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Nodes, Edges, and Artistic Wedges: A Survey on Network Visualization in Art History

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Abstract

*Art history traditionally relies on qualitative methods. However, the increasing availability of digitized archives has opened new possibilities for research by integrating visual analytics. This survey presents a comprehensive review of the intersection between art history and visual analytics, focusing on network visualization and how it supports researchers in analyzing and understanding complex art historical relationships through **nodes** (e.g., artists, artworks, institutions) and **edges** (the relationships between them). We explore how these approaches enable dynamic analysis, offering novel perspectives on artistic influence, stylistic evolution, and social interactions within the art world. Through this, we also examine **wedges**, a metaphor for the friction often present in art history between individuals and institutions. These tensions, which have historically played a pivotal role in shaping artistic movements, are now better understood through the lens of network visualization, revealing how conflicts and power dynamics influenced the development of art. Through a hierarchical categorization of the literature, we outline saturated problems and research areas as well as ongoing challenges in art historical research. Furthermore, we highlight the potential of visual analytics to bridge the gap between traditional qualitative research and modern computational analysis, offering interactive exploration, temporal analysis, and complex network visualization. We provide a structured foundation for future research in art history, emphasizing the value of network visualization in enriching the understanding of art history.*

CCS Concepts

• Human-centered computing** → **Information visualization; Graph drawings; • Applied computing** → **Fine arts;

1. Introduction

The increasing availability of digital resources and databases in Art History (AH) opens new and promising research prospects [Kli18, GD18]. Recent advancements in technologies, such as ontological representations, open-linked semantic data, and knowledge graphs [MHC*15, AK21] have added layers of richness and complexity to historical datasets, allowing for much more sophisticated analysis. Organizing and linking diverse information sources and datasets makes them more accessible to a broader audience. These advancements present opportunities, including the potential to leverage approaches, previously not considered within AH (i.e., quantitative analysis and interactive visualization), for exploring the intricacies and complexity of these data. While digital resources provide "raw" materials for AH research, existing tools often fall short in finding links between the data and addressing the dynamic nature of research in this domain [LBT*18, LMA*20]. This presents the key challenge—transforming these "raw" materials into insights—from which AH researchers can derive conclusions about cultural and historical changes and plausible causes. Current tools for analyzing AH data are not well-suited to handle the complexity of the questions researchers have. For instance, they allow basic database querying or provide standard visualization techniques, but fall short when it comes to advanced analyses (e.g., artistic influence networks or comparing stylistic trends).

Research in AH relies on traditional qualitative methods [BK03, BDK*08, LYHW12]. However, new techniques extend these methods and provide novel perspectives, specifically Visual Analytics (VA) is quickly gaining momentum to explore and analyze data and disseminate the results of AH research to broader audiences. VA provides an interface for art historians to interactively explore their data and address their research questions, making the invisible visible—generating insights and discovering relationships that might otherwise remain hidden. The goal is to offer art historians a better understanding of the behaviors and interactions between the elements of an art system (i.e., artists, artworks, exhibitions, and institutions). This is one of the major topics of interest in this domain—analyzing relationships and their attributes [Lin20]. Examples of such relationships are, e.g., student–teacher relationships, social network analysis of artistic collectives, and as well as the similarities and influences between them. Network visualization and analysis presents a notable contribution in AH [KM20].

Motivation. Network visualization is gathering significant attention, evidenced by the growing number of surveys that propose categorizations across various fields and problems [MGM*19, FAM23, PWS08, DW12, CF09]. However, its potential within AH has remained under-investigated. A survey of cultural heritage collections [WFS*18] outlines the broad range of visualizations used, yet only a few focus specifically on network visualization. The bibliography maintained by the Historical Network Research Community [DG21] further highlights the lack of a comprehensive survey addressing network visualization in AH. This gap motivates our survey, which aims to outline the state of the art of network visualization in AH, identify key research questions and challenges, and explore how VA, particularly network visualization, facilitates novel insights and interpretations of historical data. We aim to lay the foundations for integrating network visualization into AH, demonstrating its potential to enrich the field with new perspectives.

Contribution. In this interdisciplinary survey, we investigate research from AH and VA perspectives. We propose a hierarchical categorization of literature, analyzing research from both domains. This survey provides a comprehensive overview of key studies, research questions, and problems to investigate how network visualization is employed in AH. Our objectives are: (i) identify and categorize the challenges and network visualization solutions addressing AH research questions; (ii) compile a curated collection of publicly available historical data resources; and (iii) uncover research gaps and opportunities in the intersection of AH and VA. Summarizing, our contributions are:

- Providing a structured overview of research at the intersection of AH and VA focusing on network visualization (see Sections 2 and 3);
- Presenting our new categorization, which investigates the AH problems and their solutions supported by VA and network visualization (see Section 4);
- Collecting online available data resources (see Section 5);
- Contextualizing the major ongoing challenges in the domain of AH as well as existing approaches in VA that could be leveraged to support these (see Section 6).

