navigate the collection. For example, selecting a timeline year on the left or a name on the right filters the central grid, while clicking on a document reveals its connections, attributes, and detailed metadata.

Unlike traditional art collections online that prioritize singular objects, *Raoul Hausmann* highlights relationships among documents, showing single objects and metadata only at a deeper level. Experts can utilize sophisticated search capabilities while also reaching the general public through intuitive, visually interesting interfaces.

5.3 Designing Sophisticated Data Visualizations

The design of interactive data visualizations is essential in creating user-friendly interfaces, particularly for the general public. Successful visualization design is rooted in visual communication theory, which emphasizes documenting, structuring, and targeting information to suit the intended audience.[977] The goal is to convey information through a harmonious arrangement of images and typography,[978] offering clarity and navigational ease.

975 "Projects," Urban Complexity Lab, University of Applied Sciences Potsdam, accessed May 24, 2021, https://uclab.fh-potsdam.de/projects.

976 *Raoul Hausmann*, Urban Complexity Lab, University of Applied Sciences Potsdam, accessed December 9, 2018, https://uclab.fh-potsdam.de/hausmann.

977 Kerstin Alexander, *Kompendium der visuellen Information und Kommunikation* (Springer Vieweg, 2013), 1, https://doi.org/10.1007/978-3-642-35450-2.

978 Alexander, *Kompendium der visuellen Information*, 2.

Infographics, a common product of information visualization, combine text and imagery in graphical form,[979] condensing complex topics into digestible formats.[980] They guide viewers linearly through a narrative, supported by visual elements that communicate central themes.[981] Design thinking in data visualization centers generalization and abstraction,[982] reducing complex datasets to the essentials for visual communication.

Interactive visualizations must balance data potency with user accessibility. While infographics convey central ideas, interactive visualizations examine broader data relationships.[983] Riccardo Mazza defines data visualization as:

> The graphical representation of information, generated and assisted by computer, can be helpful in carrying out explorative analysis on the data, effectively communicating ideas, data, or concepts, and helping to demonstrate or disprove a hypothesis on data.[984]

This versatility supports its potential for attracting a range of audiences and satisfying research questions when thoughtfully designed.

Lev Manovich identifies three criteria for model visualizations: (1) departing from standard techniques to challenge viewers; (2) introduce innovative methods that advance the visualization field; and (3) making broader societal or historical statements that go beyond revealing data patterns.[985] Achieving such sophistication requires expertise in the use of graphical means, data interpretation, and the ability to glean important information.

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979 Alexander, *Kompendium der visuellen Information*, 8.

980 Ben Willers, "Show, Don't Tell," in *New Challenges for Data Design*, ed. David Bihanic (Springer, 2015), 4, https://doi.org/10.1007/978-1-4471-6596-5_1.

981 Willers, "Show, Don't Tell," 11.

982 Alexander, *Kompendium der visuellen Information*, 33.

983 Willers, "Show, Don't Tell," 14.

984 Riccardo Mazza, *Introduction to Information Visualization* (Springer, 2009), viii.

985 Lev Manovich, "Artistic Visualization," in *A Companion to Digital Art*, ed. Christiane Paul (Wiley Blackwell, 2016), 430.

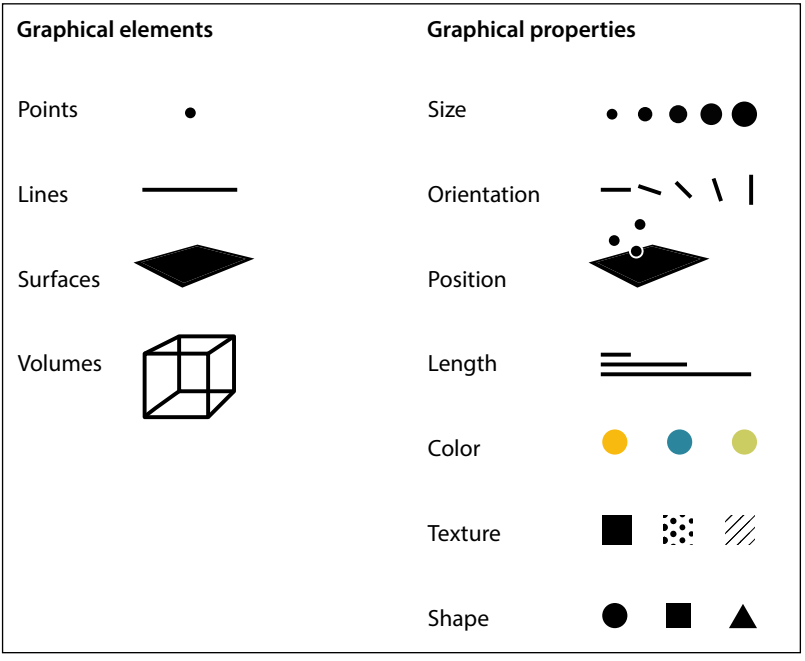


Figure 50. *Fundamental design elements for data visualizations. Graphical elements* (left) *and graphical properties* (right) Designed by Sonja Gasser, CC BY 4.0 (after: Mazza, *Introduction to Information Visualization*, 21–22)

Reduction is a fundamental principle in both design and data visualization. In data visualizations, "graphical primitives such as points, straight lines, curves, and simple geometric shapes" represent data objects and connections between them "to reveal patterns and structures."[986] Figure 50 shows graphical elements and their properties, whose terminology varies from one author to the next. Apart from reduction, Lev Manovich identifies "spatial variables," such as size, position, shape, curvature of lines, and movement, as secondary core principles "to represent ... data and reveal the most important patterns and relations," while visual attributes like tone, color, and texture add subordinate details.[987] In data visualizations, spatial dimensions are prioritized over visual dimensions, which means that the more important data properties are mapped to topology and geometry. These elements, when meaningfully combined, form the building blocks of effective visualizations.

986 Manovich, "Artistic Visualization," 430.

987 Manovich, "Artistic Visualization," 431.

So, the new visual and graphic formalisms for representing massive datasets incorporate not only established visualization types but also advanced design elements.[988] Beyond traditional formats like diagrams and maps, more sophisticated visualizations integrate attributes like edge, contour, area, and volume to represent complex datasets comprehensively.[989]

From Data to Visualization

Creating impactful visualizations begins with data preparation, a process requiring substantial efforts to clean and structure datasets.[990] Errors and anomalies must be addressed to ensure accuracy.[991] Documenting these steps and publishing the data alongside the final visualization promotes transparency, ensures reproducibility, and encourages reuse in future research.[992]

Data alone lacks inherent meaning.[993] Transforming data into information requires thorough communication, alongside careful processing, organization, and presentation.[994] Visualizations aid in this transformation by contextualizing data for analysis and communication.

Interactive Visualizations

Data visualizations fall into three categories—static, manipulable, and transformable representations—each offering different levels of user interaction.[995] Static representations provide fixed, unmodifiable views.[996] Manipulable displays allow user actions like zooming, rotating, and switching between overview and detail.[997] Transformable representations enable dynamic adjustments, such as filtering data and modifying visual arrangements.[998] These capabilities make interactive data visualizations a powerful tool for engaging with cultural content.

Even though visualizations simplify complex ideas by presenting them

988 David Bihanic, "Giving Shape to Data," in *New Challenges for Data Design*, ed. David Bihanic (Springer, 2015), 31–32, https://doi.org/10.1007/978-1-4471-6596-5_2.

989 Bihanic, "Giving Shape to Data," 32.

990 Lauren Magnuson, ed., *Data Visualization: A Guide to Visual Storytelling for Libraries* (Rowman & Littlefield, 2016), xi.

991 Eric Phetteplace, "Sculpting Data for a Successful Visualization," in *Data Visualization: A Guide to Visual Storytelling for Libraries*, ed. Lauren Magnuson (Rowman & Littlefield, 2016), 3.

992 Phetteplace, "Sculpting Data," 8.

993 Mazza, *Introduction to Information Visualization*, 8–9.

994 Mazza, *Introduction to Information Visualization*, 8–9.

995 Mazza, *Introduction to Information Visualization*, 106.

996 Mazza, *Introduction to Information Visualization*, 106.

997 Mazza, *Introduction to Information Visualization*, 106–107.

998 Mazza, *Introduction to Information Visualization*, 106.

in an easy-to-grasp way, Franco Moretti summarizes that "distance is … not an obstacle but *a specific form of knowledge:* fewer elements, hence a sharper sense of their overall interconnection. Shapes, relations, structures. Forms. Models."[999] A broader perspective on a topic, created in this way, allows for the recognition of overarching structures that may remain hidden when focusing on a limited set of works. Reducing data complexity is a key strength of data visualizations, enabling effective communication by highlighting relevant aspects.

In addition to a robust data foundation, information visualizations' user engagement must be critically evaluated.[1000] Interactive visualizations aimed at engaging users with social or cultural topics are designed to attract attention and shed light on complex issues by allowing users to explore shifting perspectives.[1001] Designers' intentions and values shape visualizations, as highlighting and omission are effective techniques for revealing specific patterns in a dataset.[1002] Inherently, visualizations present a particular perspective and can influence viewers.[1003] Their interpretation is subjective, relying on the designer's assumptions and the viewer's context. It is impossible to create an all-encompassing visualization that accounts for every possible aspect of a dataset from both the creator's and the user's perspective.[1004]

Given this subjectivity, certain principles are essential when designing interactive data visualizations. A well-crafted visualization: (1) exposes the design's underlying decisions, (2) offers a plurality of views and interpretations, (3) allowing users to delve into various facets of the dataset, and (4) empowers users to control data transformations through interactive features.[1005] Transparency in visualization design not only clarifies the available content and its limitations but also helps guide users.

Engaging users can be achieved through several strategies. Providing an introduction about the visualization's purpose orients users by placing it in a thematic context.[1006] Entrance visualizations, such as maps, give a high-level overview, connecting the topic to users' prior knowledge.[1007]

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999 Franco Moretti, *Graphs, Maps, Trees: Abstract Models for a Literary History* (Verso, 2005), 1.

1000 Marian Dörk et al., "Critical InfoVis: Exploring the Politics of Visualization," in *CHI '13 Extended Abstracts on Human Factors in Computing Systems on – CHI EA '13*, ed. Wendy E. Mackay et al. (ACM Press, 2013), https://doi.org/10.1145/2468356.2468739.

1001 Dörk et al., "Critical InfoVis," 2189.

1002 Dörk et al., "Critical InfoVis," 2190.

1003 Dörk et al., "Critical InfoVis," 2192.

1004 Dörk et al., "Critical InfoVis," 2192.

1005 Dörk et al., "Critical InfoVis," 2192.

1006 Dörk et al., "Critical InfoVis," 2195.

1007 Dörk et al., "Critical InfoVis," 2195–2196.

Allowing users to customize visualizations based on their preferences enhances engagement through interaction.[1008] Exposing the underlying data provides further information into objects of particular interest and fosters a clearer understanding of the representation's basis, in addition to supporting data reuse.[1009] Incorporating biographical information establishes a personal connection through storytelling.[1010] Applications that incorporate these principles are much more accessible to diverse audiences than those that do not.

These principles are well-illustrated in the *VIKUS Viewer*.[1011] This software, derived from the application *Past Visions: Penned by Frederick William IV* (discussed in section 3.6), begins with a website containing contextual information before users launch the application. The website introduces Frederick William IV (1795–1861), details the source collection, and credits the collaborators, partners, and technology used.[1012] Within the application, biographical notes with concise descriptions position the images within a timeline of Frederick William IV's life.

Narrative-driven approaches to data visualization are distinct from exploration-led visualizations.[1013] Linear storytelling directs users on a prescribed path, dictated by the designer.[1014] In contrast, exploration-led visualizations offer several exploratory paths where they can uncover stories independently.[1015] The latter approach is promising as it allows users to identify personally relevant content, making the experience more memorable.[1016]

The most effective visualizations combine these approaches by revealing overarching themes while encouraging users to find stories independently.[1017] This duality—providing a qualitative narrative element alongside rich quantitative data—compels users to engage with the material.

1008 Dörk et al., "Critical InfoVis," 2196.

1009 Dörk et al., "Critical InfoVis," 2196.

1010 Dörk et al., "Critical InfoVis," 2196.

1011 *VIKUS Viewer*, Urban Complexity Lab, University of Applied Sciences Potsdam, accessed May 18, 2021, https://vikusviewer.fh-potsdam.de.

1012 *Past Visions*, Urban Complexity Lab, University of Applied Sciences Potsdam, accessed May 18, 2021, https://uclab.fh-potsdam.de/fw4/en.

1013 Willers, "Show, Don't Tell," 4.

1014 Willers, "Show, Don't Tell," 4.

1015 Willers, "Show, Don't Tell," 4.

1016 Willers, "Show, Don't Tell," 4.

1017 Willers, "Show, Don't Tell," 4–5.

5.4 Quantitative and Qualitative Methods

Data visualizations are valuable not only for research purposes, but also for conveying complex, multi-layered connections to a broad audience. Large datasets enable the exploration of various narrative trajectories, depending on users' choices and interests. A visualization's appearance is shaped by its purpose, source, and complexity.[1018] For example, visualizations designed for public presentation differ in intent from those created for research.[1019] Additionally, the type of data, its representation, and the intricacy of the visualization design greatly influence its form and function.[1020] As mentioned in previous sections, transforming large datasets into effective visualizations requires expertise across multiple disciplines.

Data visualization integrates data science, statistics, visual communication, and design in an interdisciplinary framework,[1021] which includes experts with distinct scientific, technical, creative, or cultural backgrounds. This collaborative approach avoids rigid divisions of labor.[1022] Ideally, such collaborations lead to the implementation of visualizations that make visible relationships, trends, and patterns while welcoming interactive exploration.[1023]

While the use of data visualizations is common in scientific disciplines, it is less common in the humanities, where digitization has introduced challenges related to processing large volumes of data. In scientific contexts, visualizations—such as diagrams, illustrations, and models—serve as tools to generate, organize, and communicate knowledge.[1024] They contribute to problem-solving, filling knowledge gaps, and transferring knowledge without

1018 Martin Grandjean, "Introduction à la visualisation de données: l'analyse de réseau en histoire," in *La visualisation des données en histoire // Visualisierung von Daten in der Geschichtswissenschaft*, ed. Enrico Natale et al. (Chronos, 2015), 118, accessed October 2, 2019, https://blog.ahc-ch.ch/wp-content/uploads/2015/09/4-Grandjean.pdf.

1019 Grandjean, "Visualisation de données," 118.

1020 Grandjean, "Visualisation de données," 118.

1021 Magnuson, *Data Visualization*, xi.

1022 Luc Pauwels, "A Theoretical Framework for Assessing Visual Representational Practices in Knowledge Building and Science Communications," in *Visual Cultures of Science: Rethinking Representational Practices in Knowledge Building and Science Communication*, ed. Luc Pauwels (Dartmouth College Press / University Press of New England, 2006), 22.

1023 Magnuson, *Data Visualization*, xi.

1024 Martina Hessler, ed., *Konstruierte Sichtbarkeiten: Wissenschafts- und Technikbilder seit der frühen Neuzeit* (Wilhelm Fink, 2006), 12.

reproducing reality.[1025] Scientific visualizations summarize empirical findings and theoretical concepts, simplifying knowledge transfer to both specialized and general audiences.[1026] Similarly, art historical visualizations produce insights that would be impossible without visual processes, reinforcing the inseparability of knowledge and its representation.[1027]

The production of visualizations is influenced by social and media conditions, which determine what is visible and the knowledge that can be gained.[1028] The choice of medium—whether curves, diagrams, numbers, text, photographs, or digital images—inform the kind of knowledge conveyed.[1029]

Fundamentals of Data

Digital collections exist within specific social and cultural contexts, making data literacy essential. In their 2017 essay, Karin van Es et al. posed questions about "how researchers and their tools shape data" to encourage "for a reflexive form of data analysis and data visualization."[1030] Digital data research requires transparency in decision-making throughout the analysis process.[1031] They criticized "big data" for the fact that data is always "selected and shaped by humans and their technologies."[1032] Johanna Drucker's concept of "capta" reinforces this criticism, asserting that "data" in the humanities is not "self-evident, value neutral, and observer-independent."[1033] "*Data are capta*, taken not given, constructed as an interpretation of the phenomenal world, not inherent in it."[1034]

In contrast, Forrest W. Young et al. adhere to a traditional definition—understanding "datum" as something given and "data" as a set of given things—stating, "*Data* are a set of facts suited to the rules of arithmetic that

1025 Luc Pauwels, "Introduction: The Role of Visual Representation in the Production of Scientific Reality," in *Visual Cultures of Science: Rethinking Representational Practices in Knowledge Building and Science Communication*, ed. Luc Pauwels (Dartmouth College Press / University Press of New England, 2006), vii–viii.

1026 Pauwels, "A Theoretical Framework," 18–19.

1027 Hessler, *Konstruierte Sichtbarkeiten*, 32.

1028 Hessler, *Konstruierte Sichtbarkeiten*, 31–32.

1029 Hessler, *Konstruierte Sichtbarkeiten*, 32.

1030 Karin van Es et al., "Towards a Reflexive Digital Data Analysis," in *The Datafied Society: Studying Culture Through Data*, ed. Mirko Tobias Schäfer and Karin van Es (Amsterdam University Press, 2017), 171.

1031 van Es et al., "Reflexive Digital Data Analysis," 172.

1032 van Es et al., "Reflexive Digital Data Analysis," 173.

1033 Johanna Drucker, "Humanities Approaches to Graphical Display," *Digital Humanities Quarterly* 5, no. 1 (2011): 49, accessed March 14, 2021, https://www.digitalhumanities.org/dhq/vol/5/1/000091/000091.html.

1034 Drucker, "Humanities Approaches," 8.

are organized for processing and analysis. Data is often, although not necessarily, numeric."[1035] But they also stress that,

> commonly, data do not make a clear and unambiguous statement about our world, often requiring tools and methods to provide such clarity. These methods, called *statistical data analysis*, involve collecting, manipulating, analyzing, interpreting, and presenting data in a form that can be used, understood, and communicated to others.[1036]

Another misconception is viewing data analysis solely as quantitative approach to detect underlying patterns.[1037] Van Es et al. argue that, "In the humanities, data analysis often combines quantitative and qualitative approaches."[1038] They continue, "we should not forget that even research that relies heavily on computational tools for the calculation of large amounts of data and the visualization of patterns still requires the researcher to interpret these patterns."[1039] It is imperative that researchers reflect critically on the different stages of acquiring, cleaning, and analyzing data, because the result depends on "how the given tools work with and shape the data."[1040]

Qualitative data analysis in the humanities requires scholars, "either to reduce the volume or the complexity of the data, or to expand the existing material by writing new texts consisting of interpretations about it."[1041] Uwe Flick defines qualitative data analysis as, "the classification and interpretation of linguistic (or visual) material to make statements."[1042] In doing so, qualitative data analysis often "combines approaches of a rough analysis of the material (overviews, condensation, summaries) with approaches of a detailed analysis (elaboration of categories, hermeneutic interpretations or identified structures)."[1043] Through the comparison of multiple materials, like texts or images, general conclusions are made.[1044] Hermeneutics focuses on individual objects, analyzing and interpreting them within their contexts without relying on quantitative measurements.[1045] It remains the primary

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1035 Young et al., *Visual Statistics*, 29.

1036 Young et al., *Visual Statistics*, 29.

1037 van Es et al., "Reflexive Digital Data Analysis," 173.

1038 van Es et al., "Reflexive Digital Data Analysis," 173.

1039 van Es et al., "Reflexive Digital Data Analysis," 173.

1040 van Es et al., "Reflexive Digital Data Analysis," 174.

1041 Uwe Flick, "Mapping the Field," in *The SAGE Handbook of Qualitative Data Analysis*, ed. Uwe Flick (SAGE Publications, 2014), 3–4, https://doi.org/10.4135/9781446282243.n1.

1042 Flick, "Mapping the Field," 5.

1043 Flick, "Mapping the Field," 5.

1044 Flick, "Mapping the Field," 5.

1045 Stefan Lüddemann, "1.2 Stichwort Hermeneutik," in *Einführung in die Bildhermeneutik: Methoden und Beispielanalysen*, ed. Stefan Lüddemann and Thomas Heinze (Springer, 2016), 17–18.

method in art history for interpreting images.[1046] As art historians increasingly use data and digital technologies in their research, the implications of this shift warrant discussion.

Alberto Romele points out that digital technologies are inherently hermeneutic "because they structurally have and offer representations of the world that must be interpreted to access the world," and more generally "because in this field one has to be able to discriminate between the interpretative agencies of humans and non-humans."[1047] He reasons:

> In conclusion, the hermeneutics of information (and, more broadly, digital hermeneutics) is a material hermeneutics for three reasons: (1) because it starts from an analysis which is internal and not extrinsic to the object in question; (2) because it deals with the varieties of contexts of production and reception of meaning; (3) because it is interested in the matter (the techniques and technologies) through which digital traces are transformed into data, and data into information.[1048]

A thoughtful approach to data, acknowledging its non-neutrality and the interpretive nature of visualizations, is crucial for working with digital collections. While quantitative analyses offer valuable justifications, qualitative methods remain indispensable for interpretation.

Data in the Humanities

Freely accessible digital collections from GLAM institutions have advanced the digital humanities by making primary sources available.[1049] The development of Web 2.0 technologies furthered interactive engagement with digital content and research, moving beyond static websites.[1050] These advances promote interdisciplinary collaboration by integrating digital primary sources with digital approaches.[1051] As to Lorna Hughes et al. observe:

> Digital methods—including text analysis and mining, image analysis, moving image capture and analysis, and quantitative and qualitative data analysis—

1046 Stefan Lüddemann and Thomas Heinze, "1.1 Aufbau und Ziele des Bandes," in *Einführung in die Bildhermeneutik: Methoden und Beispielanalysen*, ed. Stefan Lüddemann and Thomas Heinze (Springer, 2016), 11–12.

1047 Alberto Romele, *Digital Hermeneutics* (Routledge, 2020), 10, https://doi.org/10.4324/9780429331893.

1048 Romele, *Digital Hermeneutics*, 38.

1049 Lorna Hughes et al., "Digital Methods in the Humanities: Understanding and Describing Their Use Across the Disciplines," in *A New Companion to Digital Humanities*, ed. Susan Schreibman et al. (Wiley Blackwell, 2016), 151.

1050 Hughes et al., "Digital Methods," 151.

1051 Hughes et al., "Digital Methods," 151.

> can be found at a key point of intersection between disciplines, collections, and researchers.[1052]

Access to digitized materials in addition to digital tools and methods is transforming humanities research, making it possible to address new research questions that depend on digital resources, tools, and methods.[1053] Practicing digital humanities methods means expanding and transforming scholarship "in all aspects of data capture, investigation, analysis, modeling, presentation, and the communication of the results."[1054]

The increasing availability of larger datasets raises questions about the role of big data in the humanities. Lev Manovich argues that humanities datasets can hardly be called big data compared to the massive datasets used in the natural sciences, requiring supercomputers.[1055] Similarly, Maximilian Schich resists categorizing digital art history projects as big data endeavors, emphasizing that,

> As a consequence, like most quantitative scientists, when working towards publication, we are worried about issues of undersampling and bias; in short, we worry about having enough data, not about being overwhelmed by too much.[1056]

Matt Turck started a series of blog posts to present a growing chart of the data technology landscape, offering a comprehensive overview of tools for large-scale data analysis. His annual series reflects the evolution from big data to artificial intelligence (AI).[1057] Initially titled "Big Data Landscape" in 2012, the visualization became "Data & AI Landscape" in 2019 and "Machine Learning, AI and Data (MAD) Landscape" by 2021.[1058] The most recent version from March 2024 categorizes the tools and technologies into

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1052 Hughes et al., "Digital Methods," 152.

1053 Hughes et al., "Digital Methods," 153.

1054 Hughes et al., "Digital Methods," 153.

1055 Lev Manovich, "Trending: Verheißungen und Herausforderungen der Big Social Data," in *Big Data: Analysen zum Digitalen Wandel von Wissen, Macht und Ökonomie*, ed. Ramón Reichert (transcript, 2014), 66.

1056 Maximilian Schich, "Figuring Out Art History," *International Journal for Digital Art History*, no. 2 (2016): 50, https://doi.org/10.11588/dah.2016.2.24761.

1057 Matt Turck, "Is Big Data Still a Thing? (The 2016 Big Data Landscape)," 2016, accessed April 15, 2018, https://mattturck.com/big-data-landscape/#more-917.

1058 Matt Turck, "A Chart of the Big Data Ecosystem," 2012, accessed April 9, 2021, https://mattturck.com/a-chart-of-the-big-data-ecosystem/; Matt Turck, "A Turbulent Year: The 2019 Data & AI Landscape," 2019, accessed April 9, 2021, https://mattturck.com/data2019/; Matt Turck, "Red Hot: The 2021 Machine Learning, AI and Data (MAD) Landscape," 2021, accessed July 14, 2024, https://mattturck.com/data2021/.

the layers infrastructure, analytics, machine learning and artificial intelligence, applications, open source infrastructure, data sources and APIs, and data and AI consulting.[1059]

Karin van Es and Mirko Tobias Schäfer define "big data" as a label that is "used to describe a set of practices involving the collection, processing and analysis of large data sets."[1060] Quantitative analysis, while not always aligned with the traditional focus of humanities and art historical research, can provide valuable perspectives. For example, algorithms analyzing paintings across genres and time periods can measure changes in perceptions of beauty or detect patterns unrecognizable through basic visual analysis.[1061] Machine learning and AI offer promising approaches for processing large image datasets, identifying features beyond those captured in manually recorded metadata. Similarly, these methods also apply to large text corpora, offering faster ways to extract key aspects than traditional close reading.

Distant View

Franco Moretti argued in 2013 that no one is able to read the literature of an entire century and proposed finding "a new critical method."[1062] His concept of "distant reading" addresses the challenge of analyzing vast literary corpora. He proposed bypassing individual text readings to detect trends and structures across large datasets.[1063] Distant reading complements traditional "close reading" by focusing on quantitative analysis of texts in order to explore broader patterns.[1064] The methodology is equally relevant to visual data, as seen in "distant viewing," a term K. Bender applies to art history.[1065] By shifting from a close to a distant perspective, researchers and users can

1059 Matt Turck, "Full Steam Ahead: The 2024 MAD (Machine Learning, AI & Data) Landscape," 2024, accessed March 15, 2025, https://mattturck.com/mad2024/. Access the interactive visualization here: https://mad.firstmark.com/.

1060 Karin van Es and Mirko Tobias Schäfer, "Introduction: New Brave World," in *The Datafied Society: Studying Culture Through Data*, ed. Mirko Tobias Schäfer and Karin van Es (Amsterdam University Press, 2017), 13.

1061 Javier de la Rosa and Juan-Luis Suárez, "A Quantitative Approach to Beauty: Perceived Attractiveness of Human Faces in World Painting," *International Journal for Digital Art History*, no. 1 (2015): 114, https://doi.org/10.11588/dah.2015.1.21640.

1062 Franco Moretti, *Distant Reading* (Verso, 2013), 45–46; See also his book *Graphs, Maps, Trees*, where he calculates how many novels could be read at all from a literary corpus: Moretti, *Graphs, Maps, Trees*, 3–4.

1063 Moretti, *Distant Reading*.

1064 Moretti, *Distant Reading*, 48, 212.

1065 K. Bender, "Distant Viewing in Art History: A Case Study of Artistic Productivity," *International Journal for Digital Art History*, no. 1 (2015), https://doi.org/10.11588/dah.2015.1.21639.

analyze extensive image collections to identify tendencies and connections within datasets.

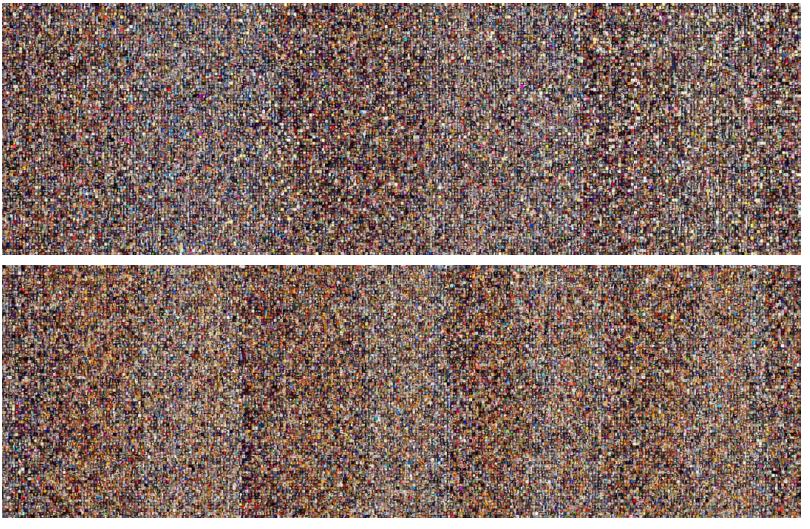


Figure 51. *Comparison of two montage visualizations. Instagram photos shared over four consecutive 24-hour periods in New York City* (top) *and Tokyo* (bottom). *The photos are sorted by publication date* (top to bottom) *and time of day* (left to right). Phototrails*, Cultural Analytics Lab, City University of New York, 2013, https://phototrails.net* (reproduced by permission from, "Montage," *Phototrails*, accessed August 8, 2025, https://phototrails.net/visualizations/montage-visualizations/)

The seemingly infinite digital image data available today through social media and digitized collections presents new issues for humanists, who have traditionally worked with smaller sets.[1066] Lev Manovich coined the term "cultural analytics" to describe methods and techniques for analyzing large datasets of images and video through visualization.[1067] This process begins with digital image processing, where characteristics like contrast, texture, curvature of lines, edges, hue, saturation, and brightness are automatically extracted. Next, 2D visualizations are created by positioning the images two axes based on these extracted feature values—for example, using brightness for one axis and saturation for the other.[1068] This automatic image analysis

1066 Lev Manovich, "How to Compare One Million Images?" in *Understanding Digital Humanities*, ed. David M. Berry (Palgrave Macmillan, 2012), 250.

1067 Manovich, "How to Compare?" 262.

1068 Manovich, "How to Compare?" 262–263.

"generates numerical descriptions of various visual characteristics of the images" and produces "visualisations that show the complete image set organised by these characteristics."[1069] Such analyses allow a single artifact to be viewed in relation to broader patterns.[1070]

The montages in figure 51 showing Instagram photos uploaded over a four-day period in New York City and in Tokyo, illustrate this technique. Over 50,000 images are arranged in each grid by upload sequence (*top-to-bottom*) and time (*left-to-right*), with the oldest in the top-left corner and the newest in the bottom-right. From a distance, stripes and hue patterns emerge, offering a basis for comparing the two cities.

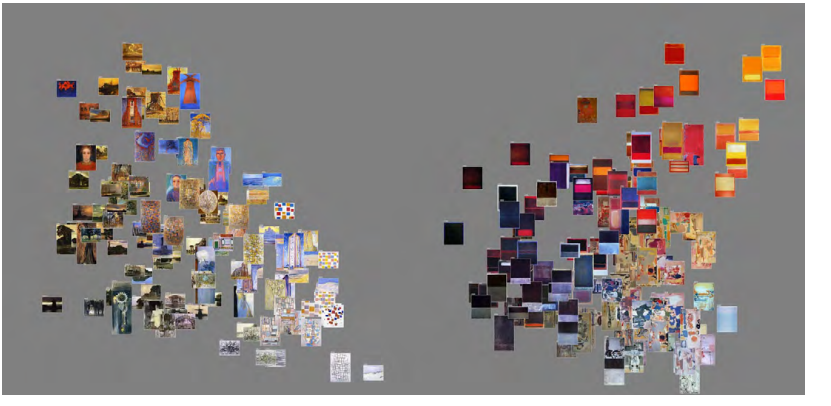


Figure 52. *Two image plots. 128 paintings by Piet Mondrian, created from 1905–1917* (left) *and 151 paintings by Mark Rothko, created from 1944–1957* (right). *The x-axis represents the brightness mean, the y-axis the saturation mean* (Reproduced by permission from Lev Manovich, *Mondrian vs Rothko: Revealing the Comparative "Footprints" of the Modern Painters* (2011), accessed May 25, 2021, https://lab.culturalanalytics.info/2016/04/mondrian-vs-rothko.html)

Manovich also uses a technique called "image plot."[1071] These scatter plots, created with the open-source software ImagePlot,[1072] superimpose images on points in a Cartesian coordinate system. In these plots, two measured values—such as average brightness and average saturation—determine the

1069 Manovich, "How to Compare?" 251.

1070 Manovich, "How to Compare?" 252.

1071 Manovich, "How to Compare?" 264.

1072 ImagePlot, Software Studies Initiative, accessed January 31, 2025, https://blog.softwarestudieslab.com/p/imageplot.html; "ImagePlot," GitHub, accessed December 27, 2024, https://github.com/culturevis/imageplot.

position of each image.[1073] Manovich's visualization (fig. 52) compares the oeuvres Mark Rothko and Piet Mondrian, revealing distinct characteristics and differences.

This type of data visualization aligns with criteria identified by Katrin Glinka and Marian Dörk. The primary goal of computer-aided visualization is to uncover, understand, and communicate trends and relationships in data. This is based on the assumption that human perception is particularly adept at recognizing visual patterns, allowing complex relationships within large datasets to be captured and understood more efficiently through visual means.[1074] Visualizations not only facilitate hypotheses testing but also offer new insights that can only be detected through visual representation.[1075] Stefka Hristova notes that "cultural analytics calls upon the understanding of images as objects with features, and more specifically as image-data in and of themselves" in contrast to digital humanities methodologies that "tend to focus on the metadata: historical and cultural information about the artifact."[1076] This distinction reflects Hristova's view of the digital humanities as text-oriented, though digital art history typically prioritizes images over text.

The use of large image datasets raises important questions about how these resources are created and accessed. One critical issue in research is "how can we compile *representative samples* that systematically cover everything created in a particular period, geographic area and media—or in many such periods and areas together?"[1077] However, even in the most comprehensive digitization, each collection reflects decisions about what is included or excluded, leading to uncertainties about what constitutes a representative sample.

When using genuine digital media from social media networks rather than retro-digitized artworks, the situation differs. Social media data is accessible to developers, users, and researchers via APIs, allowing the extraction of large samples.[1078] Application programming interfaces (APIs), such as the former Twitter-API (now X-API), provide standardized access to data, which

1073 Manovich, "How to Compare?" 263–264.

1074 Katrin Glinka and Marian Dörk, "Zwischen Repräsentation und Rezeption: Visualisierung als Facette von Analyse und Argumentation in der Kunstgeschichte," in *Computing Art Reader: Einführung in die digitale Kunstgeschichte*, ed. Piotr Kuroczyński et al. (arthistoricum.net, 2018), 237, https://doi.org/10.11588/arthistoricum.413.c5825.

1075 Glinka and Dörk, "Zwischen Repräsentation und Rezeption," 237.

1076 Stefka Hristova, "Images as Data: Cultural Analytics and Aby Warburg's Mnemosyne," *International Journal for Digital Art History*, no. 2 (2016): 117, https://doi.org/10.11588/dah.2016.2.23489.

1077 Lev Manovich, "Cultural Data: Possibilities and Limitations of Working with Historical Cultural Data," in *Museum and Archive on the Move: Changing Cultural Institutions in the Digital Era*, ed. Oliver Grau (De Gruyter, 2017), 264, https://doi.org/10.1515/9783110529630-017.

1078 Manovich, "Cultural Data," 273.

can then be retrieved, combined, and visualized to study correlations that may answer cultural questions. This requires the development of new methods to process and analyze large datasets.[1079] Open APIs also enable access to digital collections from museums and other cultural institutions, aiding research and data reuse. In addition to offering technical specifications for accessing data, APIs allow developers to embed content into websites and create new applications.[1080] Machine-readable data is essential for processing large datasets.

Maximilian Schich addresses the uncertainties around data in art history, noting:

> I am not saying that there are no well-defined groups of objects. What I am saying is that, based on existing evidence, we have to deal with massive gradients of uncertainty. If we want to understand the art market, beyond some well-identified paintings, collectors, auction houses, etc., we have to deal with a vast majority of uncertain attributions, a majority of rare and unknown actors, and of course the unknown amount of "dark data." In other words, art history has to deal with probability distributions and potential sources of bias, just like social science, biology, and other quantitative fields.[1081]

Despite this, Schich advocates for integrating humanities research, computation, natural science, and information design to better understand art and cultural history. Digital technology, often criticized by qualitative humanities as mere data management, has the potential to advance art history if researchers, computer experts, and designers embrace collaboration.[1082]

Claire Bishop has voiced concerns about digital art history, criticizing its focus on computational metrics, which, while useful for identifying patterns, fail to explain causality or provide interpretative depth.[1083] Jorge Sebastián Lozano counters that "minimal interest for interpretive purposes is connected to qualitative and quantitative methods; more exactly, to their possibilities and limitations."[1084] He argues that any computer-aided analysis of art historical data involves interpretation, as all digital resources and tools

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1079 Jean Burgess and Axel Bruns, "Twitter-Archive und die Herausforderungen von *Big Social Data* für die Medien- und Kommunikationswissenschaft," in *Big Data: Analysen zum digitalen Wandel von Wissen, Macht und Ökonomie*, ed. Ramón Reichert (transcript, 2014), 192.

1080 Burgess and Bruns, "Twitter-Archive," 194.

1081 Schich, "Figuring Out Art History," 56.

1082 Schich, "Figuring Out Art History," 52.

1083 Claire Bishop, "Against Digital Art History," *International Journal for Digital Art History*, no. 3 (2018): 127, https://doi.org/10.11588/dah.2018.3.49915.

1084 Jorge Sebastián Lozano, "Digital Art History at the Crossroads," *kunsttexte.de*, no. 4 (2017): 3, https://doi.org/10.18452/18695.

carry inherent assumptions about what the data encompasses and how it is analyzed.[1085] It is imperative to consider the conditions under which data is collected, how it is analyzed, and how it is visualized since these factors influence possible interpretations.

5.5 Visualizations as Models

As demonstrated throughout previous discussions, interactive information visualizations, through dynamic content selection, maintain clarity while also providing more thorough information than static visualizations.[1086] That said, further examination is needed to understand the underlying conditions that enable these results, particularly the statistical aspects of data visualization.

Statistical analysis provides deep insights into data, but it requires expertise. To address this challenge, Forrest W. Young et al. proposed a system that uses visual statistics to simplify user interaction via dynamic, interactive graphics.[1087] Their strategy aimed to make data analysis more intuitive by translating mathematical statistics into visual forms, transforming "algebraic obscurity into geometric clarity."[1088] In this framework, "Mathematically, computationally, perceptually, and cognitively appropriate … [graphics] can induce intuitive visual understanding."[1089] By using graphics to model complex data, visualizations help make abstract, multifaceted information more accessible. However, care must be taken to avoid oversimplification. The ability to view data from multiple perspectives leads to a more nuanced understanding. Young et al. stress the importance of well-designed user interfaces, noting that interactive graphics are more complicated than static ones since they require active user engagement, rather than passive viewing.[1090] Consequently, the visualization's design can incorporate statistical methods without requiring users to execute it themselves. While this makes the process more intuitive, it limits flexibility, since users cannot choose the underlying statistical methods, potentially hindering outcomes.

Visualizations are inherently models, shaped by decisions which data to

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1085 Sebastián Lozano, "Digital Art History," 3.

1086 Jens Weber and Andreas Wolter, "Interaktive Visualisierungen als Erkenntnismodelle am Beispiel des Projekts *impulsBauhaus*," in *La visualisation des données en histoire // Visualisierung von Daten in der Geschichtswissenschaft*, ed. Enrico Natale et al. (Chronos, 2015), 291, accessed October 5, 2019, https://blog.ahc-ch.ch/wp-content/uploads/2015/09/12-Weber-Wolter.pdf.

1087 Young et al., *Visual Statistics*, xiii.

1088 Young et al., *Visual Statistics*, 5.

1089 Young et al., *Visual Statistics*, 5.

1090 Young et al., *Visual Statistics*, 122.

include and how to present it. Ingeborg Reichle et al. meticulously dissected the concept of a model in their 2008 book.[1091] A model is an idealized representation that does not replicate reality but still claims validity. Mathematical and scientific models make abstract relations, relationships, and structures tangible and comprehensible.[1092] Models are always influenced by the context in which they are created and should be evaluated in terms of their intended purpose. Furthermore, models are not static; they are tools that enable specific actions and help generate new knowledge.[1093] Models used to access cultural heritage in digital collections, for example, may differ from those used in art historical research due to divergent epistemic interests and interaction requirements.

Rather than simply representing what is already known, models aim to construct a reality that reflects the model's interpretation.[1094] For instance, 3D modeling, like the construction of perspective in the Renaissance, results from decisions and interpretations.[1095] The epistemic value of a model lies in its ability to transform abstract structures into comprehensible forms, making it possible to manipulate and predict outcomes that would not be possible with the original object. A model is a stand-in that, via theoretical actions, provides an understanding of the object.[1096] Models are dynamic tools that incorporate knowledge about change, offering alternatives, and evolving over time. If viewed as a final product, a model is still the result of iterative processes that test and evaluate multiple possibilities.[1097]

Visual models' strength lies in their ability to organize complex relationships into manageable components, thereby reducing overall complexity. Rather than directly representing reality, models depict a version of reality composed of discrete parts. Models define what kinds of statements are meaningful, but they also have blind spots[1098] They may suggest particular interpretations, exclude others, or emphasize certain aspects while obscuring others.[1099] While no model is perfect, they remain valuable tools for analysis and understanding.

1091 Ingeborg Reichle et al., eds., *Visuelle Modelle* (Wilhelm Fink, 2008).

1092 Reichle et al., *Visuelle Modelle*, 9.

1093 Reichle et al., *Visuelle Modelle*, 10.

1094 Reichle et al., *Visuelle Modelle*, 11.

1095 Theodor Wyeld, "The Implications of David Hockney's Thesis for 3D Computer Graphics," in *Knowledge Visualization Currents: From Text to Art to Culture*, ed. Francis T. Marchese and Ebad Banissi (Springer, 2013), 134, https://doi.org/10.1007/978-1-4471-4303-1_7.

1096 Reichle et al., *Visuelle Modelle*, 10–11.

1097 Reichle et al., *Visuelle Modelle*, 12.

1098 Reichle et al., *Visuelle Modelle*, 12.

1099 Reichle et al., *Visuelle Modelle*, 12.

Reinhard Wendler stressed that a model's properties depend on the material or medium used to realize it.[1100] Digital technologies, for instance, make possible the creation of models with unique characteristics that may differ from their analog counterparts. Digital models take various forms including data visualizations with diagrams and 3D visualizations of cultural heritage.

3D Reconstructions and Transparency

3D reconstructions, particularly when paired with virtual reality (VR) techniques, can model environments that no longer exist due to destruction or alteration over time, like recreating a city before it was destroyed by an earthquake[1101] or virtually restoring lost polychromy in ancient Greek and Roman art and architecture.[1102]

Sander Münster et al. explored the benefits and limitations of 3D reconstruction in a 2018 article.[1103] They define a digital reconstruction as "a spatial, temporal, and semantic virtual model."[1104] The objectives of such reconstructions include documentation, data quality assessment, visualization, process investigation, conceptualization, contextualization, numerical analysis, and hypothetical simulations.[1105] To ensure precision, 3D reconstructions must "answer questions which existing sources leave open."[1106] Consequently,

> possible gaps in the sources must be documented, identified and made traceable as such. Any supplementary conclusions made by analogy also have to be accompanied by a valid explanation. Only through such supplementary information can an architectural model, which at first glance seems to be self-explanatory, be open to scientific scrutiny and thus be comparable. This subsequently gives rise to the question whether 3D reconstructions represent a step backwards in the evolution of historical scholarship.[1107]

1100 Reinhard Wendler, *Das Modell zwischen Kunst und Wissenschaft* (Wilhelm Fink, 2013), 20.

1101 Helena Murteira and Paulo Simões Rodrigues, "Lost Cities in the Digital Era: The Case of Pre-Earthquake Lisbon," in *Space and Time Visualisation*, ed. Maria Boştenaru Dan and Cerasella Crăciun (Springer, 2016).

1102 Eliana Siotto et al., "Ancient Polychromy," *Journal on Computing and Cultural Heritage* 8, no. 3 (2015): 1–20, https://doi.org/10.1145/2739049.