2. Background

Since our survey's focus is on network visualization in AH, in the following we discuss the background of AH, how network visualization is used in this domain, and the possibilities of integrating VA within AH.

AH encompasses the study of artists, artworks, and the complex web of relationships that shape historical narratives and movements. Research has relied on qualitative methodologies to interpret and analyze artistic events and sociocultural influences. However, recent advancements in digitization and the rising availability of public resources serve as catalyst for integrating interactive visualization and analysis techniques, providing different perspectives.

Historically, such developments can be traced back to machine-assisted information processing, which laid the foundations for early digital humanities [LD18]. One of the significant breakthroughs has been the emergence of open-linked data and knowledge graphs, providing a structured approach of modeling, integrating, and enriching historical data from diverse sources [MHC*15, AK21]. This standardized how data within this domain should be modeled and expanded their accessibility, enabling researchers to query and analyze relationships between artworks, artists, and institutions across temporal and spatial contexts. With these technologies in place, the field of AH is now presented with opportunities and possibilities to investigate novel research questions that were difficult (or impossible) to address previously [Kli18, GD18].

Supported by network visualization, these advancements expose both the explicit and hidden structures within the data, uncovering patterns and emergent global structures [Sch10]. Network visualization makes it possible to analyze relationships between artistic styles' development, how they spread, and how venues facilitate their popularity [Smi23]. The availability of these resources also drives the development of novel visualization methods providing insights into both the completeness and complexity of datasets [Sch10]. Visualization enables researchers to map relationships between artworks, artists, and historical events and serves as a process to reflect on, question, and refine the data. This discovery and critique process underscores how important computational methods are becoming to address gaps in AH [Smi23, HNCG20].

Adopting quantitative methodologies allows to revisit established narratives from a data-driven perspective. Bridging the gap between AH and VA fosters interdisciplinary collaboration, providing novel ways of investigating and tackling complex questions [SRF*19]. These exceed the grasp of traditional qualitative methods and provide completely novel perspectives and research directions. However, this collaboration requires both technical literacy and domain expertise to be equally prioritized [HBH*20]. Research emphasizes that digital methods must complement existing traditional approaches rather than replace, respecting the focus on nuanced interpretation [LBT*18]. Addressing these challenges enables AH and VA to unlock new insights and interpretations.

3. Scope and Methodology

To compile a comprehensive set of related literature for this survey, we conduct a systematic literature review for resources related to network visualization in AH [PR06]. This process involves multiple steps: literature search and collection, filtering, applying inclusion and exclusion criteria, and coding and categorizing the literature. In the following, we present our scope, research methodology, selection and filtering, and the inclusion and exclusion criteria.

Scope This state-of-the-art report focuses on the intersection of AH and VA. Specifically, we examine how network visualization techniques are applied to the study of painters (i.e., artists), paintings (i.e., artworks), and their relationships. This work focuses on understanding these intricate and complex relationships within AH, therefore, we opted to exclude other visualization types not explicitly involving relationships or their visualization. While such visualization methods (e.g., scatter plots, timelines, and static maps) are valuable for certain analytical tasks and frequently appear as supporting views complementing network visualization techniques (e.g., timelines showing temporal aspects or maps providing spatial context), they are not our primary focus. Instead, we concentrate on the visualization of networks with the goal of capturing and analyzing relationships, such as artistic influence, collaboration, and exhibition co-occurrence.

Paintings are the primary research interest of art historians and a majority of literature in the AH domain focuses on paintings or painters. Therefore, we limit our scope to the core interest of AH, resulting in a reasonable number of papers, we only considered network visualizations of painters and paintings. This further implies that we had to exclude resources that focus solely on contemporary art, which became popular around 1970 and after. Contemporary art often encompasses a diverse range of media, forms, materials, and practices that extend beyond the traditional definitions of paintings and artists [Reb13] (e.g., mixtures between paintings and other art forms, like sculptures or photographs). Further, from our discussion with art historians, we concluded that the period of time around the early 20th century was the most fascinating and dynamic one to explore because artists started exhibiting rather than just being commissioned by clients to create paintings. Since our primary interest lies in analyzing painters, paintings, and their associated networks, we limit our scope to pre-modern and modern art periods before 1970, where these elements are more clearly defined.

Research Methodology In our survey, we incorporate the PRISMA statement [PMB*21] to ensure a transparent systematic literature review. Our scope is tightly related to both VA and AH. The selection of publications was based on predefined inclusion and exclusion criteria to ensure relevance to the topic of network visualizations in AH. Initially, we included all resources, such as journal articles, conference proceedings, book chapters, theses, and online resources focused on network-based visualizations involving painters, paintings, and related art historical topics. These were filtered and excluded if they lacked visualizations, focused on non-network visualization techniques, or were unrelated to AH, such as works on contemporary art or network visualizations in other fields. We conducted a two-step screening process: first by title and abstract and then by full-text review to assess the relevance of the publications. This ensured that all papers included in the review aligned with our scope. After applying the inclusion and exclusion criteria, the final dataset was reduced to 95 papers, which were coded and categorized. We conducted a comprehensive search across multiple academic search engines, including Google Scholar, Elsevier, Springer, ResearchGate, Scopus, IEEE Xplore, ACM, SAGE, and Kubikat. We queried the following keyword combinations:

(“*Art History*” | “*Painter*” | “*Painting*” | “*Artist*” | “Artwork”)
&
(“*Graph*” | “*Graph Visualization*” | “*Network*” | “*Network Analysis*” | “*Network Visualization*”)

Inclusion & Exclusion Criteria In the following, we outline the inclusion and exclusion criteria used during our literature review. We provide examples clarifying our selection process.

We prioritize journal papers for their comprehensive coverage of research topics, however, since in AH most publications are books or conference proceedings, we also included these. Additionally, we incorporate online resources, such as websites, blogs, or prototypes, that presented novel or interesting perspectives on network visualizations within AH. These are further discussed in the supplementary material [TFK*25]. We consider documents in German and English, where the primary focus is visualizing painters and/or paintings.

Inclusion The following define the scope of the related literature, the topics, and the visualization types we consider in this report:

- **I1 Scope**: We include different kinds of publications—journal articles, conference papers, book chapters, preprints, websites, and blogs—ensuring comprehensive coverage of network visualizations in AH. Interactive web pages are only considered if they present novel examples.
- **I2 Relevance**: We focus on painters and paintings as primary entities, including visualizations of other art forms or non-artist entities only when painters or paintings are dominant (e.g., larger nodes, most connections) or filterable within the visualization.
- **I3 Network**: We focus on network visualizations that explicitly represent relationships and network structures, including node-link diagrams, hierarchies, visualized adjacency matrices, maps with relational links, timelines with links, and treemaps.

Exclusion The following specify the limits of our review, i.e., resources not aligning with our focus of network visualization in AH:

- **E1 Scope**: We exclude related work lacking explicit visualizations, such as theoretical or conceptual works (i.e., approaches without presenting network-based visualization techniques).
- **E2 Relevance**: We exclude publications where painters and paintings are not the main objective. AH has a wide range of topics, including sculptures, architecture, artifacts, or contemporary art. These are not relevant to our review.
- **E3 Network**: We exclude visualization approaches where the central aspect is not the representation of data relationships. These include e.g., scatterplots, static maps, simple timelines, and database schema diagrams or ontologies.

Selection & Filtering After the initial search, we collected 655 items. We examined duplicates, according to the title and author list, and after their removal, we obtained 582 unique results. Additional papers were identified through backward searches (cited references, i.e., snowballing), which resulted in a total of 657 publications. Of these, 222 papers contain visualization approaches and were included in our first set of papers. From the 222 papers we apply our inclusion and exclusion criteria to ensure that the final set of papers would align with the scope of our work. Through this process, we reduced the dataset to 123 resources, 95 of them peer-reviewed papers and 28 blog posts and interactive online approaches without publications (see supplementary material [TFK*25]) forming the foundation of this survey. This categorization is further detailed in Section 4, where we describe how the selected resources align with network visualization techniques and AH research.

4. Categorization

We propose a hierarchical categorization of related literature on network visualization in AH. Our categorization begins with (early) hand-drawn visualizations providing an introduction to the topic. Beyond this, we discuss related work according to the relationships (*edges*) and subjects (*nodes*) represented in the network. For each, we elaborate on the visualization approaches, interactivity, temporal and spatial contexts, and conclude with a summary. We further discuss anecdotal art historical examples that might contain frictions (*wedges*) between artists at the beginning of each main section