1103 Sander Münster et al., "3D Reconstruction Techniques as a Cultural Shift in Art History?" *International Journal for Digital Art History*, no. 3 (2018): 39–59, https://doi.org/10.11588/dah.2018.3.32473.

1104 Münster et al., "3D Reconstruction Techniques," 40.

1105 Münster et al., "3D Reconstruction Techniques," 48–49.

1106 Münster et al., "3D Reconstruction Techniques," 49.

1107 Münster et al., "3D Reconstruction Techniques," 49.

Transparency in documenting methods and decisions behind 3D reconstructions is imperative for ensuring reliability.[1108] As Principle 4 in the London Charter for the Computer-Based Visualisation of Cultural Heritage states: "Sufficient information should be documented and disseminated to allow computer-based visualisation methods and outcomes to be understood and evaluated in relation to the contexts and purposes for which they are deployed."[1109] There was awareness of the need for documentation early on within the digital heritage community, as evidenced by Hugh Denard's statement:

> The London Charter for the Computer-Based Visualisation of Cultural Heritage was conceived, in 2006, as a means of ensuring the methodological rigour of computerbased visualization as a means of researching and communicating cultural heritage. Also sought was a means of achieving widespread recognition for this method.[1110]

Denard argues further for intellectual transparency, "there is a need to reconcile heritage visualization with professional norms of research, particularly the standards of argument and evidence."[1111] The London Charter has meanwhile become widely established "as the de facto benchmark to which heritage visualization processes and outputs should be held accountable" and thus has met the goal of creating an "international consensus on the principles that should inform best practice in heritage visualization across disciplines."[1112]

The results of 3D modeling are either an "acquired artefact" or a "synthetic artefact."[1113] Acquired artefacts are based on data captured via photography or laser scanning, while synthetic artefacts are created in 3D modeling software and can "represent hypotheses of the past."[1114] This means that 3D models exist as computational simulations of artifacts or architecture.[1115]

1108 Anna Bentkowska-Kafel, "'I Bought a Piece of Roman Furniture on the Internet. It's Quite Good but Low on Polygons.'—Digital Visualization of Cultural Heritage and Its Scholarly Value in Art History," *Visual Resources* 29, no. 1–2 (2013): 42–43, https://doi.org/10.1080/01973762.2012.761117.

1109 London Charter for the Computer-based Visualisation of Cultural Heritage, London Charter 2.1, revised February 2009, accessed December 27, 2024, https://www.londoncharter.org.

1110 Hugh Denard, "A New Introduction to the London Charter," in *Paradata and Transparency in Virtual Heritage*, ed. Anna Bentkowska-Kafel et al. (Ashgate, 2012), 57.

1111 Denard, "New Introduction," 58.

1112 Denard, "New Introduction," 58.

1113 Sven Havemann, "Intricacies and Potentials of Gathering Paradata in the 3D Modelling Workflow," in *Paradata and Transparency in Virtual Heritage*, ed. Anna Bentkowska-Kafel et al., Digital Research in the Arts and Humanities (Ashgate, 2012), 145.

1114 Havemann, "Intricacies and Potentials," 145.

1115 Jens Schröter, "Medienästhetik, Simulation, und 'Neue Medien'," in *Medienästhetik*, ed. Erich Hörl and Mark B. N. Hansen, Zeitschrift für Medienwissenschaft 8 (Diaphanes, 2013), 92,

Augmented Reality and Virtual Reality

Simulated 3D objects can be explored through augmented reality (AR) or virtual reality (VR). In AR, digital elements are overlaid on the physical world, while in VR, users are immersed in and interact with an entirely computer-generated environment. In a technical sense, immersion means that a VR environment attends to sensory perception as comprehensively as possible by using one or more output devices.[1116] Victoria Szabo defines AR as "the use of digitally delivered overlays or supplements to existing material environments."[1117] AR adds content—such as images, sounds, or 3D models—to real-world settings via smartphones or headsets.[1118] By using image recognition or GPS location,[1119] "AR systems have the potential to help users create situated knowledge by bringing scholarly interpretation and archival resources in dialog with the lived experience of a space or object."[1120] This hybrid technology is particularly valuable for museums or cultural heritage sites.[1121]

Information Representation

Sander Münster contends that 3D reconstructions of historical objects should not be viewed as replacements for physical models but as tools for research and education.[1122] These digital models are used to visualize and interpret reconstructed historical architecture, always only approximations, which inherently involves abstraction and information gaps.[1123] Dominik Lengyel and Catherine Toulouse focus their research on how 3D models can indicate uncertainty, as in the visualization of blurred

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https://e-text.diaphanes.net/doi/10.4472/9783037342404.0006.

1116 Ralf Dörner et al., "Einleitung," in *Virtual und Augmented Reality (VR / AR): Grundlagen und Methoden der Virtuellen und Augmentierten Realität*, ed. Ralf Dörner et al. (Springer Vieweg, 2013), 14.

1117 Victoria Szabo, "Apprehending the Past: Augmented Reality, Archives, and Cultural Memory," in *The Routledge Companion to Media Studies and Digital Humanities*, ed. Jentery Sayers (Routledge Taylor & Francis Group, 2018), 372.

1118 Szabo, "Apprehending the Past," 372.

1119 Szabo, "Apprehending the Past," 374.

1120 Szabo, "Apprehending the Past," 372.

1121 Szabo, "Apprehending the Past," 373.

1122 Münster, *Interdisziplinäre Kooperation*, 23.

1123 Jan-Eric Lutteroth and Stephan Hoppe, "Schloss Friedrichstein 2.0: Von digitalen 3D-Modellen und dem Spinnen eines semantischen Graphen," in *Computing Art Reader: Einführung in die digitale Kunstgeschichte*, ed. Piotr Kuroczyński et al. (arthistoricum.net, 2018), 186.

features in historical architecture.[1124] As seen in the work of Erica Calogero et al., 3D models are also employed to represent unrealized architecture as they did with the facade designs for the Louvre's east wing.[1125] Furthermore, 3D models can serve as preservation tools, capturing more detailed information than traditional 2D documentation, which is especially useful for objects at risk of deteriorating or disappearing altogether. Katsushi Ikeuchi and Daisuke Miyazaki offer a straightforward reminder that:

> Currently, a large number of cultural heritage objects around the world are deteriorating or being destroyed because of natural disasters, such as earthquakes and floods, or man-made disasters, such as civil wars and vandalism.[1126]

They argue that in comparison to 2D pictures that only preserve the appearance of a cultural heritage object, 3D data records "can record 3D shapes of objects permanently and then safely pass these down to future generations."[1127] Moreover, the data can be used for restoration simulation and online presentation.[1128]

3D Modeling

The creation of 3D models of cultural heritage sites consists of several steps. First, data is collected through sensors, such as laser scanning or photogrammetry to generate a point cloud of the object's shape. Next, overlapping datasets are aligned, and their mesh structures are merged to a unified surface. Photometric modeling maps color and lighting onto the surface, and the model can then be used for analysis, interface design, and multimedia display.[1129]

Piotr Kuroczyński emphasizes the need for documentation standards in 3D reconstruction and computer-aided visualization of cultural heritage to

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1124 Dominik Lengyel and Catherine Toulouse, "Visualisierung von Hypothesen: Zur Gestaltung von Abstraktion bei der Darstellung unscharfen Wissens in Archäologie, Bauforschung und Kunstgeschichte," in *Computing Art Reader: Einführung in die digitale Kunstgeschichte*, ed. Piotr Kuroczyński et al. (arthistoricum.net, 2018), 204.

1125 Erica Calogero et al., "Using Procedural Modeling to Explore Alternative Designs for the Louvre," *Journal on Computing and Cultural Heritage* 6, no. 4 (2013): 1–22, https://doi.org/10.1145/2532630.2512883.

1126 Katsushi Ikeuchi and Daisuke Miyazaki, "Introduction," in *Digitally Archiving Cultural Objects*, ed. Katsushi Ikeuchi and Daisuke Miyazaki (Springer, 2008), 1.

1127 Ikeuchi and Miyazaki, "Introduction," 1.

1128 Ikeuchi and Miyazaki, "Introduction," 1.

1129 Ikeuchi and Miyazaki, "Introduction," 2–7.

avoid the loss of information.[1130] To address this, current research focuses on creating Virtual Research Environments (VREs) and interoperable data models.[1131] Future advancements in Semantic Web and 3D web technologies will further enhance digital 3D reconstructions, providing frameworks for collaborative research and art historical inquiry.[1132]

A 3D model is a simplified representation of reality, useful for several purposes: visualizing existing or speculative objects, supporting scholarly publications, or enhancing interactives.[1133] The advantage of 3D models lies in their ability to provide different views, such as floor plans, sections, and elevations, within a singular spatial context, which can be customized to meet specific needs.[1134] Models incorporating semantically enriched 3D data and annotations can aid in interpreting the significance of objects in the context of their historical environment.[1135] A 3D model can be used and reused in a variety of ways, for animation videos, in a game, in an immersive VR or AR application, or made tangible by 3D printing.[1136]

Immersive Space

An immersive three-dimensional space can be combined with data visualization, as shown in the research of Sarah Kenderdine et al. who use "interactive, immersive, and collaborative techniques to explore large-scale datasets."[1137] Their projects offer 360° immersion in ultra-high stereoscopic resolution.[1138] Such experimental projects tap into diverse fields, including "multimedia analysis, visual analytics, interaction design, embodied cognition, stereographics and immersive display systems, computer graphics, semantics and

1130 Piotr Kuroczyński, "Neuer Forschungsraum für die Kunstgeschichte: Virtuelle Forschungsumgebungen für digitale 3D-Rekonstruktionen," in *Computing Art Reader: Einführung in die digitale Kunstgeschichte*, ed. Piotr Kuroczyński et al. (arthistoricum.net, 2018), 162.

1131 Kuroczyński, "Neuer Forschungsraum für die Kunstgeschichte," 162.

1132 Kuroczyński, "Neuer Forschungsraum für die Kunstgeschichte," 162.

1133 Kuroczyński, "Neuer Forschungsraum für die Kunstgeschichte," 162.

1134 Kuroczyński, "Neuer Forschungsraum für die Kunstgeschichte," 164.

1135 Felix Lange and Martin Unold, "Semantisch angereicherte 3D-Messdaten von Kirchenräumen als Quellen für die geschichtswissenschaftliche Forschung," in *Grenzen und Möglichkeiten der Digital Humanities: Sonderband 1 der ZfdG*, ed. Constanze Baum and Thomas Stäcker (HAB – Herzog August Bibliothek, 2015), https://doi.org/10.17175/sb001_015.

1136 Kuroczyński, "Neuer Forschungsraum für die Kunstgeschichte," 164.

1137 Sarah Kenderdine et al., "Cultural Data Sculpting: Omnidirectional Visualization for Cultural Datasets," in *Knowledge Visualization Currents: From Text to Art to Culture*, ed. Francis T. Marchese and Ebad Banissi (Springer, 2013), https://doi.org/10.1007/978-1-4471-4303-1_11, 199–200.

1138 Kenderdine et al., "Cultural Data Sculpting," 200.

intelligent search, and computational linguistics.".[1139] The Advanced Visualization and Interaction Environment (AVIE), makes possible projects that address the "core challenges of visual analytics, multimedia analysis, text analysis, and visualization … to provide … an omnidirectional exploration of museum collections, archaeological laser scan data, and multiple textual data sets" that can be explored "through interactive navigation … in 360° 3D space."[1140]

Uta Hinrichs et al. foreground the potential of digital technology for physical museum spaces. They see digital information presentation as informal visualizations designed for "people from various backgrounds and with differing experiences rather than targeting domain-expert audiences."[1141] Notably, they emphasize the role of "real and virtual public spaces" in this context.[1142] Hinrichs et al. argue that in GLAM institutions, "large display technology can be combined with information visualization to provide information access in a more immersive and engaging way."[1143] Information visualization, in this sense, goes well beyond text panels and labels to conveying content that objects alone cannot communicate.[1144]

Mitchell Whitelaw observes, "Visualisation enables us to literally show everything, to display large volumes of data in a way that reveals patterns and communicates context, but also provides access to the fine grain of individual elements."[1145] Digital technology offers an expanse of possibilities to create intuitive interfaces for exploring collection databases, extending beyond simple keyword searches.[1146]

1139 Kenderdine et al., "Cultural Data Sculpting," 201.

1140 Kenderdine et al., "Cultural Data Sculpting," 217–18.

1141 Uta Hinrichs et al., "EMDialog: Bringing Information Visualization into the Museum," *IEEE Transactions on Visualization and Computer Graphics* 14, no. 6 (2008): 1181, https://doi.org/10.1109/TVCG.2008.127.

1142 Hinrichs et al., "EMDialog," 1181.

1143 Hinrichs et al., "EMDialog," 1181.

1144 Hinrichs et al., "EMDialog," 1181.

1145 Mitchell Whitelaw, "Visualising Archival Collections: The Visible Archive Project," *Archives and Manuscripts* 37, no. 2 (2009): 24, accessed December 8, 2020, https://publications.archivists.org.au/index.php/asa/article/view/10033/10027.

1146 Florian Windhager et al. created the following website with a collection of papers that present a variety of interfaces for the visualization of digital cultural collections: Visualization of Cultural Heritage Collection Data, accessed April 15, 2021, http://collectionvis.org (site discontinued). They used these sources for their journal article: Florian Windhager et al., "Visualization of Cultural Heritage Collection Data: State of the Art and Future Challenges," *IEEE Transactions on Visualization and Computer Graphics* 25, no. 6 (2019): 2311–2330, https://doi.org/10.1109/TVCG.2018.2830759.

Data Visualizations in the Humanities

Historians are increasingly engaging with data visualizations—networks, maps, statistics, multimedia, and research environments.[1147] This shift raises questions about where to source usable data, how to structure it, which visualization best suits the results, and how to maximize programs' and algorithms' effectiveness.[1148] Johanna Drucker cautions against using visualizations in the digital humanities without critically questioning "the intellectual implications of the use of graphical arguments built on tools borrowed from other disciplines."[1149] She reiterates us that information visualizations and interface displays "are premised on assumptions about data, knowledge design, content models, and file formats," which must be considered when they inform interpretations and projects in the humanities.[1150]

As convincing and simple as a visualization may appear, "the design of accurate and appropriate representations of quantitative information" is not an automatic process that happens at the push of a button.[1151] The design of accurate and fitting representations of quantitative information requires careful attention. Graphical elements, proportions, color schemes and arrangements are seamlessly integrated to make complex datasets clear and convey specific content. Visualizations, therefore, involve subjective decisions and intellectual work.[1152] Further, they are not neutral; they are constructed images that act as surrogates for the data they represent. In the humanities, the data itself is often extracted from a larger corpus or cultural artifact, shaped by interpretive decisions from the outset.[1153] The challenge lies in recognizing the differences between data—typically well-defined—and artifacts, which often thrive on ambiguity.[1154] Museums, art history, and the digital humanities must find ways of handling data that take into account idiosyncrasies unique to the digital form as distinct from the physical objects they represent.

1147 Enrico Natale et al., eds., *La visualisation des données en histoire // Visualisierung von Daten in der Geschichtswissenschaft* (Chronos, 2015), accessed October 2, 2019, https://blog.ahc-ch.ch/publikationen/band-18-19-2015-visualisierung/.

1148 Natale et al., *La visualisation des données*, 14.

1149 Drucker, "Graphical Approaches," 238.

1150 Drucker, "Graphical Approaches," 239.

1151 Drucker, "Graphical Approaches," 239.

1152 Drucker, "Graphical Approaches," 239.

1153 Drucker, "Graphical Approaches," 245.

1154 Drucker, "Graphical Approaches," 246.

5.6 Conclusion

This examination of interactive visualization applications reveals that design choices are always driven by content and the specific data available in digital collections of art. The data's properties determine the forms of visualization that are possible, and the same dataset can be represented in various ways to highlight different aspects. The right type of visualization depends on the data being used and the questions posed. There is no universal template. However, using open-source technology and sharing application code can foster collaboration and mutual support among researchers and museums. Applications tailored to specific projects or collections are unlikely to be useful for others without adaptations, which is why skilled professionals are needed to modify existing tools or create new ones to meet evolving research questions or museum needs.

Good visualizations demand thoughtful decisions about what should be presented and how. The approach will always depend on the data used, the intended outcome, and the target audience. Since data is inherently multifaceted, simplifying it to focus on a few key aspects is necessary. A visualization is always a simplification, as it models relationships while inevitably omitting some parameters. Interactive and generative designs have the advantage of layering more dimensions into a representation, allowing for the visualization of complex issues without confusion. When different aspects of a dataset must be highlighted, multiple visualizations or customizable, interactive visualizations may be necessary. The ability to adjust and enrich visualizations, through to hover-over features or combining multiple kinds of diagrams, complicates the design process.

A visualization cannot stand alone; it requires interpretation. Researchers must be mindful of the data used, the dataset's limits, and the conclusions that can or cannot be reached. Misinterpretations should be avoided, which is why statistical knowledge or awareness of potential biases in the data and visualization process is essential.

Certain software and tools are better suited for specific types of visualizations involving images, metadata, or both. Museums and art historians must assess which technologies and data sources best support their research and the development of interactive applications for effectively presenting art collections. From a technological standpoint, machine learning and computer vision may offer promising methods for data analysis and search. However, creating custom visualizations and data-driven applications requires expertise in software usage, development, and programming. Tools not only facilitate visualization but also many other forms of data interaction, a topic to be explored in the next chapter.

6 Software and Tools for Images and Metadata

6.1 Introduction

A software-assisted approach to art and the presentation of collections differs significantly from traditional, analog methods of researching and exhibiting art. Digital methods are reshaping both museums and art history, influencing how artworks are presented, how space is defined, how knowledge is created and disseminated, and how art is researched. This shift fosters a fundamentally new understanding of art in the digital realm.

When curating museum exhibitions, the focus is usually on physical artworks within a specific spatial context. The presentation is framed by fixed and mobile walls, pedestals, casework, video projectors, and screens. As part of the exhibition process, sometimes an exhibition catalog is produced conveying knowledge for posterity. In the digital age, however, the effectiveness of museum exhibitions, printed catalogs, guided tours, audio guides, and collections online to generate knowledge is in question. Digital tools for capturing, storing, modeling, and representing knowledge can complement existing methods, contributing to a more comprehensive, flexible knowledge system that is accessible through multiple channels. Publishing through digital technology and representing the collection as a digital collection could elevate the knowledge exchange between science and exhibition practice over time.[1155]

This chapter focuses on how software and tools can be used for images and metadata from digital collections. It explores the methods, procedures, and tools that can be used in applications and art historical research with digital data. As Sabine Lang and Björn Ommer state succinctly:

> If we continue to use techniques which resemble analog approaches to visualize digital images, we do not embrace the fact that computer-based visualization techniques significantly enhance our viewing practices.[1156]

Viewing art in the digital space is most effective when it departs from merely replicating traditional exhibition and research methods or transferring printed formats into a digital environment. It is about finding new

1155 See chapter 2, p. 66 for the distinction between a *Collection Online* and a *Digital Collection*.

1156 Sabine Lang and Björn Ommer, "Transforming Information into Knowledge: How Computational Methods Reshape Art History," *Digital Humanities Quarterly* 15, no. 3 (2021): 21, accessed August 30, 2021, https://www.digitalhumanities.org/dhq/vol/15/3/000560/000560.html.

ways of producing knowledge in art history that are different from merely replicating analog methods in a digital environment.[1157] The "methods to extract information and produce new knowledge" are different when using digital images.[1158] Computational methods make possible that "thousands of images might be viewed and compared simultaneously; the user can change perspectives, zoom in or obtain an overview of the data."[1159] This approach facilitates a deeper examination of digital collections and the creation of custom usage scenarios.

Focusing on digital images and textual information as sources expands the possibilities for art historical interpretation. Research can shift from treating catalog images as surrogates for physical artworks to emphasizing the digital image as a primary source. The original artwork may even become secondary when the digital image is the main focus, allowing for different research approaches. Interpretation of art, therefore, could extend beyond the analysis of the artwork itself or its context within an artist's oeuvre, historical periods, or social and cultural developments. While traditional research methods are still possible for the digital realm, different conditions necessitate a thorough understanding of digital tools for both the presentation and analysis of art.

Tools and software are essential not only for representing art but also for analyzing it—at the level of image data, metadata, and files—to determine relationships between other files and collections. Here, the artwork as a physical object is of less importance than the digital image as a virtual object, especially since a digital copy can be manipulated, modified, and analyzed through digital means. This flexibility is unique to digital files, allowing them to be processed with software tools in ways that physical objects cannot be. In contrast, the original artwork, once created by the artist, is considered unchangeable. Digital images, however, can be processed and altered without risking any loss to the original artwork's integrity or meaning.

The digital image serves as a virtual model of the artwork, which can be used for testing hypotheses. Unlike analog methods, digital technology offers the opportunity to explore new possibilities that would be time-consuming or impossible with traditional methods. Digital images possess a unique haptic quality, allowing reversible interventions in a virtual state that are not tied to physical reality. This expansion of research opportunities makes the digital image increasingly valuable for studying and presenting art. Computer technology enables simultaneous alteration

1157 Lang and Ommer, "Transforming Information into Knowledge," 20.

1158 Lang and Ommer, "Transforming Information into Knowledge," 21.

1159 Lang and Ommer, "Transforming Information into Knowledge," 21.

and processing of images across large collections, leading to innovative approaches for classifying and presenting art.

This chapter highlights approaches to computationally processing visual data and metadata in museums and art history. It delves into the tools and methods used in digital humanities and computer science to analyze images and metadata, looking deeper at computer vision (for shape and color analysis), algorithms, machine learning, and the *International Image Interoperability Framework (IIIF)*, which facilitates the mobilization of images from digital collections.

New approaches to researching and presenting artworks in museums and art history is a natural progression of the growing interest in working with data in both fields. These approaches incorporate methods from computer science and digital humanities, which give rise to new research questions and ways of engaging with art historical data. By adopting practices from these disciplines, museums and art historians increasingly rely on free and open-source software, programming, and coding. The use of nonproprietary software has advantages, including community support and adaptability, which ensure the sustainability and continued development of the software. Publicly released software developed in digital humanities or museum projects fosters a sense of community that drives both progress in museums and art history.

An openness to diverse technical solutions is essential, as it allows the consideration of numerous software and tools that may be useful for analyzing and visualizing images or metadata. Many tools, especially those commonly used with image collections are compiled in appendix C. Embracing a variety of tools enables researchers to address a wide range of questions and tasks in digital humanities while ensuring that museum applications are adaptable to different topics and purposes. The same problem can often be solved using different tools or programming languages, so it is less important to know the specific tools available than to understand core principles and how to apply them to data from digital collections.

Although few museums have yet adopted these approaches, there is great potential for their future application. In academia, digital humanities projects that involve collaboration between art historians and computer scientists have already embraced these methods.

This chapter introduces tools and approaches commonly used in digital humanities, cultural heritage, and museum projects. While the focus is on the methods and technologies behind analysis, the goal is to demonstrate the significance of techniques from computer science in understanding cultural data. Chapter 6 identifies two principal ways to apply tools to visual data. The first involves analyzing individual digital images or collections through

statistical analysis, algorithms, image processing, machine vision, or deep learning. The second focuses on using applications to present images or collections through web technologies, JavaScript libraries, data visualization tools (see examples discussed in chapter 5), storytelling (see section 4.5 and also figure 47 in chapter 5), or virtual exhibitions (as discussed in section 4.3). The most effective applications often combine both strategies, with computational analysis laying the foundation for creating meaningful interfaces. This chapter aims to provide an overview of the technological concepts underlying these approaches and how they can be applied to research with digital collections.

6.2 Tool Types

The use of software and tools for digital collections begins with understanding the differences between digital and analog images. Digital images, made up of pixels and accompanied by descriptive metadata, offer unique possibilities for processing and analysis.[1160] Celia Krause and Ruth Reiche note that a key characteristic differentiating digital images from analog ones is that the former cannot only be viewed, but also processed by machines.[1161] This distinction is central to the intersection of art history and computer science, as Sabine Lang and Björn Ommer reiterate that digital images of original artworks can be duplicated, modified, and analyzed using neural networks.[1162]

Software tools like *Adobe Photoshop* are often used for visual optimization, but in the context of digital art history, the focus shifts from appearance to the underlying pixel data—values that can be analyzed, visualized, and manipulated. Such operations might include analyzing color or saturation, or cropping. More advanced techniques, such as neural network analysis, further illustrate this computational perspective, shifting the image to "an object of analysis and evaluation," as Igor Gurevich and Yurii Zhuravlev describe.[1163]

1160 Celia Krause and Ruth Reiche, "Ein Bild sagt mehr als tausend Pixel? Über den Einsatz digitaler Methoden in den Bild- und Objektwissenschaften," *Kunstgeschichte. Open Peer Reviewed Journal*, no. 10 (2014): 4, accessed October 14, 2015, https://www.kunstgeschichte-ejournal.net/420/1/EinBildsagtmehralstausendPixel_CK_RR.pdf.

1161 Krause and Reiche, "Mehr als tausend Pixel?," 4.

1162 Lang and Ommer, "Transforming Information into Knowledge," 20.

1163 Igor Boris Gurevich and Yurii Ivanovich Zhuravlev, "Computer Science: Subject, Fundamental Research Problems, Methodology, Structure, and Applied Problems," *Pattern Recognition and Image Analysis* 24, no. 3 (2014): 340, https://doi.org/10.1134/S1054661814030195.

In contrast to straightforward image editing, which is concerned with visual appearance, computational methods emphasize measurable features of the image.[1164] Programs like *ImageMagick*[1165] or the *Python Imaging Library (Pillow)*[1166] offer command-line tools to process images in bulk, which is more efficient than manually manipulating each image. This batch processing enables large-scale image transformations, like color adjustment or resizing, which are crucial for preparing digital images for analysis.

For more complex tasks, libraries like *scikit-image*[1167] provide algorithms for advanced image processing with Python—detecting edges, performing geometric transformations, and segmenting objects. Such capabilities are essential for analyzing large collections and extracting specific features using machine learning. *OpenCV*, another powerful open-source tool, expands these capabilities by supporting real-time computer vision applications such as face recognition, object detection, motion tracking, and 3D modeling.[1168]

These advanced tools are central to image retrieval, a key aspect of digital image analysis. Adriana Kovashka and Kristen Grauman define image retrieval as a "task in which a human user poses a query using either text or an image to a search engine, and the engine returns image results."[1169] Digital images can be searched using metadata, tags, or content-based image retrieval (CBIR), which analyzes low-level features like color, shape, and texture.[1170] More advanced methods, like Emotion Semantic Image Retrieval (ESIR), combine emotion analysis with CBIR to refine search results based on human emotional responses to art.[1171]

Despite the potential of these techniques, museums and art historians have only begun to explore their unprecedented applications for digital collections and research. A simple example is color extraction, used by muse-

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1164 Celia Krause and Ruth Reiche, *Ein Bild sagt mehr als tausend Pixel? Digitale Forschungsansätze in den Bild- und Objektwissenschaften* (vwh Verlag Werner Hülsbusch, 2016), 14.

1165 *ImageMagick*, ImageMagick Studio, accessed December 27, 2024, https://imagemagick.org.

1166 *Python Imaging Library (Pillow)*, accessed July 14, 2021, https://python-pillow.org.

1167 *scikit-image*, accessed December 27, 2024, https://scikit-image.org.

1168 *OpenCV*, accessed December 27, 2024, https://opencv.org.

1169 Adriana Kovashka and Kristen Grauman, "Attributes for Image Retrieval," in *Visual Attributes*, ed. Rogerio Schmidt Feris et al. (Springer International Publishing, 2017), 90, https://doi.org/10.1007/978-3-319-50077-5_5.

1170 Kitsuchart Pasupa et al., "Using Image Features and Eye Tracking Device to Predict Human Emotions Towards Abstract Images," in *Image and Video Technology: 7th Pacific-Rim Symposium, PSIVT 2015, Auckland, New Zealand, November 25–27, 2015, Revised Selected Papers*, ed. Thomas Bräunl et al. (Springer International Publishing, 2016), 419, https://doi.org/10.1007/978-3-319-29451-3_34.

1171 Pasupa et al., "Using Image Features," 420.

ums like Cooper Hewitt[1172] and formerly the Rijksmuseum's *Rijksstudio*,[1173] allowing users to find artworks by color. The Barnes Foundation[1174] took this a step further by using machine learning and computer vision to categorize images in its online collection, enabling users to browse artworks based on visual features such as color, line, light, space, and similarity. However, few museums have fully embraced such technologies to enhance the user experience.

In addition to the tools for image analysis, there are many approaches to data processing and presentation. For instance, software environments and tools like *R*, *OpenRefine*, *RapidMiner*, and *KNIME* support data mining and data modeling,[1175] enabling researchers to extract patterns, organize information, and visualize connections across large datasets.[1176]

However, presenting this data requires specialized tools that can handle the complex metadata and data models inherent to digital collections. For example, tools for creating ontologies (*Protégé*[1177]), visualizing data structures, storytelling (Digitorials/Stories, p. 231), presenting virtual tours and exhibitions (p. 216), or displaying images (p. 328), all help present digital collection images and metadata.

Susan Schreibman and Ann M. Hanlon consider the development of tools in the digital humanities as scholarly output just like articles, books, and conference presentations, while also driving intellectual and methodological advancements that often lead to traditional scholarly outputs.[1178]

The type of data determines the method of analysis: text and images can be processed manually or automatically, relying on distinct features suited to visual or linguistic structures. In traditional research with digital art collections, source discovery typically depends on assigned textual metadata,

1172 *Explore the Collection*, Cooper Hewitt, accessed December 27, 2024, https://collection.cooperhewitt.org.

1173 *Rijksstudio*, Rijksmuseum, accessed July 14, 2021, https://www.rijksmuseum.nl/en/rijksstudio (site discontinued). New site: *Collection*, Rijksmuseum, accessed December 27, 2024, https://www.rijksmuseum.nl/en/collection.

1174 *Our Collection*, Barnes Foundation, accessed December 27, 2024, https://collection.barnesfoundation.org.

1175 *R*, R Foundation, accessed December 27, 2024, https://www.r-project.org; *OpenRefine*, accessed December 27, 2024, https://openrefine.org; *RapidMiner*, Altair, accessed December 27, 2024, https://rapidminer.com; and *KNIME*, accessed December 27, 2024, https://www.knime.com.

1176 Nan Cao and Weiwei Cui, *Introduction to Text Visualization* (Atlantis Press, 2016), 5.

1177 *Protégé*, Stanford University, accessed December 27, 2024, https://protege.stanford.edu.

1178 Susan Schreibman and Ann M. Hanlon, "Determining Value for Digital Humanities Tools: Report on a Survey of Tool Developers," *Digital Humanities Quarterly* 4, no. 2 (2010): 1–41, accessed October 24, 2014, https://digitalhumanities.org/dhq/vol/4/2/000083/000083.html.

limiting accessibility when relevant details are absent. Crowdsourcing platforms, such as Amazon's *Mechanical Turk*,[1179] or *Zooniverse,*[1180] enable metadata enhancement through crowd annotations.[1181] While crowdsourced annotations can be noisy, clear instructions improve accuracy.[1182] For tasks requiring domain expertise, involving specialists ensures higher-quality results.[1183] A key advantage of crowdsourced tagging is that annotations can be precisely positioned within images using landmarks or bounding boxes to indicate object locations.[1184] These annotated datasets help assign metadata to previously untagged artworks, improving searchability and filtering within digital collections.

Digital collection can be explored by clustering images into categories based on keywords from artwork records.[1185] This enables filtering of large image collections by creating networks of similar images based on crowd annotations, without relying on computer vision. Here, individual annotations become secondary to algorithmically extracted latent concepts.[1186] These image clusters can then be used to train convolutional neural networks (CNNs), allowing automatic classification of digital collection images, independent of existing metadata.[1187]

Even the most comprehensive metadata can never anticipate every possible question. Adriana Kovashka and Kristen Grauman argue:

> It is infeasible to pre-assign tags to images that are sufficient to satisfy any future query. Further, due to the "semantic gap" between the system's low-level image representation and the user's high-level concept, one-shot retrieval performed by matching images to keywords is unlikely to get the right results.[1188]

1179 *Mechanical Turk*, Amazon, accessed December 27, 2024, https://www.mturk.com/mturk/welcome.

1180 *Zooniverse*, accessed December 27, 2024, https://www.zooniverse.org.

1181 Lars Wieneke et al., "Building the Social Graph of the History of European Integration: A Pipeline for Humanist-Machine Interaction in the Digital Humanities," in *Social Informatics: SocInfo 2013 International Workshops, QMC and HISTOINFORMATICS, Kyoto, Japan, November 25, 2013, Revised Selected Papers*, ed. Akiyo Nadamoto et al. (Springer, 2014), 95.

1182 Subhransu Maji, "A Taxonomy of Part and Attribute Discovery Techniques," in *Visual Attributes*, ed. Rogerio Schmidt Feris et al. (Springer International Publishing, 2017), 261, https://doi.org/10.1007/978-3-319-50077-5_10.

1183 Wieneke et al., "Building the Social Graph," 96.

1184 Maji, "Part and Attribute Discovery," 258.

1185 Stefanie Schneider and Hubertus Kohle, "The Computer as Filter Machine: A Clustering Approach to Categorize Artworks Based on a Social Tagging Network," *Artl@s Bulletin* 6, no. 3 (2017): 81–89, accessed August 8, 2021, https://docs.lib.purdue.edu/artlas/vol6/iss3/6/.

1186 Schneider and Kohle, "Computer as Filter Machine," 84.

1187 Schneider and Kohle, "Computer as Filter Machine," 88–89.

1188 Kovashka and Grauman, "Attributes for Image Retrieval," 90.

Consequently, most research questions can only be answered through rough approximations of sources. A promising method for locating similar artworks in a collection is to rely on the features of the images themselves, utilizing content-based image retrieval (CBIR). By mathematically representing the visual content of images as feature vectors—like color, texture, and shape—CBIR quantifies the image's characteristics and enables comparisons independent of assigned keywords or indexing terms.[1189] CBIR searches based on images rather than metadata. Malcolm Collier notes, analyzing images in a digital collection of art "is a search for pattern and meaning."[1190] On one hand, the content of images is directly analyzed as data to identify subjects or features within them; on the other, images often are "vehicles or triggers for information not necessarily present in the images themselves," requiring archival or other research to understand the broader context.[1191]

Textual sources central to art history are also valuable resources when combined with digital images and metadata. Scholarly publications and archival documents, increasingly available in digital form, can enrich digital collection data. Automated text analysis is possible if the texts are machine-readable. For digitized printed texts, optical character recognition (OCR) can be used, and scanned handwritten documents can be made searchable through text recognition algorithms.[1192] This shift towards digital access to archival material changes how research is conducted.[1193] In some cases, digital methods and tools are more efficient than close reading, especially for processing and analyzing large amounts of textual data. Text mining, for example, allows for systematic retrieval of text data across corpora through automated analysis.[1194] Automatic text analysis often requires visualization, such as n-gram analysis (fig. 43, p. 258), to make the results interpretable and support distant reading.[1195]

1189 Theo van Leeuwen and Carey Jewitt, eds., *Handbook of Visual Analysis* (SAGE Publications, 2001), 101–104.

1190 Malcolm Collier, "Approaches to Analysis in Visual Anthropology," in *Handbook of Visual Analysis*, ed. Theo van Leeuwen and Carey Jewitt (SAGE Publications, 2001), 35.

1191 Collier, "Analysis in Visual Anthropology," 36–39.

1192 Tobias Hodel, "Lesende Algorithmen: Projekt READ," *Das Mittelalter* 24, no. 1 (2019): 224–227, https://doi.org/10.1515/mial-2019-0016.

1193 Hodel, "Lesende Algorithmen," 224.

1194 Stefan Wagner and Daniel Méndez Fernández, "Analyzing Text in Software Projects," in *The Art and Science of Analyzing Software Data*, ed. Christian Bird et al. (Morgan Kaufmann, 2015), 39–40.

1195 Wagner and Méndez Fernández, "Analyzing Text," 40.

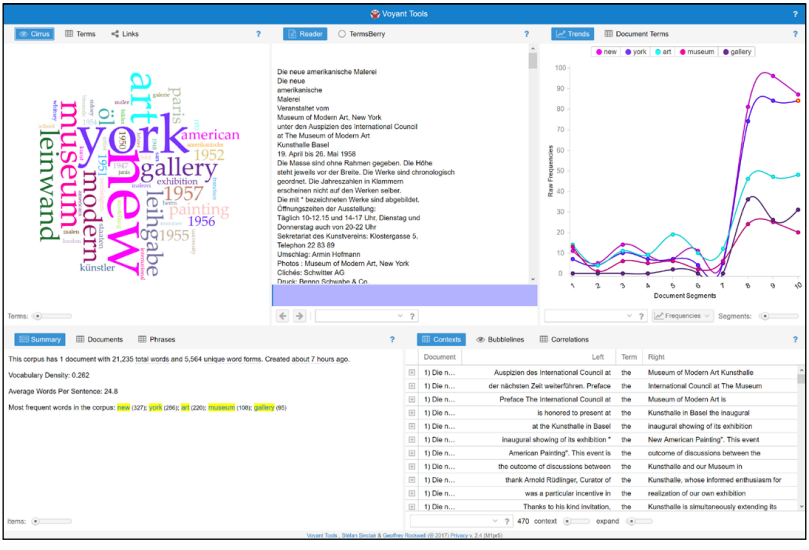


Figure 53. Voyant Tools *dashboard. Featuring applied stop word list for German, English, and French, text from the 1958 Kunsthalle Basel catalog* Die neue amerikanische Malerei. *Created with* Voyant Tools*, accessed October 8, 2017, https://voyant-tools.org*

Voyant Tools,[1196] a platform developed in linguistics for digital text analysis, provides various visualizations to assist in data interpretation. For example, to analyze a printed exhibition catalog like Kunsthalle Basel's *Die neue amerikanische Malerei* (1958),[1197] of the Kunsthalle Basel from 1958, the text must first be scanned and processed with OCR (fig. 53). The best results occur when the text is in one language, but since the catalog includes German, English, and French, manual correction was necessary.[1198] Once prepared, the text (including captions and biographies) can be analyzed for repeated

1196 *Voyant Tools*, accessed December 27, 2024, https://voyant-tools.org.

1197 Kunsthalle Basel, ed., *Die neue amerikanische Malerei* (Kunsthalle Basel, 1958).

1198 The text in MoMA's catalog was only published in English but is available as a scanned PDF with OCR. Museum of Modern Art, ed., *The New American Painting: As Shown in Eight European Countries, 1958–1959* (Museum of Modern Art, 1959); scanned PDF version, accessed November 6, 2017, https://www.moma.org/documents/moma_catalogue_1990_300190211.pdf.

words using *Voyant Tools*.[1199] Applying a stop word list, created from lists in English, German, and French,[1200] filters out common terms like "the" or "and," resulting in the most significant terms. The word cloud visualization in the dashboard highlights the most used words with larger ones indicating higher frequency. Even without knowing the catalog's content, the prominent terms suggest its subject matter. Terms like "Museum of Modern Art" and "New York" appear often, and further analysis indicates the catalog likely discusses 1950s oil painting on canvas, possibly in Paris, with a focus on American artists.

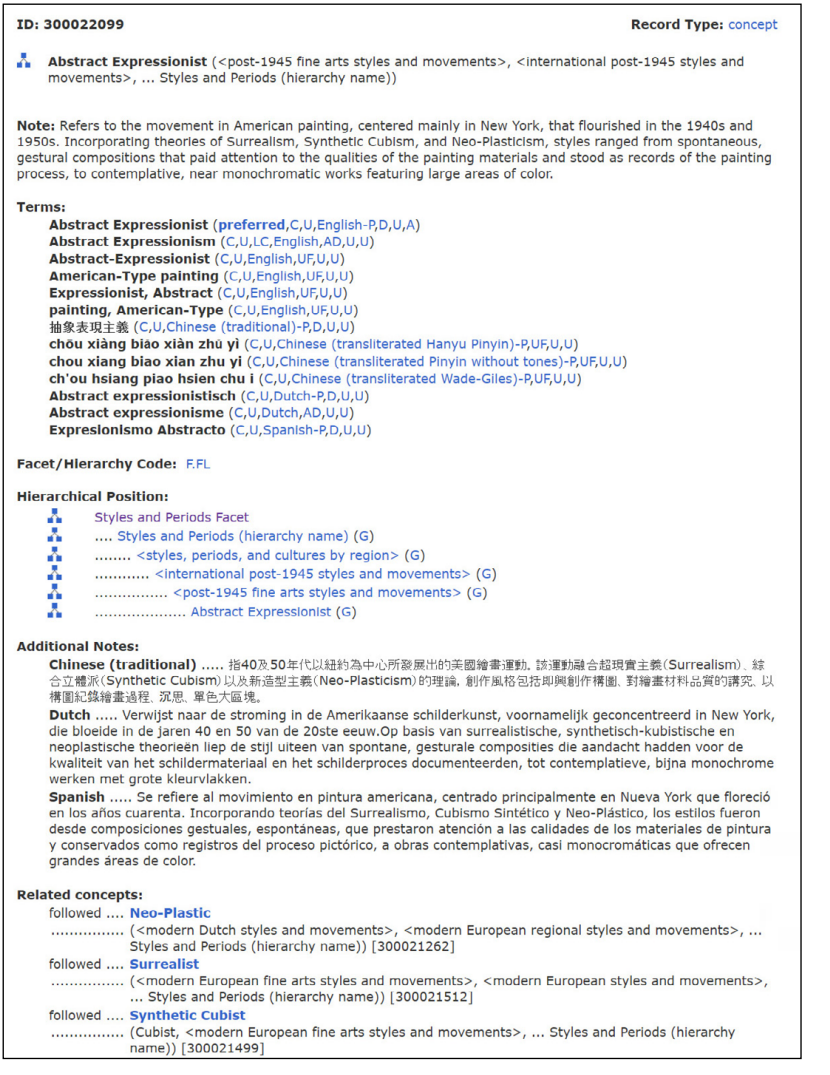
At first glance, a list of isolated words might seem insignificant, as full comprehension requires concentrated reading. However, Franco Moretti's "distant reading" allows for quantitative analysis of the literature, enabling researchers to evaluate corpora too vast for a single person to read in its entirety.[1201] Moreover, extracted terms from the catalog form a semantic field connected to *The New American Painting* exhibition. Revealing this semantic field, especially within an art context, can uncover new perspectives and connections. Thus, linking terms to datasets that provide additional information is crucial. The Getty Research Institute's vocabularies, published as linked open data (LOD), offer such resources.[1202]

1199 The project created in *Voyant Tools* for the text analysis of Kunsthalle Basel's catalog *Die neue amerikanische Malerei* was discontinued at the link below. *Voyant Tools*, accessed October 8, 2017, https://voyant-tools.org/?corpus=885bbbcf99567f90349c283e536e7885 (discontinued).

1200 The applied combined stop word list for German, English, and French has the reference "keywords-48a6d057307980a9faaf64adc10bdfc7" in *Voyant*.

1201 Moretti, *Distant Reading* (Verso, 2013).

1202 *Getty Vocabularies*, Getty Research Institute, accessed November 7, 2017, https://www.getty.edu/research/tools/vocabularies.



ID: 300022099 **Record Type:** concept

Abstract Expressionist (<post-1945 fine arts styles and movements>, <international post-1945 styles and movements>, ... Styles and Periods (hierarchy name))

Note: Refers to the movement in American painting, centered mainly in New York, that flourished in the 1940s and 1950s. Incorporating theories of Surrealism, Synthetic Cubism, and Neo-Plasticism, styles ranged from spontaneous, gestural compositions that paid attention to the qualities of the painting materials and stood as records of the painting process, to contemplative, near monochromatic works featuring large areas of color.