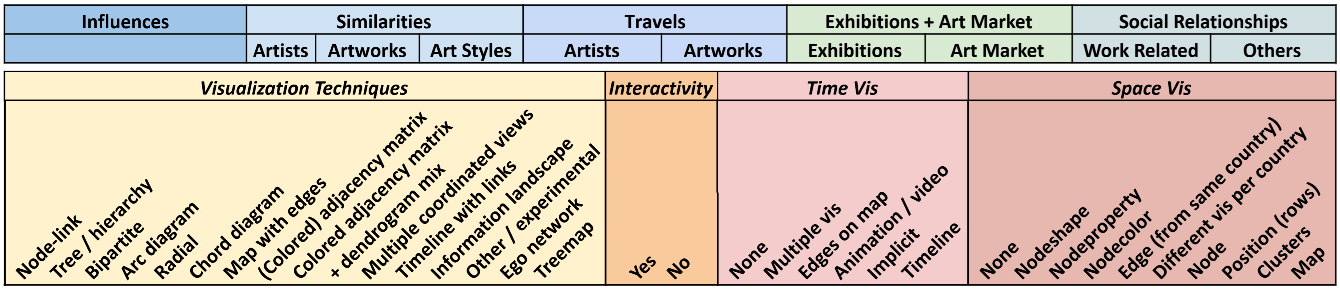


Figure 1: *The categorization scheme with main categories in blue and green hues and sub-categories in yellow and red hues. The papers are categorized according to the relationships they visualize (first row) and their subjects (second row), e.g. similarities between artists, and discussed in separate sections according to this categorization. Within the sections the papers are discussed in the four sub-categories (i.e., visualization techniques, interactivity, time vis, and space vis.).*

in the categorization to motivate and underscore the importance of certain relationships for art historians. In the following, we outline the **main** and *sub* categories we propose (see Figure 1).

Subjects and Relationships. Various subjects and relationships can be depicted in the visualizations. Examples are artists (subjects) and their influences (relationship) between each other [CDSV22] or which paintings (subjects) are similar (relationship) to others [Seg18]. Ordering the papers according to their subjects and relationships will make it possible to find papers that specialize, for example, in analyzing similarities between artists or paintings.

Visualization approaches. Here, we differentiate network visualization techniques. Examples for such techniques are node-link diagrams [AFG*12], trees [SPR18], ego-networks [Kim22], (colored) adjacency matrices [LSK*20], or tree maps [Rei].

Interactivity. As some papers present an online demo [DCW12] and some approaches only exist online [Kin], we highlight, which can be interactively used, as well as their associated publications.

Temporal and Spatial Contexts. Many visualization techniques include temporal aspects, e.g., when different paintings were created and exhibited, or when artists were born or died. Therefore, our aim is to complement the discussion with how these aspects were visualized in conjunction with network structures. The visualization techniques can be timeline [SI17], animation [Tra], small multiples [SSCO*13], or integrated approaches [LSK*20]. Spatial aspects, e.g., where paintings were exhibited, or where artists were born and died, are also of great relevance and interest to art historians. We discuss how they were encoded in the visualization approaches, e.g., in a map [SRM19] or as node properties [Dzi24].

We group papers into categories based on their relationships and subject types, with some papers spanning multiple categories. Each paper is discussed within its corresponding sub-category (visualization approach, interactivity, or temporal and spatial context) to minimize repetition. Tables accompanying each main category indicate the sub-categories to which each paper belongs.

In the following, we highlight several topics that fall outside of our focus, but are worth mentioning and can be found in our supplementary material [TFK*25]. Attributes are commonly encoded using various visual cues either on the nodes or the edges of network visualizations. Examples are node shapes encoding an artist's nationality [Sun14] or edge width showing the strength of stylistic borrowing [Li21]. Moreover, aside the main focus on relationships between objects and their attributes, providing approaches to compare the objects leads to new insights. Examples are juxtaposition [GZV21] or superimposition [Artb]. Often, additional visualization techniques are used to support the analysis. These can either be further visualizations in the same paper [BT16], on the same website alongside a network representation [Ben15], or in multiple-coordinated views alongside the network [Int]. Finally, while the most common approach is 2D [ITW18], 1D [DCW12] and 3D visualizations [LW22] are also discussed. 3D techniques are also employed in immersive environments using virtual reality [TWB22]. We only categorize network representations and their temporal and spatial aspects, not temporal and spatial aspects used in the supportive visualizations.

4.1. Hand-drawn Visualizations

Hand-drawn visualizations of art historical topics existed long before the invention of computers. They belonged to the first attempts of making relationships in the art world visible and contained relationships (e.g., influences, similarities) and visualization techniques (e.g., trees, maps with trajectories) that are also discussed in the following sections about computer-generated visualizations. Some of the hand-drawn visualizations are very well-known in the domain of AH and were also recreated in papers discussed in later sections, others might have served as inspirations. As they are not strictly based on quantitative data and have unique encodings, they cannot be compared to the other approaches. Therefore, we present them as an introduction to explain the tradition of visualizing networks in AH (see Figure 2 for examples discussed in this section).

With hand-drawn visualizations, artists and art historians proposed a continuity in the development of art, reducing it to its most elementary coefficients and, at the same time, making it visible. Thus, when it came to introducing new artistic and theoretical ideas into the art historical canon, they could also serve as a means of legitimization. The earliest network visualization was printed in a German art magazine in 1890 [Pec90]. It displays cities of exhibitions in that year as nodes and was printed multiple times between 1887 and 1900 as part of a calendar view in the magazine (see Figure 2 (a)). In earlier issues mostly German cities were shown,

(a) (b) (c) (d)

Figure 2: *Four different hand-drawn visualizations between (a) 1890 and (d) 2013. (a) Map from 1890 showing the locations and travels of exhibitions [Pec90]. (b) "The Family Tree of American Painting" from 1934 [Unk34]. Courtesy of The Richard Pousette-Dart Foundation, New York. (c) "A Gestaltian Chart of Contemporary American Art" by Pousette-Dart from 1938 [PD38]. Courtesy of The Richard Pousette-Dart Foundation, New York. (d) Metro map from 2013 showing different art movements and their connections [Gom13]. Courtesy of Gompertz and Penguin Random House UK.*

later also other cities in Europe [KR20]. The nodes for the exhibition places are arranged according to their relative geographical positions to each other, but no country borders are shown. The node color denotes if exhibitions are periodical, permanent, or both. Edges between the cities denote traveling exhibitions. An underlined city name means that the exhibition was organized by a gallery or art dealership. Another visualization dates back to 1933. It was painted by Miguel Covarrubias [Cov] and depicts the evolutions and connections of modern art movements and their pioneering artists in a tree, also known as "The Tree of Modern Art" [Cov] and was published in an issue of "Vanity Fair". The tree has seven roots and fifty leaves showing artist names. The art movements (and certain artists) are displayed in the trunk and branches. Alfred H. Barr, Jr., the founding director of the Museum of Modern Art (MoMA), is drawn at the base of the tree.

In some cases, the diagrams even stood in opposition to a public perception rather than working alongside it. Relatively shortly after the publication of Covarrubias' tree [Cov], Alfred H. Barr, Jr. made an exhibition about "Cubism and Abstract Art" at the MoMA in 1936 and drew his own diagram, a genealogy of art [AHB36, SB00], probably the most famous hand-drawn visualization in the history of art [Cov]. It is said that Barr's inspiration and source was Covarrubias' tree [Cov]. In the introduction to the catalog of his exhibition, he informs the readers that when he imported abstract works from Europe, many of them were not considered as such by American customs [AHB36]. His chart, prominently placed on the jacket of the catalog, of course, proves the opposite. Barr's diagram depicts the art movements, their places and years of origin, and links to corresponding artists and movements, showing their influences on a timeline. The movements are written in uppercase letters so they can be distinguished from the artist nodes. The ones in boxes are said to have influenced the development of European Modernism. In the catalog of an exhibition in 1940 about "Italian Masters", Barr drew two other similar diagrams about Italian painting and sculpture between 1300 and 1800 and Italian sources of three traditions of European painting. The first shows the artists from the exhibition and their links or relationships to each other as well as the Italian region they are coming from. The names are aligned on a timeline where names of master painters are displayed in uppercase and artists that were not part of the exhibition in brackets. The second diagram also shows artists and their links to each other on a timeline but also aligns them according to three different traditions.

In a website article from 2022, Heller [Hel] introduced different diagrams from del Junco et al.'s book "Genealogies of Art, or, the History of Art as Visual Art" [dJSÁ*19]. It features the visualizations by Covarrubias [Cov] and Barr [AHB36, SB00], as well as others drawn between 1934 and 1961. The earliest of these, from 1934, is "The Family Tree of American Painting" [Unk34] by an anonymous creator and can be seen in Figure 2 (b). It shows painters and their connections as branches of a tree. Numbers in apples correspond to page numbers in the book the tree was published in. Another tree visualization from 1938 by Nathaniel J. Pousette-Dart shows "A Gestaltian Chart of Contemporary American Art" [PD38] (see Figure 2 (c)). Trunk and roots correspond to different art schools, branches to art movements, and leaves to artists. The website also features Newton's "Diagram of the History of Art" from 1956, which shows artists as nodes and their connections as links and art schools as clusters of different patterns surrounding the nodes on a timeline ranging from 1255 to 1955. Hand-drawn visualizations could also have humorous or satirical undertones, especially when they were designed by artists. An example is Reinhardt's visualization of "How to Look at Modern Art in America" published in "Art News" in 1961. It depicts a half-felled tree of art. Roots and the trunk show artists arranged by art movement from left to right. The soil in which the tree is planted also contains artists and art movements. The leaves denote artists, some of them are falling off the tree. Critics, curators, dealers, and others are drawn as birds that seem to fight with each other. The tree is weighed down by weights containing words like "lines", "shapes", or "collage" and below the tree, there is a cornfield containing other artists with banners showing names of museums in front of the field. Soucet's "Chart of Modern Painting" from 1955 is from its looks comparable to Barr's diagram [AHB36, SB00]. It also shows different art movements in uppercase letters, as well as corresponding artists and connections between movements and artists. In between there are also some artist associations and art schools.