Terms:

Abstract Expressionist (**preferred**,C,U,English-P,D,U,A)
Abstract Expressionism (C,U,LC,English,AD,U,U)
Abstract-Expressionist (C,U,English,UF,U,U)
American-Type painting (C,U,English,UF,U,U)
Expressionist, Abstract (C,U,English,UF,U,U)
painting, American-Type (C,U,English,UF,U,U)
抽象表現主義 (C,U,Chinese (traditional)-P,D,U,U)
chōu xiàng biǎo xiàn zhǔ yì (C,U,Chinese (transliterated Hanyu Pinyin)-P,UF,U,U)
chou xiang biao xian zhu yi (C,U,Chinese (transliterated Pinyin without tones)-P,UF,U,U)
ch'ou hsiang piao hsien chu i (C,U,Chinese (transliterated Wade-Giles)-P,UF,U,U)
Abstract expressionistisch (C,U,Dutch-P,D,U,U)
Abstract expressionisme (C,U,Dutch,AD,U,U)
Expresionismo Abstracto (C,U,Spanish-P,D,U,U)

Facet/Hierarchy Code: F.FL

Hierarchical Position:

Styles and Periods Facet
.... Styles and Periods (hierarchy name) (G)
..... <styles, periods, and cultures by region> (G)
..... <international post-1945 styles and movements> (G)
..... <post-1945 fine arts styles and movements> (G)
..... Abstract Expressionist (G)

Additional Notes:

Chinese (traditional) ..... 指40及50年代以紐約為中心所發展出的美國繪畫運動。該運動融合超現實主義(Surrealism)、綜合立體派(Synthetic Cubism)以及新造型主義(Neo-Plasticism)的理論，創作風格包括即興創作構圖、對繪畫材料品質的講究，以構圖紀錄繪畫過程、沉思、單色大區塊。

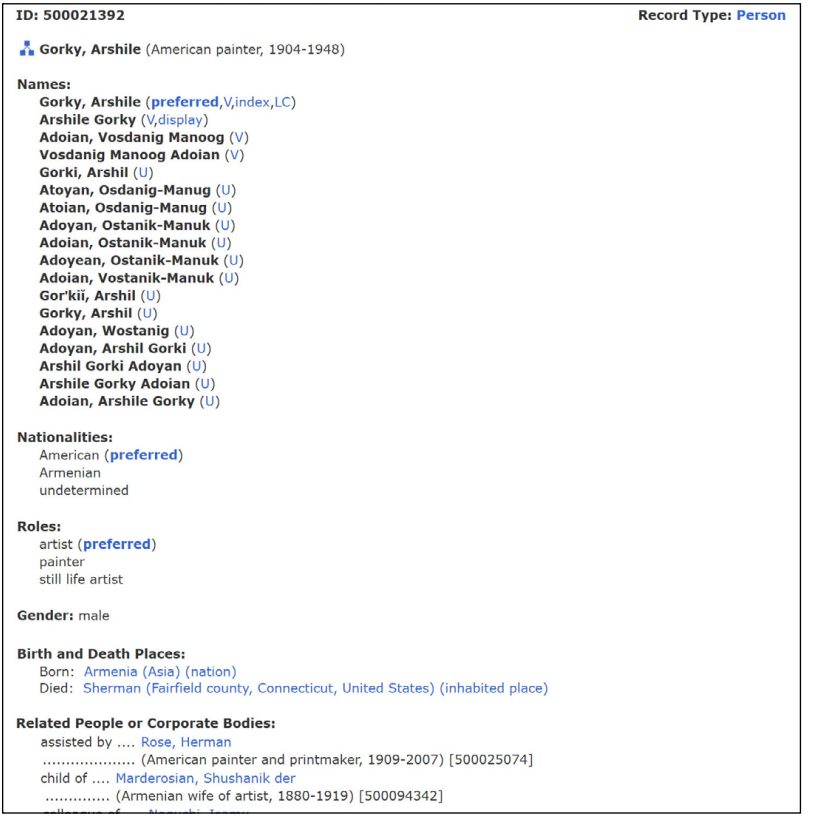
Dutch ..... Verwijst naar de stroming in de Amerikaanse schilderkunst, voornamelijk geconcentreerd in New York, die bloeide in de jaren 40 en 50 van de 20ste eeuw.Op basis van surrealistische, synthetisch-kubistische en neoplastische theorieën liep de stijl uiteen van spontane, gesturale composities die aandacht hadden voor de kwaliteit van het schildermateriaal en het schilderproces documenteerden, tot contemplatieve, bijna monochrome werken met grote kleurvlakken.

Spanish ..... Se refiere al movimiento en pintura americana, centrado principalmente en Nueva York que floreció en los años cuarenta. Incorporando teorías del Surrealismo, Cubismo Sintético y Neo-Plástico, los estilos fueron desde composiciones gestuales, espontáneas, que prestaron atención a las calidades de los materiales de pintura y conservados como registros del proceso pictórico, a obras contemplativas, casi monocromáticas que ofrecen grandes áreas de color.

Related concepts:

followed .... **Neo-Plastic**
..... (<modern Dutch styles and movements>, <modern European regional styles and movements>, ... Styles and Periods (hierarchy name)) [300021262]
followed .... **Surrealist**
..... (<modern European fine arts styles and movements>, <modern European styles and movements>, ... Styles and Periods (hierarchy name)) [300021512]
followed .... **Synthetic Cubist**
..... (Cubist, <modern European fine arts styles and movements>, ... Styles and Periods (hierarchy name)) [300021499]

Figure 54. *"Abstract Expressionist" record in the* Art & Architecture Thesaurus (AAT), *Getty Research Institute, accessed May 13, 2019, https://vocab.getty.edu/page/aat/300022099*


ID: 500021392 Record Type: Person

Gorky, Arshile (American painter, 1904-1948)

Names:
Gorky, Arshile (preferred,V,index,LC)
Arshile Gorky (V,display)
Adoian, Vosdanig Manoog (V)
Vosdanig Manoog Adoian (V)
Gorki, Arshil (U)
Atoyan, Osdanig-Manug (U)
Atoian, Osdanig-Manug (U)
Adoyan, Ostanik-Manuk (U)
Adoian, Ostanik-Manuk (U)
Adoyean, Ostanik-Manuk (U)
Adoian, Vostanik-Manuk (U)
Gor'kiĭ, Arshil (U)
Gorky, Arshil (U)
Adoyan, Wostanig (U)
Adoyan, Arshil Gorki (U)
Arshil Gorki Adoyan (U)
Arshile Gorky Adoian (U)
Adoian, Arshile Gorky (U)

Nationalities:
American (preferred)
Armenian
undetermined

Roles:
artist (preferred)
painter
still life artist

Gender: male

Birth and Death Places:
Born: Armenia (Asia) (nation)
Died: Sherman (Fairfield county, Connecticut, United States) (inhabited place)

Related People or Corporate Bodies:
assisted by .... Rose, Herman
..... (American painter and printmaker, 1909-2007) [500025074]
child of .... Marderosian, Shushanik der
..... (Armenian wife of artist, 1880-1919) [500094342]

Figure 55. *"Arshile Gorky" record in the* Union List of Artist Names (ULAN)*, Getty Research Institute, accessed May 13, 2019, https://vocab.getty.edu/page/ulan/500021392*

Keywords identified with *Voyant Tools* can be connected to the *Getty Vocabularies*. For instance, searching for "painting," a prominent term in the word cloud, in the *Art & Architecture Thesaurus (AAT)*[1203] leads to the record "Abstract Expressionist" (fig 54). The record includes language variants of the term, description, and hierarchical classifications related to art styles and periods. The *Union List of Artist Names (ULAN)*[1204] contains information on

1203 *Art & Architecture Thesaurus (AAT)*, Getty Research Institute, accessed November 7, 2017, https://www.getty.edu/research/tools/vocabularies/aat.

1204 *Union List of Artist Names (ULAN)*, Getty Research Institute, accessed November 7, 2017, https://www.getty.edu/research/tools/vocabularies/ulan.

the 17 artists[1205] featured in the exhibition. Analyzing artist Arshile Gorky's record, for example, reveals name variants, biographical details, and artistic classifications (fig. 55). The records offer insights beyond brief catalog biographies, providing a richer understanding of artists and their work. In digital environments, institutions with works by these artists can assign corresponding *ULAN* IDs, facilitating searches across multiple inventories regardless of how an artist's name is spelled. By combining such records with the data from the exhibition catalog, researchers can establish meaningful connections and contextualize artworks within broader art-historical frameworks.

Topic modeling, a technique that automatically identifies key themes in a text based on the co-occurrence of words, offers a quick way to grasp core topics.[1206] While no algorithm is perfect, as topics are inherently imprecise, topic modeling helps create networks or clusters of documents with shared topics.[1207] Unlike word clouds, which rely on word frequency and are better suited for shorter texts, topic modeling uncovers semantic relationships between terms.[1208] Another approach for extracting potentially relevant information is part-of-speech (POS) tagging, which uses machine learning to identify the grammatical role of words in a text (e.g., noun, verb, adjective).[1209] This technique can be useful for extracting nouns, which may be helpful keywords for enriching digital collection records.

Statistical methods are essential to drawing conclusions from large datasets. In data science, a field closely connected to the digital humanities, these methods enable data-driven decision-making.[1210] Data organization informs how easy machine processing is. Structured data, such as CSV files, XML files, geo-coordinates, sensor data, and spreadsheets, is easier to analyze, as it follows a predefined format. In comparison, unstructured data—such as books, documents, images, or social media content—typically requires pre-

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1205 Seventeen artists featured in the Basel and New York presentations of *The New American Painting* are listed below with their *ULAN* ID in parentheses: William Baziotes (500023351), James Brooks (500017163), Sam Francis (500115537), Arshile Gorky (500021392), Adolph Gottlieb (500004904), Philip Guston (500023901), Grace Hartigan (500027518), Franz Kline (500007696), Willem de Kooning (500000974), Robert Motherwell (500016415), Barnett Newman (500000960), Jackson Pollock (500015134), Mark Rothko (500014869), Theodoros Stamos (500006236), Clyfford Still (500020155), Bradley Walker Tomlin (500016014), Jack Tworkov (500009670).

1206 Wagner and Méndez Fernández, "Analyzing Text," 49–50.

1207 Wagner and Méndez Fernández, "Analyzing Text," 50.

1208 Wagner and Méndez Fernández, "Analyzing Text," 51.

1209 Wagner and Méndez Fernández, "Analyzing Text," 51.

1210 Christian Bird et al., eds., *The Art and Science of Analyzing Software Data* (Morgan Kaufmann, 2015), 3.

processing before statistical analysis.

The humanities often work with unstructured data, such as text corpora and digital image archives. Structured data, including links to controlled vocabularies, measurements, or dates, is more likely to be found in systematically recorded cultural datasets. Common data types in the digital humanities—text, images, geodata, and networks—can be processed using the statistical programming language *R*.[1211] A thriving community of statisticians and developers has contributed packages that increase *R*'s functionality for statistical analysis, data acquisition, visualization, and reporting tools.[1212] For example, the *ggvis* package[1213] facilitates the creation of interactive data visualizations that can be embedded on websites.[1214] While *R* is powerful, its advanced programming requirements can be a barrier for some users.

To address this, tools have been developed to make data analysis more accessible without requiring programming skills. *Museum Analytics (MAX)*[1215] is a free online platform designed to allow art history students to analyze and visualize museum collection metadata.[1216] Similarly, the Cleveland Museum of Art offers tools through its *Virtual CMA Dashboards*,[1217] providing public access to usage statistics for the most popular works across curatorial departments, as accessed through *Collections Online*, the Open Access API, and *Wikipedia*. While *MAX* and the *Virtual CMA Dashboards* are focused on existing datasets, *RAWGraphs*[1218] helps users create their own visualizations from raw data. Originating from the design field, *RAWGraphs* allows users without programming knowledge to transform tabular data (CSV, XLSX, JSON) into visualizations that can be exported (as SVG, PNG, or JPG).[1219]

1211 *R*, https://www.r-project.org. Taylor Arnold and Lauren Tilton, *Humanities Data in R: Exploring Networks, Geospatial Data, Images, and Text* (Springer, 2015), v.

1212 Tim Dennis, "Using R and ggvis to Create Interactive Graphics for Exploratory Data Analysis," in *Data Visualization: A Guide to Visual Storytelling for Libraries*, ed. Lauren Magnuson (Rowman & Littlefield, 2016), 150.

1213 *ggvis*, RStudio, accessed December 27, 2024, https://ggvis.rstudio.com.

1214 Dennis, "Using R and ggvis," 150.

1215 *Museum Analytics (MAX)*, Ludwig-Maximilians-Universität München, accessed December 27, 2024, https://www.max.gwi.uni-muenchen.de.

1216 Stefanie Schneider, "Museum Analytics: Museale Sammlungen neu und anders entdecken," *Museumskunde* 84 (2019): 95, accessed June 17, 2020, https://www.museumsbund.de/wp-content/uploads/2020/04/final-schneider.pdf.

1217 *Virtual CMA Dashboards*, Cleveland Museum of Art, accessed December 27, 2024, https://www.clevelandart.org/virtual-cma-dashboards/collection-online-dashboard.

1218 *RAWGraphs*, accessed December 27, 2024, https://rawgraphs.io.

1219 Michele Mauri et al., "RAWGraphs: A Visualisation Platform to Create Open Outputs," in *Proceedings of the 12th Biannual Conference on Italian SIGCHI Chapter*, ed. Fabio Paternò et al. (ACM, 2017), https://doi.org/10.1145/3125571.3125585.

To do this, preparing the data to ensure that it contains the required types of values is usually the first step before generating visualizations.

Data preparation is a crucial part in analysis, especially since raw data is often messy and prone to errors. This process includes cleaning, manipulating, filtering, transforming, reconciling, and linking data. *OpenRefine*[1220] is a tool that aids in the preparation of large datasets and can be used for sensitive data since it operates locally on the user's computer. Along with guides on using *OpenRefine*, there are also resources available for reconciling collection data with external authorities, such as *Wikidata* and the *Getty Vocabularies*.[1221] This allows for the supplementation of datasets with additional information, like an artist's birth date or field of activity.

Automated processes are essential for managing large volumes of data. Data harvesting—collecting data from websites via web crawlers, scrapers, or APIs—is one example. In the context of GLAM institutions, the Open Archives Initiative Protocol for Metadata Harvesting (OAI-PMH)[1222] supports interoperability and data retrieval from collection databases.[1223] Tony Gill notes that the OAI protocol may eventually be replaced by linked open data (LOD) as it becomes more widely adopted.[1224]

Beyond static data from digital collections, real-time data from social media networks can also be analyzed using platform APIs. For example, Twitter (now X) data can be used for network analysis, sentiment analysis, and both quantitative and qualitative research.[1225] The *Twitter API*[1226] (now limited via the *X API*[1227]) allows access to real-time data from posts, which

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1220 *OpenRefine*, accessed December 27, 2024, https://openrefine.org.

1221 Ruben Verborgh and Max de Wilde, *Using OpenRefine: The Essential OpenRefine Guide That Takes You from Data Analysis and Error Fixing to Linking Your Dataset to the Web* (Packt Publishing, 2013); Stephanie Bolliger et al., *How to Link Your Institution's Collections to Wikidata? A Short Manual to a Semi-Automatic Way of Using the 'Archives at' Property (P485)* (ETH Zürich, 2020), https://doi.org/10.3929/ethz-b-000393724; Lindsey Gant, *Getty Vocabularies OpenRefine Tutorial and Tips for Advanced Users: How to Use the Getty Vocabularies Reconciliation Service for OpenRefine: Step by Step Process from Program Installation to Implementation* (Getty, 2019).

1222 Open Archives Initiative Protocol for Metadata Harvesting (OAI-PMH), accessed December 27, 2024, https://www.openarchives.org/pmh/tools/.

1223 Tony Gill, "Metadata and the Web," in *Introduction to Metadata*, ed. Murtha Baca, 3rd ed. (Getty Research Institute, 2016), 32, accessed June 23, 2021, https://www.getty.edu/publications/intrometadata/metadata-and-the-web/.

1224 Gill, "Metadata and the Web," 32.

1225 Katrin Weller, "Twitter und Wahlen: Zwischen 140 Zeichen und Milliarden von Tweets," in *Big Data: Analysen zum digitalen Wandel von Wissen, Macht und Ökonomie*, ed. Ramón Reichert (transcript, 2014), 239.

1226 Twitter API, Twitter, accessed November 28, 2021, https://developer.twitter.com.

1227 *X API*, X, accessed December 27, 2024, https://developer.x.com/.

can be analyzed for trends in social and cultural activity.[1228]

Social media data, including text from X and images from Instagram, can be analyzed and visualized interactively to study emotional and social relationships.[1229] Sentiment analysis algorithms can detect emotions in posts, while computer vision techniques can identify faces in Instagram images to study personal relationships.[1230] Projects like Lev Manovich's *Selfiecity*[1231] and *On Broadway*[1232] combine these techniques to explore correlations across different data sources through interactive interfaces that merge image and abstract data visualizations.

By understanding the capabilities of software and tools, researchers can rethink how cultural content is explored in the digital realm. This leads to questions about how digital analysis can be applied to data from digital collections, and how it departs from traditional methods of analyzing artworks.

6.3 Data Analysis

While original artworks are exhibited, received, and contextualized in their fixed form, the digital image's true potential is realized when it is reimagined for new methods of exhibition, reception, and contextualization. This potential is unlocked when the focus shifts from preserving the untouchable original to engaging the digital image, exploring technological possibilities, and enabling self-directed use. A solid understanding of existing approaches to image data analysis allows researchers to frame questions specific to these methodologies.

Digital collections or artworks can be analyzed at the level of individual images or entire image sets through statistical analysis, algorithms, image processing, computer vision, or deep learning. Algorithm-based search, leveraging techniques from computer vision, machine learning, and artificial intelligence, allows for direct image processing without relying on metadata. A foundational understanding of image processing methods that interpret pixels mathematically—such as those outlined by Melissa Terras—is vital.[1233]

1228 Kay L. O'Halloran et al., "The Role of Images in Social Media Analytics: A Multimodal Digital Humanities Approach," in *Visual Communication*, ed. David Machin (De Gruyter, 2014), 565–566.

1229 O'Halloran et al., "Images in Social Media," 565.

1230 O'Halloran et al., "Images in Social Media," 566–567.

1231 *Selfiecity*, accessed December 27, 2024, https://selfiecity.net.

1232 *On Broadway*, Software Studies Initiative, accessed December 27, 2024, http://www.on-broadway.nyc.

1233 Melissa Terras, "Image Processing in the Digital Humanities," in *Digital Humanities in Practice*, ed. Claire Warwick et al. (Facet, 2012), https://doi.org/10.29085/9781856049054.005.

Image processing tasks include geometric transformations (rotating, cropping, resizing), color adjustments (calibration, correction, conversion from RGB to greyscale), and image stitching. Analysis techniques include image registration, object recognition, and segmentation.[1234]

When analyzing artworks via digital images, it is important to note that reproductions may distort color, contrast, light, and sharpness.[1235] Despite these inaccuracies, digital technologies still offer significant value. Image processing makes possible searches for specific features and allows virtual restoration without touching the original artwork.[1236] As Terras observes: "The use of image processing techniques has allowed novel research to be undertaken on primary source material, providing new insights into culture and the arts."[1237]

These techniques are increasingly relevant not just in academia, but also in museums, which are expanding and enhancing their digital collections. CBIR can be used to create search engines for finding specific objects, motifs, compositions, or styles across large datasets or to design interfaces that visualize images based on analysis results.[1238] Holger Volland suggests that machine learning and AI may be of help in curating art by analyzing and comparing large datasets.[1239] Metric learning, a training algorithm, clusters and classifies similar patterns,[1240] revealing structures in images that can be used in applications to represent artworks and demonstrate correlations.

Reverse image search made possible by image processing, is underutilized in digital collections. *TinEye*[1241] and *Google Image Search*[1242] provide this functionality, but only a few platforms, like *Bavarikon*[1243] have implemented an image similarity search. Bavarikon allows users to adjust color, edge, and

1234 Terras, "Image Processing," 73.

1235 Lang and Ommer, "Transforming Information into Knowledge," 15.

1236 Terras, "Image Processing," 74.

1237 Terras, "Image Processing," 75.

1238 Lang and Ommer, "Transforming Information into Knowledge," 39.

1239 Holger Volland, "Einsatzgebiete Künstlicher Intelligenz in der inhaltlichen Arbeit von Kulturbetrieben," in *Der digitale Kulturbetrieb: Strategien, Handlungsfelder und Best Practices des digitalen Kulturmanagements*, ed. Lorenz Pöllmann and Clara Herrmann (Springer, 2019), 118, https://doi.org/10.1007/978-3-658-24030-1_6.

1240 Galina V. Iofina and Yurii V. Maximov, "Reduction Based Similarity Learning for High Dimensional Problems," *Pattern Recognition and Image Analysis* 26, no. 2 (2016): 374, https://doi.org/10.1134/S105466181602005X.

1241 *TinEye*, accessed December 27, 2024, https://tineye.com.

1242 *Google Image Search*, Google, accessed December 27, 2024, https://images.google.com.

1243 *Bavarikon*, Bayerische Staatsbibliothek, accessed December 27, 2024, https://www.bavarikon.de/imagesimilarity.

fuzziness settings to find similar motifs.[1244]

One example of research using CBIR is *iART*,[1245] which offers keyword- and content-based image retrieval using machine learning techniques and clustering. Designed for art historians, *iART* allows users to query using an image or keywords. The platform has several features to refine search results, including the ability to adjust algorithm weighting, a function usually hidden in the program code.[1246]

This points to the broader issue with any digital tool: coding is not neutral. As seen in previous chapters, decisions made by programmers shape the software's functionality. As Stefan Wagner and Daniel Méndez Fernández state, "Manual coding is a creative process that depends on the experiences, views, and interpretations of those who analyze the data to build a hierarchy of codes."[1247] The selectivity inherent in digital technologies must be considered when using such applications. Tools like *iART* mitigate this by providing users with control over certain decision-making processes through the interface. Similarly, *imgs.ai*,[1248] a deep visual search engine for digital art history, permits users to customize search metrics and refine rankings by marking images as relevant or irrelevant. Unlike *iART*, *imgs.ai* relies on image analysis entirely, without using metadata or vocabularies like *Iconclass*, making only image-based searches possible.

There are compelling benefits to image-based searches. A notable advantage of computer vision is retrieving images based on visual content, which is not described in metadata.[1249] In fact, Peter Bell and Leonardo Impett used pose recognition to identify similar depictions of biblical events like the Annunciation and Baptism by analyzing the gestures and postures of figures in medieval artworks.[1250] This method allowed for comparisons of

1244 Klaus Ceynowa and Stephan Kellner, "Das bayerische Kulturportal bavarikon – digital, vernetzt, spartenübergreifend," in *Handbuch Kulturportale: Online-Angebote aus Kultur und Wissenschaft*, ed. Ellen Euler et al. (De Gruyter Saur, 2015).

1245 *iART*, TIB Leibniz Information Centre for Science and Technology and University Library, Leibniz University Hannover, accessed December 27, 2024, https://www.iart.vision/.

1246 Matthias Springstein et al., "iART: A Search Engine for Art-Historical Images to Support Research in the Humanities," in *Proceedings of the 29th ACM International Conference on Multimedia*, ed. Heng Tao Shen et al. (ACM Special Interest Group on Multimedia Systems; Association for Computing Machinery, 2021), https://doi.org/10.1145/3474085.3478564.

1247 Wagner and Méndez Fernández, "Analyzing Text," 45.

1248 *imgs.ai*, Deutsches Dokumentationszentrum für Kunstgeschichte—Bildarchiv Foto Marburg, Philipps-Universität Marburg, accessed December 27, 2024, https://imgs.ai.

1249 Peter Bell and Leonardo Impett, "Ikonographie und Interaktion: Computergestützte Analyse von Posen in Bildern der Heilsgeschichte," *Das Mittelalter* 24, no. 1 (2019): 32, https://doi.org/10.1515/mial-2019-0004.

1250 Bell and Impett, "Ikonographie und Interaktion."

iconography across genres, techniques, styles, and periods.[1251] Even when trained on 21st-century photographs, neural networks can successfully identify art historical reproductions, despite the abstract nature of artworks.[1252] By encoding poses and reducing figures to skeletal representations, systems can compute and visualize similarities between images.[1253] This approach enables more intuitive searches for artworks based on visual content, making it easier for researchers to find works for thematic studies, even when metadata is limited.

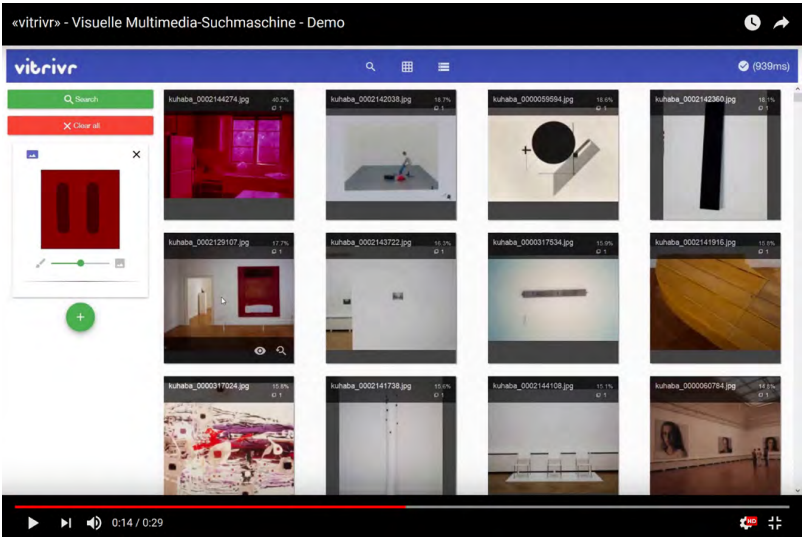


Figure 56. *Image search engine* Vitrivr*, developed by the Databases and Information Systems (DBIS) Group at the University of Basel and customized for Kunsthalle Basel's photo archive* (screenshot from a video, accessed May 7, 2022, https://www.youtube.com/watch?v=lCjcBiJuhgQ&t=14s)

Visual search enables further search methodologies that are not yet widely used. *Vitrivr*,[1254] a visual search engine developed by the University of Basel's Databases and Information Systems (DBIS) Group, allows for image retrieval based on sketches, an extension of its original use for video sequence

1251 Bell and Impett, "Ikonographie und Interaktion," 37.

1252 Bell and Impett, "Ikonographie und Interaktion," 38.

1253 Bell and Impett, "Ikonographie und Interaktion," 39–42.

1254 *Vitrivr*, Databases and Information Systems research group, University of Basel, accessed December 27, 2024, https://www.vitrivr.org.

searches, of Kunsthalle Basel's *Photo Archive*[1255] (fig. 56).[1256] This "sketch recognition," system enables users to search for photographs based on hand-drawn images, expanding the scope of possible search methods.[1257]

Collaboration across disciplines is essential for advancing these technologies. While art historians bring expertise in visual analysis, computer scientists provide the tools and methodologies for implementing image recognition. Such interdisciplinary collaborations result in valuable tools like image search. Although text processing and mining are better established in the digital humanities, the visual domain is poised for equally valuable advancement.

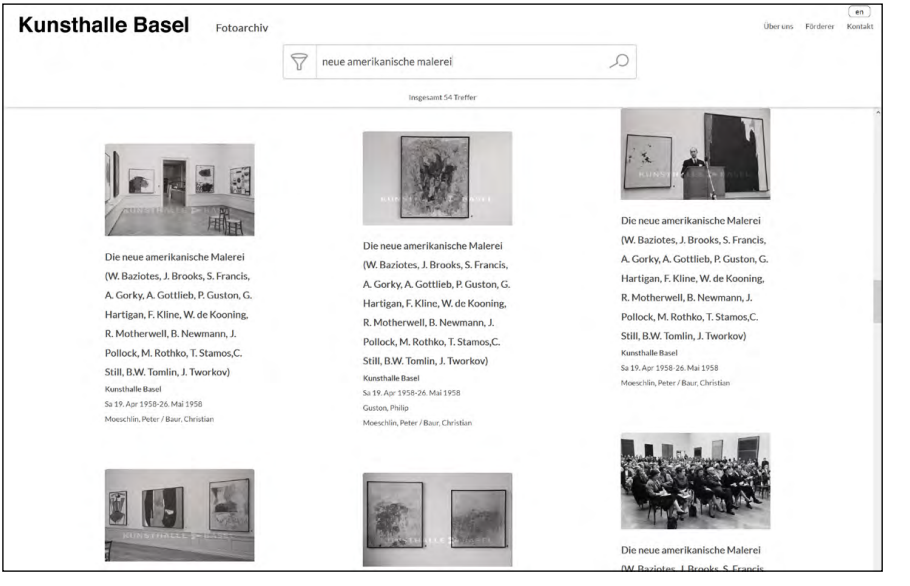


Figure 57. *Keyword search results for "neue amerikanische malerei" at* Photo Archive*, Kunsthalle Basel, accessed November 28, 2021, https://data.dasch.swiss/kuhaba*

1255 *Photo Archive*, Kunsthalle Basel, accessed December 27, 2024, https://www.kunsthallebasel.ch/en/photo-archive, direct access: https://data.dasch.swiss/kuhaba.

1256 During the exhibition *Exposed Exhibitions: Fotoarchiv der Kunsthalle Basel*, Kunsthalle Basel, September 22 to November 12, 2017, the public could test the search engine at a computer station installed in the first room.

1257 Georgy A. Kukharev et al., "Methods of Face Photo-Sketch Comparison," *Pattern Recognition and Image Analysis* 24, no. 1 (2014): 102–113, https://doi.org/10.1134/S1054661814010076.

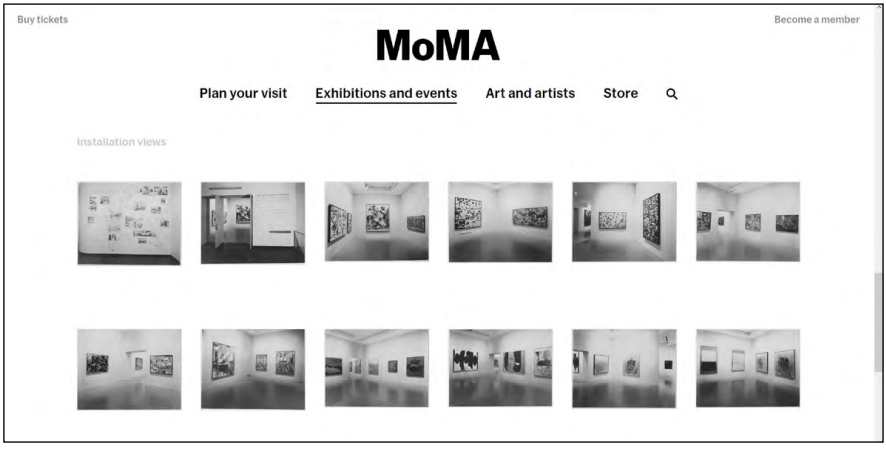


Figure 58. *Installation views of* The New American Painting as Shown in Eight European Countries 1958–1959 *exhibition (May 28 to September 8, 1959) at* Exhibition History*, MoMA, accessed October 25, 2017, https://www.moma.org/calendar/exhibitions/1990*

This potential becomes evident when applying digital tools to images from sources like Kunsthalle Basel's digitized *Photo Archive*[1258] (fig. 57) and MoMA's digitized installation views in the *Exhibition History* (fig. 58).[1259] Both institutions document *The New American Painting* exhibition, which popularized Abstract Expressionism in Europe.[1260] Kunsthalle Basel provides detailed metadata for installation views, while MoMA's metadata is

1258 *Photo Archive*, Kunsthalle Basel, accessed October 25, 2017, https://data.dasch.swiss/kuhaba. A keyword search of "neue amerikanische malerei" results in 54 photographs that document the exhibition *Die neue amerikanische Malerei*. Only 44 of these are produced by and show Kunsthalle Basel's galleries.

1259 MoMA provides 25 installation photographs, the digitized catalog, and other archival documents related to the exhibition. *The New American Painting as Shown in Eight European Countries 1958–1959*, MoMA, accessed October 25, 2017, https://www.moma.org/calendar/exhibitions/1990.

1260 Kunsthalle Basel was the first of eight art institutions in Europe to show *Die neue amerikanische Malerei* in 1958 prior to being exhibited at MoMA, finally, in 1959 as *The New American Painting*. Initiated by Arnold Rüdlinger, head of Kunsthalle Basel at the time, MoMA's International Program organized a touring exhibition featuring about 80 artworks from private collections, galleries, and museums. The International Program, supported by a grant from the Rockefeller Brothers Fund, was founded in 1952 to organize and tour exhibitions globally.

sparse.[1261] Searching across databases and languages for installation views showing the same artwork is challenging. Machine learning techniques can help address this disparity, using supervised and unsupervised learning to recognize patterns in images and classify artworks. In supervised learning, algorithms are trained with labeled images to automatically identify and label similar images in an unlabeled dataset. Unsupervised learning is the automated analysis of existing characteristics in the data.

The Computer Vision Group at the Heidelberg University[1262] developed a tool that analyzes and compares image files using computer vision and machine learning. It is a visual-based search that recognizes patterns and establishes similarities between images. Search results can be continuously fine-tuned through supervised training of the algorithms.



Figure 59. *Two highlighted paintings in a MoMA installation view photograph, using the image search tool developed by the Computer Vision Group, Heidelberg Collaboratory for Image Processing, Heidelberg University*

1261 Sören Schmeling and Sonja Gasser, "Ausstellungsgeschichte als Ansichtssache: Das Fotoarchiv der Kunsthalle Basel," *Rundbrief Fotografie* 26, no. 3 (2019): 38; MoMA Press, "The Museum of Modern Art Launches Comprehensive Online Exhibition History," September 14, 2016, archived March 14, 2017, at https://web.archive.org/web/20170314164024/http://press.moma.org/2016/09/exhibition-history-digital-archive/. Kunsthalle Basel's installation views have been online since 2013, and MoMA's have been online since 2016.

1262 At the time, the Computer Vision Group was directed by Professor Björn Ommer and was part of the interdisciplinary Heidelberg Collaboratory for Image Processing at the Heidelberg University. Meanwhile it has become the Computer Vision & Learning research group at Ludwig-Maximilians-Universität München, accessed May 27, 2023, https://ommer-lab.com/.



Figure 60. *Results for image search in figure 59. The two highlighted paintings followed by sections found in other images of the dataset*



Figure 61. *Contextual results for image search in figure 60. The sections containing the found artworks are highlighted within the context of the whole installation photograph*

Applied to the dataset of *The New American Painting*, which consists of 67 images—25 installation views from MoMA and 42 from the Kunsthalle Basel—the tool identifies those images containing the same artwork. For instance, using a single installation view at MoMA as a source image, if two sections containing a painting are marked with rectangles (fig. 59), the recognized sections are displayed as soon as the calculations are completed (fig. 60). The two selected image areas featured first and second in the results are followed by a section that is obviously the same painting as in the second image, but from a different perspective as photographed obliquely from the side. Switching from the cropped view to the full image reveals that the search using the MoMA installation view successfully identified a corresponding Kunsthalle Basel exhibition view of the same artwork (fig. 61). The tool effectively recognizes images featuring the same artworks, despite different perspectives and distortions.

MoMA's collaboration with Google Arts & Culture Lab used object recognition in exhibition views to link images to corresponding artworks in their digital collection.[1263] This integration makes it possible for users to display artworks in different exhibition contexts and discover related objects through hotspots in installation images. This project improved the usability of MoMA's digital collections by providing a more holistic view of the artworks without time-consuming manual work.

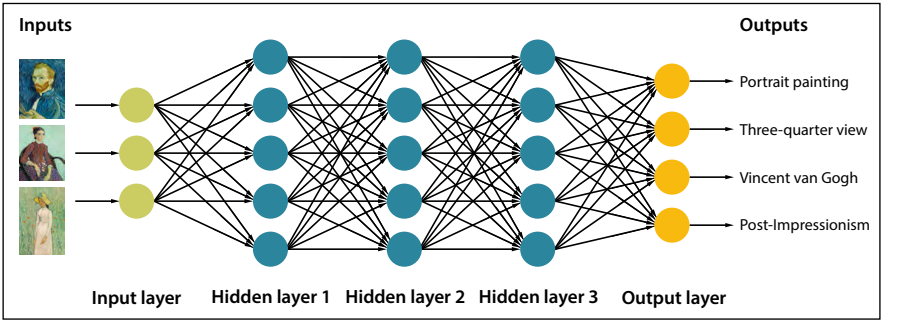


Figure 62. *Deep learning neural network* Designed by Sonja Gasser, CC BY 4.0 (artwork image source: National Gallery of Art, CC0 1.0.)

Even partial or occasionally incorrect associations made by automated image content recognition can be more useful than having no classification at all. As digital technologies become more capable of analyzing and associating image content, museums can benefit from improved connections between their collections, allowing for more refined searches and better-informed scholarly research.

Deep learning, a branch of machine learning, utilizes neural networks to analyze and interpret two-dimensional digital images through multiple layers of processing.[1264] By employing convolutional neural networks (CNNs), deep learning models facilitate tasks like image classification, object detection, visual similarity, pattern recognition, pose estimation, segmentation,

1263 "Identifying Art Through Machine Learning: A Project with Google Arts & Culture Lab," MoMA, accessed December 27, 2024, https://www.moma.org/calendar/exhibitions/history/identifying-art.

1264 Emily L. Spratt, "Dream Formulations and Deep Neural Networks: Humanistic Themes in the Iconology of the Machine-Learned Image," *kunsttexte.de*, no. 4 (2017): 2–3, https://doi.org/10.18452/18693.

and style transfer.[1265] These networks extract features to analyze the form, content and style of an artwork.

A neural network consists of multiple layers of nodes (artificial neurons), each associated with specific features (fig. 62).[1266] With each successive layer, the network generalizes and synthesizes features from the previous layer.[1267] For example, when images are fed into the input layer, the first layer synthesizes pixels, the second edges, the third combinations of edges, and so forth.[1268] In CNNs, information is processed through linear and nonlinear algorithms, filtered according to numerous parameters.[1269] The resulting output, entirely influenced by the algorithm's training, provides information about the input images such as style, subject, or artist.

Training CNNs involves numerous sets of adjustable parameters.[1270] Typically, training begins with unsupervised pre-training using unlabeled data, followed by supervised fine-tuning.[1271] At the network's final layer, each output neuron represents a conditional probability assigning an image to a specific class.[1272] Unlike traditional programming, where tasks are broken into smaller, solvable units, deep learning allows computers to develop solutions independently through layered processing.[1273] However, because the process is opaque, deep learning is a black box.[1274]

The opacity of algorithms poses challenges for research conducted on them.[1275] While the inability to see intermediate processes might seem problematic, researchers can evaluate the plausibility of outputs through experimentation and comparative analysis.[1276] An even bigger challenge lies in the training data: CNNs are highly sensitive to the datasets on which they are

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1265 Pavel N. Druzhkov and Valentina Dmitrievna Kustikova, "A Survey of Deep Learning Methods and Software Tools for Image Classification and Object Detection," *Pattern Recognition and Image Analysis* 26, no. 1 (2016): 9–15, https://doi.org/10.1134/S1054661816010065; Lang and Ommer, "Transforming Information into Knowledge," 36.

1266 Druzhkov and Kustikova, "Survey of Deep Learning," 10.

1267 Druzhkov and Kustikova, "Survey of Deep Learning," 10.

1268 Druzhkov and Kustikova, "Survey of Deep Learning," 9.

1269 Spratt, "Dream Formulations," 3.

1270 Druzhkov and Kustikova, "Survey of Deep Learning," 10.

1271 Druzhkov and Kustikova, "Survey of Deep Learning," 10.

1272 Druzhkov and Kustikova, "Survey of Deep Learning," 11.

1273 Spratt, "Dream Formulations," 3.

1274 Spratt, "Dream Formulations," 3.

1275 Johannes Passmann and Asher Boersma, "Unknowing Algorithms: On Transparency of Unopenable Black Boxes," in *The Datafied Society: Studying Culture Through Data*, ed. Mirko Tobias Schäfer and Karin van Es (Amsterdam University Press, 2017), 139.

1276 Passmann and Boersma, "Unknowing Algorithms," 141–42.

trained, often exhibiting biases when exposed to unfamiliar image types.[1277] For instance, networks trained on contemporary photographs may struggle to recognize abstract artworks or historical objects absent from present-day datasets. Deep convolutional neural networks have become the dominant tools for addressing computer vision problems.[1278] Anabel Martin-Gonzalez and Victor Uc-Cetina explain:

> Intelligent systems are computer systems capable of perceiving, reasoning, learning, and acting rationally, always maximizing an evaluation function. Several kinds of algorithmic methods could be used in the implementation of this type of system, methods such as neural networks, Bayesian networks, kernel machines, feature extraction and dimension reduction, deep learning, reinforcement learning, self-organizing maps, optimization methods in learning, fuzzy systems, and evolutionary computation, among others.[1279]

Among these models, Matej Uličný, Jens Lundström, and Stefan Byttner identify that: "In visual recognition problems, deep neural networks (DNN's) represent the state-of-the-art models outperforming all the other machine learning algorithms."[1280] Part and attribute discovery are techniques for visual recognition, learning, and description that allow to detect objects or recognize scene categories.[1281] Part-based models, for example, can identify individuals from partial views, such as a head, and generalize across various perspectives or poses.[1282] Trained on large labeled datasets, CNNs can achieve remarkable results,[1283] including zero-shot classification, which allows for "recognizing categories for which no training examples are available."[1284] This is particularly promising for art history, where the limited number of artworks constrains training datasets, while the vast diversity of visual categories in artworks makes it unrealistic to create annotated training sets that encompass all possible topics of interest.

1277 Spratt, "Dream Formulations," 4.

1278 Rogerio Schmidt Feris et al., "Introduction to Visual Attributes," in *Visual Attributes*, ed. Rogerio Schmidt Feris et al. (Springer International Publishing, 2017), 1, https://doi.org/10.1007/978-3-319-50077-5_1.

1279 Anabel Martin-Gonzalez and Victor Uc-Cetina, eds., *Intelligent Computing Systems: First International Symposium, ISICS 2016, Mérida, México, March 16–18, 2016, Proceedings* (Springer, 2016), vi, https://doi.org/10.1007/978-3-319-30447-2.

1280 Matej Uličný et al., "Robustness of Deep Convolutional Neural Networks for Image Recognition," in *Intelligent Computing Systems: First International Symposium, ISICS 2016, Mérida, México, March 16–18, 2016, Proceedings*, ed. Anabel Martin-Gonzalez and Victor Uc-Cetina (Springer, 2016), 16, https://doi.org/10.1007/978-3-319-30447-2.

1281 Maji, "Part and Attribute Discovery," 247.

1282 Maji, "Part and Attribute Discovery," 247–48.

1283 Maji, "Part and Attribute Discovery," 248.

1284 Schmidt Feris et al., "Introduction to Visual Attributes," 1.

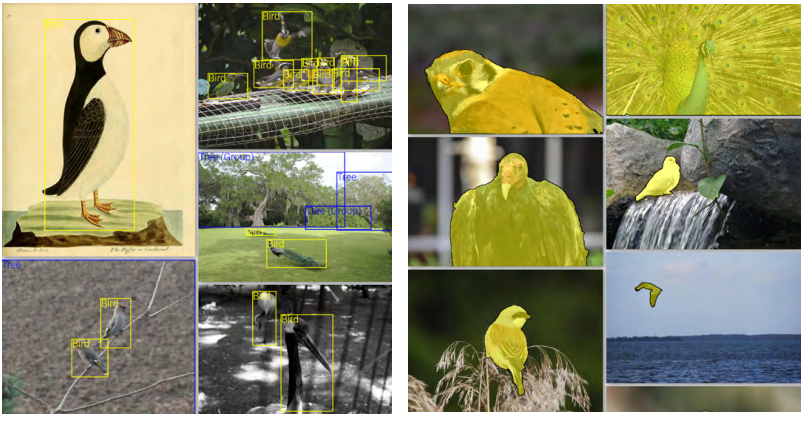


Figure 63. *Sample images of the "bird" category; type: detection* (left)*; type: segmentation* (right) *at Open Images Dataset V6, accessed August 13, 2021, https://g.co/dataset/open-images*

Datasets like *ImageNet*[1285] and *Open Images Dataset*,[1286] which have annotated objects and bounding boxes, are commonly used to train CNNs for object recognition. However, these datasets primarily reflect modern, everyday subjects, limiting their utility for art historical research. *ImageNet* is a database containing images with annotated objects that is structured according to the *WordNet* hierarchy[1287] (see p. 168) while *Open Images Dataset* (fig. 63) contains a large collection of images with detected and annotated objects, making it a useful resource to train deep convolutional neural networks for computer vision tasks. Bounding boxes, as seen on the left half of figure 63, mark the position of the object in the image and label the detected objects. Segmentation masks, as in the right half of figure 63, indicate the shape of the object and thus the exact pixels in the image that belong to that object. This dataset consists of pictures from *Flickr*[1288] shared under a CC BY license, so its content largely depends on the motifs that current photos contain.