The paper by Chroscicki and Odinec [CO81] from 1981 analyses influences in art theory using graphs. Their node-link diagrams show influences and inspirations as edges between artists, patrons, and artworks, which are the nodes in the graph. They are aligned on a timeline. Artworks are grouped in clusters displayed by circles enclosing multiple nodes and have superscripts that denote the artwork type (e.g., painting, drawing) and subscripts that identify the artwork in the accompanying text.

Finally, Gompertz published a metro map of art movements (see Figure 2 (b)) in his book where he looks at 150 years of modern art [Gom13] in 2013. Compared to the other hand-drawn visualizations, this one is generated on a computer, but it is also the only metro map in the whole report and, therefore, hard to compare to the other visualizations. The different "lines" denote different modern art movements; the smaller "stations" are artists, and the bigger ones are art movements or artist groups. Like for a metro, some of the lines run parallel to each other or intersect at stations, thereby showing the relationships between the different movements.

Summary Many of the early approaches either used a tree visualization, where an actual tree is painted, similar to Covarrubias' [Cov] or a node-link diagram-like visualization similar to Barr's [AHB36, SB00]. Some of them also grouped the "nodes" by putting them in certain branches of a tree (e.g., Covarrubias [Cov]) or surrounding them with circles (e.g., Newton [dJSÁ*19] or Chroscicki and Odinec [CO81]). Nearly all of the visualizations analyze the evolution or influences between artists and art movements, with the exception of the visualization about exhibition cities that also used a map-like visualization compared to all others. Chroscicki and Odinec [CO81] also pay attention to the influence a patron has on an artist and how the patron is influenced by artworks. Compared to the other visualizations, Reinhardt's [dJSÁ*19] tree also contains some playful criticism.

These visualizations thus reflect not only the advancing scientificization of AH and its approach to quantitative thinking [SB05], but also the question of the most fundamental nature of art, what it should look like and how theory can guide its perception.

4.2. Influences, Rivalry, and Dominance

Imitatio and *aemulatio* are terms frequently used by art historians to characterize early modern art production. *Imitatio* (imitating) refers to the practice of copying or emulating nature or existing works, while *aemulatio* (surpassing) denotes the pursuit of transcending the same. This means that early modern aesthetics were characterized by influence and competition [MP11], resulting in many similar images since the most effective means of exceeding someone is improving upon their work. Raphael's *Marriage of the Virgin* (see Figure 3a) was finished around the same time as the painting with the same title by his teacher Pietro Perugino (see Figure 3b). This example clearly shows the influence of the teacher, but

(a) **(b)**

Figure 3: *(a) Raphael, The Marriage of the Virgin, 1504 [Wikc]. (b) Pietro Perugino, The Marriage of the Virgin, 1500-1504 [Wikc].*

at the same time Raphael's stylistic evolution. According to Giorgio Vasari [Vas68], the Renaissance artist Raphael, surpassed his teacher in this work. Perugino, who had triumphed in the competition with his colleagues in the Sistine Chapel, soon had to watch his student and peers outpace him [Gio99].

The study of influences, rivalry, and dominance between artists has long been a central theme within AH. The main questions addressed within this topic are understanding how stylistic movements evolve, how social dynamics shape artistic practices, and how cultural exchanges impact creativity. Network visualizations have proven instrumental in uncovering these complex and intricate relationships, enabling researchers to analyze explicit influences, such as teacher-student dynamics, and implicit ones, such as stylistic borrowing or competitive interactions. Table 1 shows the 22 papers discussed in this subsection.

Visualization Approaches Network visualization techniques to investigate influence predominantly use **node-link** diagrams for their intuitive and easily understandable representation of relational data. Li [Li21] provides a use case, visualizing the rivalry between Rembrandt and his contemporaries. Here, node size reflects the level of influence, while edge width encodes the strength of stylistic borrowing, ranging from faint resemblances to clear acquisitions. Moreover, neighborhood-based clustering is introduced to distinguish artists by geographic proximity and stylistic similarities, providing a multidimensional view of rivalry.