1285 *ImageNet*, Stanford Vision Lab, Stanford University, accessed December 27, 2024, https://image-net.org.

1286 Open Images Dataset, version 7, accessed April 5, 2025, https://g.co/dataset/open-images.

1287 *WordNet*, Princeton University, archived November 18, 2024, at https://web.archive.org/web/20241118012222/http://wordnetweb.princeton.edu/perl/webwn.

1288 *Flickr*, accessed December 27, 2024, https://www.flickr.com.

Using contemporary photographs as training data creates difficulties for recognizing artworks.[1289] Neural networks excel at analyzing naturalistic paintings, but often struggle with abstract or nonrepresentational artworks, which means that only objects for which the networks have been trained can be recognized. Effective adaptation requires extensive training data, which is often lacking due to the diverse styles, genres, and techniques throughout the history of art. The limitations of general datasets like *Open Images Dataset* illustrate the need for specialized datasets tailored to art history.

General-purpose datasets, such as the *Open Images Dataset*, often emphasize current everyday objects like "mobile phone," "hamburger," "traffic sign," or "surfboard," which will not be identified in historic artworks. Conversely, categories like "flower," "tree," "bird," or "human eye," may still yield meaningful results when applied to artworks. The class "sculpture" with the subclasses "bronze sculpture" and "bust," are the only directly art-related categories present in the dataset.[1290] However, research projects like *iART* or *imgs.ai* demonstrate the importance of training networks on datasets designed for art history.

Image data processing such as pattern recognition, image analysis, and artificial intelligence are products of computer science and also closely related to mathematics,[1291] making it abundantly clear that the success of technologies like this, among many others, requires interdisciplinary collaboration. John Nerbonne emphasizes that digital humanities projects succeed when computer scientists and humanities scholars combine their expertise to address significant research questions, critically validate results, and expand those results to other topics. Computer scientists provide the technical framework, while humanities scholars contribute the critical evaluation necessary for meaningful analysis.[1292] It is those different competencies that make for a fruitful collaboration.

Giacomo Mercuriali similarly advocates for integrating computational techniques with art history to study images in cultural and historical contexts. Without a critical humanities approach, computer science applications risk addressing culturally insignificant issues. Conversely, humanities

1289 Peter Hall et al., "Cross-Depiction Problem: Recognition and Synthesis of Photographs and Artwork," *Computational Visual Media* 1, no. 2 (2015): 96, https://doi.org/10.1007/s41095-015-0017-1.

1290 For all bounding box object classes and their hierarchies, see: accessed December 27, 2024, https://storage.googleapis.com/openimages/2018_04/bbox_labels_600_hierarchy_visualizer/circle.html.

1291 Gurevich and Zhuravlev, "Computer Science."

1292 John Nerbonne, "Die Informatik als Geisteswissenschaft," in *Grenzen und Möglichkeiten der Digital Humanities: Sonderband 1 der ZfdG*, ed. Constanze Baum and Thomas Stäcker (HAB – Herzog August Bibliothek, 2015), https://doi.org/10.17175/sb001_003.

scholars often limit their research to text or metadata analysis due to limited or a lack of technological skills for processing large image sets.[1293] As Mercuriali summarizes: "The multidisciplinary field of digital art history tries to integrate the mathematical and statistical expertise of information technology scientists with art history and visual culture studies."[1294]

Sabine Lang and Björn Ommer have examined how computational methods are reshaping art history, particularly in analyzing and accessing large image datasets.[1295] They provide an overview of computer vision techniques and discuss the potential of digital art history to study images in contrast to traditional approaches. "Computational methods are mostly developed by computer scientists to solve tasks such as classification and recognition using large collections of real images."[1296] In doing so they "transform information inherent in digital images into new knowledge" by processing and analyzing large image collections.[1297] Traditional art historical methods, by comparison, "operate on smaller image collections and results are based on visual observations and knowledge of art historians."[1298] In utilizing automatic data analysis and data exploration, new perspectives on art can emerge, for example, by clustering paintings based on the age and social status of the subject or by finding artworks depicting a hat in a large collection using visual search input.[1299] Techniques like these allow art historians to "study changes in form, content or image context."[1300]

Computer vision, also called machine vision, relies on image processing algorithms,[1301] which manage preprocessing, feature detection (e.g., edges, straight lines, corners), segmentation, shape analysis, and object identification.[1302] It is used for tasks such as image classification, object detection, image segmentation, finding visual similarities, or for image generation, for example, by style transfer. In this context, classification determines whether an object of a specific class exists in an image, while detection locates the object within the image.[1303] Recognition in computer vision encompasses

1293 Giacomo Mercuriali, "Digital Art History and the Computational Imagination," *International Journal for Digital Art History*, no. 3 (2018): 141, https://doi.org/10.11588/dah.2018.3.47287.

1294 Mercuriali, "Digital Art History," 143.

1295 Lang and Ommer, "Transforming Information into Knowledge."

1296 Lang and Ommer, "Transforming Information into Knowledge," 2.

1297 Lang and Ommer, "Transforming Information into Knowledge," 1.

1298 Lang and Ommer, "Transforming Information into Knowledge," 2.

1299 Lang and Ommer, "Transforming Information into Knowledge," 4.

1300 Lang and Ommer, "Transforming Information into Knowledge," 4.

1301 Lutz Priese, *Computer Vision: Einführung in die Verarbeitung und Analyse digitaler Bilder* (Springer, 2015), v–vi.

1302 Priese, *Computer Vision*, 1.

1303 Hall et al., "Cross-Depiction Problem," 93.

both image classification and detection.[1304] The bag-of-words method is widely used for visual object classification. In this approach, visual object classes are represented as histograms of visual words, which are clusters in feature space. However, as Peter Hall and colleagues note, the bag-of-words method struggles with recognizing images across different genres such as photography, painting, and drawing. Incorporating additional features, such as edgelets or region shapes, improves results, though these depend on the presence of recognizable edges—an attribute not guaranteed in paintings.[1305]

Low-level features, like average pixel intensity (brightness), color histograms (color composition), and edge counts (contours), capture an image's formal characteristics.[1306] Intermediate-level features are localized regions within an image. The bag-of-words model clusters these regions into a codebook of visual vocabulary, generating histograms that indicate image frequency distributions.[1307] Semantic-level features identify content classes (like person, tree, or ship), enabling semantic similarity rankings.[1308] Generative models, such as topic models, can capture thematic structures in images.[1309]

Sparse coding is a bag-of-words method for classifying unlabeled images.[1310] Pavel Druzhkov and Valentina Kustikova describe the classification process: "The dictionary is learned from a set of unlabeled images, code is computed for each labeled image at hand, and a classifier is trained trying to predict the class by the code."[1311] Fahad Khan et al. used this method to categorize paintings in a large database containing 4,266 images by 91 painters.[1312] They acknowledge that, "The problem of computational painting categorization can be sub-divided into two tasks namely: artist classification and style classification,"[1313] meaning that the challenge lies in the fact that works by a single artist can vary in style, but also because Internet images are created under a range of conditions.[1314] Despite this,

1304 Hall et al., "Cross-Depiction Problem," 93.

1305 Hall et al., "Cross-Depiction Problem," 93.

1306 Babak Saleh et al., "Toward Automated Discovery of Artistic Influence," *Multimedia Tools and Applications* 75, no. 7 (2016): 3572, https://doi.org/10.1007/s11042-014-2193-x.

1307 Saleh et al., "Toward Automated Discovery," 3573.

1308 Saleh et al., "Toward Automated Discovery," 3573.

1309 Saleh et al., "Toward Automated Discovery," 3573.

1310 Druzhkov and Kustikova, "Survey of Deep Learning," 9.

1311 Druzhkov and Kustikova, "Survey of Deep Learning," 10.

1312 Fahad Shahbaz Khan et al., "Painting-91: A Large Scale Database for Computational Painting Categorization," *Machine Vision and Applications* 25, no. 6 (2014): 1395, https://doi.org/10.1007/s00138-014-0621-6.

1313 Khan et al., "Painting-91," 1386.

1314 Khan et al., "Painting-91," 1386.

the bag-of-words approach has proven effective by "creating efficient visual features and sophisticated learning schemes."[1315]



Figure 64. *Images matched by AI through composition recognition. Press image from Reuters* (left) *and artwork from Tate* (right) *with highlighted areas and descriptive phrases for the recognized objects at* Recognition*, Tate, 2016, accessed November 26, 2021, http://recognition.tate.org.uk/archive/gallery/TM3EC9C1GOV01*

Artificial intelligence (AI) applications in museums are still largely in the experimental phase, but good examples do exist.[1316] The Tate's *Recognition* project used algorithms to identify similar artworks from its collection and Reuters news images, employing object, facial, composition, and context recognition.[1317] Results were displayed with highlighted image regions and matching probabilities (fig. 64).

1315 Khan et al., "Painting-91," 1386.

1316 Oonagh Murphy and Elena Villaespesa, *The Museums and AI Network: AI: A Museum Planning Toolkit* (Goldsmiths, University of London, 2020), accessed February 18, 2022, https://themuseumsai.network/toolkit/. Examples can be found in the "List of Artificial Intelligence (AI) Initiatives in Museums," accessed February 18, 2022, https://t.co/588ExRZ50T, compiled by Elena Villaespesa, Oonagh Murphy, and Kate Nadel.

1317 *Recognition*, Tate, accessed November 26, 2021, http://recognition.tate.org.uk.

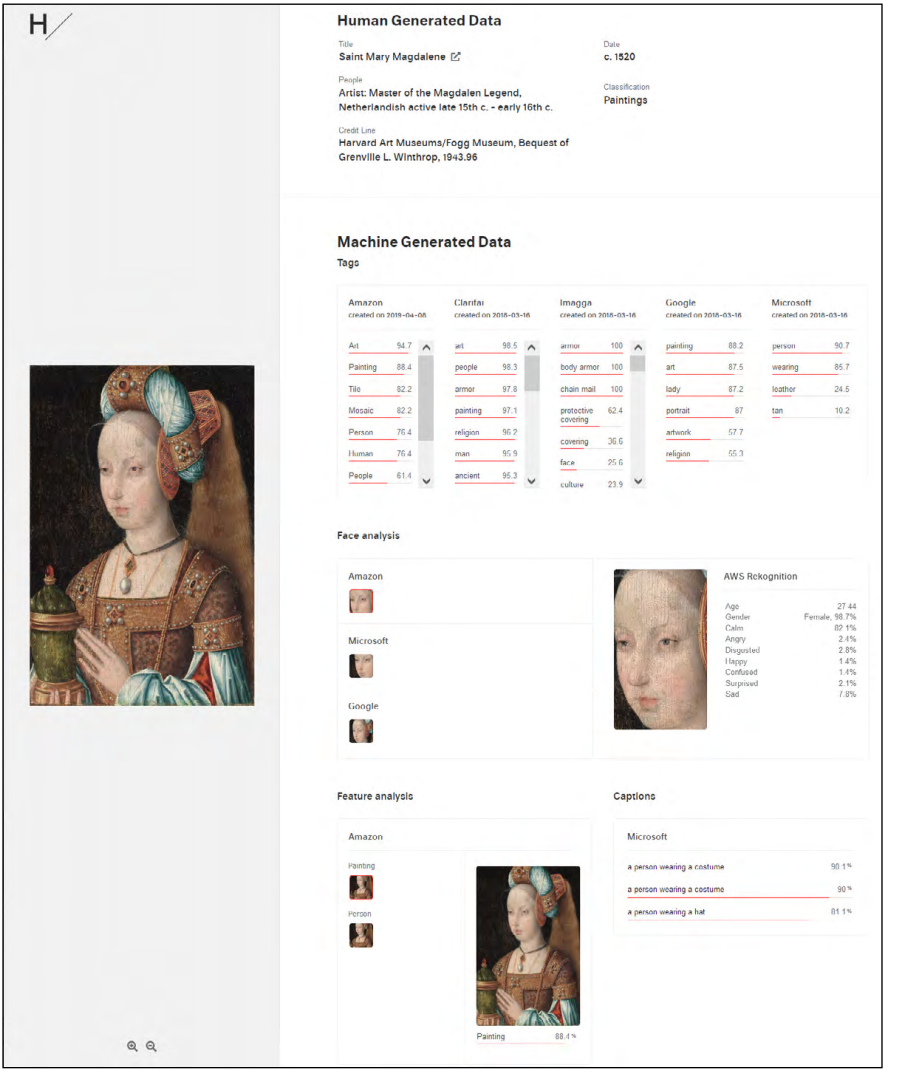


Figure 65. AI Explorer, *Harvard Art Museums, accessed July 10, 2021, https://ai.harvardartmuseums.org/object/230310*

The Harvard Art Museums' *AI Explorer*[1318] augmented artwork metadata with AI-generated tags and descriptions from services like Amazon, *Clarifai*, *Imagga*, Google, and Microsoft (fig. 65).[1319] These tools expand search possibilities by offering intuitive keywords beyond traditional art historical terminology. However, AI-generated metadata can be inconsistent, demonstrating both accurate and erroneous results. For example, in figure 65 Google and Amazon both point to a high probability that the image is of a painting, while *Imagga* is 100 % sure that it has recognized armor in the image. Although this is not completely out of the question, it is still not correct. Microsoft suggests a vague, but accurate caption: "a person wearing a costume." Amazon's facial recognition was able to identify the sitter as a woman aged 27 to 44 with a 98.7 % probability, enabling targeted searches for portraits within specified parameters.

Computer vision makes possible tailored techniques for addressing the complexities of art analysis. Shape analysis aids in object segmentation, while contour extraction is used to identify the objects.[1320] Inexact graph matching algorithms facilitate character recognition and object identification by mapping shapes to known object graphs.[1321] "An image is divided into regions and then described by a graph where nodes represent the regions and edges represent spatial relations between the regions."[1322] Geometric analysis can be used to virtually reconstruct 3D objects, such as reassembling archaeological fragments.[1323] Line drawings can be analyzed, as Thomas Hurtut et al. state, through "the automatic analysis of the pictorial content of line-drawings, defined as the combination of the artistic style and the visual features

1318 *AI Explorer*, Harvard Art Museums, accessed December 27, 2024, https://ai.harvardartmuseums.org.

1319 *Amazon Rekognition*, Amazon, accessed December 29, 2024, https://aws.amazon.com/rekognition; *Clarifai*, accessed December 29, 2024, https://www.clarifai.com/; *Imagga*, Imagga Technologies, accessed December 29, 2024, https://imagga.com; *Cloud Vision API*, Google, accessed December 29, 2024, https://cloud.google.com/vision; *Azure AI Vision*, Microsoft, accessed December 29, 2024, https://azure.microsoft.com/en-us/products/ai-services/ai-vision/.

1320 Michael Breuss et al., eds., *Perspectives in Shape Analysis* (Springer, 2016), viii, https://doi.org/10.1007/978-3-319-24726-7; Amal Dev Parakkat et al., "A Graph-Based Geometric Approach to Contour Extraction from Noisy Binary Images," *Computer-Aided Design and Applications* 12, no. 4 (2015): 403, https://doi.org/10.1080/16864360.2014.997636.

1321 Paul Morrison and Ju Jia Zou, "Inexact Graph Matching Using a Hierarchy of Matching Processes," *Computational Visual Media* 1, no. 4 (2015): 291, https://doi.org/10.1007/s41095-015-0030-4.

1322 Morrison and Zou, "Inexact Graph Matching," 291.

1323 Ruggero Pintus et al., "A Survey of Geometric Analysis in Cultural Heritage," *Computer Graphics Forum* 35, no. 1 (2016): 9–11, https://doi.org/10.1111/cgf.12668.

formed by the set of strokes composing the drawing."[1324]

Dee and colleagues examine computer vision as a method for analyzing and classifying paintings, particularly in datasets from diverse sources.[1325] Paintings can be analyzed using metadata (assigned information), stylistic data (visual properties derived from pixels), and content (object recognition).[1326]

From a computational perspective, the style of an artwork involves understanding how information is represented and organized structurally.[1327] Style analysis is commonly employed to authenticate artworks in the art market, often by building a two-class classifier to determine whether a painting was created by a specific artist.[1328] Most computer vision-based analysis focuses on brushstroke detection and analysis, enabling the assignment of individual works to specific periods within an artist's oeuvre.[1329] However, brushstroke analysis is limited to artists or groups using similar techniques and is not universally applicable.[1330]

As always, the quality of source of image materials and metadata impact the effectiveness of computer vision. High-resolution images captured under controlled conditions yield more reliable results compared to those scanned from books or web-sourced visuals, for instance.[1331] In collections with incomplete metadata, images with metadata help infer that similar artworks, identified through computer vision, share the same information (e.g., a creation date).[1332] Features for analysis range from "simple analysis of the way in which colour changes over time, through edge detection, to texture analysis."[1333]

Quantitative techniques have been used to authenticate paintings, study the evolution of specific artists, examine statistical properties of artworks, and assist in restoration efforts.[1334] Large-scale projects analyzing tens or

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1324 Thomas Hurtut et al., "Artistic Line-Drawings Retrieval Based on the Pictorial Content," *Journal on Computing and Cultural Heritage* 4, no. 1 (2011): 2, https://doi.org/10.1145/2001416.2001419.

1325 Hannah M. Dee et al., "Visual Digital Humanities: Using Image Data to Derive Approximate Metadata," in *Managing Digital Cultural Objects: Analysis, Discovery and Retrieval*, ed. Allen Foster and Pauline Rafferty (Facet, 2014), https://doi.org/10.29085/9781783301539.005.

1326 Dee et al., "Visual Digital Humanities," 91–92.

1327 Shlomo Argamon et al., eds., *The Structure of Style: Algorithmic Approaches to Understanding Manner and Meaning* (Springer, 2010), vii.

1328 Dee et al., "Visual Digital Humanities," 96–97.

1329 Dee et al., "Visual Digital Humanities," 97.

1330 Dee et al., "Visual Digital Humanities," 97.

1331 Dee et al., "Visual Digital Humanities," 97–98.

1332 Dee et al., "Visual Digital Humanities," 98–99.

1333 Dee et al., "Visual Digital Humanities," 100.

1334 Higor Y. D. Sigaki et al., "History of Art Paintings Through the Lens of Entropy and Com-

hundreds of thousands of images have identified remarkable differences in color use and contrast across periods.[1335] Beyond color, changes in pixel patterns over time can reveal shifts in visual art.[1336] In one project, Higor Sigaki et al. analyzed pixel arrangements in 140,000 artworks, calculating complexity measures to classify styles based on "distinct degrees of order and regularity in the pixel arrangements."[1337] These findings align with art historical determinations like those of Heinrich Wölfflin and Alois Riegl, offering an automated alternative to traditional qualitative approaches.[1338]

Machine analysis can also establish relationships among artists and art movements.[1339] Lior Shamir and Jane Tarakhovsky used "numerical image content descriptors ... originally developed for complex morphological analysis of biomedical imaging,"[1340] to identify stylistic similarities among artists and movements. Their method generated networks of related artists, consistent with those identified by art historians.[1341] They concluded, "These results demonstrate that machine vision and pattern recognition algorithms are able to mimic the complex cognitive task of the human perception of visual art."[1342] By detecting stylistic commonalities, computer vision can classify large image sets that may lack metadata, shedding light on artistic relationships.

Complex research questions, such as measuring influence among artists, can also be addressed with computational methods. Babak Saleh et al. explored "computer-based measuring and determining of influence between artists."[1343] This is significant because it is not clear what influence means exactly and required experimentation with different similarity measures and features,[1344] including "a computer quantified judgement about which artists and paintings may have similarity" to determine "which paintings are connected using mathematical criteria."[1345] These methods assess visual similarity through high- and low-level features while considering artists'

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plexity," *Proceedings of the National Academy of Sciences of the United States of America*, 2018, 1, https://doi.org/10.1073/pnas.1800083115.

1335 Sigaki et al., "History of Art Paintings," 1.

1336 Sigaki et al., "History of Art Paintings," 2.

1337 Sigaki et al., "History of Art Paintings," 2–6.

1338 Sigaki et al., "History of Art Paintings," 6.

1339 Lior Shamir and Jane A. Tarakhovsky, "Computer Analysis of Art," *Journal on Computing and Cultural Heritage* 5, no. 2 (2012): 1, https://doi.org/10.1145/2307723.2307726.

1340 Shamir and Tarakhovsky, "Computer Analysis of Art," 3.

1341 Shamir and Tarakhovsky, "Computer Analysis of Art," 1–2.

1342 Shamir and Tarakhovsky, "Computer Analysis of Art," 9.

1343 Saleh et al., "Toward Automated Discovery," 3567.

1344 Saleh et al., "Toward Automated Discovery," 3567.

1345 Saleh et al., "Toward Automated Discovery," 3567.

chronological relationships.[1346] Additionally, computational tools are able to identify recurring subjects, categorize artworks, and suggest connections among artists.

Computational techniques can also be used to manipulate images, such as automatically colorizing black-and-white photographs by applying user-specified colors based on underlying grayscale intensities.[1347] Sotirios Tsaftaris et al. applied this to glass negatives capturing Pablo Picasso's artworks in his studio, reconstructing color layers from various stages of his painting process.[1348] By combining conservational observations with the knowledge that "Picasso used a limited set of commercial enamel paints," the color application allowed for "an enhanced understanding of the chromatic evolution of *La Joie de Vivre*."[1349] Colorization can be done by manually adding reference colors for automated extension, using a defined color palette for a segmented image, or transferring colors from a reference image.[1350]

Despite obvious progress, obtaining meaningful results from these processes is a key hurdle for applying computational analysis to digital art collections.

6.4 Data Presentation

An application dedicated to the exhibition *The New American Painting*, utilizing the identified data sources and technologies, could be developed to incorporate all hosting institutions and historical materials. If all existing catalog versions (Dutch, English, French, German, Italian, and Spanish) were included, the application could support multilingual search options, even for terms found only in running text and not referenced through external datasets. By comparing individual exhibitions, the application could highlight curatorial variations in checklists and presentations, such as the Berlin presentation, which included George Cup instead of James Brooks.[1351] Incorporating *ULAN* IDs could expand the network of relationships, connecting

1346 Saleh et al., "Toward Automated Discovery," 3567.

1347 Sotirios A. Tsaftaris et al., "A Novel Visualization Tool for Art History and Conservation: Automated Colorization of Black and White Archival Photographs of Works of Art," *Studies in Conservation* 59, no. 3 (2014): 126, https://doi.org/10.1179/2047058413Y.0000000104.

1348 Tsaftaris et al., "Novel Visualization Tool," 128.

1349 Tsaftaris et al., "Novel Visualization Tool," 128–33.

1350 H. Sheikh Faridul et al., "Colour Mapping: A Review of Recent Methods, Extensions and Applications," *Computer Graphics Forum* 35, no. 1 (2016): 68, https://doi.org/10.1111/cgf.12671.

1351 See Hochschule für Bildende Künste Berlin, ed., *Die neue amerikanische Malerei* (Hochschule für Bildende Künste, 1958), unpaginated.

to other artists or entities and illustrate a bigger picture. One example, the Städel Museum's *Digital Collection* uses artist relationships to link records, allowing users to discover other artists by browsing.[1352] Such data links make digital collections more digestible and coherent.

Similar to the relationship networks seen in other art movements, it would be illuminating to visualize the connections among artists featured in *The New American Painting* to determine the depth of their connections. A timeline could show artists' lifespans, who was still living at the time of the exhibition, map locating artists over time, or interactive tools highlighting artist roles, such as "painter" or "still-life artist," to refine searches. Additionally, computer vision and machine learning could analyze installation views to study how spatial conditions influenced exhibition layouts. Identifying artworks included in each presentation and their current collections could link to further information, including color images and provenance.

Digital collections typically display artwork records with images and metadata. However, web technologies (HTML, CSS, JavaScript, SVG, JSON, APIs, etc.) allow more dynamic representations that benefit users. These technologies are foundational for web interfaces requiring adaptability and ideal for presenting images or collections online.[1353] Tools based on these technologies can be used for data visualization, storytelling, and virtual exhibitions, including two-dimensional or three-dimensional representations. User-friendly design and interactive interfaces are vital for communicating cultural memory and heritage reconstructions to non-specialists.[1354] But even for specialists, the presentation format determines the conclusions drawn from the data.

Maps reveal underlying structures not evident in raw datasets. As Ina Dietzsch and Daniel Kunzelmann note, maps are spatial and social constructs based on mathematical models rather than representations of the objective reality.[1355] Geographic information systems (GIS) link geographic and factual data, allowing dynamic, multilayered visualizations that can

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1352 See Robert Motherwell artist record. *Digital Collection*, Städel Museum, accessed December 12, 2021, https://sammlung.staedelmuseum.de/de/person/motherwell-robert.

1353 Urban Complexity Lab's applications, such as *VIKUS Viewer* or *Coins*, are good examples. "Projects," Urban Complexity Lab, University of Applied Sciences Potsdam, accessed December 27, 2024, https://uclab.fh-potsdam.de/projects.

1354 Daniela Calciu, "Memories and the City, Heritage and Urbanity: Space and Time Visualization as Advocacy Tool for the Importance of Heritage to Urban Development in Bucharest," in *Space and Time Visualisation*, ed. Maria Boştenaru Dan and Cerasella Crăciun (Springer, 2016), 115.

1355 Ina Dietzsch and Daniel Kunzelmann, "Kartieren und rechnende Räume: Zur Digitalisierung einer Kulturtechnik," in *Digitalisierung: Theorien und Konzepte für die empirische Kulturforschung*, ed. Gertraud Koch (Herbert von Halem Verlag, 2017), 284.

model and narrate relationships.[1356] In this way, maps form a conglomerate of movable information units stored in databases that can be recombined in many ways.[1357] Such flexibility is desirable for other non-geographic data presentations.

As with other technological applications discussed, creating interactive maps and visualizations necessitates proficiency in web technologies and design principles.[1358] Tools like *D3.js*,[1359] a JavaScript library for browser-based data visualizations, use web standards (HTML, SVG, and CSS) to create interactive charts and graphs.[1360] As its developers Michael Bostock et al. detail, *D3*'s seamless integration of "HTML for page content, CSS for aesthetics, JavaScript for interaction, SVG for vector graphics" within a Document Object Model (DOM) enables real-time document manipulation in the browser.[1361] The graphs and charts in *Deutsche Digitale Bibliothek Visualized*,[1362] for example (see also fig. 44 in chapter section 5.2), are generated using *D3*. Data preparation for visualizations, always a critical precursor to any digital collection project, involves, as Tim Dennis lists,

> Creating interactive web graphics requires a heterogeneous set of technical skills that can include data cleaning, analysis, web development, and design. Data need to be acquired, munged, transformed, and then sent to a web application for rendering as a plot.[1363]

As *Deutsche Digitale Bibliothek Visualized* and other visualization projects by the Urban Complexity Lab[1364] (see also fig. 22 in chapter section 3.6) demonstrate, impactful visualizations are integrated into comprehensive applications that convey content and establish meaningful references.

While data visualizations are often two-dimensional, artworks can also be presented in 3D. Advanced presentation of 3D objects can draw on

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1356 Dietzsch and Kunzelmann, "Kartieren und rechnende Räume," 286–87.

1357 Dietzsch and Kunzelmann, "Kartieren und rechnende Räume," 289.

1358 Mark van Rijmenam, *Think Bigger: Developing a Successful Big Data Strategy for Your Business* (American Management Association, 2014), 99–100.

1359 *D3.js*, Observable, accessed December 29, 2024, https://d3js.org.

1360 Michael Bostock et al., "D: Data-Driven Documents," *IEEE Transactions on Visualization and Computer Graphics* 17, no. 12 (2011): 2301–2309, https://doi.org/10.1109/TVCG.2011.185; Nick Qi Zhu, *Data Visualization with D3.js Cookbook: Over 70 Recipes to Create Dynamic Data-Driven Visualization with D3.js* (Packt Publishing, 2013), 1.

1361 Bostock et al., "D^3: Data-Driven Documents," 2301.

1362 *Deutsche Digitale Bibliothek Visualized*, Urban Complexity Lab, University of Applied Sciences Potsdam, accessed May 24, 2021, https://uclab.fh-potsdam.de/ddb.

1363 Dennis, "Using R and ggvis," 149.

1364 "Projects," https://uclab.fh-potsdam.de/projects.

gaming industry tools like *Unity*,[1365] a development engine for interactive 3D content. Created with *Unity*, the Centre Pompidou's *Prisme7* game,[1366] offers an immersive experience of artworks from the museum's collection. The game runs locally on the computer or as a mobile app. Applications using *Unity* or *Unreal Engine*[1367] can also run in browsers via *WebGL*,[1368] a JavaScript API. The British Museum's *The Museum of the World* application[1369] arranges objects on an interactive 3D timeline, linking high-resolution images with cultural and historical context. In the cultural domain, *Unity* can help develop e-learning games that capitalize on gamification by combining the aspects of immersion, spatial learning, active learning, positive reinforcement of behavior and conditioning, emotional attachment, cognitive flow, and a safe practice environment.[1370] In *Prisme7*, the focus is on gameplay, not learning. In comparison, *The Museum of the World* prioritizes educational content. Both pave the way for more serious games in the future that balance learning and entertainment.

Many digital collections lack interoperability, trapping images within monolithic web applications without public API support.[1371] This hinders scholars interested in art museum's digital image data. Lang and Ommer underline that restricted data models, databases, and predefined categories work against free exploration of image data. Flexible, adaptive database models are imperative for accommodating scholars from different disciplines with a wide range of research questions.[1372]

To overcome the limitations of image repositories, a "community of academic and national libraries, museums, archives, nonprofits and commercial organizations has worked together to agree on common APIs for image delivery and developed an ecosystem of compliant systems," as Stuart Snydman et al. recount.[1373] The result was the *International Image Interoperability Framework (IIIF)*, which enhances digital image presentation and

1365 *Unity*, Unity Technologies, accessed December 29, 2024, https://unity.com.

1366 *Prisme7*, Centre Pompidou, accessed December 29, 2024, https://prisme7.io.

1367 *Unreal Engine*, Epic Games, accessed December 29, 2024, https://www.unrealengine.com.

1368 *WebGL*, Khronos Group, accessed December 29, 2024, https://www.khronos.org/webgl.

1369 *The Museum of the World*, British Museum, accessed May 24, 2021, https://britishmuseum.withgoogle.com.

1370 David Horachek, *Creating e-Learning Games with Unity: Develop Your Own 3D e-Learning Game Using Gamification, Systems Design, and Gameplay Programming Techniques* (Packt Publishing, 2014), 8–10.

1371 Stuart Snydman et al., "The International Image Interoperability Framework (IIIF): A Community & Technology Approach for Web-Based Images," *Archiving Conference*, 2015, 16.

1372 Lang and Ommer, "Transforming Information into Knowledge," 21.

1373 Snydman et al., "International Image Interoperability Framework," 16.

accessibility.[1374] *IIIF* exists for "delivering cultural heritage images on the web, promoting a community of adopters, and fostering a marketplace of robust software implementations—both commercial and open-source."[1375] *IIIF* fosters interoperability across institutions by enabling image delivery, metadata transfer, authentication, and resource searches.[1376] As Ina Mertens notes, *IIIF* offers museums and cultural institutions opportunities to expand the existing presentation mechanisms and uses of their image collections.[1377]

The *IIIF* community aligns with the Semantic Web's goal of creating a web of data for facilitating data reuse across applications. With its Image, Presentation, Authentication, and Search APIs, *IIIF* provides machine-readable interfaces for interoperable image delivery including descriptive metadata, authentication, and search functions.[1378] *IIIF* enables high-resolution image access across collections, in addition to "multi-image object rendering, pan, deep zoom, and annotation, while following a standard set of interaction patterns across multiple content repositories."[1379]

Mirador,[1380] like the *DFG-Viewer*,[1381] is a *IIIF* viewer originally developed for digitized medieval manuscripts that enables the simultaneous display and comparison of digital objects from multiple sources.[1382]

1374 *International Image Interoperability Framework (IIIF)*, accessed December 29, 2024, https://iiif.io.

1375 Snydman et al., "International Image Interoperability Framework," 16.

1376 Snydman et al., "International Image Interoperability Framework," 16.

1377 Ina Mertens, "Zwei Seiten einer Medaille: IIIF und die Arbeit mit digitalen Bildbeständen," *ZfdG – Zeitschrift für Digitale Geisteswissenschaften*, 2021, 6, https://doi.org/10.17175/2021_002.

1378 "API Specifications," International Image Interoperability Framework, accessed July 14, 2021, https://iiif.io/technical-details.

1379 Snydman et al., "International Image Interoperability Framework," 16, 20.

1380 *Mirador*, *IIIF*, accessed December 29, 2024, https://projectmirador.org.

1381 *DFG-Viewer*, Deutsche Forschungsgemeinschaft (DFG), accessed December 27, 2024, https://dfg-viewer.de.

1382 Snydman et al., "International Image Interoperability Framework," 20.

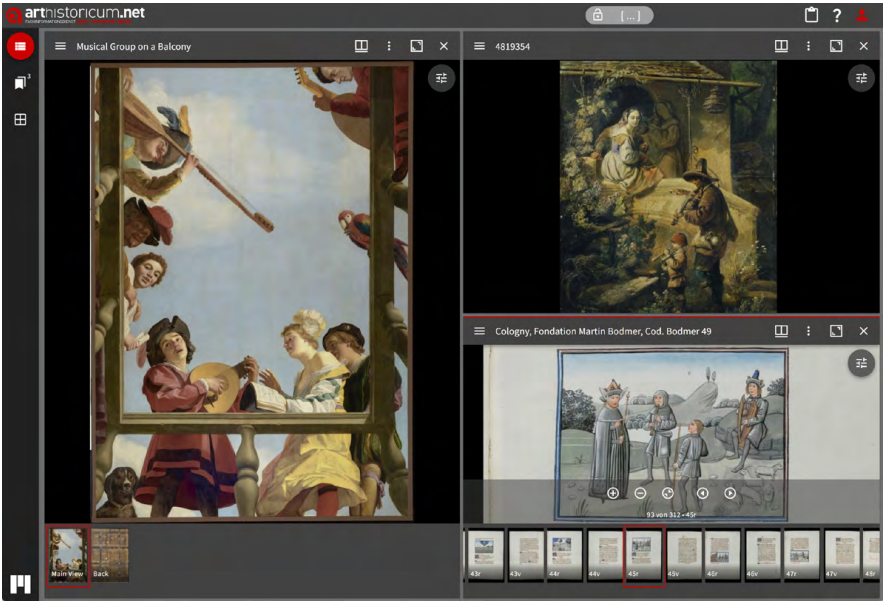


Figure 66. *Gallery view of artworks from the Getty* (left)*, Belvedere* (top right)*, and a manuscript from* e-codices (bottom right) *at* Bildviewer Mirador*, arthistoricum.net, accessed and collection created December 23, 2024, https://iiif.arthistoricum.net/mirador/?json=d4ed8c71-c140-11ef-a849-836e5bffc0e3*

The *IIIF* viewer *Mirador* can be opened in a new browser tab from any collection website that has implemented it. *Mirador* is a flexible and user-friendly viewer that allows objects from the digital collections of different museums, libraries, and archives to be brought together in one application, as illustrated in figure 66. Provided the institutions support the *IIIF* image standard, artworks from different repositories—a work from the Getty Museum (*left*), a work from the Belvedere Museum's collection (*top right*), and a manuscript from *e-codices* (*bottom right*)—can all be opened simultaneously in the same application.[1383] Within the application, users can switch between object views

1383 Gerrit van Honthorst, *Musical Group on a Balcony*, 1622, oil on panel, 309.9 × 216.4 cm, The J. Paul Getty Museum, accessed December 23, 2024, https://www.getty.edu/art/collection/object/103RAQ. Peter Johann Nepomuk Geiger, *Idylle (Italienische Bettelmusikanten)*, 1855, oil on cardboard, 39.5 × 31.5 cm, Belvedere Museum, accessed December 23, 2024, https://sammlung.belvedere.at/objects/1817/idylle-italienische-bettelmusikanten. *Christine of Pisan, Epitre d'Othea*, France, around 1460, parchment, 150 ff, 28 × 20 cm, Cod. Bodmer 49, Fondation Martin Bodmer, Cologny, *e-codices*, accessed December 23, 2024, https://www.e-codices.ch/en/list/one/fmb/cb-0049.

(like the back of an artwork or individual book pages), zoom independently into the high-resolution images, make image manipulations (such as adjusting brightness), and add annotations. The info buttons display object information and the source links of the objects. Additional areas and objects can be added to the viewer, and collections shared via links, as demonstrated by arthistoricum.net's *Mirador* instance via "Share image collection."[1384]

IIIF and *Mirador* facilitate comparative analysis of artworks and cultural objects, offering more than static image examination. While objects leave their native digital collection environments, their provenance remains traceable—critical for scholarly use and institutional reputation.

The Getty Research Institute's *12 Sunsets*[1385] application exemplifies *IIIF*'s potential.[1386] It integrates contemporary artist Ed Ruscha's 65,000 photographs of Sunset Boulevard in Los Angeles, taken between 1965 and 2007, with narrative texts, a timeline, and a map for an interactive experience. Users navigate the interface dynamically by driving (horizontally) or moving from one year to another (vertically), with the option to view several years at once. Google's *Cloud Vision API* [1387] adds to the application by tagging images with machine learning-based labels. *12 Sunsets* is a good example of how technical expertise combined with the right open-source software results in compelling online art presentations.

6.5 Open-Source Software

Using open-source software has multiple advantages, but the most useful benefit for nonprofit GLAM organizations is that it can be used without relying on a vendor's product or paying licensing fees. This flexibility is valuable for the creation of customized infrastructures, but the software's implementation still requires staff for development, maintenance, and continuous improvement. Because the code is open and adaptable, this makes it sustainable in the long-term, especially when backed by a large, active community. Cross-institutional initiatives like *IIIF*, with such community support, are a promising model for digital technology in museums. Rather than addressing challenges in isolation, these projects tackle broader issues

1384 *Bildviewer Mirador*, arthistoricum.net, accessed December 23, 2024, https://iiif.arthistoricum.net/mirador.

1385 *12 Sunsets: Exploring Ed Ruscha's Archive*, Getty, accessed December 29, 2024, https://12sunsets.getty.edu.

1386 David Newbury, "IIIF Enables Research and Storytelling for Two New Digital Projects at the Getty," 2020, accessed August 21, 2021, https://iiif-io.medium.com/iiif-enables-research-and-storytelling-for-two-new-digital-projects-at-the-getty-da7d5fe18c32.

1387 *Cloud Vision API*, Google, accessed December 29, 2024, https://cloud.google.com/vision.

of digital transformation that affect museums more broadly.

As discussed in previous chapters and examples, successful digital projects in both universities and museums require cross-departmental and -disciplinary collaborations involving stakeholders not previously reflected in workflows,[1388] such as art historians, computer scientists, IT specialists, information scientists, database managers, curators, educators, and UX designers. Further, collaboration across institutions can bridge gaps in technological capabilities, especially when museums partner with other institutions or major tech companies like Google and Microsoft.[1389] That said, transdisciplinary projects do present challenges, as they bring together different research practices and methodologies.[1390] The digital humanities, for instance, have been successful in the execution of such interdisciplinary work, as Cathy N. Davidson and Danica Savonick observe: "Perhaps more than any other area of the academy, the digital humanities have succeeded in making linkages across disciplines that are radically disparate in focus and methodology."[1391] Successful interdisciplinary collaboration demands a shared goal, with participants incorporating diverse perspectives and aligning their research questions.[1392] Networked technologies further improve collaboration across geographic distances, while a shared vocabulary, collaborative willingness, clear management, and fitting technology are the bases for success.[1393] Gary M. Olson points out, "Different fields frequently have their own unique vocabularies. These matters are particularly troublesome when the same words mean different things in different fields."[1394] For example, an art historian has a very different conception of an image than a computer scientist.

In the digital humanities, the approach to research has changed, but so

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1388 Cathy N. Davidson and Danica Savonick, "Digital Humanities: The Role of Interdisciplinary Humanities in the Information Age," in *The Oxford Handbook of Interdisciplinarity*, ed. Robert Frodeman, 2nd ed. (Oxford University Press, 2017), 168, https://doi.org/10.1093/oxfordhb/9780198733522.013.14.

1389 Volland, "Einsatzgebiete Künstlicher Intelligenz," 119.

1390 Rico Defila et al., "Hotspots der transdisziplinären Kooperation," in *Transdisziplinär forschen – zwischen Ideal und gelebter Praxis: Hotspots, Geschichten, Wirkungen*, ed. Rico Defila and Antonietta Di Giulio (Campus, 2016), 27.

1391 Davidson and Savonick, "Digital Humanities," 161.

1392 Rico Defila and Antonietta Di Giulio, "Managing Consensus in Inter- and Transdisciplinary Teams: Tasks and Expertise," in *The Oxford Handbook of Interdisciplinarity*, ed. Robert Frodeman, 2nd ed. (Oxford University Press, 2017), 332, https://doi.org/10.1093/oxfordhb/9780198733522.013.27.

1393 Gary M. Olson, "Collaboratories," in *Handbook of Science and Technology Convergence*, ed. William Sims Bainbridge and Mihail C. Roco (Springer Reference, 2016), 391–394, https://doi.org/10.1007/978-3-319-07052-0_34.

1394 Olson, "Collaboratories," 394.

has teaching. Learning has become "experiential, peer-led, and participatory" with students gaining hands-on experience with software, tools, and digital platforms. This increases their digital literacy, often through collaborative group work.[1395] The *DHVLab*[1396] reflects this shift. It is a virtual teaching and research environment where art history students can access the necessary software via a browser to learn data analysis.[1397] Rather than traditional lectures and seminar presentations, students lead small workshops to demonstrate processes in the virtual environment, acquiring both theoretical knowledge and practical skills.[1398] A similar initiative, *Digitales Storytelling*,[1399] teaches art history students the fundamentals of digital storytelling using *IIIF*. These digital teaching environments and tutorials promote digital literacy, preparing students for their academic or professional futures. As Cathy N. Davidson and Danica Savonick note, "Digital humanists are not only developing new areas for analysis by new computational tools but also, while developing such tools, expanding our understanding of the implications and consequences of their development."[1400]

Like open-source software, open data provides more flexibility in using digitized cultural heritage. However, Barbara Fischer points out that cultural institutions often unaware of the potential for repurposing digitized cultural heritage for new contexts and knowledge creation.[1401] To address this, hackathons like *Coding da Vinci* in Germany aim to make cultural data more accessible and encourage the development of new applications.[1402] Many digitized objects are in the public domain—either because the copyright has expired or because museums have waived usage rights—and can be freely reused.[1403] Cultural hackathons provide opportunities for developers,

1395 Davidson and Savonick, "Digital Humanities," 165.

1396 *DHVLab*, IT-Gruppe Geisteswissenschaften, Ludwig-Maximilians-Universität München, accessed December 29, 2024, https://dhvlab.gwi.uni-muenchen.de.

1397 Harald Klinke, "Datenanalyse in der Digitalen Kunstgeschichte: Neue Methoden in Forschung und Lehre und der Einsatz des DHVLab in der Lehre," in *#DigiCampus: Digitale Forschung und Lehre in den Geisteswissenschaften*, ed. Harald Klinke (readbox, 2018), 29–30, https://doi.org/10.5282/ubm/epub.42415.

1398 Klinke, "Datenanalyse," 32.

1399 *Digitales Storytelling*, Kunstgeschichtliches Institut, Goethe University Frankfurt, accessed December 29, 2024, https://leszimmermann.github.io/digitales-storytelling.

1400 Davidson and Savonick, "Digital Humanities," 168.

1401 Barbara Fischer, "Coding da Vinci: oder für eine Renaissance der Allmendekultur mit digitalen Mitteln," in *Der digitale Kulturbetrieb: Strategien, Handlungsfelder und Best Practices des digitalen Kulturmanagements*, ed. Lorenz Pöllmann and Clara Herrmann (Springer, 2019), 417, https://doi.org/10.1007/978-3-658-24030-1_19.

1402 Fischer, "Coding da Vinci," 416.

1403 Fischer, "Coding da Vinci," 416–417.

designers, and others with a range of digital and cultural skillsets to create experimental applications in a short period, often on their own time.[1404] These events help institutions see the value and potential of their data.

Such experimentation with digital data makes it possible to develop new applications that meet stakeholder needs. By combining, aggregating, and transforming various web resources in applications—often referred to as mashups—developers can bring new services to users.[1405] Brigitte Endres-Niggemeyer defines mashups as integrating "existing web resources in order to produce helpful new resources or services."[1406] For museums, mashups can integrate additional data that improves digital collection content but is not available in the collection database. Mashups rely on standards to enable the free exchange of data,[1407] which is essential for the advancement of digital applications and art historical research.

6.6 Conclusion

The examples and techniques discussed in this chapter demonstrate how various data types and technological applications can yield new approaches to analyzing art. Beyond traditional methods in art history—such as studying works in isolation, reading relevant literature, and conducting keyword searches in databases—technology can generate new ways to engage with and analyze information. Computational methods like text and image analysis, along with the integration of diverse data pools, point to interpretations that complement art historians' established tools. These technologies make possible alternative forms of access to museum digital collections, beyond basic keyword searches. Furthermore, images and metadata can be incorporated into applications that provide valuable context and rigor.

The availability of digital objects also opens up new avenues for museums to utilize their collections beyond presenting physical objects in exhibitions. For museums, the integration of digital tools requires both an understanding of data within its cultural context and technological proficiency. Bringing together these two areas of expertise through interdisciplinary collaboration is increasingly important, as museums and universities continue navigating an evolving digital landscape. This

1404 Fischer, "Coding da Vinci," 418–420.

1405 Brigitte Endres-Niggemeyer, "Preface," in *Semantic Mashups: Intelligent Reuse of Web Resources*, ed. Brigitte Endres-Niggemeyer (Springer, 2013), v.

1406 Endres-Niggemeyer, "Preface," v.

1407 Brigitte Endres-Niggemeyer, "Mashups Live on Standards," in *Semantic Mashups: Intelligent Reuse of Web Resources*, ed. Brigitte Endres-Niggemeyer (Springer, 2013), 51, https://doi.org/10.1007/978-3-642-36403-7_2.

synergy will be further explored in chapter 7 "Digital Technology for Art History and Museums," which summarizes digital technology's significance for art history and museums.

7. Digital Technology for Art History and Museums

7.1 Introduction

As addressed in previous chapters, the technological advancements in representing digital collections and analyzing the digital images and metadata they contain have reached a sophisticated level. Digital collections of art and the introduction of digital imagery catalyzed broader changes than initially apparent. Artworks transformed into data allow museums to present their collections in digital formats, while digital methods provide new approaches for art historical research. This chapter bridges the preceding discussions by situating digital collections and imagery within the current landscape of museums and art history by examining the conditions for using digital technology effectively and highlighting notable developments. Finally, this chapter identifies essential criteria for aligning digital collections and museums with contemporary technological demands.

While the digitization of collections began as an extension of routine museum practices, it has transformed how art is approached in the digital realm. Successfully navigating the changes brought about by digital collections and technologies requires acknowledging this paradigm shift as disruptive. The practical guide *Digital Basic Cataloguing* reflects this awareness by outlining principles for museums digitizing their collections.[1408] As noted in previous chapters, several developments—including the increasing availability of digitized collections, the possibilities of data reuse, new methods of analyzing and presenting images and metadata, and digital literacy as a foundational skill—indicate that some have already adapted to these changes. However, many museums still aim merely to put collections online without further strategic considerations, such as implementing a digital strategy, open data policies, or advanced digital applications. Similarly, while some art historians utilize digital humanities methods, many others can benefit from adopting digital competencies or pursuing interdisciplinary collaborations. Museums and art history face numerous challenges that must be addressed thoughtfully and productively. This chapter explores the relationship between museums and art history concerning the role of digital technology within these fields.

1408 Winfried Bergmeyer and Klimpel Paul, eds., *Digital Basic Cataloguing: 10 Principles* (Network of European Museum Organisations and German Museums Association, 2022), https://www.ne-mo.org/fileadmin/Dateien/public/Publications/NEMO_Report_Working_Group_Digitalisation-and-IPR_Digital_Basic-Cataloguing_12.22.pdf.

When digitizing collections, museums become content providers for art historians and digital humanities scholars. Embracing this role, museums can strategically make images and metadata accessible to meet the needs of scholars working with digital data. Conversely, art historians proficient in digital technology and adept at locating useful data can study art using digital methods. Thus, museums, like academic art historians, must be digitally and technically literate in order to develop applications that clearly present and communicate art to diverse audiences. Digital technology offers numerous opportunities for working with digital collection data, as discussed in examples throughout this book. Yet, harnessing these opportunities for art historical research and museum practices remains a challenge. Digital imagery and metadata must be leveraged to resolve questions and enable future developments in museums, digital art history, and the digital humanities.

Whether art historians make use of technology-based methods depends on their willingness to incorporate them. Some voices advocate for greater openness to digital technology within both art history and art museums, emphasizing the potential for progress.[1409] Skillful use of technology involves more than simply translating previously analog activities—research, viewing images, or writing—into digital formats. Instead, technology must be recognized as a generative tool for new research questions and innovative scholarly approaches to art using digital sources.

A wealth of information, including digital images, metadata, archival documents, and scholarly texts, is now available online, presenting myriad opportunities for new methods. To maximize this potential, scholars must familiarize themselves with digital resources and consider how to integrate them to generate new scholarship. Successful reuse of cultural data hinges on data quality and characteristics—whether images or text—compared to physical reproductions and originals. The best method for analyzing, visualizing, and interpreting digital sources depends on the available data and research questions.

1409 Peter Bell and Björn Ommer, "Computer Vision und Kunstgeschichte: Dialog zweier Bildwissenschaften," in *Computing Art Reader: Einführung in die digitale Kunstgeschichte*, ed. Piotr Kuroczyński et al. (arthistoricum.net, 2018); Harald Klinke, "Datenanalyse in der Digitalen Kunstgeschichte: Neue Methoden in Forschung und Lehre und der Einsatz des DHVLab in der Lehre," in *#DigiCampus: Digitale Forschung und Lehre in den Geisteswissenschaften*, ed. Harald Klinke (readbox, 2018), https://doi.org/10.5282/ubm/epub.42415; Hubertus Kohle, *Digitale Bildwissenschaft* (vwh Verlag Werner Hülsbusch, 2013), https://doi.org/10.11588/artdok.00002185; Hubertus Kohle, *Museen digital: Eine Gedächtnisinstitution sucht den Anschluss an die Zukunft* (Heidelberg University Publishing, 2018), https://doi.org/10.17885/heiup.365.515; Sabine Lang and Björn Ommer, "Transforming Information into Knowledge: How Computational Methods Reshape Art History," *Digital Humanities Quarterly* 15, no. 3 (2021): 1–48, accessed August 30, 2021, https://www.digitalhumanities.org/dhq/vol/15/3/000560/000560.html.

Digital technology and increasing the availability of collection data pose major challenges for museums and art history, making interdisciplinary collaboration, robust technological infrastructure, and digitally oriented forms of publication essential, all of which are addressed in this chapter. Changes associated with the digital image—in contrast to the analog era—impact museums, art history, and the objects they engage with. Collaboration across disciplines and institutions is becoming more and more important in order to ensure access to necessary skills and data,[1410] meaning that art historians can work alongside programmers and data scientists to realize relevant digital projects that best address everyone's needs. Open-source tools and software make possible flexible and customizable applications. Frameworks offering user-friendly tools minimize barriers for using digital technology.

Representing digital collections and art historical research with data requires infrastructures that serve as virtual research, presentation, and long-term archiving environments. In digital humanities projects, the creation of systems is as important as the benefits that come from using the final product. Widespread adoption of digital infrastructure, along with accessible digital images and publications, has implications for scholarly publishing. Digital platforms that integrate images and textual information directly from sources, along with interactive content, are increasingly useful. This also applies to digital exhibition catalogs and catalogs raisonnés.

Digital images have transformed the way art is studied, presented, researched, and communicated. While the digital transformation in art museums and art history is still evolving, progress in related fields, such as the digital humanities, libraries, and archives, provide fertile ground for further development. Inevitably, digital technology raises new questions, and the challenge lies in integrating digital workflows and identifying the best ways to present art digitally. Discourses in digital art history and digital humanities provide valuable insight into the state of the field.

7.2 Art History and Museum Perspectives

The creation and availability of knowledge depends entirely on the extent of access to digital sources. In essence, as the volume of digitally available information grows, so does the knowledge generated with digital support. Some institutions, including the Getty Museum, Georgia O'Keeffe Museum, Kunstmuseum Bern, Louvre, the Met Metropolitan Museum of Art (Met),

1410 Franco Moretti reminds readers that "quantitative work is truly *cooperation*" because it is based upon others' achievements, e.g. a prepared collection of data that can be reused. Franco Moretti, *Graphs, Maps, Trees: Abstract Models for a Literary History* (Verso, 2005), 5.

Brooklyn Museum, and *Van Gogh Worldwide*, have begun to include in available digital material different views of artworks, such as their backs, labels, inscriptions, and frames, as well as employing photographic techniques commonly used in conservation and restoration.[1411] Such documentation reveals details usually inaccessible to the viewer, but may provide additional information to better understand the object.

The movement toward more and more detailed and comprehensive representation of art objects manifests in various ways. Fully reproduced manuscripts, as seen in *e-codices*,[1412] or sketchbooks, as "Rudolf Koller's Sketchbooks,"[1413] allow individual pages to be contextualized within the object as a whole. This contrasts with traditional research which often required extensive communication, coordination, and physical visits to museum study rooms. Holistic digitization emphasizes the physical attributes of artworks in digital collections, moving beyond merely reproducing motifs to convey style and concept. For art historical research, these digital forms of documentation offer a more thorough understanding of an artwork than previous forms of documentation allowed. Increased convenience and availability of reliable information, once accessible only through research across multiple locations, guarantees the advancement of art historical inquiry.

Digitization's progress has also introduced ultra-detailed imaging models like *Google Arts & Culture's*[1414] gigapixel images or the Rijksmuseum's ultra-high-resolution photograph of Rembrandt van Rijn's *The Night Watch* (1642).[1415] These technologies allow users to examine artworks in ways that deemed impossible when viewing an original at a museum, revealing individual brushstrokes and craquelure of paintings in extraordinary detail.

1411 See *Museum Collection*, Getty Museum, accessed December 29, 2024, https://www.getty.edu/art/collection; *Collections Online*, Georgia O'Keeffe Museum, accessed December 29, 2024, https://collections.okeeffemuseum.org/object/; *The Gurlitt Estate*, Kunstmuseum Bern, accessed December 29, 2024, https://gurlitt.kunstmuseumbern.ch/en; *Collections*, Louvre, accessed December 29, 2024, https://collections.louvre.fr; *The Met Collection*, Met, accessed December 29, 2024, https://www.metmuseum.org/art/collection; *Collection*, Brooklyn Museum, accessed December 29, 2024, https://www.brooklynmuseum.org/opencollection/collections/9; *Van Gogh Worldwide*, accessed December 29, 2024, https://vangoghworldwide.org.

1412 *e-codices*, University of Fribourg, accessed December 29, 2024, https://www.e-codices.unifr.ch.

1413 "Rudolf Koller's Sketchbooks," Kunsthaus Zürich, accessed December 29, 2024, https://digital.kunsthaus.ch/viewer/search/-/-/1/-/DC%3Askizzenbuechervonrudolfkoller/.

1414 *Google Arts & Culture*, Google, accessed December 29, 2024, https://artsandculture.google.com/project/gigapixels.

1415 "Ultra High Resolution Photo," Rijksmuseum, accessed December 29, 2024, https://www.rijksmuseum.nl/en/stories/operation-night-watch/story/ultra-high-resolution-photo.

Techniques like 3D imaging further improve digital reproductions, capturing changes in surface texture and reflection to provide a more tactile sense of objects. For example, Reflectance Transformation Imaging (RTI) can depict shiny surfaces, as demonstrated by objects in the *Basel Cathedral Treasury*,[1416] while 3D models, like the one MoMA provides for Vincent van Gogh's *The Starry Night* (1889),[1417] allow users to study the painting's brushstrokes in three dimensions.

Advanced imaging techniques, including X-radiography, infrared reflectography, and macrophotography, expose layers detail beneath an artwork's surface otherwise accessible only to conservators. Applications like *Closer to Van Eyck*[1418] provide multilayered views of restored artworks like the *Ghent Altarpiece* while the Germanisches Nationalmuseum in *Deutsche Tafelmalerei des Spätmittelalters*[1419] offers similar views of German panel painting from the late Middle Ages.

Detailed reproductions are just one feature of museum digitization today. More museums are digitizing related materials such as exhibition catalogs, archival documents, installation views, making a wealth of peripheral information accessible online.[1420] This expanded accessibility aligns with ongoing provenance research efforts, which aim to increase museum

1416 *muensterschatz.ch*, Historisches Museum Basel, accessed December 29, 2024, https://www.muensterschatz.ch/en.

1417 *Collection*, MoMA, accessed December 29, 2024, https://www.moma.org/collection/works/79802.

1418 *Closer to Van Eyck*, accessed December 29, 2024, https://closertovaneyck.kikirpa.be.

1419 *Deutsche Tafelmalerei des Spätmittelalters*, Germanisches Nationalmuseum, accessed December 29, 2024, https://tafelmalerei.gnm.de/wisski/navigate/145/view.

1420 For digitized exhibition catalogs, see "Exhibition Catalogues," Kunsthaus Zürich, accessed December 29, 2024, https://digital.kunsthaus.ch/viewer/search/-/-/1/-/DC%3Aausstellungskataloge/; "Exhibition History," MoMA, accessed December 29, 2024, https://www.moma.org/history; Met, accessed December 29, 2024, https://www.metmuseum.org/met-publications/all?waysToRead=downloadPdf. For digitized exhibition views: "Exhibition History," MoMA, accessed December 29, 2024, https://www.moma.org/history. For digitized archival material: MoMA Archives Image Database (MAID), MoMA, accessed December 29, 2024, https://maid.moma.org; Archive Items, Tate, accessed December 29, 2024, https://www.tate.org.uk/search?type=archive; "Thomas J. Watson Library Digital Collections," Met, accessed December 29, 2024, https://www.metmuseum.org/art/libraries-and-research-centers/watson-digital-collections.

and collection transparency.[1421] Digitized inventory books and provenance documents augment a growing repository of online resources.[1422]

Digital collection platforms are evolving into robust information hubs with advanced search functionalities, providing tools and applications that advance accessibility and encourage data reuse. A recent publication, based on a survey of user preferences for digital collection platforms, discusses the functionalities and content users value most.[1423] The 2024 book is a practical guide for institutions seeking to improve digital access to collections.

Currently, locating digital content on museum websites can be challenging due to decentralized distribution. Content is often managed by different departments and stored in separate databases, like collection databases, library catalog systems, or archival information systems. Additionally, digital applications may be created for specific purposes, such as exhibitions, educational initiatives, or marketing projects, resulting in fragmented access points. To address this, some institutions, including MoMA, the Städel Museum, and the Met, have adopted strategies that link artworks to related content such as videos, audio streams, archival materials, publications, and

1421 Jane C. Milosch and Nick Pearce, eds., *Collecting and Provenance: A Multidisciplinary Approach* (Rowman & Littlefield, 2019); Arthur Tompkins, ed., *Provenance Research Today: Principles, Practice, Problems* (Lund Humphries and IFAR, 2020). Guidelines: Andrea Baresel-Brand et al., *Leitfaden Provenienzforschung: Zur Identifizierung von Kulturgut, das während der nationalsozialistischen Herrschaft verfolgungsbedingt entzogen wurde* (Deutsches Zentrum Kulturgutverluste, 2019; Carolin Lange and Thomas Schmutz, *Provenienzforschung im Museum I: NS-Raubgut: Grundlagen und Einführung in die Praxis* (Verband der Museen der Schweiz, 2021)). Websites: Getty Provenance Index, Getty Research Institute, accessed December 29, 2024, https://www.getty.edu/research/tools/provenance/search.html; Deutsche Zentrum Kulturgutverluste, accessed December 29, 2024, https://www.kulturgutverluste.de; Kommission für Provenienzforschung, accessed December 29, 2024, https://provenienzforschung.gv.at; *Lexikon der österreichischen Provenienzforschung*, Kommission für Provenienzforschung, accessed December 29, 2024, https://www.lexikon-provenienzforschung.org; Provenance research in Switzerland, Federal Office of Culture, accessed December 29, 2024, https://www.bak.admin.ch/bak/en/home/cultural-heritage/looted-art-from-the-nazi-period/provenance-research-in-switzerland.html.

1422 See "List of Works," MoMA, accessed December 29, 2024, https://www.moma.org/collection/provenance/works; "Provenienzforschung," Kunsthaus Zürich, accessed December 29, 2024, https://collection.kunsthaus.ch/de/collection/?f=1005&v=2; "Open Access Bayerische Staatsgemäldesammlungen," accessed December 29, 2024, https://www.pinakothek.de/de/museum/forschung/open-access.

1423 Sonja Gasser, *Digitale Sammlungen: Anforderungen an das digitalisierte Kulturerbe* (transcript, 2024), https://doi.org/10.14361/9783839470213.

applications.[1424] The Met's website, for example, features a section explaining drawing and printing techniques, with direct links to corresponding works in its digital collection and vice versa.[1425] Approaches like these guide users between related resources and deepen their understanding of the content.

Comprehensive digitization in museums does not align neatly with the business principle of "you do it once, do it right, and use it everywhere," since digitization is an ongoing, iterative process.[1426] Nevertheless, merging platforms and systems into interconnected networks using linked data and common standards remains a goal for the cultural sector, but ultimately, those networks facilitate the exchange and use of digitized artworks and related information.

Today's digital collections offer visual data of unprecedented quality, surpassing that of analog photography and early low-resolution digital reproductions. Beyond providing high-quality images, digital collections impact museum operations and art historical research by addressing structural, technological, conceptual, and methodological considerations unique to digital environments. Initiatives that incorporate linked open data (LOD),[1427] such as those by the Georgia O'Keeffe Museum,[1428] *Van Gogh Worldwide*,[1429] and *Bilder der Schweiz Online*[1430] by the Swiss Art Research Infrastructure (SARI),[1431] demonstrate the promise for data accessibility and interconnected collections. The digital collection understood as an infrastructure that supports meaningful connections across artworks, archival

1424 For digital collections in which this strategy is applied, see *Collection*, MoMA, accessed December 29, 2024, https://www.moma.org/collection; *Digital Collection*, Städel Museum, accessed December 29, 2024, https://sammlung.staedelmuseum.de/de/werk/goethe-in-der-roemischen-campagna; *The Met Collection*, Met, accessed December 29, 2024, https://www.metmuseum.org/art/collection.

1425 "Engraving," Met, accessed December 29, 2024, https://www.metmuseum.org/about-the-met/collection-areas/drawings-and-prints/materials-and-techniques/printmaking/engraving.

1426 Hossein Eslambolchi, "Reasons for Optimism," *IEEE Communications Magazine* 41, no. 3 (2003): 18, https://doi.org/10.1109/MCOM.2003.1186542; Hossein Eslambolchi, "The Concept of One: Do It Once, Do It Right, Use It Everywhere," *LinkedIn*, 2013, accessed January 4, 2022, https://www.linkedin.com/pulse/20130306202342-5213223-the-concept-of-one-do-it-once-do-it-right-and-use-it-everywhere.

1427 "What Are Linked Data and Linked Open Data?" Ontotext, accessed December 29, 2024, https://www.ontotext.com/knowledgehub/fundamentals/linked-data-linked-open-data/.

1428 "About Collections Online," Georgia O'Keeffe Museum, accessed December 17, 2021, https://collections.okeeffemuseum.org/about/.

1429 *Van Gogh Worldwide*, accessed December 29, 2024, https://vangoghworldwide.org.

1430 *Bilder der Schweiz Online*, Swiss Art Research Infrastructure (SARI), University of Zurich, accessed December 29, 2024, https://bso.swissartresearch.net.

1431 Swiss Art Research Infrastructure (SARI), University of Zurich, accessed December 29, 2024, https://swissartresearch.net.

items, publications, etc. of one institution and across different institutions supports a more comprehensive understanding of the context of an artwork.[1432] Using the *CIDOC-CRM*-based[1433] *Linked Art*[1434] target model, these collections establish semantic, machine-readable relationships using standard vocabularies like *Art & Architecture Thesaurus (AAT)*[1435] or *Union List of Artist Names (ULAN)*.[1436] Knowledge graphs, such as *Wikidata*,[1437] further connect these resources within the Semantic Web.[1438]

By incorporating linked vocabularies, digital collections can expand their scope, integrating additional information like artist biographies or relationships. Structuring data in a knowledge graph allows for a more comprehensive and humanities-focused collection presentation. In summary, the ideal digital collection is built with openness, connectivity, and robust data structures in mind, all of which are outlined in the next section.

1432 See "About the Online Collections," Georgia O'Keeffe Museum, accessed December 29, 2024, https://collections.okeeffemuseum.org/about/.

1433 *CIDOC-CRM,* International Committee for Documentation (CIDOC), accessed December 29, 2024, https://www.cidoc-crm.org.

1434 *Linked Art*, accessed December 29, 2024, https://linked.art.

1435 *Art & Architecture Thesaurus (AAT)*, Getty Research Institute, accessed December 29, 2024, https://www.getty.edu/research/tools/vocabularies/aat/.

1436 *Union List of Artist Names (ULAN)*, Getty Research Institute, accessed December 29, 2024, https://www.getty.edu/research/tools/vocabularies/ulan/.

1437 *Wikidata*, accessed December 29, 2024, https://www.wikidata.org/wiki/Wikidata:Main_Page.

1438 See "About the Online Collections," Georgia O'Keeffe Museum, accessed December 29, 2024, https://collections.okeeffemuseum.org/about/.

Data Standards for Digital Collections

Adhering to the following standards ensures that data—both images and metadata—from digital collections can be adapted for a range of applications by museums, art historians, digital humanists, and other stakeholders.

1. **Linked Data**
   A platform like *ResearchSpace*[1439] provides a workspace for utilizing linked data. It employs the *Linked Art*[1440] model, *CIDOC CRM*,[1441] and the *Getty Vocabularies*[1442] for domain-specific terminology, delivering an API for LOD with JSON-LD as the exchange format.

2. **Interoperable Images**
   The International *Image Interoperability Framework* (*IIIF*)[1443] is recommended to ensure image interoperability. *IIIF* manifests enable flexible usage, such as loading images into the *IIIF* viewer *Mirador*,[1444] which includes practical image manipulation tools.

3. **Open Licenses**
   Data providers should use widely recognized public domain tools like Public Domain Mark or CC0 to indicate that images to indicate that images and metadata are free to use.[1445] Creative Commons licenses such as CC BY or CC BY-SA, categorized as "Approved for Free Cultural Works," are also viable options.[1446] For artworks where a Creative Commons license cannot be applied, RightsStatements.org[1447] is recommended to communicate usage rights clearly to both humans and machines.

Following these guidelines reinforces digital collection data's importance as

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1439 *ResearchSpace*, British Museum, accessed December 29, 2024, https://researchspace.org.

1440 *Linked Art*, https://linked.art.

1441 *CIDOC CRM*, https://www.cidoc-crm.org.

1442 *Getty Vocabularies*, Getty Research Institute, accessed December 29, 2024, https://www.getty.edu/research/tools/vocabularies/.

1443 *International Image Interoperability Framework (IIIF)*, accessed December 29, 2024, https://iiif.io.

1444 *Mirador*, *IIIF*, accessed December 29, 2024, https://projectmirador.org.

1445 "Public Domain," Creative Commons, accessed December 29, 2024, https://creativecommons.org/share-your-work/public-domain/; "Understanding Free Cultural Works," Creative Commons, accessed December 29, 2024, https://creativecommons.org/share-your-work/public-domain/freeworks/.

1446 "CC BY 4.0," Creative Commons, accessed December 29, 2024, https://creativecommons.org/licenses/by/4.0/; "CC BY-SA 4.0," Creative Commons, accessed December 29, 2024, https://creativecommons.org/licenses/by-sa/4.0/.

1447 RightsStatements.org, accessed December 29, 2024, https://rightsstatements.org.

foundational for generating and disseminating knowledge in the digital age. Ensuring technical interoperability enables seamless data linkage between various databases, institutions, and digital objects from museums, archives, and libraries. Once this infrastructure is established, using data for research and creating applications for museums is an easy next step. This process necessitates art history and digital humanities scholars, along with museum staff, to skillfully use digital technology.

Digital images technical attributes foster environments tailored to their analysis. Digital images afford greater interpretive potential as they can be quantitatively analyzed by machines.[1448] Unlike humans, who recognize color areas, shapes, symbols, or figures, computers analyze individual pixels for color value, saturation, and brightness.[1449] Machine-aided analysis of digital image collections begins with pixel-level examination, extending beyond the acknowledgment that raster images consist of pixels.[1450] This shift from presentation to analysis makes digital images objects of investigation in humanities research.[1451]

Traditionally, art history emphasizes the depictions within images, rather than images themselves.[1452] However with digital collections, both the digital image and the subjects represented possess equal importance, especially when research questions are addressed using digital methods.

Museum databases containing art-related data facilitate statistical analyses. Despite this, critical evaluation of the historical, institutional, and technological contexts in which the database was created remains essential. For instance, determining the number of artworks by female artists in a collection—a very general example—still requires attention to metadata availability. Collections are often not yet entirely digitized, leading to gaps. Older collections, reflecting historical biases, typically have and exhibit fewer works by female artists. Even more mindful acquisitions in recent years cannot offset the disproportionately large number of male artists in older collections. Moreover, the number of works by an artist does not correlate with their significance. Quantitative analyses must account for the numerical relationships within the data. For example, an artist with thousands of drawings may overshadow another artist with only a few paintings. Similarly, series or installations recorded across multiple data records pose challenges in defining a single artwork. To ensure transparency, data providers must disclose the scope and limits of their metadata.

1448 Celia Krause and Ruth Reiche, *Ein Bild sagt mehr als tausend Pixel? Digitale Forschungsansätze in den Bild- und Objektwissenschaften* (vwh Verlag Werner Hülsbusch, 2016), 19.

1449 Krause and Reiche, *Mehr als tausend Pixel?*, 2016, 25.

1450 Krause and Reiche, *Mehr als tausend Pixel?*, 2016, 12.

1451 Krause and Reiche, *Mehr als tausend Pixel?*, 2016, 14–15.

1452 Krause and Reiche, *Mehr als tausend Pixel?*, 2016, 17.

Digital Humanities and Art History

The integration of digital technologies into research is a critical topic in the humanities. Amanda Wasielewski critically examined the strengths and weaknesses of applying machine learning in art history, juxtaposing traditional and computational formalistic methods.[1453] Humanities disciplines possess rich cultural data and scholars with deep expertise in their fields' historical and discursive frameworks. Conversely, fields like computer science and statistics are proficient in advanced data processing and analysis. Such competencies usually belong to separate schools and faculties within universities, presenting hurdles for collaboration and requiring efforts to bridge gaps between organizational structures and different research cultures. Nevertheless, as shown previously, interdisciplinary collaboration is essential for the success of digital research projects. They achieve the best results when different researchers from various disciplines in the humanities and sciences, as well as stakeholder communities, such as museum, archive, and library staff, but also technical experts and data scientists collaborate.[1454]

Within this interdisciplinary context, "digital humanities" have emerged, focusing on the application of digital tools in text-centric fields like philology or history.[1455] A subset of this field, "digital art history," centers visual data and developed as a distinct domain around 2005.[1456] Definitions of digital art history vary, sometimes overlapping or diverging. Johanna Drucker, in a 2013 essay, questioned whether digital art history truly exists.[1457] She argued that methodological breakthroughs driven by digital work are still absent.[1458] Angela Dressen, in 2017, observed that digital art history comprises only part of the digital humanities.[1459] Digitizing collections or using electronic finding aids qualify under a broad definition, but a narrower view considers technology central to research, demanding more advanced digital skills.

1453 Amanda Wasielewski, *Computational Formalism: Art History and Machine Learning*, Leonardo (The MIT Press, 2023), https://doi.org/10.7551/mitpress/14268.001.0001.

1454 Hannah M. Dee et al., "Visual Digital Humanities: Using Image Data to Derive Approximate Metadata," in *Managing Digital Cultural Objects: Analysis, Discovery and Retrieval*, ed. Allen Foster and Pauline Rafferty (Facet, 2014), 90, https://doi.org/10.29085/9781783301539.005.

1455 Many authors have already pointed this out. See Angela Dressen, "Grenzen und Möglichkeiten der digitalen Kunstgeschichte und der Digital Humanities: Eine kritische Betrachtung der Methoden," *kunsttexte.de*, no. 4 (2017): 1, https://doi.org/10.18452/18692.

1456 See the following early publication dedicated to digital art history: Anna Bentkowska-Kafel et al., eds., *Digital Art History: A Subject in Transition* (Intellect, 2005).

1457 Johanna Drucker, "Is There a 'Digital' Art History?" *Visual Resources* 29, no. 1–2 (2013): 5–13, https://doi.org/10.1080/01973762.2013.761106.

1458 Drucker, "Is There a 'Digital' Art History?" 5.

1459 Dressen, "Grenzen und Möglichkeiten," 1–2.

Art history conducted with digital tools is distinct from digital art history, which introduces new tasks, questions, and methods.[1460] While digital tools facilitate access to images or texts, they do not fundamentally transform disciplinary practices.[1461] By contrast, digital art history dictates a methodological shift, as digital sources and tools differ entirely from analog or physical materials.[1462] Researchers in art history seek to understand traditional subjects using new technological prospects.[1463] The legitimization and advancement of digital art history requires, at a minimum, that research projects be developed collaboratively in an interdisciplinary context capitalizing on discipline-specific expertise.[1464]

Both university and museum art historians must acquire the skills necessary for digital research. The choice of technology, software, or tools is determined by the source material, research question, data structure, and type of presentation. Flexibility and commitment to learning in perpetuity are essential. Familiarizing with digital tools often develops through hands-on practice, bolstered by basic knowledge about the tool's capabilities. While awareness of digital benefits grows among museums and art historians, establishing technological proficiency is a work in progress. Collaboration with computer scientists, networking with digital humanities centers, and participating in summer schools provide valuable opportunities to grow these

1460 Drucker made this distinction in her 2013 article, to which other authors later referred. See: Drucker, "Is There a 'Digital' Art History?" 4; Jorge Sebastián Lozano, "Digital Art History at the Crossroads," *kunsttexte.de*, no. 4 (2017): 2–3, https://doi.org/10.18452/18695; Alexander Brey, "Digital Art History in 2021," *History Compass* 19, no. 8 (2021): 1–2, https://doi.org/10.1111/hic3.12678; Benjamin Zweig, "Forgotten Genealogies: Brief Reflections on the History of Digital Art History," *International Journal for Digital Art History*, no. 1 (2015): 40, https://doi.org/10.11588/dah.2015.1.21633.

1461 Sebastián Lozano, "Digital Art History," 2.

1462 Sebastián Lozano, "Digital Art History," 2–3.

1463 Schich, "Figuring Out Art History," 47.

1464 These research initiatives could shape digital art history in German-speaking countries: the German Research Foundation's (Deutsche Forschungsgemeinschaft, DFG) interdisciplinary priority program "Das digitale Bild" (The Digital Image). In Germany, DFG centered the topic within art history and other related disciplines between 2019–2025. In Switzerland, the *Digital Visual Studies* project at the University of Zurich, funded by the Max Planck Society from 2020–2024, was dedicated to digital art history methodologies. "SPP 2172: Das digitale Bild," Deutsche Forschungsgemeinschaft (DFG), accessed December 29, 2024, https://gepris.dfg.de/gepris/projekt/402352280; "Das digitale Bild," Deutsches Dokumentationszentrum für Kunstgeschichte, Bildarchiv Foto Marburg, Philipps-Universität Marburg, accessed December 29, 2024, https://www.digitalesbild.gwi.uni-muenchen.de; Digital Visual Studies, University of Zurich, accessed December 29, 2024, https://www.dvs.uzh.ch/en.html.

skills.[1465] As digital technologies become increasingly relied upon for research, museum workflows, and publishing, cultivating digital literacy is imperative.

7.3 Research and Publishing Digital Workflows

The rise of digital technology is reshaping how knowledge is created, shared, and published, particularly for research and exhibition catalogs, with projects that take advantage of digital technology's unique features. When sources, such as the data from digital collections, are available online and can incorporate interactive visualizations, publication systems must also adapt. It is therefore worthwhile to reevaluate what distinguishes digital publications from their physical counterparts and how best to design them. Digital publishing, specifically in art history and museum catalogs, now requires approaches that go beyond traditional typesetting to harness the possibilities of digital technology.

For museum catalogs that incorporate images from digital collections, embedding high-resolution images with zoom functionality improves image quality compared to printed catalogs. In some cases, these images may

1465 The University of Leipzig's "'Culture & Technology' European Summer University in Digital Humanities" takes place annually. Since 2009 they have offered lectures and hands-on workshops with a primary focus on text. "Culture & Technology" The European Summer University in Digital Humanities, University of Leipzig, archived September 21, 2019, https://web.archive.org/web/20190921175922/http://www.culingtec.uni-leipzig.de/ESU_C_T/. Also focused on text, the "Münchner Digital Humanities Summerschool" had three summer sessions from 2015 to 2017. After 2017, it continued under the name "Bayern Digital Humanities Summerschool." "Summerschool 2017," Zentrum für digitale Geisteswissenschaften, Bayerische Akademie der Wissenschaften, accessed June 5, 2017, https://dhmuc.hypotheses.org/summerschool-2017. "DHCH Summer School" in Rome started in 2021. "DHCH Summer School," DHCH, accessed February 4, 2022, https://dh-ch.ch/dhch-isr/21/index.html. There are also several programs dedicated specifically to digital art history including "Computing Art: A summer school for digital art history," which took place in Heidelberg in 2015. "Computing Art: A summer school for digital art history," Heidelberg Collaboratory for Image Processing, Heidelberg University, accessed June 5, 2017, https://hci.iwr.uni-heidelberg.de/CompVis_Summerschool2015. A 2016 Getty-funded "Digital Collections" summer institute in Zurich and Lausanne allowed participants to confer with experts, try tools, and learn new skills. "Grants Awarded," Getty, accessed June 5, 2017, https://www.getty.edu/foundation/initiatives/current/dah/dah_grants_awarded.html. The annual "Digital Art History Summer School (DAHSS)" in Malaga started in 2016. "Digital Art History Summer School (DAHSS)", Departamento de Historia del Arte, Universidad de Málaga, accessed June 1, 2022, https://dahss.iarthislab.eu/2022/. "Coding Dürer: International Interdisciplinary Hackathon for Art History and Information Science," funded by the Volkswagen-Stiftung, brought together art historians and computer scientists in 2017. Coding Dürer, Institut für Kunstgeschichte, Ludwig-Maximilians-Universität München, accessed June 5, 2017, https://codingdurer.de.

provide a closer view of the artwork than possible in person. Additionally, multimedia content and interactive visualizations require formats outside of those used for static text, images, and graphs as in traditional publications. Digital publishing frameworks, such as *OSCI Toolkit*[1466] or *Quire*,[1467] transfer the traditional format of the museum catalog to the digital environment and adapt the museum catalog to the digital medium. For instance, the Art Institute of Chicago uses the *OSCI Toolkit* for its digital publications,[1468] integrating archival documents and conservation imagery. The Nelson-Atkins Museum of Art employed *Quire* for its *Catalogue of French Paintings*,[1469] including timelines, zoomable image galleries, detailed object information, and digital object identifiers (DOIs)[1470] for essays and entries. These formats reflect changing reading habits influenced by digital technology and enable more engaging and interactive ways of presenting data.

The ability to visualize and interact with data from digital collections has precipitated a growing demand for scholarly publications to incorporate interactive content. Tools like *Idyll*[1471] enable the embedding of interactive visualizations in publications, allowing users to adjust parameters or explore datasets dynamically.[1472] Similarly, *Jupyter Books*[1473] support code-based content, including graph visualization and executable code from *Jupyter Notebooks*.[1474] Melusina Press integrates such features into its open-access articles,[1475] while

1466 *OSCI Toolkit*, accessed December 29, 2024, https://www.oscitoolkit.org.

1467 *Quire*, accessed December 29, 2024, https://quire.netlify.app.

1468 "Digital Publications," Art Institute of Chicago, accessed December 29, 2024, https://www.artic.edu/digital-publications.

1469 "Catalogue of French Paintings," Nelson-Atkins Museum of Art, accessed December 29, 2024, https://nelson-atkins.org/fpc/.

1470 Digital object identifier (DOI), DOI Foundation, accessed December 29, 2024, https://www.doi.org.

1471 *Idyll*, accessed December 29, 2024, https://idyll-lang.org.

1472 An overview of *Idyll*'s components and functionalities can be found via the following link. See "Built-In Components," *Idyll*, accessed December 29, 2024, https://idyll-lang.org/docs/components. One example from *Idyll*'s Gallery includes artworks from the Met's collection. See Matthew Conlen and Fred Hohman, "The Beginner's Guide to Dimensionality Reduction: Explore the methods that data scientists use to visualize high-dimensional data," July 16, 2018, https://dimensionality-reduction-293e465c2a3443e8941b016d.vercel.app. Another example demonstrates manipulation of a network visualization through links and sliders. See Jeffrey Heer, "The Barnes-Hut Approximation: Efficient computation of N-body forces," accessed December 29, 2024, https://jheer.github.io/barnes-hut/.

1473 *Jupyter Books*, Jupiter Book Community, accessed December 29, 2024, https://jupyterbook.org.

1474 *Jupyter Notebooks*, Project Jupyter, accessed December 29, 2024, https://jupyter.org.

1475 See the article: Philipp Koncar et al., "A Sentiment Analysis Tool Chain for 18th Century Periodicals," in *Fabrikation von Erkenntnis: Experimente in den Digital Humanities*, ed. Manuel Burghardt et al. (Université du Luxembourg, 2021), https://doi.org/10.26298/ezpg-wk34.

the *Journal of Digital History (JDH)*[1476] offers a platform for data-driven scholarship with layered narratives, hermeneutics, and datasets.[1477]

Access to digital collections significantly affects how knowledge is organized and shared. Museums and researchers alike must adopt tools that allow flexible use and presentation of data. This flexibility supports thematic linkages between texts, artworks, and visualizations. Research questions in the humanities are diverse, necessitating digital environments capable of accommodating a variety of methods and approaches. Success in art history and museums requires sharing not just findings but also skills, tools, vocabularies, and digitized content, encouraging skill development.

The broader adoption of open science (OS) principles—encompassing open access (OA), open data, open peer review, and open educational resources—calls for museums and researchers to share all aspects of their work.[1478] This includes data, software, research processes, and publications, all under open licenses. The *FAIR Principles*[1479] provide guidelines for research data management, emphasizing findability, accessibility, interoperability, and reusability.[1480] First outlined by Mark Wilkinson and 52 co-authors—stakeholders from academia, industry, science funders, and scholarly publishers—in 2016,[1481] the *FAIR Principles* aim to enhance machine-driven data use and create infrastructure for automated processes.[1482] Some museums, such as the Rijksmuseum, have begun applying these guidelines to their collection data.[1483]

1476 "Journal of Digital History (JDH)", University of Luxembourg, accessed December 29, 2024, https://journalofdigitalhistory.org.

1477 The *Journal of Digital History*'s writing environment, for which the journal provides a template, is based on *Jupyter Notebooks* and thus can accommodate data and code-based elements. "Frequently Asked Questions," Journal of Digital History, accessed June 16, 2022, https://journalofdigitalhistory.org/en/faq. See "Guidelines for Authors," Journal of Digital History, accessed June 16, 2022, https://journalofdigitalhistory.org/en/guidelines.

1478 Ulrich Riehm and Michael Nentwich, "Open Science aus Perspektive der Technikfolgenabschätzung: Zu Begriff, gesellschaftlicher Einbettung und möglichen Entwicklungen eines ubiquitären Konzepts," *TATuP Zeitschrift für Technikfolgenabschätzung in Theorie und Praxis* 26, no. 1–2 (2017): 11–17, https://doi.org/10.14512/tatup.26.1-2.11.

1479 *FAIR Principles*, GO FAIR, accessed May 26, 2022, https://www.go-fair.org/fair-principles/.

1480 Mark D. Wilkinson et al., "The FAIR Guiding Principles for Scientific Data Management and Stewardship," *Scientific Data* 3 (2016): 1–5, https://doi.org/10.1038/sdata.2016.18.

1481 Wilkinson et al., "FAIR Guiding Principles."

1482 Wilkinson et al., "FAIR Guiding Principles," 1.

1483 "Our Data in a Nutshell," Rijksmuseum, accessed December 29, 2024, https://www.rijksmuseum.nl/en/research/conduct-research/data/overview.

Providing open access to data—ideally via an API—benefits both external stakeholders and institutions themselves. Museums and their staff know their collections better than anyone, making them well-equipped to develop applications that present their content to the public in innovative ways outside of traditional exhibitions, catalogs, or education programming. In mobilizing their expertise, museums can realize applications that offer an informed perspective grounded in art historical knowledge.

7.4 Perspectives on Data and Digital Literacy

For scholars to effectively reuse data from museum collections, access to raw, unprocessed data is essential. While institutional interfaces display data and provide an initial overview of collections, creating customized datasets often requires entirely separate interfaces. Decoupling data and interface in digital collections allows for diverse applications of the same database, enabling the design of interfaces tailored to distinct audiences.

A growing trend among museums is their move beyond conventional digital access to collections toward a broader participation in the digital ecosystem, including the sharing of data and technical resources. Institutions such as the Cooper Hewitt, Rijksmuseum, Art Institute of Chicago, and Getty provide public APIs alongside metadata, vocabularies, and source code for developers and researchers.[1484] By hosting code repositories in platforms like GitHub, museums like the Art Institute of Chicago and the Getty encourage collaboration within the museum community.[1485] These initiatives allow institutions to adopt, adapt, and share tools like *JourneyMaker* or *Quire* to meet their specific needs.[1486]

When museums develop open-source software and share it with the museum community, they strengthen collective efforts to address common technological challenges. Collaborative development allows institutions to distribute workloads and refine tools for representing art in digital

1484 "Developers," Cooper Hewitt, accessed December 29, 2024, https://collection.cooperhewitt.org/developers; "Our Data in a Nutshell," https://www.rijksmuseum.nl/en/research/conduct-research/data/overview; "Open Access," Art Institute Chicago, accessed December 29, 2024, https://www.artic.edu/open-access; "Resources for All," Getty, accessed December 29, 2024, https://www.getty.edu/resources.

1485 "Open Source Code," Art Institute of Chicago, accessed December 19, 2021, https://www.artic.edu/open-access/open-source-code; "Software and APIs," Getty, accessed June 4, 2022, https://www.getty.edu/resources/#software-and-apis.

1486 "JourneyMaker," GitHub, accessed December 29, 2024, https://github.com/art-institute-of-chicago/journeymaker-cms; "Quire," GitHub, accessed December 29, 2024, https://github.com/thegetty/quire/.

environments. For example, the Berlin-based *museum4punkt0* project[1487] aimed to create reusable digital prototypes for museums, and in doing so, treating digital innovation as its own field of research.[1488] Historically focused on cataloging artworks and exhibitions, museums now have the additional responsibility of documenting and sharing their advancements in digital technology, encouraging openness and transparency.

Rather than relying solely on third-party services, museums benefit from custom technological solutions that align with their collections, missions, and objectives. Pioneering applications emerge when cultural content informs implementation, rather than being constrained by canned systems. While some applications may fit multiple institutions, the tools must remain adaptable to individual institutions' needs.

Museums are also digitizing materials beyond core collections of art, such as archival documents, catalogs, and exhibition records. For example, MoMA and Tate integrate these sources directly into object records,[1489] while Kunsthalle Basel and Kunsthaus Zürich use specialized platforms for archives and digitized catalogs.[1490]

Many museums hesitate to make public domain artwork images freely available, fearing that third parties could generate significant commercial profit. Institutions like the Barnes Foundation, Rijksmuseum, Städel Museum, and London's National Portrait Gallery counter this by releasing images under CC0 or CC BY-SA, while offering their own commercial

1487 *museum4punkt0*, Stiftung Preußischer Kulturbesitz, accessed December 29, 2024, https://www.museum4punkt0.de.