Kitromilidis and Evans [KE18] visualize influences among Western art painters through a node-link diagram. Here, artists are represented as nodes, with their size reflecting their degree centrality, whereas their color denotes their corresponding cluster (i.e., art movements or geographic locations). Edges between nodes encode influences or other social connections. To complement the network visualization, the authors include analytical views, such as dot plots showing degree distributions, boxplots highlighting the centralities of prominent artists, and scatter plots to explore correlations between centrality measures. By integrating multiple perspectives,

Table 1: *22 papers analyzing influences, partitioned into visualization methods, interaction, temporal and spatial visualization. Yellow highlights the section where a paper is discussed. Numbers in brackets denote cases in which it can be argued about the categorization.*

Vis method	**Node-link**	17	[VHW08], [Bra16], [Li21], [NS21], [SM24], [Sun14], [ZJZ*19], [Ber22], [CDSV22], [CLV21], [Gor02], [GZV21], [ITW18], [Kim21], [KE18], [DCW12], [SSCO*13]
	Tree / hierarchy	6	[VHW08], [SI17], [Sun14], [Ber22], [Gor02], [GZV21]
	Bipartite	1	[Bra16],
	Arc diagram	2	[ZJZ*19], [DCW12]
	Radial	5	[PCPR13], [SI17], [BT16], [ITW18], [Kim21]
	Ego network	2 (+1)	[SI17], [Gor02], ([PCPR13])
	Information landscape	2	[GAFM11, GAF*11]
	Multiple coordinated views	3	[SI17], [GAFM11, GAF*11]
	Other / experimental	1	[Kim21]
	Colored adjacency matrix + dendrogram mix	1 (in supplement)	[GZV21]
Interaction	**Interactive**	7 (+1)	[PCPR13], [SI17], [BT16], [GAFM11, GAF*11], [Gor02], [DCW12], ([Ber22])
Timevis	**None**	12	
	Multiple vis	2	[GZV21], [SSCO*13]
	Implicit	6	[SM24], [Sun14], [GAFM11, GAF*11], [GZV21], [Kim21]
	Timeline	5	[SI17], [ZJZ*19], [GAFM11, GAF*11], [DCW12]
Spacevis	**None**	16	
	Nodeshape	2	[Li21], [Sun14]
	Node	3	[Sun14], [Ber22], [ITW18]
	Clusters	2	[KE18], [SSCO*13]
	Total	**22 Papers**	

their approach facilitates a detailed exploration of how influence dynamics vary across movements and locations.

Narag and Soriano [NS21] use CNN-based artist categorization and similarity retrieval to compute influences between artists from Expressionism, Impressionism, and Surrealism. The results are visualized as node-link diagrams for each of the different art styles.

Castellano et al. [CLV21] apply CNNs to calculate stylistic similarities, producing influence node-link diagrams that cluster artists based on shared stylistic traits. They further create an "ArtGraph" [CDSV22] database scheme and use it for art style prediction of paintings from various art movements in a CNN, showing an influence node-link diagram between artists using directed edges.

Shinichi and Matsui [SM24] visualize feature-based influences among Ukiyo-e artists, encoding the strength and direction of relationships through edge width and arrowheads. Additional ridgeline plots (distributions of a numeric value across various groups) show the creativity of artworks in different decades.

Brandes [Bra16] investigates **bipartite** graphs, linking artists to categorical attributes such as drawing, composition, and color and aligning them on the x-axis according to the total ratings in the categories (see Figure 4). Edge opacity denotes the ratings per category. In two other node-link diagrams, dominance relationships are visualized using node colors and node placement according to cer-

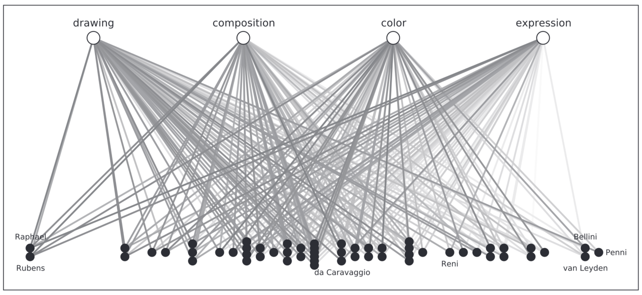


Figure 4: *Artists (black nodes) aligned along the x-axis according to their total ratings in four categories (white nodes). Courtesy of Brandes [Bra16].*

tain properties presenting an analytical framework for evaluating artistic hierarchies.

Van Ham and Wattenberg [VHW08] contribute to the methodological understanding of layout algorithms by comparing different approaches for small-world networks, using datasets of artists and their influences. Their work underscores the importance of a networks layout, demonstrating how varying layouts (e.g., **trees** or node-link diagrams) can highlight different aspects of influence structures, such as clusters, hierarchies, or long-range connections.

Influence networks are further explored using **radial** visualizations, particularly ego-centric analyses. Pinos Cisneros and Pardo Rodriguez [PCPR13] interactively visualized Rembrandt's network, incorporating relationships such as student-teacher dynamics, shared techniques, and thematic overlaps. Their approach supports filtering connections, accessing contextual information about artists, and viewing associated artworks. Similarly, ArtViz by Balaceanu and Takeda [BT16] combines interactive radial layouts with timelines and bar charts, offering multiple perspectives to analyzing influences across art movements and geographic regions.