1488 Katrin Glinka, "The Process Is Part of the Solution: Insights from the German Collaborative Project museum4punkt0," *Museum International* 70, no. 1–2 (2018): 92, https://doi.org/10.1111/muse.12195.

1489 See *Collection*, MoMA, accessed December 29, 2024, https://www.moma.org/collection; "Artworks," Tate, accessed December 29, 2024, https://www.tate.org.uk/search?type=artwork.

1490 See *Photo Archive*, Kunsthalle Basel, accessed December 29, 2024, https://www.kunsthallebasel.ch/en/photo-archive. Note that Kunsthaus Zürich Library's *Dada Collection* is entirely separate from the *Online Collection*. "Digitized Special Collections," Kunsthaus Zürich Library, accessed December 29, 2024, https://digital.kunsthaus.ch; *Online Collection*, Kunsthaus Zürich, accessed December 29, 2024, https://collection.kunsthaus.ch.

services, such as ordering art reproductions from their digital collections.[1491] Users will likely prefer these official services. Additionally, researchers are encouraged to share complimentary copies of publications that reference any museum materials promoting a reciprocal flow of information. A more advanced solution would integrate museum images into digital publications via linked data, allowing semantic web queries to reveal broader usage contexts.

To advance digital art history, museums, libraries, archives, and research institutions must provide data in formats that adhere to *FAIR Principles* and open data standards, while public domain dedication and Creative Commons licenses enable broader use. While institutions may use data to fulfill their own missions, scholars and developers also depend on access to these sources. Designing digital collections access should account for the interests of diverse stakeholders, ensuring inclusivity. Art historians, in turn, should embrace digital resources as opportunities to develop new methodologies and questions. If both institutions and scholars approach digital collections and their analyses thoughtfully and intentionally, this will hopefully result in a broader scholarly practice.

Digital Collections: Museums as Content Providers

Digital collections are valuable art historical resources when they meet the following criteria.

1. **Technological Infrastructure**
   Museums should use open-source software and employ staff capable of adapting or developing code for collection representation. This includes using existing resources, such as JavaScript libraries or sector-specific tools, and contributing their solutions back to the community.

2. **Design and Usability**
   In addition to system architecture, an appealing interface and user-friendly design are critical. Well-designed applications encourage repeated use.

1491 See Custom Print Shop, Barnes Foundation, accessed December 29, 2024, https://prints.barnesfoundation.org/detail/455015/van-gogh-the-postman-joseph-%C3%89tienne-roulin-1889; *Rijksstudio,* Rijksmuseum, accessed December 11, 2018, https://www.rijksmuseum.nl/en/rijksstudio/artists/vincent-van-gogh/objects#/SK-A-3262,0 (site discontinued, feature not available in the collection anymore); "Planteuse de pommes de terre—Vincent van Gogh," Myartprints.com, accessed December 29, 2024, https://www.myartprints.com/cgi-bin/map?HTML=show/frame_studio.htm&INCLUDE=-SHOW&VS_MOTIV_ID=1612394947193956 61&utm_source=staedel-museum\&utm_medium=kooperation&utm_campaign=motive-staedel-museum; and NPG Shop, National Portrait Gallery, accessed December 29, 2024, https://npgshop.org.uk/products/sir-walter-ralegh-raleigh-npg-4106-print.

3. **Program Code and Data Accessibility**
   Providing program code and data via repositories (e.g., GitHub) or application programming interfaces (APIs) ensures accessibility. Users should face minimal barriers when integrating data into their work or creating custom applications.

4. **Use of Existing Resources**
   Open-source tools, like *CIDOC CRM*, *Getty Vocabularies*, Google Maps, or JavaScript libraries, address specific challenges and can be tailored to meet institutional needs.

5. **Long-Term Sustainability**
   A digital collection's longevity depends on ongoing use and development. Expanding the digital collection as a platform, integrating new applications, and making available data for public reuse, ensures continued interest and growth.

Developing and integrating data into applications requires significant resources, which most museums cannot provide individually. Sharing data publicly is a pathway to new developments in the cultural field. Promoting data use often requires proactive outreach by institutions and researchers. Open data initiatives, such as annual cultural hackathons like Coding da Vinci (Germany, 2014–2022) or the Swiss Open Data Cultural Hackathon (since 2015), generate awareness and showcase collaboration's potential.[1492] These events produce experimental prototypes that inspire larger-scale museum or scholar projects. When third parties create compelling applications, museums benefit from increased visibility and broader public engagement with their collections.

1492 Coding da Vinci: Der Kultur-Hackathon, accessed December 11, 2018, https://codingdavinci.de/. Swiss Open Cultural Data Hackathon (GLAMhack), OpenGLAM CH, accessed December 11, 2018, https://glam.opendata.ch/. See the following practical guide to organizing a cultural hackathon: Philippe Genêt et al., eds., *Coding da Vinci – Das Playbook: Schritt für Schritt zum eigenen Kultur-Hackathon* (De Gruyter, 2023), https://doi.org/10.1515/9783111085883.

Digital Art History: An Emerging Field

Determining potential research questions, technologies, and technological skills remains an ongoing challenge. There is no one-size-fits-all method for conducting digital art history; instead, a variety of approaches exist for analyzing digital collections, visualizing results, and interpreting them using technology.

For art historians proficient in coding, the ability to apply and adapt tools provides significant flexibility in addressing research needs and developing applications. Proprietary software, while task-specific, often proves too restrictive for the diverse requests of art historians and museums. Open-source software, offering more adaptability, demands skilled users familiar with programming. Universities and museums must prioritize skill development to cultivate digital literacy among staff. Additionally, fostering exchanges between cultural institutions and universities will enable continuous knowledge transfer, further enhancing staff capabilities and improving work outcomes. Ideally, staff will be able to program the tools they need and release them as open-source software, allowing other institutions to use or further develop them.

Digital technologies enhance research with digital data in the humanities, but accessing free software alone does not make tasks like retrieving, storing, and analyzing data easy, requiring training in research methods.[1493] This presents an opportunity for digital humanities and digital art history to teach scholars and art historians how to effectively use digital technology. Rather than mastering a specific set of tools or programming languages, it is about understanding programming logic and acquiring the skills needed for particular tasks.

7.5 Interdisciplinary Collaboration

Awareness of technological trends and ongoing developments lays the groundwork for creating effective digital applications in museums. While the presentation of art in museums relies on established workflows and defined roles, the same is still evolving for the representation of digital collections. Museums must recognize the need for specialized staff dedicated to this field of activity—roles that cannot be covered by exhibition curators or communications teams. New job profiles, such as Digital Strategy Manager, Digital Collections Curator, Digital Interactive Experience Developer, and Online

1493 Gabriele Griffin and Matt Hayler, "Introduction," in *Research Methods for Reading Digital Data in the Digital Humanities*, ed. Gabriele Griffin and Matt Hayler (Edinburgh University Press, 2016), 3.

Community Manager,[1494] reflect the skills and competencies required to manage digital technologies. Establishing these roles is crucial for building sustainable structures in museums that support long-term digital initiatives.

Digitizing collections and aggregating data in databases form the foundation for developing various applications. Online collections require platforms with interactive tools for engaging with art, ideally designed by staff proficient in programming and digital applications development. If in-house expertise is unavailable, museums can collaborate with external companies. In cases of limited budgets, pursuing externally funded projects or partnering with universities, universities of applied sciences, or art schools is a promising approach. One option is to offer a bachelor's or master's thesis topic that benefits the museum but requires specialized skills. While results may not match the polish of professional media agencies, these partnerships foster innovation and knowledge exchange. For projects focused on basic research, museums can also join academic research initiatives.

What sets digital projects apart—and ensures the successful navigation of today's digital challenges in art history and museums—is the collaboration between a range of experts and institutions.[1495] Universities are often key partners, with projects initiated by either researchers or exhibition institutions. Such partnerships ensure that both content and technological aspects are addressed. While computer scientists provide expertise in digital technology and programming, their independent use of cultural data may not align with art historical perspectives. Jointly developing research questions that engage both fields requires negotiation and the integration of specialized knowledge from both sides. Digital humanities play a pivotal role as a bridge between computer science and the humanities, fostering collaboration across disciplines.

Interdisciplinary collaboration thrives when art historians and computer scientists engage as equal partners rather than viewing one another as ser-

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1494 Mu.SA: Museum Sector Alliance published a compilation of museum jobs related to digital technology and their areas of responsibility. Mu.SA: Museum Sector Alliance, ed., *Museum Professionals in the Digital Era: Agents of Change and Innovation*, 2017, accessed July 14, 2020, http://www.project-musa.eu/wp-content/uploads/2017/03/MuSA-Museum-professionals-in-the-digital-era-full-version.pdf.

1495 Tracey Berg-Fulton et al., "A Role-Based Model for Successful Collaboration in Digital Art History," *International Journal for Digital Art History*, no. 3 (2018): 153–180, https://doi.org/10.11588/dah.2018.3.34297; Oliver Grau, ed., *Museum and Archive on the Move: Changing Cultural Institutions in the Digital Era* (De Gruyter, 2017), 10; Joseph R. Matthews, *Adding Value to Libraries, Archives, and Museums: Harnessing the Force that Drives Your Organization's Future* (Libraries Unlimited, 2016), xv; Sander Münster, *Interdisziplinäre Kooperation bei der Erstellung geschichtswissenschaftlicher 3D-Modelle* (Springer VS, 2016), 196, https://doi.org/10.1007/978-3-658-13857-8.

vice providers. Project that address topics relevant to both fields yield richer, more comprehensive outcomes. While traditional university structures may hinder cross-disciplinary efforts, hackathons and summer schools create spaces for experimental projects.[1496] Long-term, establishing dedicated centers and developing master's and doctoral programs can consolidate such partnerships and advance digital scholarship in art history and museums.[1497]

Virtual Research Environment and Data Storage

Constructing a robust infrastructure using the Semantic Web is critical for preserving and sharing data. This includes metadata, digitized artworks, videos, databases, applications, 3D models, publications, and other project outputs. A virtual research environment (VRE) should incorporate versatile tools for those who seek to analyze, visualize, and present data. For instance, *The Database of Modern Exhibitions (DoME)*[1498] at the University of Vienna exemplifies this by providing metadata on European art exhibitions and integrating search, visualization features, and downloadable results. Platforms like DoME illustrate the value of reusable data and integrated tools, empowering art historians to engage with materials within their cultural contexts despite limited technical expertise.

7.6 Conclusion

Traditional *Collections Online*, as defined on page 66, often fail to meet the needs of both the general public and specialists. Two-dimensional, low-resolution images and limited metadata do not adequately represent artworks. Similarly, database search functions hinder user engagement by using predefined interfaces. The museum represents the collection in the static form of an accessible and searchable online database, without the opportunity to contextualize the data otherwise.

To advance digital research methods, art historians require comprehensive access to digital sources and customizable tools. APIs facilitate machine-readable access, allowing museums to create bespoke applications for their collections. Effective system architecture and flexible tools are crucial for the generation of meaningful research and representation.

1496 Coding Dürer was organized to bring together art history and digital technology. Coding Dürer: International Interdisciplinary Hackathon for Art History and Information Science, March 13 to 17, 2017, Institut für Kunstgeschichte, Ludwig-Maximilians-Universität München, accessed December 11, 2018, https://codingdurer.de/.

1497 Kohle, *Digitale Bildwissenschaft*, 11–12.

1498 *The Database of Modern Exhibitions (DoME)*, Department of Art History, University of Vienna, accessed December 4, 2019, https://exhibitions.univie.ac.at.

Interdisciplinary collaboration among numerous stakeholders remains fundamental to successful digital initiatives. Museums, as custodians of cultural data, must embrace their responsibility to provide high-quality digital resources.

By making data freely accessible, museums advocate for innovation beyond their immediate purview, such as integrating 3D models into games or enabling advanced image recognition methods.

Future developments in digital art history are contingent upon the expansion of technological knowledge and infrastructure. This book has outlined the opportunities and challenges of integrating digital collections into research and public engagement, emphasizing the importance of interdisciplinary collaboration. By building on these principles, museums and scholars can unlock digital technology's potential to deepen and strengthen our understanding of art and culture.

8. Conclusion

Research Question

This book examined the significance of digitally accessible art museum collections in addition to the digital image, focusing on the implications for museums, the representation of art in digital environments, and art historical research that employs digital technology. It explored how museums can develop digital offerings to engage broad audiences and facilitate expert use of digital images and artwork information for research. From the perspectives of art museums and art historians, data accessibility and digital literacy are required for effectively deploying and using digital tools and methods.

The research herein showed that some international digital collections are especially advanced in content scope and technological infrastructure, and that those institutions value flexible data use, digital representation, and linked data for knowledge generation. Advanced technological infrastructures are critical for museums seeking to create applications that represent collections and communicate art while facilitating digital humanities and art history research. However, proper use of digital collections demands digital proficiency and awareness of challenges unique to the digital realm—topics addressed in depth in previous chapters.

To establish a foundation for investigating digital collections, a comparative study analyzed the digital footprint of 25 museums—the five most visited in Switzerland, Austria, Germany, Europe, and the US in 2019. A systematic table cataloged the museum collections' technological status, digital offerings, and openness to data reuse. This comparative analysis revealed international disparities and brought to light criteria worth further attention, while also acknowledging other institutions not included in the table.

Through interdisciplinary research across art history, museum studies, digital humanities, and computer science, this study examined the shift from viewing images as visual material to analyzing them as digital objects. Grounded in Jay David Bolter and Richard Grusin's remediation theory, earlier chapters explored how digital images exist within broader networks of medial representations,[1499] contributing to a comprehensive understanding of digital collections' potential for museums and art historians.

As museums take on the additional role of providers and custodians of data, they should be thoughtful when selecting technologies that best meet their and their stakeholders' needs. Preceding chapters addressed the conditions under which digital collections become sources of data and why museums and art historians have that interest to begin with.

1499 Jay David Bolter and Richard A. Grusin, *Remediation: Understanding New Media* (MIT Press, 2000).

Results

Chapter 2 examined the construction of digital collections, technological foundations, and the structuring of data and metadata. Using MoMA as a key example, the chapter distinguished between *Collections Online* and more advanced *Collection* interfaces, which often include APIs, open data policies, and machine-readable formats. Standards like controlled vocabularies, linked open data, and licensing frameworks (e.g., CC0 and Public Domain Mark) are essential for facilitating data reuse. These findings laid the groundwork for subsequent discussions on user interaction, knowledge creation, and data visualization.

Chapter 3 investigated metadata and image-based retrieval methods for navigating digital collections. While text-based image retrieval (TBIR) remains prevalent, content-based image retrieval (CBIR), which uses AI to analyze image files is indeed a promising approach. Exploratory search, enabled by linked data and semantic connections, is indispensable for thematic discovery and serendipitous exploration. Data visualization interfaces are central to making complex relationships in digital collections more accessible to users.

Chapter 4 considered interaction, visual spaces, and narrative construction in digital collections and applications to convey knowledge. Advanced interfaces encourage personalized engagement and contextual learning. Digital spaces offer opportunities to link geographically distant content and create virtual galleries. Narratives, including multimedia storytelling and interactive elements, are key to user participation and deeper engagement with the material.

In chapter 5 data visualization was contextualized as a method for simplifying complexity and revealing patterns within digital collections. Diagrams, timelines, and maps—often combined in sophisticated interfaces—were shown to provide both broad overviews and detailed information, as seen in Ben Shneiderman's mantra "overview first, zoom and filter, then details-on-demand."[1500] Visualizations enable new knowledge generation by uncovering networks and relationships invisible in database formats.

Chapter 6 surveyed the use of software and tools for analyzing images and metadata in digital collections. Methods included pixel-level analysis, crowdsourcing, deep learning, and data extraction from textual sources. Web technologies, APIs and *IIIF* protocols are preferable given their

1500 Ben Shneiderman, "The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations," in *Proceedings 1996 IEEE Symposium on Visual Languages* (IEEE Comput. Soc. Press, 1996), 337, https://doi.org/10.1109/VL.1996.545307.

flexibility for creating customized applications. Open-source tools are crucial for enabling both museums and art historians to adapt and innovate.

Building on topics discussed in previous chapters, chapter 7 explored the broader impact of digital technology on museums and art history, emphasizing the importance of digital literacy and standards like *Linked Art* and *CIDOC CRM*. The integration of digital tools into publishing platforms and research methodologies has been transformative, making possible interactive content and machine-readable data (in compliance with the *FAIR Principles*). Interdisciplinary collaboration—between different disciplines, but also between museums and universities—is essential to the development and implementation of these opportunities.

Method

The systematic comparison of 25 museums yielded valuable insight into their digital collections and functionalities, though its scope was limited to institutions in the US and Europe, resulting in unavoidable Ameri- and Eurocentrism. Flexibility in case study selection allowed for inclusion of noteworthy examples outside the initial dataset. Observation of developments over time highlighted both hurdles and promising digital solutions. Recent increases in scholarly publications and compelling applications underline the growing significance of the field.

Contribution

The research herein has demonstrated the benefits of digital collections for museums and art historians, offering a balanced perspective that integrates theoretical, scholarly, and practical considerations. Considerable promise exists for digital collections well beyond image archives, establishing their relevance for museum work and art historical research. The interdisciplinary approach addressed gaps in existing literature, which often separates discussions of museums and digital art history, resulting in a comprehensive monograph on this evolving subject.

Implications

For museums, these findings make obvious the importance of online collection representations and data reuse. For art history, the findings underscore digital methods' potential studying collections and generating scholarship. The digital image, distinct from the original artwork, offers unique prospects for analysis, manipulation, and presentation. The expanding confluence of digital applications, museum practices, and art historical research promises significant developments in the years ahead.

Outlook

Key questions remain about how museums will embrace digital technology (or not) and offer engaging digital experiences. In art history, development of research questions that capitalize on digital methods is crucial. Ensuring the long-term accessibility of digital projects and tools requires strategic planning for sustainability in museums and academia. The transformation of art museums and the discipline of art history, generally referred to in previous chapters as the digital transformation, through digital collections and technologies is in process, providing thrilling opportunities for collaboration and innovation on the ground floor of a fascinating and flourishing area of study.

Appendices

A
Glossary

This glossary lists common terms, acronyms, and standards encountered in digital humanities and digital art history.

Alliance of Digital Humanities Organizations (ADHO): The international umbrella organization that embraces and coordinates activities across its constituent organizations and promotes and supports digital research and teaching across arts and humanities disciplines. https://adho.org/

API key: A unique key distributed by the API creator for access upon signing up.

application programming interface (API): An API is a technological interface of a source of structured data. A series of requests can be sent to the API to retrieve information often returned in the data format JSON or XML.

Art & Architecture Thesaurus (AAT): A controlled vocabulary with generic terms for describing artworks, architecture, and material culture. *AAT* is maintained by the Vocabulary Program at the Getty Research Institute in Los Angeles. https://www.getty.edu/research/tools/vocabularies/aat/

artificial intelligence (AI): Cognitive functions, such as learning and problem solving, mimicked by machines.

artificial neural network: A framework for many different machine learning algorithms to work together and process complex data inputs. It builds an interconnected group of nodes similar to the network of neurons in a brain.

ASCII (American Standard Code for Information Interchange): A character encoding standard for electronic communication. ASCII encodes a limit of 128 characters including the digits 0 to 9, lower- and uppercase letters A to Z, and punctuation.

back end: The layer of software where data is stored.

Cascading Style Sheets (CSS): A style sheet language that enables the separation of presentation and content. It is a cornerstone technology of the World Wide Web in combination with HTML and JavaScript. https://www.w3.org/Style/CSS/

CIDOC (Comité International pour la Documentation): ICOM's International Committee for Documentation that provides standards and advice on museum documentation.

CIDOC CRM (CIDOC Conceptual Reference Model): The international standard provides an ontology for concepts and information in cultural heritage and museum documentation. https://www.cidoc-crm.org/

close reading: The careful, sustained interpretation of a brief passage of a text by emphasizing the single and particular over the general. This stands in opposition to Franco Moretti's term distant reading.

comma-separated values (CSV): A common data exchange format that stores tabular data in a machine-readable text file. Each line is a data record and the fields of each record are separated by commas.

computer vision: An interdisciplinary scientific field that applies computing methods such as image processing, pattern recognition, machine learning, and deep learning for acquiring, processing, analyzing, and understanding digital images or videos.

content management system (CMS): An environment for the management, creation, and modification of digital content. Popular content management systems for websites are WordPress, Joomla, and Drupal.

controlled vocabulary: A selected list of words and phrases to organize knowledge for subsequent retrieval.

Creative Commons (CC): Several copyright licenses that allow creators to communicate which rights they reserve and which they waive. https://creativecommons.org/

crowdfunding: The practice of funding a project with small amounts of money from a large group of people.

crowdsourcing: Distributes the work among a large group of Internet users to achieve a cumulative result.

Cultural Objects Name Authority (CONA): A Getty vocabulary that compiles titles, attributions, depicted subjects, and other metadata about works of art, architecture, and other cultural heritage, both extant and historical as well as physical and conceptual, linked to museum collections, archives, libraries or scholarly research. *CONA* is linked to the following other *Getty Vocabularies*: *AAT*, *TGN*, *ULAN*, and *IA*. https://www.getty.edu/research/tools/vocabularies/cona/

data model: An abstract model that determines data structure.

deep learning: A class of machine learning algorithms that learn in supervised and unsupervised manners and are applied in computer vision, speech, audio and image recognition, natural language and visual art processing, image restoration, social network filtering, and machine translation.

digital art history (DAH): Using digital technology and methods for art historical research.

digital humanities (DH): An interdisciplinary field of research at the intersection of computer science and the humanities.

Digital Humanities im deutschsprachigen Raum (DHd): Association of the Digital Humanities in German-speaking Countries. https://digitalhumanities.de/

Digital Object Identifier (DOI): A persistent identifier is an interoperable standard used to uniquely identify objects like journal articles or data sets. https://www.doi.org/

distant reading: A term introduced by Franco Moretti in literary studies in opposition to close reading. A quantitative approach to analyze a large body of text.

Document Object Model (DOM): A cross-platform and language-independent application programming interface. https://dom.spec.whatwg.org/

Dublin Core Metadata Initiative (DCMI): A project focused on metadata standards and best practices with regard to describing digital and physical resources. https://dublincore.org/

Encoded Archival Description (EAD): An XML standard for encoding archival finding aids used by archives, libraries, and museums. https://www.loc.gov/ead/

European Association for Digital Humanities (EADH): Represents the digital humanities in Europe. https://eadh.org/

Exif (exchangeable image file format): A standard for storing metadata in image and audio files.

Extensible Markup Language (XML): A markup language for structuring, annotating, and formatting texts.

FAIR data principles (findable, accessible, interoperable, reusable): Guiding principles for research data management. https://www.go-fair.org/fair-principles/

front end: The part of a software that provides the graphical user interface.

Geographic Information System (GIS): A system to capture, store, manipulate, analyze, manage, and present geographic data.

GIF (Graphics Interchange Format): An image format with a palette limited to 256 colors suitable for simple diagrams, shapes, and logos.

GitHub: A development platform to host code, manage projects, and build software. https://github.com/

GLAM (galleries, libraries, archives, and museums): Collecting cultural heritage institutions in the public interest that preserve and make accessible valuable primary sources for researchers.

graphical user interface (GUI): Allows users to interact with electronic devices by manipulating graphical elements instead of typing in a command-line interface.

HTML (HyperText Markup Language): The fifth standard of HTML supports application programming interfaces (APIs) and the Document Object Model (DOM) for complex web applications. https://www.w3schools.com/html/html_intro.asp

HTTP (HyperText Transfer Protocol): The protocol for transferring files on the World Wide Web.

human-computer interaction (HCI): The interaction and interfaces between users and computers.

ICOM (International Council of Museums): A global, nongovernmental organization of museums and museum professionals.
https://icom.museum/en/

Iconclass: A classification system designed for art and iconography.
https://iconclass.org

image processing: Using computer algorithms on digital images.

information extraction (IE): The task of automatically extracting structured information from unstructured machine-readable documents.

integrated development environment (IDE): A software application for software development.

Internationalized Resource Identifier (IRI): A complement to the URI consisting of the sequence of characters from the Universal Coded Character Set.
https://www.ietf.org/rfc/rfc3987.txt

International Organization for Standardization (ISO): ISO develops and publishes the requirements, specifications, guidelines, or characteristics to ensure that materials, products, processes, and services are fit for their purpose.
https://www.iso.org/

interoperability: Exchange of information between different systems and institutions using common technical standards.

IPTC Photo Metadata (International Press Telecommunications Council's Photo Metadata Standard): A schema that defines metadata structure, properties, and fields to describe digital images and also provides images' copyright and licensing information online.
https://iptc.org/standards/photo-metadata/

ISBN (International Standard Book Number): A unique numeric commercial book identifier.
https://www.isbn-international.org/

JPG/JPEG (Joint Photographic Experts Group): A lossy, compressed image file format.

JSON (JavaScript Object Notation): A data interchange format that is easy for humans to read and write and easy for machines to parse and generate. It is often used for visualizations with JavaScript libraries.

JSON-LD: A lightweight, linked data format that is easy for humans to read and write.
https://json-ld.org/

knowledge graph: A flexible, formal data structure organized as a graph based on an ontology. Useful for semantic search, intelligent chatbots, content-based recommender engines, and knowledge management systems. The Google Knowledge Graph is the box showing up to the right of a search results page.

linked data (LD): A method of publishing structured data on the web in a manner that it can be interlinked and become useful through semantic queries.

Lightweight Information Describing Objects (LIDO): An XML harvesting schema for delivering metadata describing museum objects to use it in a variety of online services, e.g., an online collection database, for portals of aggregated resources or to expose, share, and connect data on the web.
https://cidoc.mini.icom.museum/working-groups/lido/lido-overview/about-lido/what-is-lido/

linked open data (LOD): Linked data that can bee freely used and distributed.

machine learning: A subset of artificial intelligence. Machine learning algorithms build a mathematical model of sample data to make predictions or decisions without being explicitly programmed to perform the task.

MARC (machine-readable cataloging): An international standard for bibliographic data in libraries.

metadata: Data that describes other data.

metadata harvesting: The process of automatically gathering metadata descriptions from various sources to compile comprehensive collections and related services.

Multilingual Access to Subjects (MACS): A collaboration between the British Library, German National Library, National Library of France, and the Swiss National Library with the objective to provide multilingual subject access on the basis of the indexing schemes LCSH, GND, and RAMEAU.

MuseumPlus: A collection management system by Zetcom.

named-entity recognition (NER): Information extraction that detects and classifies automatically named entities such as names of people, organizations, locations, time expressions, and quantities in unstructured text.

Online Computer Library Center (OCLC): A global library cooperative that supports libraries make information more accessible and useful.
https://www.oclc.org

Online Information Exchange (ONIX): An XML-based international standard for representing and communicating book industry product information in electronic form. Provides a consistent way for publishers, retailers, and their supply chain partners to communicate rich book metadata.
https://www.editeur.org/83/Overview/
https://www.editeur.org/8/ONIX/

ontology: Encompasses a representation, formal naming, and definition of the categories, properties, and relations between the concepts, data, and entities.

open access (OA): Research publications that are accessible online for free to everyone.
https://open-access.network

Open Archival Information System (OAIS): The *OAIS* Reference Model (ISO 14721) defines concepts and responsibilities that an archive or repository must fulfill for the long-term preservation of digital information.
https://www.oais.info/

Open Archives Initiative (OAI): Develops and promotes interoperability standards to facilitate an efficient dissemination of content.
https://www.openarchives.org/

Open Archives Initiative Protocol for Metadata Harvesting (OAI-PMH): An application-independent interoperability framework based on metadata harvesting.
https://www.openarchives.org/OAI/openarchivesprotocol.html

open data: Data from culture, science, finance, statistics, weather, environment, etc. that is free to use without any restrictions.
https://opendefinition.org/

Open Database License (ODbL): A license agreement that allows users to freely share, modify, and use a database.
https://opendatacommons.org/licenses/odbl/index.html

open source: The source code of a software that is released under a license in which the copyright holder grants users the rights to study, change, and distribute software for any purposes.
https://opensource.org/osd

optical character recognition (OCR): Process to identify the characters in a scanned document. By adding a computer-readable text layer on the digital image, full-text search becomes possible.

ORCID (Open Researcher and Contributor ID): A unique persistent identifier for scientific and academic authors.
https://orcid.org/

permalink: A URL that is a type of persistent identifier intended to remain unchanged.

PNG (Portable Network Graphics): A lossless image file format suitable for vector graphics.

Python: A programming language.

QR code (quick response code): A matrix barcode consisting of black squares arranged in a square grid on a white background. QR codes, that often link to an external URL, are scanned with the camera of a mobile device or an app.

regular expression (regex): A sequence of characters that define precise patterns for text search.

relational database: A database model that organizes data into one or more tables.

Resource Description Framework (RDF): A standard model for data interchange on the World Wide Web.
https://www.w3.org/TR/rdf11-concepts/

Resource Description Framework Schema (RDFS): A data modelling vocabulary for RDF data.
https://www.w3.org/TR/rdf-schema/

responsive web design: Adaptable design based on fluid, proportion-based grids to render web pages for various screen sizes and devices.

REST (Representational State Transfer): A software architectural style that defines a set of constraints to be used for creating web services. RESTful web services (RWS) provide interoperability between computer systems on the Internet.

Semantic Web: A web of linked data empowered by technologies such as RDF, SPARQL, OWL, and SKOS.
https://www.w3.org/2001/sw/wiki/Main_Page

serendipity: Finding something valuable in search results when looking for something else.

SGML (Standard Generalized Markup Language): A standard for defining generalized markup languages for documents.

SKOS (Simple Knowledge Organization System): Part of the Semantic Web family of standards built upon RDF and RDFS. Provides a model for expressing the basic structure and content of concept schemes such as thesauri, classification schemes, subject heading lists, taxonomies, and other similar types of controlled vocabulary.
https://www.w3.org/2004/02/skos/

SPARQL (SPARQL Protocol and RDF Query Language): A semantic query language for databases able to retrieve and manipulate data stored in the Resource Description Framework (RDF) format.
https://www.w3.org/TR/rdf-sparql-query/

SQL (Structured Query Language): A language for managing data held in a relational database. Allows to access many records with a single command.

structured data: Clearly defined, easily searchable data types in a database.

SVG (Scalable Vector Graphics): An XML-based vector image format for two-dimensional graphics that supports interactivity and animation in a browser.
https://www.w3.org/Graphics/SVG/

tab-separated values (TSV): A data exchange format that stores tabular data in a machine-readable text file. Each line is a data record and the fields of each record are separated by tabulators.

tag: A keyword or term assigned to a digital image or a database record to allow the retrieval of an item with the help of this kind of metadata by browsing or searching.

Text Encoding Initiative (TEI): Guidelines that define standards for encoding methods of machine-readable texts.
https://www.tei-c.org/

text mining: The process of deriving high-quality information from text, which includes text categorization, text clustering, concept extraction, entity extraction, production of granular taxonomies, sentiment analysis, document summarization, and entity relation modeling.

The Museum System (TMS): A collection management system by Gallery Systems.
https://www.gallerysystems.com/

Thesaurus of Geographic Names (TGN): A Getty vocabulary that includes names, descriptions, and other metadata for extant and historical cities, empires, archaeologist sites, and physical features.
https://www.getty.edu/research/tools/vocabularies/tgn/

TIFF (Tagged Image File Format): A lossless image file format for storing raster graphics images.

training data: A dataset of examples used in machine learning to train algorithms.

Unicode Transformation Format – 8-bit (UTF-8): A character encoding scheme using one to four 8-bit bytes. The first 128 characters of Unicode correspond with ASCII.

Uniform Resource Identifier (URI): A string of characters that unambiguously identifies a particular resource.

Uniform Resource Locator (URL): A reference to a web resource.

Union List of Artist Names (ULAN): A Getty vocabulary that includes names of people and corporate bodies with biographical information and other data.
https://www.getty.edu/research/tools/vocabularies/ulan/

unstructured data: Data, such as text files, webpages, images, audio, or video, that is not structured via a predefined data model or schema and therefore difficult to search.

user experience (UX): Includes the practical, experiential, affective, meaningful, and valuable aspects of human-computer interaction.

user interface (UI): The part of the system that handles the human-machine interaction usually designed for a user-friendly operation of the machine.

Virtual International Authority File (VIAF): Combines multiple name authority files into a single authority service.
https://viaf.org/

virtual research environment (VRE): An online system for researchers that supports collaboration, document hosting, and provides tools for tasks like data analysis and visualization.

Web ontology language (OWL): A family of knowledge representation languages for authoring ontologies used for the Semantic Web.
https://www.w3.org/TR/owl-ref/

what you see is what you get (WYSIWYG): A user interface that allows to edit text and graphics within the layout of the finished product.

World Wide Web Consortium (W3C): An international community that develops web standards.
https://www.w3.org/

XQuery: A language to query XML data.

B
Digital Resources

Freely accessible data from art collections available for reuse is listed below, along with general resources that complement art-related data. The listed resources prioritize linked data and the Semantic Web.

Dataset Collections

Awesome OpenAccess: A collection of datasets and APIs provided by art museums.
https://github.com/micahwalterstudio/awesome-openaccess

Coding da Vinci: List of open data provided by GLAM institutions in Germany. Collected by the German open data hackathon Coding da Vinci.
https://codingdavinci.de/daten/

DH Toychest: Link collection of datasets (text and image) useful for the digital humanities.
http://dhresourcesforprojectbuilding.pbworks.com/w/page/69244469/Data%20Collections%20and%20Datasets

Digicoord: A list of completed, ongoing, and forthcoming digitized collections in Swiss libraries.
https://www.digicoord.ch/index.php/Digitalisierungsprojekte

Museum APIs: Collection of APIs for machine-readable data from museums, galleries, libraries, archives, and archaeology.
http://museum-api.pbworks.com/w/page/21933420/Museum%C2%A0APIs

MuseWeb Wiki: Links to data published by museums including GitHub accounts, spreadsheets, and APIs.
https://www.museweb.wiki/category/datasets/

Open Art Data: A collection of datasets relating to art provenance research.
https://www.openartdata.org/p/provenance-datasets.html

Open Cultural Data: Lists of open cultural data worldwide for open collections, authority files, SPARQL Endpoints for linked data, and further resources collected by opendata.ch.
https://make.opendata.ch/wiki/data:glam

OpenDataSoft: On this platform, datasets from various resources can be directly visualized or downloaded in different formats.
https://data.opendatasoft.com

Open GLAM survey: A spreadsheet of GLAM open access policies worldwide, collected by Andrea Wallace and Douglas McCarthy.
https://bit.ly/OpenGLAMsurvey

Open Image Collections: A collection of image databases that provide reusable digital images.
https://blogs.ntu.edu.sg/openimagecollections/

re3data.org (Registry of Research Data Repositories): Enables searching data repositories from different academic disciplines.
https://www.re3data.org/

Semantic Web and Linked Data: Linked Data resources collected by the UCLA Library.
https://guides.library.ucla.edu/semantic-web

Swiss Heritage Data: List of open data provided by GLAM institutions in Switzerland. Collected by opendata.ch for the Swiss Open Cultural Data Hackathon.
https://make.opendata.ch/wiki/data:glam_ch

Reusable Data from Art Museums

Albertina: Users can download and use the public domain images. Provides the *IIIF* manifest.
https://sammlungenonline.albertina.at

American Art Collaborative: A consortium of 14 art museums in the United States that offers linked open data (data and images) under different Creative Commons licenses.
http://browse.americanartcollaborative.org/

Art Institute of Chicago: Offers open access to images of the works of art in the permanent collection under a CC0 license and an API.
https://www.artic.edu/open-access

Belvedere: *IIIF* is used for all artworks in the digital collection. Images of artworks in the public domain can be reused under a CC BY-SA 4.0 license.
https://sammlung.belvedere.at/opencontent

Brooklyn Museum: Users can include the collection images and data in their custom applications by using the provided API.
https://www.brooklynmuseum.org/opencollection/api

Cleveland Museum of Art: Provides large TIFF and JPG images under a CC0 license that are available via an API together with metadata. The metadata are also available in CSV and JSON format on GitHub.
https://openaccess-api.clevelandart.org

Coding Dürer, Data: List of data collections useful for art historians.
https://codingdurer.de/data

Cooper Hewitt: Access to the metadata and images of the Smithsonian Design Museum Collections via an API.
https://collection.cooperhewitt.org/api/

dati.beniculturali.it: A platform for cultural heritage data in Italy provided as linked open data.
https://dati.beniculturali.it

Dati Cultura Italia: A platform for cultural heritage data in Italy provided as linked open data.
https://dati.culturaitalia.it

***Europeana* Collections:** REST API, Search API, Record API, Entity API, Annotations API, *IIIF* APIs, SPARQL, Linked Open Data, OAI-PMH service.
https://pro.europeana.eu/page/apis

Fitzwilliam Museum: The digital collection includes *IIIF* manifests, *Universal Viewer*, *Mirador*, and offers code snippets for citation in publications, for *Wikipedia*, the API link for the object, machine readable data (JSON, XML, TXT, QR code), and a contact form related to the object.
https://www.fitzmuseum.cam.ac.uk/objects-and-artworks

Frick Collection: The Digital Art History Lab (DAHL) at the Frick Art Reference Library provides datasets of the Dutch Golden Age as CSV and JSON: the Montias database and a Vermeer dataset.
https://github.com/frickcollection/age-of-vermeer

Georgia O'Keeffe Museum: The metadata for each object in the digitized collections of artworks, photographs, and archival material can be accessed and downloaded as JSON-LD.
https://collections.okeeffemuseum.org/

Getty Open Content Program: Digital images from the J. Paul Getty Museum and the Getty Research Institute collections, to which the Getty holds the rights or are in the public domain, are available free of charge and without permission.
https://search.getty.edu/gateway/search?q=&cat=highlight&f=%22Open+Content+Images%22&rows=10&srt=a&dir=s&pg=1

Harvard Art Museums: Objects, People, Exhibitions, Publications, and Galleries are a selection of accessible resources via the API.
https://www.harvardartmuseums.org/collections/api

Images d'Art: A platform with artworks from French museums created by the Réunion des musées nationaux, Grand Palais (RMN-GP). An API for the data and images is available.
https://api.art.rmngp.fr

Kress Collection Digital Archive: Access to artworks, archival materials, acquisition documents, people, and organizations related to the collection.
https://kress.nga.gov

M+: The art museum M+ in Hong Kong shares the metadata for its collection of 20th- and 21st-century visual culture via GitHub and API.
https://api.mplus.org.hk/en/documentation/about

Metropolitan Museum of Art: Datasets of information on artworks from the collection, including images; CC0.
https://github.com/metmuseum/openaccess

MoMA: Metadata for the artists, artworks, exhibitions, as well as the museum directors and department heads are available on GitHub; CC0.
https://github.com/MuseumofModernArt

Museum für Kunst und Gewerbe Hamburg: Collection objects with freely usable images (JPG); CC0.
https://github.com/MKGHamburg/KGCollectionOnlineLIDO_XML

National Gallery of Art: Due to an open access policy, images and metadata for works in the public domain are available under a CC0 license and free to use.
https://www.nga.gov/open-access-images.html

National Museum Oslo: Public domain images can be downloaded under a CC BY 4.0 license and the metadata are CC0.
https://www.nasjonalmuseet.no/en/collection; https://github.com/nasjonalmuseet/collection

National Museum Sweden: A dataset of paintings is available on Wikimedia Commons. Metadata for the images is available on *Wikidata* and each dataset includes a link to a *IIIF*-resource.
https://github.com/NationalmuseumSWE/WikidataCollection

Paris Musées Collections: The museums of Paris offer free access to images (CC0) and provide an API.
https://parismuseescollections.paris.fr/en

Pinakotheken Munich: Joint online collection by the Bayerische Staatsgemäldesammlungen (Bavarian State Painting Collections) including the Alte and Neue Pinakothek, the Pinakothek der Moderne, the Museum Brandhorst, the Sammlung Schack and the other state galleries of Bavaria. Images of works in the public domain and metadata can be used under the license CC BY-SA 4.0.
https://www.sammlung.pinakothek.de/en/

Rijksmuseum: Data and images that are in the public domain or subject to a CC0 license are available via an API.
https://data.rijksmuseum.nl/object-metadata/

SFMOMA: The API allows users to request data on artworks and artists.
https://sfmoma.org/artists-artworks/for-researchers/collection-api/

SMK Kopenhagen (Statens Museum for Kunst): Offers free-to-use images of artworks in the public domain.
https://www.smk.dk/en/article/smk-open/

Tate: Makes available metadata for the artworks in the collection released under CC0 license.
https://github.com/tategallery/collection

Van Gogh Museum Amsterdam: Images from the artworks in the collection can be downloaded for free for noncommercial use.
https://www.vangoghmuseum.nl/en/about/organisation/terms-and-conditions/use-and-permissions-of-collection-images

Victoria and Albert Museum: Provides an API to the collection's images and metadata.
https://developers.vam.ac.uk

Walters Art Museum: Provides an API to query information about collection artworks as well as digital images under a CC0 license.
https://api.thewalters.org/

Wikimedia Commons: The collection of freely usable media files includes images of many artworks.
https://commons.wikimedia.org/

Linked Open Data from Art Museums

Duchamp Research Portal: The platform aggregates digitized archival holdings and museum collections to provide access to source materials related to Marcel Duchamp. A bulk download of the data in JSON and RDF is available and documentation of the data models and technologies used is accessible.
https://github.com/philamuseumarchives/drp-data

Getty's Collection Data: Documentation of the Getty Museum's APIs for public access to collection data.
https://data.getty.edu

Rijksmuseum: The collection of Rijksmuseum Amsterdam as linked open data.
https://old.datahub.io/dataset/rijksmuseum

Yale Center for British Art: Linked open data service that provides machine-readable access to the collection data. The data is expressed in *RDF* and *CIDOC CRM* is used for the ontology.
https://britishart.yale.edu/collections-data-sharing

Other Relevant Sources

Artstor: The Artstor Digital Library is an online resource of images in the arts for teaching and research purposes. It is a web-based cataloging and image management software service that allows institutions to catalog, edit, store, and share local collections.
https://library.artstor.org/

Boehler re:search: The database contains information about traded artworks, transactions, and people related to the art dealer Julius Böhler. The art dealership was founded in 1882 and its archive is therefore a relevant source for provenance research.
https://boehler.zikg.eu

Catalogue of the Association Swiss Poster Collections (SPC): Swiss Posters from the second half of the 19th century to the present from various collections.
https://nb-posters.primo.exlibrisgroup.com/discovery/search?sortby=rank&vid=41SNL_53_INST:posters&lang=en

e-codices: Virtual Manuscript Library of Switzerland: A search, browse, presentation, and annotation platform that provides free access to medieval manuscripts.
https://www.e-codices.unifr.ch/en

e-manuscripta.ch: Platform for digitized manuscripts and drawings from Swiss libraries and archives.
https://www.e-manuscripta.ch/

e-rara.ch: Platform for digitized rare books and prints from Swiss libraries.
https://www.e-rara.ch

Europeana: Metadatabase with artworks, artefacts, books, films, and videos from European museums, galleries, libraries and archives.
https://www.europeana.eu

Gallica: IIIF API for the images in Gallica, the digital collection of the Bibliothèque nationale de France (BnF).
https://api.bnf.fr/api-iiif-de-recuperation-des-images-de-gallica

Getty Pronvenance Index: Records from historical source materials like archival inventories, auction catalogs, and dealer stock books.
https://www.getty.edu/research/tools/provenance/search.html

Kunstdenkmäler der Schweiz: The digitized volumes from the book series *Art Monuments of Switzerland* are open access on an innovative search platform.
https://ekds.ch

lobid-gnd: A search interface for the GND that visualizes the linked data and provides *OpenRefine* integration and an API based on JSON-LD.
https://lobid.org/gnd

Memobase: Information and search portal for Memoriav, the association for the preservation of audiovisual cultural heritage in Switzerland, that offers access to photography, sound, film, and video. Provides an OAI-PMH API.
https://memobase.ch, https://ub-basel.atlassian.net/wiki/spaces/MD

Old Maps Online: A search engine for historical maps from archives and libraries worldwide.
https://www.oldmapsonline.org

Prometheus: A distributed image archive that connects databases with digitized images from institutes, research facilities, and museums using a common user interface. It is possible to perform searches, retrieve metadata of images, and query collections via an API.
https://prometheus.uni-koeln.de/en/api

RKDartists as Linked Open Data: Biographical data of Dutch and foreign artists from the Middle Ages to the present.
https://rkd.triply.cc/rkd/RKD-SDO-Knowledge-Graph

RKD-Knowledge-Graph: Access to the linked data of the collection.
https://rkd.triply.cc/rkd/RKD-Knowledge-Graph/

RKD Netherlands Institute for Art History: The documentation and research institute provides access to knowledge, research, and information about Netherlandish art and offers various digital resources.
https://rkd.nl/en/

Stadt Zürich Open Data: Open government data from the City of Zurich, e.g., art in public spaces, museums in the Zurich region, photographs of Zurich, 3D city model, and LIDAR laser scanning point cloud.
https://data.stadt-zuerich.ch/dataset?q=kunst&sort=score+desc%2C+date_last_modified+desc

swisscollections.ch: Catalog of special collections from Swiss libraries and archives including manuscripts, rare books, sheet music, maps, and images.
https://swisscollections.ch/

WikiArt: Visual Art Encyclopedia: Aims to make art freely accessible for everyone, is user-editable, and offers an API.
https://www.wikiart.org/en/App/GetApi

Zentralinstitut für Kunstgeschichte (ZI): The Munich-based art-historical research institute provides access to digitized resources such as Munich Secession or Glaspalast exhibition catalogs, in addition to letters by Heinrich Wölfflin.
http://digital.bib-bvb.de/collections/ZIKG/#/collection/DTL-5691

Reusable Data Collections

DBpedia: RDF store with information automatically extracted from *Wikipedia*.
https://live.dbpedia.org/

DELAUNAY: A dataset with images of abstract and nonfigurative artworks by 53 artists including Sonia and Robert Delaunay, Piet Mondrian, and Josef Albers.
https://github.com/camillegontier/delaunay_dataset

Dictionary of Art Historians: A biographical database of historic art historians. Data can be downloaded as CSV or XML.
https://arthistorians.info

Freesound: A collaborative database of audio snippets, samples, and other recordings released under Creative Commons licenses for reuse. An API is available.
https://freesound.org

Internet Archive: A nonprofit digital library of Internet sites and other cultural artifacts. A good resource for images, videos, audio recordings, and books that are in the public domain or under a free license that allows redistribution. The advanced search returns JSON, XML, CSV, and other formats.
https://archive.org

Training Datasets with Images

COCO (Common Objects in Context) dataset: A dataset of photographs for object detection, segmentation, and captioning.
https://cocodataset.org

DEArt (Dataset of European Art): Useful for paintings between the twelfth and the eighteenth centuries, it is an object detection and pose classification dataset for machine learning.
https://zenodo.org/record/6984525#.Y2V1VeSZNJ1

ImageNet: An image database for computer vision and deep learning research that is organized according to the WordNet hierarchy. The image classification and localization dataset with object classes, training images, validation images and test images can be used for noncommercial research.
https://www.image-net.org

LAION (Large-scale Artificial Intelligence Open Network): Provides open datasets with multilingual image-text pairs, code, and machine learning models.
https://laion.ai/

Materials in Paintings (MIP): An image dataset of paintings annotated with bounding boxes and assigned coarse and fine-grained labels.
https://materialsinpaintings.tudelft.nl

Open Images Dataset V7: A large dataset of photographs with annotations, object bounding boxes, and object segmentation masks.
https://storage.googleapis.com/openimages/web/download_v7.html

Papers with Code, Datasets: A collection of datasets (images, texts, videos, audio, medical, and 3D) suitable for machine learning.
https://paperswithcode.com/datasets

Papers with Code, Methods: A collection of machine learning components including Computer Vision, Natural Language Processing, Reinforcement Learning, Audio, Sequential, and Graphs.
https://paperswithcode.com/methods

Quickdraw: A large dataset of crowd-sourced drawings of objects that can be used to train neural networks.
https://quickdraw.withgoogle.com/data

Visual Question Answering (VQA): A dataset of photographs that contains open-ended questions about images that require an understanding of vision, language, and commonsense knowledge for the answer.
https://visualqa.org

Digital Collections

Aargauer Kunsthaus Aarau: Search and browse a collection with a focus on Swiss art.
https://sammlung-online.aargauerkunsthaus.ch/eMP/eMuseumPlus

Auckland Art Gallery: Searchable collection online.
https://www.aucklandartgallery.com/art-ideas/explore-art-and-ideas

Barnes Foundation: Collection online allows to browse the artworks based on visual characteristics like color, lines, light, space, and aesthetic similarity. Images in the public domain are available for free download.
https://collection.barnesfoundation.org

Bildindex der Kunst und Architektur (Marburg Picture Index): An open image index of art and architecture with vast collections of photographs of artworks and architecture operated by the German Documentation Center for Art History, Bildarchiv Foto Marburg.
https://www.bildindex.de/

Collection Dadaism: High-resolution images of journals, brochures, letters, books, leaflets, posters, photographs, and artworks in Kunsthaus Zürich's Dada collection.
https://digital.kunsthaus.ch/viewer/browse/dadaismus/-/1/-/-/

Der Nachlass Gurlitt: Database with all artworks from the Cornelius Gurlitt Estate at Kunstmuseum Bern, including images of the verso of the works.
https://gurlitt.kunstmuseumbern.ch/

eMuseum: The collection of the Museum für Gestaltung Zürich (Museum of Design) with objects from the 19th to the 21st century which also includes posters of art exhibitions.
https://www.emuseum.ch

Fotomuseum Winterthur: Search and browse the large collection of photography online.
https://www.fotomuseum.ch/en/sammlung-fotomuseum-winterthur/

Google Arts & Culture: A portal with artworks from the collections of museums worldwide. Provides additional information on artworks, arranges them on a timeline, allows searches via colors, and sharing the works on social media.
https://artsandculture.google.com/

Graphikportal: A metadatabase for searches across various collections of prints and drawings from Germany, Austria, and Switzerland.
https://www.graphikportal.org

Haus Konstruktiv: Collection of works by 20th- and 21st-century Concrete artists. Each artist has a short text.
https://www.hauskonstruktiv.ch/en/collection

KHI Photothek: The Photo Library of the Kunsthistorisches Institut in Florenz documents Italian art and architecture.
https://photothek.khi.fi.it/

Kunsthalle Basel: The online *Photo Archive* of Kunsthalle Basel documents the organization's exhibition history.
https://www.kunsthallebasel.ch/en/photo-archive/

Kunsthaus Zürich: Online Collection and, on a separate platform, digital resources such as documents and artworks from the Dada collection, artist letters, and exhibition catalogs.
https://collection.kunsthaus.ch, https://digital.kunsthaus.ch

Kunstmuseum Luzern: Online collection catalog with search interfaces for works and artists as well as collection tours.
https://www.kunstmuseumluzern.ch/en/collection/collection-catalogue-online/

Kunstmuseum Basel: Collection online with search interfaces for works, artists, and periods. Images in the public domain are available for free download.
https://sammlungonline.kunstmuseumbasel.ch

LACMA: Los Angeles County Museum of Art's permanent collection.
https://collections.lacma.org/

Migros Museum für Gegenwartskunst: Works from the collection are linked to the corresponding exhibitions in which they have been included.
https://migrosmuseum.ch/en/collection?lang=en#search

MFA: Museum of Fine Art Boston's permanent collection.
https://www.mfa.org/collections

Museo del Prado: Online access to the collection. The museum's collection platform is based on a knowledge graph to ensure structured and interconnected data through linked data principles.
https://www.museodelprado.es/en/the-collection, https://www.museodelprado.es/en/grafo-de-conocimiento/el-prado-en-la-web

New Museum Digital Archive: Online access to museum's exhibition history, installation photography, digitized documents, videos, and recordings.
https://archive.newmuseum.org/

Philadelphia Museum of Art: Allows users to explore the collection by artists, collectors, theme, or places.
https://www.philamuseum.org/collections/search

Stedelijk Museum Amsterdam: Online access to the collection of modern and contemporary art and design.
https://www.stedelijk.nl/en/dig-deeper/collection-online

Tate: Search the collection for artworks, artists, archive items, video, audio, and other categories.
https://www.tate.org.uk/art

Van Gogh Letters: An open access edition of Vincent van Gogh's letters.
https://vangoghletters.org/vg/

Virtuelles Kupferstichkabinett: A joint online research database for prints and drawings from the Herzog Anton Ulrich-Museum in Braunschweig and the Herzog August Bibliothek in Wolfenbüttel. They offer incredibly detailed metadata for the works, *Iconclass* references, as well as image comparison.
http://www.virtuelles-kupferstichkabinett.de/

Vitrosearch: Online database of the Vitrocentre and Vitromusée Romont dedicated to Swiss glass art.
https://vitrosearch.ch/en

Zentrum Paul Klee: Online access to artworks, biographical photographs in the collection, as well as literature.
http://www.emuseum.zpk.org/eMuseumPlus

Metadata Standards / Ontologies / Lexical Databases

BabelNet: A large multilingual lexical database that links *WordNet* with *Wikipedia* and uses machine translation.
https://www.babelnet.org/

Categories for the Description of Works of Art (CDWA): A set of guidelines that include around 540 categories and subcategories of information for cataloging and describing artworks.
https://www.getty.edu/research/publications/electronic_publications/cdwa/

CIDOC-CRM: An international standard providing an ontology for cultural heritage information.
https://cidoc-crm.org/

Cultural-ON: An ontology model for data from cultural institutions and events, as well as multimedia files and visitor information.
https://dati.beniculturali.it/cultural-ON/ENG.html#d4e5081

Dublin Core (DC): A metadata schema with a small set of vocabulary terms to describe digital or physical resources.
https://www.dublincore.org/specifications/dublin-core/dcmi-terms/

EODEM (Exhibition Object Data Exchange Model): A standard coordinated by ICOM's CIDOC Documentation Standards Working Group to organize loan requests between museums based on data. The *EODEM LIDO* profile enables museums to export object's data from one collection management system and to import it into another.
https://cidoc.mini.icom.museum/working-groups/documentation-standards/eodem-home/

fotoCH: A specialized platform for the documentation of photography in Switzerland (records of Swiss and international photographers, photo collections, institutions, exhibitions, and bibliographies). An API is available.
https://foto-ch.ch; API documentation: https://de.foto-ch.ch/doc/API-Dokumentation.html

Gemeinsame Normdatei/Integrated Authority File (GND): An international authority file for name of people, subject headings, and corporate bodies taken from catalogs managed by the German National Library. GND is used for documentation in libraries but also in archives and museums.
https://www.dnb.de/gnd

GeoNames: Global geographical database with over eleven million placenames. Available data includes latitude, longitude, elevation, population, administrative subdivisions, and postal codes.
https://www.geonames.org

Getty Vocabularies: Structured multilingual vocabularies that contain terms for concepts and names with other metadata related to art, architecture, and decorative arts: *Art & Architecture Thesaurus* (*AAT*), *Cultural Objects Name Authority* (*CONA*), *Thesaurus of Geographic Names* (*TGN*), and *Union List of Artist Names* (*ULAN*).
https://www.getty.edu/research/tools/vocabularies/

Global WordNets: A collection of wordnets for various languages and multilingual wordnets.
https://globalwordnet.org/wordnets-in-the-world/

Iconclass: A classification system designed for art and iconography for the description and retrieval of subjects represented in images (artworks, book illustrations, reproductions, photographs, and other mediums) available as linked open data.
https://iconclass.org/

Identifiers for Heritage Collections: A resource that describes different aspects of developing Persistent Identifiers (PIDs) within the context of heritage collections.
https://tanc-ahrc.github.io/PIDResources/

Linked Art: A community project to create a model based on linked open data to describe art.
https://linked.art

Media Art Research Thesaurus: A controlled vocabulary for media art.
https://www.vocabularyserver.com/mediaart

Nomenclature for Museum Cataloging: A structured and controlled list of object terms for indexing and cataloging collections of human-made objects.
https://www.nomenclature.info

Object Name Thesaurus: A controlled vocabulary for British Museum collection objects.
https://terminology.collectionstrust.org.uk/British-Museum-objects

Open Calais: A web service for automatically tagging unstructured text. It identifies entities, topic codes, events, relations, and social tags and returns the results in RDF format to be used on the Semantic Web.
https://developers.refinitiv.com/en/api-catalog/open-perm-id/intelligent-tagging-restful-api, https://github.com/akashdathan/opencalais-tagging

Schema.org: Provides schemas for structured data markup on webpages. The vocabularies cover entities, relationships between entities, and actions. Search engine spiders and other parsers can recognize such markup.
https://schema.org/

SIK-ISEA's research portal: Rich resource of interlinked information about art and art history in Switzerland. It provides biographical data about artists, reproductions of works, lexicon entries, references to exhibitions and literature, digitized archival documents, artist videos, and online catalogs raisonnés. Includes the SIKART Lexicon on art in Switzerland.
https://recherche.sik-isea.ch

SIKART: Swiss art lexicon generated by the Swiss Institute for Art Research (SIK-ISEA).
https://recherche.sik-isea.ch/en/everything/on/sikart

Terminologies: A collection of terminologies for the documentation of object names, materials, locations, artists, makers, subjects, and historical periods.
https://collectionstrust.org.uk/terminology/published-terminologies/

Tesauros: Thesaurus and dictionaries of Spain's cultural heritage including materials, techniques, furniture, and geography.
https://tesauros.cultura.gob.es/tesauros/tesauros

Thesaurus for Graphic Materials (TGM): Tool by the Library of Congress allows to index visual materials by subject and by genre and format.
https://www.loc.gov/pictures/collection/tgm/

Virtual International Authority File (VIAF): A service that connects multilingual name authority files worldwide.
https://viaf.org/

Visual Representation Ontology: An extension of *CIDOC-CRM* dedicated to visual items.
https://ncarboni.github.io/vir/

Wikidata: A free and open knowledge database with structured data for the linked data web.
https://www.wikidata.org

WordNet: A large English lexical database.
https://wordnet.princeton.edu/

C
Digital Tools

The following software and tools are useful for working with data and data visualization. Most of these are free to use (as a free version or with an education license), open source, and favor linked data and the Semantic Web.

Collections of Tools

Coding Dürer, Tools: A collection of image analysis, data visualization, and annotation tools useful for digital art history.
https://codingdurer.de/tools

DARIAH Tools and Services: DARIAH-EU provides tools and services for digital humanities, such as TextGrid, RTIViewer, and Hypotheses.
https://www.dariah.eu/tools-services/tools-and-services

Datavisualization.ch: A range of data visualization tools, sortable by type (maps, charts, data, and color).
https://selection.datavisualization.ch

DH Toychest: Links to digital humanities tools.
http://dhresourcesforprojectbuilding.pbworks.com/w/page/69244319/Digital%20Humanities%20Tools

DiRT: Digital Research Tools wiki contains a list of tools and resources for scholars (specifically in the humanities and social sciences).
https://digitalresearchtools.pbworks.com

DMI Tools: The Digital Methods Initiative wiki lists useful tools for data harvesting and mining.
https://wiki.digitalmethods.net/Dmi/ToolDatabase

Europeana Pro: Tools to engage with cultural heritage data.
https://pro.europeana.eu/about-us/services-and-tools#tools

museum4punkt0: Open-source tools for digital applications in museums.
https://www.museum4punkt0.de/ergebnisse/; source code: https://github.com/museum4punkt0

Semantic Web and Linked Data: Research guide for Semantic Web and linked data tools assembled by the UCLA Library.
https://guides.library.ucla.edu/semantic-web

TAPoR: Lists research tools for text analysis.
https://tapor.ca

Visualising Data: Collection of data visualization software, including tools for charting, mapping, statistical analysis, design, and data handling, curated by Andy Kirk.
https://www.visualisingdata.com/resources

Data Preparation / Retrieval

Calc: LibreOffice's open-source spreadsheet software for organization, analysis, and storage of data in tabular form. Alternative to Microsoft Excel or Apple Numbers.
https://www.libreoffice.org/discover/calc

Cocoda: Mapping editor on the web for classifications, authority files, and thesauri.
https://coli-conc.gbv.de/cocoda

DataTables: Plug-in for the jQuery JavaScript library for adding advanced interaction controls to HTML tables.
https://datatables.net

DBpedia SPARQL query interface: Interface for SPARQL queries on triples in *DBpedia*.
https://dbpedia.org/sparql

Elasticsearch: Open-source search and analytics engine.
https://github.com/elastic/elasticsearch

FFmpeg: Command-line-based software for video and audio processing that allows for extracting images from videos.
https://ffmpeg.org/

From Data to Viz: Find a suitable visualization based on data type, appropriate tools to realize it and the code to build it.
https://www.data-to-viz.com

GLAM-Workbench: Series of Jupiter-Notebooks to harvest data from galleries, libraries, archives, and museums.
https://glam-workbench.net

Highcharts: Interactive charts for web pages.
https://www.highcharts.com

HistoricalDating: Ruby Gemfile that allows parsing historical dating and converts them to Julian day ranges (e.g., "nicht vor 1883" becomes from 1883-1-1 to 1896-12-31). Used by *Prometheus*.
https://github.com/wendig-ou/historical_dating

iART: Online platform for making large amounts of art history image data retrievable based on similarities in color, texture, shape, and the semantic content of the image.
https://www.iart.vision

ImageMagick: Open-source software that consists of a number of command-line interface utilities for manipulating images (resize, flip, mirror, rotate, distort, shear and transform images, adjust image colors, apply various special effects, or draw text, lines, polygons, ellipses, and Bézier curves).
https://imagemagick.org

imgs.ai: Deep visual search engine for digital art history based on neural networks.
https://imgs.ai/; source code: https://github.com/zentralwerkstatt/imgs.ai

Instaloader: Tool for downloading images from Instagram including the captions and metadata.
https://instaloader.github.io/

IrfanView: Image processing software for Windows that supports batch processing.
https://www.irfanview.com

Karma: Tool for mapping data from databases, spreadsheets, XML, JSON, web APIs, and other data sources to structured RDF.
https://usc-isi-i2.github.io/karma

Kartograph: Framework for building interactive map applications.
https://github.com/kartograph/kartograph.org

KNIME: Open-source data analytics platform for data mining, machine learning, modeling, and visualization.
https://www.knime.com

Metafacture: Open-source toolkit for processing semi-structured data.
https://metafacture.org

Mr. Data Converter: Converts CSV, TSV, and Excel tables to web-friendly formats including HTML, JSON, and XML.
https://shancarter.github.io/mr-data-converter

OCR4all: Free, open-source software for Optical Character Recognition in early modern prints.
https://www.ocr4all.org

OpenRefine: Free, open-source tool for exploring large datasets, cleaning messy data, transforming it into another format, and linking and extending datasets with various web services.
https://openrefine.org

Pattypan: Open-source tool for bulk image uploads to Wikimedia Commons.
https://commons.wikimedia.org/wiki/Commons:Pattypan

Pillow: Python Image Library for image processing.
https://github.com/python-pillow/Pillow

Polymaps: Free JavaScript library for dynamic, interactive maps in web browsers.
http://polymaps.org

Protégé: Open-source editor and framework for developing ontologies.
https://protege.stanford.edu

RapidMiner: Data science platform for data preparation, data mining, text mining, machine learning, and deep learning.
https://rapidminer.com

scikit-image: Collection of algorithms for image processing in Python.
https://scikit-image.org

TinEye: Reverse image search engine for searches with images instead of keywords.
https://www.tineye.com

Vitrivr: Open-source full-stack content-based multimedia retrieval system for videos, sound, and images. Uses sketches instead of keywords as search input.
https://vitrivr.org; source code: https://github.com/vitrivr

VLC Media Player: Open-source multimedia player and framework for video and audio files that allows for extracting images from videos.
https://www.videolan.org/vlc/

Wikidata Query Builder: Graphical user interface (GUI) that empowers users who have no SPARQL experience to perform simple *Wikidata* queries.
https://query.wikidata.org/querybuilder/

Wikidata Query Service: GUI for SPARQL queries in *Wikidata*.
https://query.wikidata.org/

Crowdsourcing

Accurator: Crowdsourcing framework to add expert knowledge to cultural heritage collections.
https://github.com/rasvaan/accurator

Annotorious: Image annotation tool for the web.
https://annotorious.github.io

FromThePage: Free software for crowdsourced transcription of documents.
https://fromthepage.com

liiive: Collaborative live annotation tool for *IIIF* materials.
https://liiive.now/

Pybossa: Crowdsourcing framework to classify, geotag, or transcribe images, videos, or sound.
https://pybossa.com

Zooniverse: Crowdsourcing platform for professional researchers to help build useful datasets.
https://www.zooniverse.org

Artificial Intelligence

Clarifai: AI computer vision platform and deep learning workspace for processing images, video, and text.
https://www.clarifai.com

Clip: Neural network that learns visual concepts from natural language supervision.
https://github.com/openai/CLIP

Google Cloud Vision API: Machine learning models that detect objects, faces, and printed text within images.
https://cloud.google.com/vision

Imagga: AI-powered image recognition API for automated tagging and visual search.
https://imagga.com

ml5.js: Open-source library providing access to machine learning algorithms and models in the browser, building on top of TensorFlow.js.
https://ml5js.org/

OpenCV: Open-source computer vision and machine learning software library.
https://opencv.org

PyTorch: Open-source deep learning platform.
https://pytorch.org

Teglor: Collection of deep learning libraries organized by language.
http://www.teglor.com/b/deep-learning-libraries-language-cm569

TensorFlow: Fast, flexible, and scalable open-source machine learning library.
https://www.tensorflow.org

TensorFlow Playground: Interactive in-browser visualization enabling the simulation of small neural networks.
https://playground.tensorflow.org

Data Visualization

Chart.js: Open-source HTML5 JavaScript charting library.
https://www.chartjs.org

Collectionscope: Software engine to visualize museum collections across time and space.
https://github.com/amnh-sciviz/collectionscope

CollectionSpaceNavigator (CSN): Open-source visualization tool for multidimensional datasets of visual digital artifacts.
https://collection-space-navigator.github.io/CSN/?dataset=Compression+2k+WikiArt&projection=UMAP, https://github.com/Collection-Space-Navigator/CSN

Cytoscape: Open-source software platform for complex network analysis and visualization.
https://cytoscape.org

D3.js: Data-Driven Documents is a JavaScript library for interactive and data-driven visualizations in web browsers using HTML5, SVG, and CSS.
https://d3js.org

D3 Gallery: Interactive JavaScript notebooks for *D3* on Observable.
https://observablehq.com/@d3/gallery

Datamatic: CMS for data visualization that can be embedded in websites.
https://datamatic.io

Data Visualisation Catalogue: Library of information visualization types. Suggests useful tools to generate the corresponding visualization.
https://datavizcatalogue.com

Data Viz Project: Selection tool for finding suitable data visualization types.
https://datavizproject.com

Datawrapper: Create charts and maps with data.
https://www.datawrapper.de

Flourish Studio: Data visualization tool to turn spreadsheets into online charts, maps, and interactive stories without coding.
https://flourish.studio

Geo-Browser: Web-based tool for data visualization in time and space by DARIAH-DE.
https://geobrowser.de.dariah.eu/

geojson.io: Simple editor to draw, change, and share GeoJSON-formatted map data.
https://geojson.io

Gephi: Visualization software for graphs and networks.
https://gephi.org

Gephi Lite: Free, open-source web application for visualization of networks and graphs.
https://gephi.org/gephi-lite

Google Charts: Free chart tools.
https://developers.google.com/chart/interactive/docs/gallery

Google Data Studio: Dashboard for data visualizations.
https://lookerstudio.google.com

Google My Maps: Create and share custom maps.
https://www.google.com/intl/en/maps/about/mymaps

GPS Visualizer: Free utility that creates maps and profiles from geographic data (GPS data, driving routes, street addresses, or coordinates).
https://www.gpsvisualizer.com/

Graph Commons: Transform data into interactive map networks.
https://graphcommons.com

GRASS GIS: The Geographic Resources Analysis Support System is a free, open-source geographic information system (GIS) software suite used for geospatial data management and analysis, image processing, graphics and maps production, spatial modeling, and visualization.
https://grass.osgeo.org

Histomania: Sophisticated tool for creating interactive timelines.
https://www.histomania.com

histropediaJS: Create interactive timelines by including *Wikipedia* and *Wikidata* content.
https://js.histropedia.com

ImageJ: Open platform for image processing.
https://imagej.net

ImagePlot: Visualization software by Lev Manovich to explore patterns in large image collections.
https://blog.softwarestudieslab.com/p/imageplot.html

Infogr.am: Create infographics, charts, maps, and dashboards.
https://infogram.com

JavaScript InfoVis Toolkit: For the creation of interactive data visualizations for the web.
https://philogb.github.io/jit/

Keshif: Easy-to-use platform for creating data visualizations without programming skills.
https://keshif.me

Leaflet: Open-source JavaScript library for mobile-friendly interactive maps.
https://leafletjs.com

Mapbox: Design and development tools for mobile apps, navigation, AR, and data visualization powered by location data.
https://www.mapbox.com

Maphub: Online application for exploring and annotating digitized, high-resolution historical maps.
https://maphub.github.io

Milestones: Interactive timeline with milestones in the history of thematic cartography, statistical graphics, and data visualization.
https://datavis.ca/milestones/

Mirador: Open-source, web-based, multi-window image viewing platform for zooming, displaying, comparison, and annotating images from repositories that support *IIIF* APIs.
https://projectmirador.org

Museum Analytics (MAX): Tool for the analysis of museum collection data.
https://www.max.gwi.uni-muenchen.de

Ngram Viewer: Search engine tool that displays phrases on a graph according to the frequency it occurs in the corpus of all Google Books between 1500 and 2019.
https://books.google.com/ngrams

openFrameworks: Open-source C++ toolkit for creative coding. Provides a simple and intuitive framework for experimentation.
https://openframeworks.cc

OpenLayers: Open-source JavaScript library for integrating data into dynamic maps on web pages.
https://openlayers.org

OpenSeadragon: *IIIF* image viewer for high-resolution, zoomable images.
https://openseadragon.github.io/

OpenStreetMap: Collaborative project for a free, editable map of the world under a public license.
https://www.openstreetmap.org

Overview: Open-source platform for reading and analyzing thousands of documents and includes full text search, visualizations, entity detection, and topic clustering.
https://www.overviewdocs.com

p5.js: JavaScript library that adapts Processing for the web.
https://p5js.org

Palladio: Platform for visualizing data on a map or in a network graph.
https://hdlab.stanford.edu/palladio/

PixPlot: Tool for visualizing images by similarity in clusters in a 2D projection.
https://github.com/YaleDHLab/pix-plot

Plotly: Open-source graphing libraries for creating interactive graphs and maps with Python, R, Julia, Javascript, ggplot2, F#, MATLAB®, and Dash.
https://plotly.com/javascript/

Processing: Software for learning how to code and prototyping used by students, artists, designers, researchers, and hobbyists.
https://processing.org

QGIS: Open-source GIS (geographic information system) application.
https://www.qgis.org/de/site

RAWGraphs: Open-source framework for easy data visualization from spreadsheets.
https://rawgraphs.io

R / RStudio: *R* is a free programming language and software environment for statistical computing and graphics. *RStudio* is an integrated development environment for *R* with a graphical user interface (GUI).
https://www.r-project.org
https://posit.co/products/open-source/rstudio/

Sigmajs: JavaScript library for integrating interactive graph visualizations in web applications.
https://www.sigmajs.org/

Tableau Public: Create visualizations with ease.
https://public.tableau.com

Text Visualization Browser: Find suitable text visualization techniques by filtering the examples by categories.
https://textvis.lnu.se/

TimelineJS: Easy-to-make interactive timelines.
https://timeline.knightlab.com

Vega: Visualization grammar for describing the visual appearance and interactive behavior of a visualization in a JSON format. Generates web-based views using Canvas or SVG.
https://vega.github.io/vega

VIKUS Viewer: Open-source data visualization tool to explore digital collections. Available on GitHub.
https://vikusviewer.fh-potsdam.de

Voyant Tools: Tools for text analysis and visualization.
https://voyant-tools.org

xCurator: Makes digital collections of museums searchable and contextualized based on AI technologies.
https://github.com/Badisches-Landesmuseum/xcurator

Storytelling / Infographics / Animations

Animaker: Create animated videos by click and choose, drag and drop, edit and play.
https://www.animaker.com

ArcGIS StoryMaps: Combine interactive maps with text and other multimedia content to tell stories.
https://storymaps.arcgis.com/

Biteable: Create animated videos.
https://biteable.com

Canva: Free infographic and graph maker.
https://www.canva.com

ChronoZoom: Interactive timeline for storytelling.
http://www.chronozoom.com

Odyssey.js: Free interactive scrollytelling tool for maps.
https://cartodb.github.io/odyssey.js/

Pageflow: Open-source tool for multimedia storytelling.
https://www.pageflow.io; https://github.com/codevise/pageflow

Rasa: Open-source framework for building chat and voice-based AI assistants.
https://rasa.community

Scratch: Developed by the MIT Media Lab. Block-based visual programming language targeted primarily at children. Kids can program interactive stories, games, and animations and share them in the online community.
https://scratch.mit.edu

ScrollyVis: Free tool for scientific scrollytelling.
https://ericmoerthvis.github.io/ScrollyVis/AdditionalMaterials/; https://www.ericmoerth.at/editor/

Slices: Create simple, interactive multimedia stories for the web that can be viewed on any display by swiping or with a mouse.
https://slices.co

StoryMapJS: Create storylines on maps, artworks, or other images.
https://storymap.knightlab.com

TimeMapper: Combines storytelling with a timeline and map.
https://timemapper.okfnlabs.org/

Twine: Open-source tool for telling interactive, nonlinear stories that can be published in HTML. Writing code is not necessary, but it is possible to extend the stories with variables, conditional logic, images, CSS, and JavaScript.
https://twinery.org/

Panoramas / Virtual and Augmented Reality

A-Frame: Open-source web framework for building 3D augmented and virtual reality experiences with HTML.
https://aframe.io

ARCore: Platform for building AR experiences.
https://developers.google.com/ar

AR.js: Library for AR on the web with image tracking, location-based AR, and marker tracking.
https://github.com/AR-js-org/AR.js

ARToolkitX: Collection of open-source software tools for developing AR applications.
https://www.artoolkitx.org/

MindAR: Web AR library with image and face tracking.
https://github.com/AR-js-org/AR.js

Model-Viewer: Editor to display interactive 3D models on the web and in AR.
https://modelviewer.dev

OpenSceneGraph: Open-source 3D graphics toolkit for visual simulations, games, VR, scientific visualization, and modeling.
https://www.openscenegraph.com/

Pano2VR: Software for converting panoramic or 360° photos and videos into interactive virtual tours that can be viewed in-browser.
https://ggnome.com/pano2vr/

Collection Database and Virtual Exhibition Software and Tools

Archivematica: Free, open-source digital preservation system for maintaining long-term access to digital memory.
https://www.archivematica.org

ArchivesSpace: Open-source archives information management application for managing and providing web access to archives, manuscripts, and digital objects.
https://archivesspace.org

Atom: Web-based, open-source application for standards-based archival description and access in a multilingual, multi-repository environment.
https://www.accesstomemory.org

CollectionBuilder: Free, open-source tool for digital collection websites.
https://collectionbuilder.github.io

CollectionSpace: Web-based, open-source collections management software for museums.
https://collectionspace.org/

CollectiveAccess: Free, open-source software for managing and publishing museum and archival collections.
https://www.collectiveaccess.org

Exhibit: Storytelling tool for creating, narrating, and sharing exhibits by importing *IIIF* manifests, including 3D objects.
https://exhibit.so

Glamkit: Open-source CMS for museums.
https://glamkit.com/; source code: https://github.com/ic-labs/django-icekit/

H5P: Create quizzes, games, drag and drop tasks, interactive videos, and other interactive HTML5 content, and embed it in a website.
https://h5p.org

Islandora: Open-source DAM for digital collections.
https://www.islandora.ca/

JourneyMaker: Open-source code for an interactive, family-oriented gallery tour builder.
https://github.com/art-institute-of-chicago/journeymaker-cms

museum-digital: Community-driven platform for the presentation of museum digital collections using linked open data.
https://museum-digital.org

Omeka: Free, open-source CMS and web publishing platform for sharing digital collections and creating media-rich online exhibits.
https://omeka.org

Open Exhibits: Free, open-source software for creating digital exhibits and interactives for physically engaging visitor experiences based on human computer interaction (HCI).
https://openexhibits.org/

Digital Publishing

Docusaurus: Tool for creating single-page applications.
https://docusaurus.io

GitBook: Publish books and documentations on the web.
https://www.gitbook.com

Idyll: Create online publications with embedded, interactive data visualizations.
https://idyll-lang.org

Jupyter Book: Open-source, create books that include code-based interactive content.
https://jupyterbook.org

Material for MkDocs: Open-source tool for creating documents in Markdown.
https://squidfunk.github.io/mkdocs-material/

Observable: Notebooks for exploring and visualizing data.
https://observablehq.com

OSCI Toolkit: Open-source authoring and publishing environment for online scholarly catalogs for art history with full scholarly apparatus. The source code is available on GitHub.
https://www.oscitoolkit.org/;
source code: https://github.com/IMAmuseum/OSCI-Toolkit

Quarto: Open-source scientific and technical publishing system based on Markdown that supports dynamic content with Python, R, Julia, and Observable. Publish articles, presentations, websites, blogs, and books in HTML, PDF, MS Word, ePub, etc.
https://quarto.org

Quire: Getty's multiformat publishing tool for scholarly digital books, optimized for visual imagery.
https://quire.netlify.app

Tools / Databases / Frameworks for Digital Art History and Digital Humanities

3DHOP: 3D Heritage Online Presenter is an open-source framework for presenting high-resolution 3D models of cultural heritage on the Web.
https://3dhop.net/

arthistoricum.net Bildviewer Mirador: Implementation of the *IIIF*-Viewer *Mirador* to create, show, share, and annotate image collections.
https://www.arthistoricum.net/hilfe/werkzeugkasten; https://iiif.arthistoricum.net/mirador/

Awesome *IIIF* resources: Collection of resources for the International Image Interoperability Framework including standards, image servers, image viewers, image tools, presentation API libraries, etc.
https://github.com/IIIF/awesome-iiif

ConedaKOR: Open-source media database created for content and knowledge management organized in semantic networks.
https://github.com/coneda/kor

DFG 3D-Viewer: Free, open-source web-viewer for 3D models of art and architecture.
https://dfg-viewer.de/dfg-3d-viewer-2;
source code: https://github.com/slub/dlf-3d-viewers

Digilib: Open-source, web-based client/server technology for images.
https://robcast.github.io/digilib/index.html

GraphDB: Free semantic graph database engine by Ontotext.
https://www.ontotext.com/products/graphdb

IIPImage: Image server system for viewing and zooming web-based, high-resolution images.
https://iipimage.sourceforge.io

International Image Interoperability Framework (IIIF): Interoperable technology and community framework for image delivery.
https://iiif.io

Neo4j: Open-source graph database management system.
https://neo4j.com

Recogito: Online platform for annotating text documents and images. Data can be exported as CSV, RDF, GeoJSON, and TEI.
https://recogito.pelagios.org

Solr: Open-source enterprise search platform built on Apache Lucene. Enables full-text search, faceted search, real-time indexing, dynamic clustering, database integration, and rich document (Word, PDF, etc.) handling and is designed for scalability and fault tolerance.
https://solr.apache.org

Transkribus: Platform for the digitization, AI-powered text recognition, transcription and searching of historical handwritten, typewritten, or printed documents.
https://readcoop.eu/transkribus

Tropy: Open-source database for organizing and describing digital images used for research. Data can be exported as JSON-LD, CSV, and directly to Omeka S.
https://tropy.org

TypeDB: Open-source knowledge graph for highly interconnected data.
https://typedb.com/deploy; https://github.com/vaticle/typedb

ZB-detektIIIF: Browser plugin that automatically detects digitized resources that are *IIIF* compliant and can be collected with one click. https://viewer.zb.uzh.ch

Zenodo: Open-access repository where researchers can publish and share data sets, software, reports, posters and other research-related digital artifacts. Each submission gets a DOI, a license, can be cited in all versions, and shared on social media. https://zenodo.org/record/2612834#.XJ9FQaRCdBB

Zotero: Open-source citation management software. https://www.zotero.org

Virtual Research Environments / Infrastructures

Arches: Open-source, geospatially enabled software platform to manage cultural heritage data. https://www.archesproject.org

ARIES (ARt Image Exploration Space): Interactive image manipulation system for the exploration and organization of fine digital art. https://artimageexplorationspace.com

CENDARI (Collaborative European Digital Archival Research Infrastructure): Virtual research environment for digital historical research. http://www.cendari.eu

DARIAH (Digital Research Infrastructure for the Arts and Humanities): European network of people, expertise, information, knowledge, content, methods, tools, and technology. DARIAH aims to enhance and support digitally enabled research and teaching in the arts and humanities. https://www.dariah.eu

DaSCH (Data and Service Center for the Humanities): A platform for the long-term preservation of research data in the humanities. https://www.dasch.swiss/

DaSCH Service Platform (DSP): Virtual research environment for knowledge organization, representation, and annotation to store, share, and work with data in the humanties. https://admin.dasch.swiss

DHVLab: Virtual research environment for data analysis in art history, history, and linguistics.
https://dhvlab.gwi.uni-muenchen.de

Digital Mappa: Digital humanities platform for creating projects with image and text collections. Offers browser-based workspaces to link, annotate, and search content, as well as collaborating and publishing online.
https://www.digitalmappa.org/

Framadrive: Share documents online.
https://framadrive.org

Framapad: Online text editor for collaborative writing.
https://framapad.org/en

Framasoft: Nonprofit association that offers tools to facilitate the adoption of free software and services.
https://framasoft.org/en

Getty Scholars' Workspace: Online environment for collaborative art historical research.
https://github.com/OpenTechStrategies/GettyScholarsWorkspace

Google Drive: Permits collaborative editing of documents, spreadsheets, presentations, etc. in the cloud.
https://www.google.com/drive

histHub: Research platform for digital history in Switzerland.
https://histhub.ch

HyperImage: Virtual research environment for annotating and linking visual and audio-visual objects and documents. Projects can be published as interactive applications.
https://hyperimage.ws/en

Manifold: Free, open-source, collaborative platform for scholarly publishing.
https://manifoldapp.org

Manuscriptorium: Virtual research environment that provides access to manuscripts, incunabula, early printed books, maps, charters, and other types of documents under a single digital library interface.
https://www.manuscriptorium.com/

Nodegoat: Web-based data management environment for network analysis and visualization that can enrich data with relational, geographical, and temporal attributes.
https://nodegoat.net

ResearchSpace: Open-source platform for research with tools to explore and visualize data based on Semantic Web technologies developed by The British Museum.
https://www.researchspace.org

Scalar: Free, open-source, Semantic Web authoring and publishing platform where authors can write long-form, born-digital scholarship online.
https://scalar.me/anvc/scalar

Swiss Art Research Infrastructure (SARI): Research environment that provides digital tools and access to collection data based on Semantic Web standards.
https://swissartresearch.net

TextGrid: Virtual research environment for the humanities, useful for digital editions.
https://textgrid.de

WissKI (WISSenschaftliche KommunikationsInfrastruktur): Free, open-source virtual research environment for managing scholarly data. Scientific communication infrastructure based on Drupal.
https://wiss-ki.eu/

Text Editors / Integrated Development Environments (IDEs)

Anaconda: Data science platform for performing Python/R data science and machine learning on a single machine.
https://www.anaconda.com

Microsoft Visual Studio: Integrated development environment (IDE) for developing computer programs, websites, and web and mobile apps. The community edition is free to use.
https://visualstudio.microsoft.com

Notepad++: Free source code editor for Microsoft Windows.
https://notepad-plus-plus.org

Web Development Frameworks

Angular: Open-source web application framework for mobile, desktop, and web.
https://angular.io

Bootstrap: Open-source, front-end web framework for building responsive, mobile-first projects on the web.
https://getbootstrap.com

GitHub Pages: Websites hosted from a GitHub repository.
https://pages.github.com/

Jekyll: Open-source static site generator that allows hosting websites on GitHub.
https://jekyllrb.com

MIT App Inventor: Intuitive, visual programming environment where users can build fully functional apps for Android phones, iPhones, and Android/iOS tablets.
https://appinventor.mit.edu/

Webspaces: Create self-hosted 3D worlds on the web using HTML.
https://webspaces.space

Design and 3D Modeling Software

Blender: Free, open-source 3D creation suite for modeling, rigging, animation, simulation, rendering, compositing and motion tracking, video editing, and game creation.
https://www.blender.org

Cables: Free, web-based tool for creating interactive content without coding knowledge.
https://cables.gl

Coolors: Online color scheme generator. Users can export the created scheme as URL, PDF, PNG, SCSS, or SVG.
https://coolors.co

Figma: Browser-based design and prototyping software.
https://www.figma.com

FotoFlexer: Free online photo editor that provides retouch, coloring, distortion, resizing, and morphing tools.
https://fotoflexer.com

Marvel: Design platform for creating wireframes, mockups, website or app prototypes.
https://marvelapp.com

MeshLab: Open-source software for processing and editing 3D scans of objects. It provides a set of tools for editing, cleaning, healing, inspecting, rendering, texturing, and converting 3D triangular meshes.
https://www.meshlab.net/

Opendrndr: Open-source framework for creative coding that simplifies writing real-time interactive software.
https://openrndr.org

Penpot: Free, open-source design and prototyping platform.
https://penpot.app

Photopea: Free online design editor, similar to Adobe Photoshop.
https://www.photopea.com

Pixlr: Free, online photo editor, similar to Adobe Photoshop.
https://pixlr.com/editor

Potree: Free, open-source *WebGL*-based point cloud renderer for 3D models.
https://potree.org

SketchUp: Web-based 3D modeling application for architecture, interior design, landscape architecture, civil and mechanical engineering, film, and video game design.
https://www.sketchup.com

Three.js: JavaScript library for creating animated 3D graphics that can be viewed in-browser.
https://threejs.org/

Unity: Cross-platform game engine to create 3D and 2D games and simulations.
https://unity.com

Unreal Engine: Game engine for creating real-time 3D games and simulations with photorealistic rendering.
https://www.unrealengine.com

Vectr: Free vector graphics editor, like Adobe Illustrator.
https://vectr.com/

WebGL (Web Graphics Library): JavaScript API for rendering interactive 2D and 3D graphics within web browsers.
https://webglsamples.org/

D
Programming Tutorials and Guides

General Online Courses

Codecademy: Free courses that teach technical skills through interactive lessons.
https://www.codecademy.com/catalog/all

Edabit: Learn to code by programming in small units beginning with easy tasks that increase in difficulty.
https://edabit.com/

freeCodeCamp: Learn to code for free in HTML5, CSS3, JavaScript, Databases, Git & GitHub, *Node.js*, *React.js*, and *D3.js*.
https://www.freecodecamp.org/

Giraffe Academy: Free video tutorials on databases, programming languages, web development, and static site generators.
https://www.giraffeacademy.com/

Introduction to OpenRefine: Introduction to OpenRefine developed by Owen Stephens on behalf of the British Library.
http://www.meanboyfriend.com/overdue_ideas/wp-content/uploads/2014/11/Introduction-to-OpenRefine-handout-CC-BY.pdf

Learn JavaScript: Interactive environment for learning and practicing JavaScript fundamentals.
https://learnjavascript.online/

LinkedDataTools.com: Tutorials that introduce users to linked data and the Semantic Web.
https://www.linkeddatatools.com/

Network Science Tutorials: Tutorials for network visualizations and analysis with R and Gephi.
https://kateto.net/tutorials/

School of Data: Free online courses about key skills to understand, manage, and work with data: cleaning, exploring, extracting, mapping, collecting, and presenting data.
https://schoolofdata.org/courses/

Six easy ways to run your Jupyter Notebook in the cloud: A review of six services to publish interactive *Jupyter Notebooks*: *Binder*, *Kaggle Kernels*, *Google Colaboratory (Colab)*, *Microsoft Azure Notebooks*, *CoCalc*, and *Datalore*.
https://www.dataschool.io/cloud-services-for-jupyter-notebook/

Step-by-step guide to contributing on GitHub: GitHub for beginners.
https://www.dataschool.io/how-to-contribute-on-github/

W3Schools: Tutorials for web technologies like HTML, CSS, JavaScript, Server Side, Web Building, and XML.
https://www.w3schools.com/

Wikidata:SPARQL tutorial: Introduction into SPARQL queries.
https://www.wikidata.org/wiki/Wikidata:SPARQL_tutorial

Digital Humanities Courses

CLI for Artists + Designers: Basic instructions for using tools via a Command-Line Interface (CLI) for images and video, including ImageMagick, FFmpeg, and youtube-dl.
https://ffd8.github.io/cli-for-artists-and-designers/

DAHVC (Duke University's Digital Art History & Visual Culture Research Lab) Tutorials: Provides tutorials for common digital humanities software and tools.
https://dahvc.org/resources/

DH Tutorials: Comprehensive collection of tutorials for digital humanities tools and methods.
http://dhresourcesforprojectbuilding.pbworks.com/w/page/69244314/Tutorials%20for%20DH%20Tools%20and%20Methods

Digitales Storytelling in der Kunstgeschichte mit *IIIF*: Online workshop for digital storytelling in art history using *IIIF*.
https://leszimmermann.github.io/digitales-storytelling/

Doing Digital Scholarship: Self-guided introduction to digital scholarship. https://ssrc.doingdh.org/

***IIIF* Training:** Free online workshops and training for *IIIF*. https://training.iiif.io/

Interactive Information Visualization: An introduction to the foundation skills using *D3.js* for data visualizations on the web. https://info474-s17.github.io/book/

kuwiki Living Handbook: Guideline for art historians writing *Wikipedia* articles. https://de.wikipedia.org/wiki/Wikipedia:Arbeitsgemeinschaft_Kunstwissenschaften_%2B_Wikipedia; https://de.wikipedia.org/wiki/Wikipedia:Arbeitsgemeinschaft_Kunstwissenschaften_%2B_Wikipedia/Living_handbook

Pegasus Data Project: Digital humanities tutorials for network analysis and visualization. https://humanitesdigitales.wordpress.com/category/tutoriels/

Programming Historian: Peer-reviewed tutorials for digital humanists. https://programminghistorian.org/en/lessons/

Python Tutorials for Digital Humanities: Free courses for using Python in the digital humanities. https://pythonhumanities.com; https://www.youtube.com/c/PythonTutorialsforDigitalHumanities

Python für Historiker:innen: Introduction to Python for historians. https://digital-history-berlin.github.io/Python-fuer-Historiker-innen/home.html

RegexOne: Learn regular expressions with simple, interactive exercises. https://regexone.com/

Semantic Web and Linked Data: Instructional Resources for linked data collected by the UCLA Library. https://guides.library.ucla.edu/semantic-web#s-lg-page-section-2410785

Technical Resources: Hints, helpful tools, and introductory guidelines for Command Line, GitHub, *IIIF*, Markdown, and YAML, among others. https://quire.getty.edu/resources/resources/

Understanding *Linked Art*: Series of tutorials for *Linked Art* (https://linked.art).
https://observablehq.com/@jrladd/linked-art-1

V & A Data Explorations: Jupyter Book by the Victoria & Albert Museum for using the V & A Collections API and other museums' APIs.
https://developers.vam.ac.uk/notebooks/data-explorations

E
Examples

This list includes noteworthy examples of cultural applications and projects from GLAM institutions, as well as from digital art history and digital humanities.

Applications Using Artworks and Data from Art Collections

5th floor: The Centre d'Art Contemporain Genève's digital platform is an extension of its physical exhibition spaces for presenting contemporary art.
https://5e.centre.ch/en/

12 Sunsets: Interactive visualization of a road map combined with Ed Ruscha's photographs allows users to explore the artist's archive.
https://12sunsets.getty.edu

360° Swiss Heritage: Discover Swiss castles in virtual reality (VR).
https://www.360-swiss-heritage.ch

Africa Art Archive: Explore the Hans Himmelheber Archive using random keywords, data visualization, and object descriptions.
https://africa-art-archive.ch/explore-the-archive

AI Explorer: The Harvard Art Museums have applied various artificial intelligence techniques to the collection, from machine-generated descriptions and tags to object recognition and face analysis.
https://ai.harvardartmuseums.org/

Animal Crossing Art Generator: Getty created this tool to use artworks from the Getty Museum's collection—or any other museum that uses the *IIIF* technology—in the game Animal Crossing.
https://experiments.getty.edu/ac-art-generator

Archives on the Move: A project for the visualization and communication of Kunsthalle Basel's *Photo Archive*.
https://archivesonthemove.org/

ARTMYN: 5D artworks using Reflectance Transformation Imaging (RTI) scans.
https://artmyn.com/explore

Art of: Playful interaction with artworks from Kunsthalle Karlsruhe's collection in a series of applications.
https://www.moodfor.art

Artsy: Platform connecting artists, artworks, architecture, and design objects across history in partnership with galleries and institutions worldwide. Artsy aims to expand the art market and support artists and art.
https://www.artsy.net/

Bilder der Schweiz online: Digital collection based on linked data that brings together images from different institutions.
https://bso.swissartresearch.net

Black Sun: Interactive application created for Fondation Beyeler in Riehen/Basel's exhibition *Black Sun* (an homage to Kasimir Malewitsch and his 1915 painting *Black Square*). Users can explore contemporary artworks included in this exhibition.
http://blacksun.fondationbeyeler.ch/

Bot by Fondation Cartier: AI-based, bilingual chatbot for information about artworks, exhibitions, and publications (see the blue rectangle icon that looks like a face).
https://www.fondationcartier.com

Calico: Sample collection of fabric print patterns that can be explored in interactive visualizations using AI.
https://calico.timbayern.de

Closer to Van Eyck: Interactive application about the *Ghent Altarpiece* restoration that includes high-resolution images of all sides and wings, as well as macrophotography, infrared macrophotography, infrared reflectography, and X-radiography.
https://closertovaneyck.kikirpa.be

ColourLex: Rich source of information about pigments.
https://colourlex.com

Connect Vermeer: Discover similarities in subject, composition, style, and technique between paintings by Johannes Vermeer and his contemporaries.
https://connectvermeer.ie/

Culturebot: AI-based, multilingual chatbot for *Europeana* where users interact with the data based on semantic connections between records, persons, places, and other entities.
https://culturebot.eu/

Curiositas 5.0: Digital collection of images, 3D objects, and storytelling.
https://curiositas.digitalesschaudepot.ch

Deutsche Digitale Bibliothek Visualized: Contents of the German Digital Library using data visualizations.
https://uclab.fh-potsdam.de/ddb/index.en.html

Deutsche Tafelmalerei des Spätmittelalters: Late medieval panel paintings from the Germanisches Nationalmuseum Nürnberg are presented including high-resolution infrared reflectograms, radiographs, UV, details and macro photography. Presents the images in the *Mirador Viewer* and provides *IIIF* manifests.
https://tafelmalerei.gnm.de/objekte

Digital Curator: Exhibition generator using computer vision with artworks from various museums.
https://digitalcurator.art

DigitaltMuseum: Platform that brings together collections from Norwegian and Swedish museums and features a timeline, map, and an API.
https://digitaltmuseum.org

Duchamp Research Portal: Data-driven application that combines the art of Marcel Duchamp and archival materials from the collections of the Philadelphia Museum of Art and Centre Pompidou using linked open data (LOD) and *IIIF*. The Museum Linked Data Browser contains technical documentation for maintaining and using the data.
https://www.duchamparchives.org and https://drp.museumbrowse.org

Europeana Exhibitions: Online exhibitions curated by *Europeana* partners.
https://www.europeana.eu/portal/en/exhibitions/foyer

Faces of Sweden: Timeline application including portraits from the Nordiska Museet, Stockholm collection.
https://riksantikvarieambetet.github.io/Faces-of-Sweden

Fashion History Timeline: Open-access source for fashion history that incorporates objects and artworks from multiple museums and libraries.
https://fashionhistory.fitnyc.edu/

Gugelmann Galaxy: 3D cloud of images that users can arrange by color, technique, description, or composition.
https://www.mathiasbernhard.ch/gugelmann-galaxy/

Google Arts & Culture Experiments: Experimental projects at the crossroads of art, technology, design, and culture created by artists and creative coders affiliated with *Google Arts & Culture*.
https://experiments.withgoogle.com/collection/arts-culture

Google Arts & Culture Museum Views: Virtual tours through 3D-models of museums.
https://artsandculture.google.com/project/streetviews

GOTHA.digital: Joint platform for archival, library, and museum collections with digital exhibitions, virtual tours, and the Gotha.Lab.
https://gotha.digital

Heilbrunn Timeline of Art History: The Metropolitan Museum of Art combines essays, artworks, and chronologies to tell the story of art and global culture through its collection.
https://www.metmuseum.org/toah

Hermitage Museum: The State Hermitage Museum in St. Petersburg, offers interactive floor plans combined with interactive, 3D panoramas for VR visits.
https://www.hermitagemuseum.org/panorama?lng=en

Hirox 3D Digital Microscope: Microscopic 3D scan of a painting.
https://hirox-europe.com/PEARL/3D

Interaktive digitale Angebote (IDA): Learn about history in an entertaining interaction with objects.
https://www.dhm.de/bildung/ida/

JourneyMaker: Engaging application for composing thematic tours by selecting works from the Art Institute of Chicago's collection. The personalized tour can be printed as a booklet and contains questions for children visiting the museum with their families.
http://journeymaker.artic.edu

Julia Stoschek Collection: Online collection catalog of time-based art and a video lounge.
https://jsfoundation.art/collection/;
https://jsfoundation.art/jsf-video-lounge/

Kunsthalle Revisited: Several individually designed applications for past exhibitions provide insight into the history of the Staatliche Kunsthalle Baden-Baden, and make it possible to discover how artists have changed the exhibition space.
http://kunsthallerevisited.com

Kunsthaus Zürich Digilab: Explore the exhibition history and digital art.
https://digilab.kunsthaus.ch/

Les très riches heures du Duc de Berry: Annotated manuscript in high resolution.
https://les-tres-riches-heures.chateaudechantilly.fr

List of AI Initiatives: Collection of AI projects by museums.
https://t.co/588ExRZ50T

Louvre Virtual Tours: Virtual tours for several exhibitions shown in the Petite Galerie spaces.
https://www.louvre.fr/en/online-tours

MOMA Exhibition Spelunker: Interactively discover exhibitions, artists, curators, and departments since MoMA opened in 1929.
http://spelunker.moma.org

Muensterschatz.ch: High-resolution images of objects with glossy surfaces. The incidence of light can be changed for some objects, revealing further details.
https://www.muensterschatz.ch

Object Photo: Explore modern photographs from the Thomas Walther Collection and artists using various data visualizations.
https://www.moma.org/interactives/objectphoto

Panoramic Tours: Virtual exhibitions and panoramic tours by the Staatliche Kunstsammlungen Dresden.
https://www.skd.museum/special-pages/panorama-rundgaenge

Pipilotti Rist Exhibition: Interactive 3D model with photographic documentation of the exhibition *Pipilotti Rist: Dein Speichel ist mein Taucheranzug im Ozean des Schmerzes*, on view between February 26 and May 8, 2016 at Kunsthaus Zürich.
https://pipilotti.kunsthaus.ch

Prisme7: Immersive VR game exploring artworks in the Centre Pompidou's collection.
https://prisme7.io

Reflectance Transformation Imaging (RTI): Imaging technique for 3D models for exploring surfaces of cultural objects under varying lighting conditions.
https://truvis.ch/examples/index.html

Rembrandt in Southern California: Online exhibition on Rembrandt including high-resolution images, digital catalogs, videos, and podcasts as a joint project by the Hammer Museum, J. Paul Getty Museum, Los Angeles County Museum of Art (LACMA), Norton Simon Museum, and Timken Museum of Art.
https://rembrandtinsocal.org

RICHES Resources: Collection of innovative applications from cultural institutions.
https://resources.riches-project.eu/research/interactive-showcase/explore-the-showcase

Rijksmuseum Masterpieces Up Close: Virtual tour enhanced with audio streams, descriptive texts, and high-resolution images. Rembrandt van Rijn's *The Night Watch* (1642) is enhanced with several audio streams to learn more about the painting, its history, and its restoration. The virtual tour also offers a gamified component involving a search for hidden keys.
https://www.rijksmuseum.nl/en/masterpieces-up-close

Rijksmuseum Collection: Users are invited to set up an account to create and share virtual exhibitions and to save and use artwork images from the collection.
https://www.rijksmuseum.nl/en/collection

Sainte-Chapelle 360°: Explore the lower and upper chapel of Paris's Saint-Chapelle in 3D.
https://www.timographie360.fr/nos-realisations/la-sainte-chapelle-42

Sitterwerk Katalog: Interface for working with art library and material archive, making research traceable.
https://sitterwerk-katalog.ch

Smithsonian 3D Labs: Experiments with 3D models.
https://3d.si.edu/labs

Stadtpatrone: Application centered around underdrawings of the *Altarpiece of the City Patron Saints* in Cologne Cathedral.
https://www.museenkoeln.de/stadtpatrone/

Städel Museum's *Digital Collection:* Various kinds of access to the works in the collection, from a simple and straight keyword search to combining descriptive terms, view albums with various topics, or search for similar works with the same content.
https://sammlung.staedelmuseum.de/en/person/staedel-museum

Städel Time Machine: Virtual reality app with a reconstruction of the historical presentation of the collection that allows users to travel back to the nineteenth century and visit the Städel Museum at its three historical locations.
https://zeitreise.staedelmuseum.de/en/

St. Galler Globus 1576: 3D model of the earth and sky globe.
https://3dglobus.ch

The Art Story: Rich resource on the history of art with cross-references between artists, movements, ideas, and interactive timelines.
https://www.theartstory.org

The Museum of Drawers: Explore Herbert Distel's artwork digitally.
https://schubladenmuseum.org/

Ukiyo-e Search: Image search for Japanese woodblock prints. Allows users to upload a picture of a print to find similar prints across multiple collections.
https://ukiyo-e.org/

Unsupervised by Refik Anadol: Artist who includes MOMA's digital collection data in his artwork.
https://refikanadol.com/works/unsupervised/

Van Gogh Worldwide: Works by Vincent van Gogh from the collections of various museums brought together by linked data. The images are presented using *IIIF*.
https://vangoghworldwide.org; https://github.com/vangoghworldwide/linkedart

Videokunst.ch: Innovative platform that presents Carola and Günther Ketterer-Ertle's private collection of video art.
https://www.videokunst.ch/

Videomuseum: Metadatabase for video art organized by the consortium of French modern and contemporary public art collections.
https://www.videomuseum.fr/en

Virtual CMA Dashboards: Interactive dashboard by the Cleveland Museum of Art providing insight into usage of the Collection Online and the Open Access API.
https://www.clevelandart.org/virtual-cma-dashboards/comparison-by-work

Virtual Museums of Małopolska: Joint digital collection of several Polish museums that includes 3D objects and virtual exhibitions.
https://muzea.malopolska.pl

Visitor's Routes: The Rijksmuseum invites visitors to create personalized routes using works from their collection, which can be shared with others and loaded in the app as a guide when visiting the museum.
https://www.rijksmuseum.nl/en/tours

Visualizing Cultural Collections: Overview of applications realized at the University of Applied Sciences Potsdam for the exploration of digital cultural heritage via interactive graphical user interfaces.
https://uclab.fh-potsdam.de/vikus/

Visuelle Exploration zweier musealer Sammlungen: Collection visualization combining an image cloud with a path of similar objects.
https://visualisierung.smb.museum

WCMA Digital Project: Williams College Museum of Art initiative that provides open-access collection data and images for teaching and learning. Users can visualize it in the Collection Explorer.
https://artmuseum.williams.edu/wcma-digital-project/

xCurator: AI-based searches in a digital collection.
https://xcurator.landesmuseum.de

Applications Using Storytelling

Bayeux Tapestry: Digital representation of the Bayeux Tapestry in high resolution with annotated scenes displaying Latin inscriptions and English and French translations.
https://www.bayeuxmuseum.com/en/the-bayeux-tapestry/discover-the-bayeux-tapestry/explore-online

digitorials.ch: Multimedia storytelling about exhibitions by several Swiss museums.
https://www.digitorials.ch/#digitorials

Garden of Earthly Delights: *The Garden of Earthly Delights by Jheronimus Bosch* is an online interactive documentary. The web interface allows users to discover multiple stories in an audio-visual journey including sound, music, and high-resolution images.
https://tuinderlusten-jheronimusbosch.ntr.nl/en#

Holz macht Sachen!: Ongoing story around the little figure Vinzenz who explores various aspects of wood by touring different museums. The story can be followed on X, Facebook, and Instagram.
https://holzmachtsachen.org

Kleinmeister.ch: Souvenirs Suisses: Showcase including background information about the Swiss National Library's collection of Schweizer Kleinmeister (Swiss minor masters).
https://www.kleinmeister.ch

MoMA Through Time: Timeline to scroll through MoMA and MoMA PS1's history and explore artworks and objects from the archives.
https://www.moma.org/interactives/moma_through_time/

Persepolis Reimagined: Immersive virtual experience of Persepolis reconstructed in a 3D model enriched with museum objects and storytelling.
https://persepolis.getty.edu

Rijksmuseum Stories: Multimedia storytelling about various topics like masterpieces, exhibitions, behind-the-scenes insights, and other related topics.
https://www.rijksmuseum.nl/en/stories

Sainte-Chapelle Windows: App for image viewing and description of the meaning of the scenes depicted in the stained glass windows.
https://www.sainte-chapelle.fr/en/visit/visits-and-activities

Städel Digitorials: Sophisticated presentation and mediation applications that create narratives using informative texts, images, audio tracks, and videos to provide insights into exhibition themes or background information on artists.
https://www.staedelmuseum.de/de/angebote/digitorial

Storiiies: Experiments in digital storytelling based on *IIIF* and the *OpenSeadragon*.
https://storiiies.cogapp.com/

Unframed: VR video series about Swiss artists Arnold Böcklin, Félix Vallotton, and Ferdinand Hodler.
https://www.unframed-vr.com

Visualizing Visions: Experimental application for mediating art history and conducting art historical research with innovative digital approaches using the Rijksmuseum dataset.
http://www.visualizingvisions.com/

WDR 360 VR: Users can immerse themselves in a 360°-model of Cologne Cathedral while exploring multimedia content such as a singing choir or stories told by cathedral restorers.
https://koelnerdomlive.wdr.de

Archives, Databases, and Digital Art

Archive of Digital Art (ADA): Documents works of media art and digital installations.
https://www.digitalartarchive.at

Artport: Whitney Museum's portal highlights net.art and new media art in their collection.
https://whitney.org/artport

Digital Art Museum (DAM): Online resource for the history and practice of digital art.
https://dam.org/museum/

Digital Museum of Digital Art (DiMoDA): Virtual institution dedicated to commissioning, preserving, and exhibiting VR artworks.
https://dimoda.art

KdS-online: Database with the contents of the book series Die *Kunstdenkmäler der Schweiz (KdS)* about Swiss cultural heritage, art, and history with linked objects and persons, keywords, georeferences, and maps.
https://ekds.ch

Medienarchiv der Künste: The Media Archive of the Arts at the Zurich University of the Arts (ZHdK) offers researchers, lecturers, and students a platform for collaboratively working with media, documenting and archiving their projects and works, and for sharing contents with the public.
https://medienarchiv.zhdk.ch/

Online Archive Kunsthalle Bern: Living, online archive that grows with the ongoing digitization of Kunsthalle Bern's archival material through its users.
https://archiv.kunsthalle-bern.ch/

REALonline: Image database in which the elements on the images of medieval art are indexed in a very detailed and structured manner. The database provides a visual graph interface where users can investigate the network that the elements build.
https://realonline.imareal.sbg.ac.at/en/

Rembrandt Database: Artworks and research documentation for art historical information and technical documentation on paintings by Rembrandt. The database provides digital files and metadata brought together in an international collaboration and coordinated by the RKD Netherlands Institute for Art History.
https://rembrandtdatabase.org/

Rhizome ArtBase: Archive of born-digital art.
https://rhizome.org/

Your Uncertain Archive: Explore artworks, exhibitions, and other activities by artist Olafur Eliasson and his studio by navigating through a cloud in 3D space. The archival objects can be visualized in connected clusters using keywords.
https://olafureliasson.net/uncertain

Crowdsourcing Applications

ARTigo: Mini-games for crowd-tagging artworks.
https://www.artigo.org/

sMapshot: Georeferencing historical photographs through crowdsourcing.
https://smapshot.heig-vd.ch/

thingTAG-Mittelalter: Interactive application that combines art education and gaming to tag objects in medieval paintings using crowdsourcing.
https://thingtag.at

Digital Art History and Digital Humanities Projects

Artl@s database: Contains information about exhibitions, artists, and artworks provided by exhibition catalogs. Information can be visualized on a map, graph, and in lists and can be downloaded as CSV files.
https://artlas.huma-num.fr/map/#/

Artresearch.net: Semantic Web application built on ResearchSpace that integrates computer vision APIs with image collections of Pharos, the International Consortium of Photo Archives.
https://vision.artresearch.net

Corpus der barocken Deckenmalerei: Art historical research project on all Baroque ceiling and wall paintings from 1550 to 1800 in Germany. The aim is to create an open-access database using the Semantic Web and reconstruct the architecture in 3D models.
https://deckenmalerei.badw.de

Cranach Digital Archive: Interdisciplinary and inter-institutional online research database with paintings, archival documents, infrared reflectograms, and other information related to Lucas Cranach the Elder, his sons, and their workshop.
https://lucascranach.org/

Database of Modern Exhibitions (DoME), 1905–1915: Open-access database for researches on European paintings and drawings between 1905 to 1915 that includes metadata of around 1,000 exhibitions, 150,000 artworks, and 11,800 artists. The database offers advanced search and filter functions, integrated visualization tools, and enables the custom download of data and visualizations.
https://exhibitions.univie.ac.at/

Digital Benin: Digital platform with objects, photographs, and archival material from collections worldwide for providing an overview of the Benin Kingdom royal artefacts. The platform provides various tools to search and visualize the contents.
https://digitalbenin.org/

Joan Jonas Knowledge Base (JJKB): Open-source digital resource of archival materials, publications, photographs, videos, floor plans, and biographical information, documenting the work of multimedia and performance artist Joan Jonas.
https://artistarchives.hosting.nyu.edu/JJKB/

Performance Artist Database: Explore artists, events, and locations in a quantitative network analysis.
http://padb.net

Urban History 4D: Application for browsing and exploring historical architectural photographs via a visualization of the image collection in time and space.
https://4dbrowser.urbanhistory4d.org

Venice Time Machine: Large database of Venetian documents for extracting information from photos using machine vision algorithms in addition to making the monographs' content searchable. It aims to organize these diverse sources in a semantic graph of linked data and situate it in a historical geographical information system based on a virtual reconstruction of the city.
https://vtm.epfl.ch/

Digital Publishing

150+ Online Werkverzeichnisse der bildenden Kunst: Collection of online catalog raisonnés.
https://artvise.me/online-werkverzeichnisse/

Antoon van Dyck: Digital catalog raisonné of paintings in the Louvre collection by Antoon van Dyck.
https://livres.louvre.fr/vandyck/

Caravan: Digital interactive catalog by Aargauer Kunsthaus Aarau published as documentation of the exhibition series *Caravan* featuring young Swiss artists.
https://caravan.aargauerkunsthaus.ch/

Debates in the Digital Humanities: Open-access book series and an innovative example that demonstrates what an e-book in academic publishing could be in the digital age.
https://dhdebates.gc.cuny.edu/

Digital Publications: Art Institute of Chicago's interactive, online scholarly catalogs that include archival documents and conservation images. These monographic publications are about modern artists primarily.
https://www.artic.edu/digital-publications

Museum Publishing Digital Interest Group: Table with collected links to digital museum publications.
https://digpublishing.github.io

Online Werkverzeichnisse: Collection of online catalog raisonnés.
https://www.arthistoricum.net/themen/wvz/a-z/

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Art Museum Digital Collections and Offerings Table

The table provides an overview of the digital collections and other digital offerings of the five most visited art museums in Switzerland, Austria, Germany, Europe, and the United States of America in 2019 based on select criteria.[1501]

Museum websites and digital collections are in a constant state of flux. The table reflects the state of information at the end of 2021. In the meantime, functionality may have been added and the interface design, information architecture, accessible data, and digital offerings may have changed.

Additionally, sources such as the works in the collection, digitized exhibition catalogs, digitized archival material, or digital applications are often found in completely different areas of museum websites, which is why other individual offerings may have been overlooked when compiling the table.

1501 Sources for the 2019 visitor figures on which the selection of art museums is based, see "Die meistbesuchten Schweizer Museen nach Anzahl Eintritten 2019," in: *Taschenstatistik Kultur in der Schweiz 2020*, ed. Bundesamt für Kultur BAK, September 29, 2020, 65, https://www.bak.admin.ch/bak/de/home/themen/kulturstatistiken.html; the selection of German museums is based on information provided by the Institut für Museumsforschung der Staatlichen Museen zu Berlin and the author's own research; the selection of Austrian museums is based on "Meistbesuchte Museen 2001 bis 2018 nach Eigentümer bzw. Erhalter und Bundesland," ed. Statistik Austria: Bundesanstalt Statistik Österreich, August 6, 2020, https://www.statistik.at/web_de/statistiken/menschen_und_gesellschaft/kultur/museen_und_ausstellungen/index.html; the visitor figures are from: *Kunst und Kulturbericht 2019*, ed. Bundesministerium für Kunst, Kultur, öffentlicher Dienst und Sport, Sektion für Kunst und Kultur, 2020, 43, https://www.bmkoes.gv.at/Service/Publikationen/Kunst-und-Kultur/kunst-und-kulturberichte.html; *Art's Most Popular: Exhibition and Museum Visitor Figures 2019*, *The Art Newspaper* 29, no. 322 (April 2020): 3, 15. Sources for the 2020 visitor figures include: "List of Most-Visited Art Museums," Wikipedia, https://en.wikipedia.org/wiki/List_of_most-visited_art_museums; museums' annual reports; and *Kunst und Kulturbericht 2020*, ed. Bundesministerium für Kunst, Kultur, öffentlicher Dienst und Sport, Sektion für Kunst und Kultur, 2021, 50, https://www.bmkoes.gv.at/dam/jcr:1e6f1ff8-0285-472c-aadd-49a4a83c9fbb/KunstKulturBericht2020.pdf.

Table 18. *Art museum digital collections and offerings. A selection of the five most visited museums in Switzerland, Austria, Germany, Europe, and the United States of America in 2019. Part 1*

Last updated	List number	Area	Country code	Inauguration	Art museum	Place	Museum visitors 2020 (Corona Pandemic)	Museum visitors 2019
2021-11-26	1	Switzerland	CH	1997-10-18	Fondation Beyeler	Riehen/Basel	291'604	437'000
2021-11-26	2	Switzerland	CH	1910-04-17	Kunsthaus Zürich	Zürich	226'154	270'053
2021-11-26	3	Switzerland	CH	1936-08-29	Kunstmuseum Basel	Basel	156'773	265'981
2021-11-26	4	Switzerland	CH	1978-11-19	Fondation Pierre Gianadda	Martigny	not found	202'069
2021-11-26	5	Switzerland	CH	2005-06-20	Zentrum Paul Klee	Bern (visitor figures for 2020 incl. Kunstmuseum Bern)	137'000	150'213
2021-12-14	6	Austria	AT	1891-10-17	Kunsthistorisches Museum (whole KHM association)	Wien	454'291	1'745'070
2021-12-15	7	Austria	AT	1903-05-06	Österreichische Galerie Belvedere	Wien	271'621	1'721'399
2021-12-15	8	Austria	AT	1921-04-11	Albertina	Wien	360'073	1'001'294
2021-12-15	9	Austria	AT	2001-09-21	Leopold Museum	Wien	120'127	437'603
2021-10-10	10	Austria	AT	1962-09-21	MUMOK	Wien	113'277	289'237
2021-12-12	11	Germany	DE	1833-03-15	Städel Museum	Frankfurt am Main	318'792	580'137
2021-12-12	12	Germany	DE	1836-10-16	Alte Pinakothek	München	137'677	472'745
2021-12-13	13	Germany	DE	1986-03-14	Kunstsammlung Nordrhein-Westfalen K20/K21	Düsseldorf	not found	440'000
2021-12-13	14	Germany	DE	2017-01-20	Museum Barberini	Potsdam	146'934	392'497
2021-12-13	15	Germany	DE	1876-03-22	Alte Nationalgalerie, Staatliche Museen zu Berlin	Berlin	125'626	376'000
2021-12-16	16	Europe	EUR	1793-07-27	Musée du Louvre	Paris	2'700'000	9'600'000
2021-12-17	17	Europe	EUR	1506-01-14	Musei Vaticani	Città del Vaticano	1'300'000	6'882'931
2021-12-17	18	Europe	EUR	1759-01-15	British Museum	London	1'275'466	6'239'983
2021-12-17	19	Europe	EUR	2000-05-12	Tate Modern	London	1'432'941	6'098'340
2021-12-17	20	Europe	EUR	1838-04-09	National Gallery	London	1'197'143	6'011'007
2021-12-18	21	USA	USA	1872-02-20	Metropolitan Museum of Art (The Met)	New York	1'124'759	6'479'548
2021-12-18	22	USA	USA	1941-03-17	National Gallery of Art	Washington, DC	730'408	4'074'403
2021-12-18	23	USA	USA	1929-11-07	Museum of Modern Art (MoMA)	New York	706'060	1'992'121
2021-12-13	24	USA	USA	1968-10-07	National Portrait Gallery/SAAM	Washington, DC	321'286	1'700'000
2021-12-19	25	USA	USA	1893-12-08	Art Institute of Chicago	Chicago	365'660	1'665'516

Table 19. *Part 2, table 18*

List number	Country code	Art museum	Naming of digital collection	Artist search (list of artists)	Artwork search (advanced keyword search)	Image tiles (matrix; browse/filter)	Marking of exhibited work	Work details (title; material/technique; mass; inv. no.)	Additional information (signature; inscription)	Description text	Provenance	Exhibition history	Bibliography
1	CH	Fondation Beyeler	Sammlung	o	o	o	o	o	o	×	o	o	o
2	CH	Kunsthaus Zürich	Sammlung Online	o	o	o	o	o	o	o	o	×	×
3	CH	Kunstmuseum Basel	Sammlung Online	o	o	×	×	o	o	o	×	×	o
4	CH	Fondation Pierre Gianadda	none										
5	CH	Zentrum Paul Klee	Sammlung online	× (m)	o	×	×	o	×	o	×	×	o
6	AT	Kunsthistorisches Museum	Online-Sammlung	×	o	o	o	o	o	o	o	×	×
7	AT	Belvedere	Sammlung Online	o	o	o	o	o	o	o	o	×	×
8	AT	Albertina	Sammlungen Online	o	o	o	×	o	o	o	o	×	o
9	AT	Leopold Museum	none										
10	AT	MUMOK	Onlinesammlung	o	×	×	×	o	×	o	×	×	×
11	DE	Städel Museum	Digitale Sammlung	o	o	o	o	o	o	o	o	×	×
12	DE	Alte Pinakothek	Online-Sammlung	o	o	o	o	o	×	×	×	×	×
13	DE	K20/K21	Highlights der Sammlung	o	×	o	×	o	×	o	×	×	×
14	DE	Museum Barberini	Sammlung	o	o	o	o	o	o	o	o	o	o
15	DE	Alte Nationalgalerie	Online-Datenbank der Sammlungen	o	o	o	×	o	o	o	o	o	o
16	EUR	Louvre	Collections	o	o	o	o	o	o	×	o	o	o
17	EUR	Musei Vaticani	Catalogo online	o	o	o	o	o	o	×	o	×	×
18	EUR	British Museum	Collection online	o	o	o	o	o	o	o	o	×	o
19	EUR	Tate Modern	Our Collection	o	o	o	o	o	o	o	o	o	o
20	EUR	National Gallery	Collection	o	×	o	o	o	o	o	×	×	×
21	USA	The Met	Collection	×	o	o	o	o	o	o	o	o	o
22	USA	National Gallery of Art	Collection	o	o	o	o	o	o	o	o	o	o
23	USA	MoMA	The Collection	o	×	o	o	o	×	o	o	o	×
24	USA	National Portrait Gallery	The Portraits	×	×	o	o	o	o	o	o	o	×
25	USA	Art Institute of Chicago	The Collection	o	o	o	o	o	o	o	o	o	o

o present, × not present, (m) monographic collection

Table 20. *Part 3, table 18*

List number	Country code	Art museum	Authority data (artists): GND; ULAN; RKD; Wikipedia; Wikidata; etc.	SIKART (Swiss artists)	Controlled vocabularies; keywords (works)	Vocabulary: ICONCLASS (works)	Creditline	Citable URL / permalink / DOI	Image: high-res.; zoom	3D objects	IIIF (International Image Interoperability Framework)	Use of public domain images	Public Domain Mark/Creative Commons (for public domain works)
1	CH	Fondation Beyeler	×	×	×	×	o	×	× (limited to browser window)	×	×	× © Photographer	×
2	CH	Kunsthaus Zürich	o	o	o	×	o	×	× (limited to browser window)	×	×	× not specified; without ©	×
3	CH	Kunstmuseum Basel	×	o	×	×	o	o very long	× (fixed size, larger via download)	×	×	o own formulation: image data in the public domain – Kunstmuseum Basel	×
4	CH	Fondation Pierre Gianadda											
5	CH	Zentrum Paul Klee	× (m)	× (m)	o	×	o	×	×	×	×	×	×
6	AT	Kunsthistorisches Museum	o	×	×	×	o	o	o	×	×	o CC BY-NC-SA 4.0	×
7	AT	Belvedere	o	×	o	o	×	o	o	×	o	o CC BY-SA 4.0	×
8	AT	Albertina	o	×	×	×	×	o	o	×	o	o Public Domain	×
9	AT	Leopold Museum											
10	AT	MUMOK	×	×	×	×	×	o	×	×	×	×	×
11	DE	Städel Museum	×	×	o	o	o	o	o	×	×	o CC BY-SA 4.0	o
12	DE	Alte Pinakothek	×	×	×	×	o	o	o	×	×	o CC BY-SA 4.0	o
13	DE	K20/K21	×	×	×	×	o	×	× (fixed size)	×	×	×	×
14	DE	Museum Barberini	×	×	o	×	o	×	o	×	×	×	×
15	DE	Alte Nationalgalerie	×	×	×	×	o	o very long	× (limited to browser window)	×	×	o CC BY-NC-SA 4.0	o
16	EUR	Louvre	×	×	o	×	o	o	×	×	×	o own formulation	×
17	EUR	Musei Vaticani	×	×	×	×	×	o	o	×	o	×	×
18	EUR	British Museum	×	×	o	×	o	o	o	×	×	o CC BY-NC-SA 4.0	×
19	EUR	Tate Modern	×	×	o	o	×	o	o	×	×	o CC BY-NC-ND 3.0 (Unported)	o
20	EUR	National Gallery	×	×	×	×	×	o	o	×	o	o CC BY-NC-ND 4.0	×
21	USA	The Met	×	×	o	o	×	o	o	×	o	o Public Domain (CC 0)	o
22	USA	National Gallery of Art	×	×	×	×	o	o	o	×	o	o Public Domain (CC 0)	o
23	USA	MoMA	o	×	×	×	×	o	o	×	×	×	×
24	USA	National Portrait Gallery	×	×	×	×	o	o	o	×	o	o CC 0	o
25	USA	Art Institute of Chicago	×	×	o	×	o	o	o	o	o	o CC 0 Public Domain Designation	o

o present, × not present, (m) monographic collection

Table 21. *Part 4, table 18*

List number	Country code	Art museum	Watch list: print worksheet	Download: image	Download: metadata	Open data	Public API	Conclusion: traditional collection online?	URL digital collection	Museum website
1	CH	Fondation Beyeler	×	×	×	×	×	yes	https://www.fondationbeyeler.ch/sammlung	https://www.fondationbeyeler.ch
2	CH	Kunsthaus Zürich	o	~	×	×	×	yes	https://collection.kunsthaus.ch	https://www.kunsthaus.ch
3	CH	Kunstmuseum Basel	×	o	×	×	×	yes	https://sammlungonline.kunstmuseumbasel.ch/eMP/eMuseumPlus	https://kunstmuseumbasel.ch
4	CH	Fondation Pierre Gianadda						none	none	https://www.gianadda.ch
5	CH	Zentrum Paul Klee	o	×	×	×	×	yes	http://www.emuseum.zpk.org/eMuseumPlus	https://www.zpk.org
6	AT	Kunsthistorisches Museum	o	o	×	×	×	yes	https://www.khm.at/objektdb	https://www.khm.at
7	AT	Belvedere	o	o	×	o	×	no	https://sammlung.belvedere.at	https://www.belvedere.at
8	AT	Albertina	o	o	o	×	×	no	https://sammlungenonline.albertina.at	https://www.albertina.at
9	AT	Leopold Museum						none	none	https://www.leopoldmuseum.org
10	AT	MUMOK	×	~	×	×	×	yes	https://www.mumok.at/de/collection/online-collection	https://www.mumok.at
11	DE	Städel Museum	o	o	×	o	o	no	https://sammlung.staedelmuseum.de	https://www.staedelmuseum.de
12	DE	Alte Pinakothek	o	o	×	o	×	yes	https://www.sammlung.pinakothek.de	https://www.pinakothek.de
13	DE	K20/K21	×	~	×	×	×	yes	https://www.kunstsammlung.de/de/collection	https://www.kunstsammlung.de
14	DE	Museum Barberini	×	×	×	×	×	yes	https://sammlung.museum-barberini.de	https://www.museumbarberini.de
15	DE	Alte Nationalgalerie	o	~	×	×	×	yes	https://www.smb-digital.de/eMuseumPlus	https://www.smb.museum/museen-einrichtungen/alte-nationalgalerie
16	EUR	Louvre	o	o	o	×	×	no	https://collections.louvre.fr	https://www.louvre.fr
17	EUR	Musei Vaticani	o	×	×	×	×	yes	https://catalogo.museivaticani.va	https://www.museivaticani.va
18	EUR	British Museum	o	o	×	×	×	yes	https://www.britishmuseum.org/collection	https://www.britishmuseum.org
19	EUR	Tate Modern	×	×	×	o	×	no	https://www.tate.org.uk/search	https://www.tate.org.uk/visit/tate-modern
20	EUR	National Gallery	×	o	×	×	o	no	https://www.nationalgallery.org.uk/paintings	https://www.nationalgallery.org.uk
21	USA	The Met	×	o	×	o	o	no	https://www.metmuseum.org/art/collection	https://www.metmuseum.org
22	USA	National Gallery of Art	×	o	×	o	×	no	https://www.nga.gov/collection	https://www.nga.gov
23	USA	MoMA	×	×	×	o	o	no	https://www.moma.org/collection	https://www.moma.org
24	USA	National Portrait Gallery	o	o	o	o	o	no	https://npg.si.edu/portraits	https://npg.si.edu
25	USA	Art Institute of Chicago	o	o	×	o	o	no	https://www.artic.edu/collection	https://www.artic.edu

o present, × not present, ~ save image possible

Table 22. *Part 5, table 18*

List number	Country code	Art museum	Digital strategy	Library catalog	Exhibition views	Exhibition archive	Digital archive	Facebook	Instagram	Twitter	Pinterest	Youtube	Vimeo	Blog
1	CH	Fondation Beyeler	×	×	×	o	×	o	o	o	o	o	o	×
2	CH	Kunsthaus Zürich	×	o	×	×	o	o	o	o	×	o	o	×
3	CH	Kunstmuseum Basel	×	o	×	o	×	o	o	o	×	o	×	×
4	CH	Fondation Pierre Gianadda	×	×	×	o	×	o	o	o	×	o	×	×
5	CH	Zentrum Paul Klee	×	×	×	o	×	o	o	o	×	o	×	×
6	AT	Kunsthistorisches Museum	×	×	×	o	o	o	o	o	×	o	×	×
7	AT	Belvedere	×	o	×	o	o	o	o	o	×	o	×	×
8	AT	Albertina	×	o	×	o	o	o	o	o	o	o	o	×
9	AT	Leopold Museum	×	×	×	o	×	o	o	o	o	o	×	o
10	AT	MUMOK	×	o	o	o	×	o	o	o	×	o	o	o
11	DE	Städel Museum	o https://www.staedelmuseum.de/de/digitale-strategie	o	×	o	×	o	o	o	o	o	×	o
12	DE	Alte Pinakothek	o https://www.digital.pinakothek.de	×	×	o	o	o	o	o	×	o	o	o
13	DE	K20/K21	o https://docplayer.org/28001904-Ein-neues-haus-fuer-die-kunstsammlung-nordrhein-westfalen-vorstellung-der-digitalstrategie.html	o	×	o	×	o	o	o	×	o	×	×
14	DE	Museum Barberini	×	×	×	o	×	o	o	o	o	o	×	×
15	DE	Alte Nationalgalerie	o https://www.preussischer-kulturbesitz.de/schwerpunkte/digitales-manifest.html	o	×	o	×	o	o	×	×	o	×	o
16	EUR	Louvre	×	o	×	o	o	o	o	o	o	o	×	×
17	EUR	Musei Vaticani	×	×	×	×	o	o	o	o	×	o	×	×
18	EUR	British Museum	×	o	×	o	×	o	o	o	×	o	o	o
19	EUR	Tate Modern	o https://www.tate.org.uk/research/publications/tate-papers/19/tate-digital-strategy-2013-15-digital-as-a-dimension-of-everything	o	×	o	o	o	o	o	o	o	o	o
20	EUR	National Gallery	×	o	×	o	×	o	o	o	×	o	×	o
21	USA	The Met	o https://www.metmuseum.org/blogs/digital-underground/2015/next-steps-digital-revolution	o	o	o	o	o	o	o	o	o	×	o
22	USA	National Gallery of Art	×	o	×	o	o	o	o	o	o	o	×	o
23	USA	MoMA	o https://enfilade18thc.com/2014/02/12/fiona-romeo-appointed-momas-first-director-of-digitalcontent-and-strategy/	o	o	o	o	o	o	o	×	o	o	o
24	USA	National Portrait Gallery	o https://www.si.edu/content/pdf/about/web-newmedia-strategy_v1.0.pdf	o	×	o	×	o	o	o	×	o	o	o
25	USA	Art Institute of Chicago	o https://www.artic.edu/articles/713/behind-the-scenes-of-the-website-redesign	o	×	o	o	o	o	o	o	o	×	o

o present, × not present

Table 23. *Part 6, table 18*

List number	Country code	Art museum	Digitorial; story; interactive feature	Digital offerings	Overview digital offerings	Google Arts & Culture	Mobile app
1	CH	Fondation Beyeler	×	o	o https://www.fondationbeyeler.ch/digital	o	×
2	CH	Kunsthaus Zürich	o	×	×	o	o
3	CH	Kunstmuseum Basel	o	o	×	×	×
4	CH	Fondation Pierre Gianadda	×	×	×	×	×
5	CH	Zentrum Paul Klee	o	o	×	×	×
6	AT	Kunsthistorisches Museum	×	o	o https://www.khm.at/entdecken/digitales-museum	o	o
7	AT	Belvedere	×	o	o https://www.belvedere.at/digital	o	o
8	AT	Albertina	×	o	×	o	×
9	AT	Leopold Museum	×	o	o https://www.leopoldmuseum.org/de/digital	o	×
10	AT	MUMOK	×	o	o https://www.mumok.at/de/node/171749/	×	o
11	DE	Städel Museum	o	o	o https://www.staedelmuseum.de/de/digitale-angebote	o	o
12	DE	Alte Pinakothek	×	o	×	o	o
13	DE	K20/K21	×	o	o https://www.kunstsammlung.de/de/digital/	×	×
14	DE	Museum Barberini	×	o	×	o	o
15	DE	Alte Nationalgalerie	×	o	o https://www.smb.museum/ueber-uns/online-angebote	o	×
16	EUR	Louvre	×	o	o https://www.louvre.fr/en/explore#louvre	×	o
17	EUR	Musei Vaticani	×	×	×	×	×
18	EUR	British Museum	×	o	×	o	×
19	EUR	Tate Modern	×	o	×	o	×
20	EUR	National Gallery	×	o	×	o	×
21	USA	The Met	o	o	o https://www.metmuseum.org/art/art-at-home	o	o
22	USA	National Gallery of Art	×	o	×	o	o
23	USA	MoMA	o	o	×	o	×
24	USA	National Portrait Gallery	×	o	o https://npg.si.edu/digital-workshops	o	o
25	USA	Art Institute of Chicago	o	o	o https://www.artic.edu/visit-us-virtually	o	o

o present, × not present

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