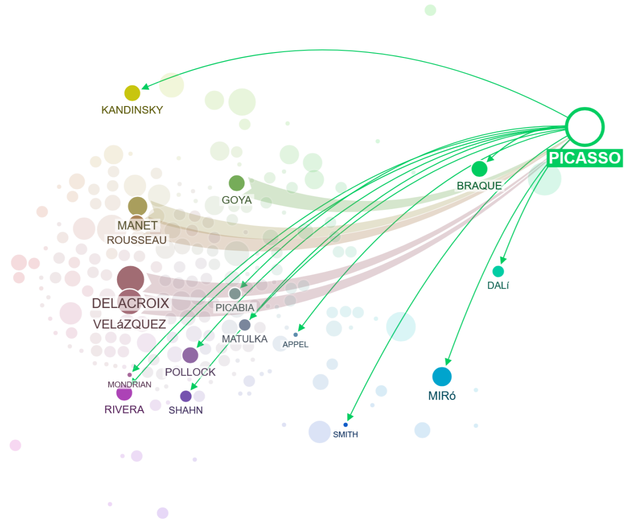
Kim [Kim21] investigates the evolution of two painter networks: one depicting teacher-student relationships among Dutch painters in the 17th century and another focusing on French Impressionists. A radial graph is employed where the artists' influences are the edges of the graph. Nodes are just points connecting the edges. The edges' curvatures (inwards or outwards) denote artists' influences on the styles, such as the maintenance of an existing style or the introduction of a novel one. Additional visualizations illustrate how including specific artists transforms the network, offering insights into the dynamics of influence and stylistic exchange.

Interactivity Interactive visualizations provide art historians with a way of dynamically exploring, navigating, and analyzing influence networks. These often combine node-link diagrams with additional views to enrich the understanding of artistic relationships.

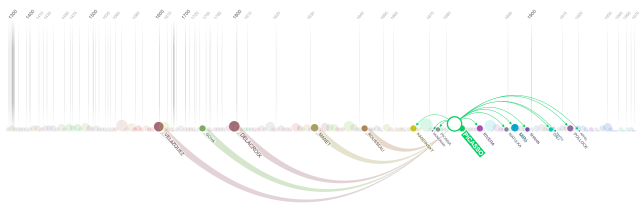
Dörk et al. [DCW12] introduce EdgeMaps [DCW] representing explicit (e.g., documented influences) and implicit (e.g., inferred stylistic similarities) relationships between artists. Figure 5a illustrates artists (nodes) in a node-link diagram, with spatial arrangement indicating similarity (closeness and color suggest greater similarity). Edges reveal influences interactively upon selecting an artist, with arrows showing directionality. Furthermore, an arc diagram organizes nodes along a timeline, highlighting temporal patterns in artistic influences (see Figure 5b). The integration of interactivity enables to dynamically explore relationships and contextualize data within its broader historical narrative.

Gordin [Gor02] similarly focuses on interactivity, presenting a network visualization tool to explore artist-centric influences. Using Titian as an example, the tool visualizes multi-level influence paths, supports ego-network layouts, and provides detailed metadata for selected artists. Such tools emphasize how important flexibility and user control are in exploring complex relational data.

Goldfarb et al. [GAFM11, GAF*11] introduced an interactive 3D information landscape to visualize influences among artists (see Figure 15). It is one of the few approaches that is three dimensional. Artists were represented with their portraits, and streams (edges)



(a)



(b)

Figure 5: *Picasso's influences on other painters (green arrows) and their influences on him in a node-link diagram (a) and in an arc diagram with a timeline (b). Similarities are depicted by similar colors of the nodes. Screenshots taken from the online demo. Dörk et al. [DCW12].*

denoted various relationship types (e.g., family, professional). Temporal aspects were integrated through a time axis, while interactive features enabled users to navigate the landscape, highlight specific connections, and explore additional metadata about artists and artworks. The third dimension (height of a node, similar to mountains in a landscape) was used to denote the node degree.

Temporal and Spatial Contexts Understanding influences often requires embedding them in temporal and spatial contexts. Schikora and Isemann [SI17] explore temporal aspects by visualizing influence probabilities between Dutch painters using interactive timelines, radial, and hierarchical views. This approach supports tracing stylistic development over time and comparing individual artworks within their historical contexts. Zhu et al. [ZJZ*19] combine node-link diagrams with arc diagrams embedded in timelines, illustrating how influences evolve across art movements and emphasizing temporal patterns in stylistic development. Suarez et al. [SSCO*13] focus on Hispanic Baroque art and use temporal snapshots in node-link diagrams to depict evolving influence networks. Some studies expanded their analyses beyond artists to include artworks, movements, and time periods. Gutiérrez et al. [GZV21] leveraged multilayer networks to represent relationships between paintings, incorporating features such as color, shape, and creativity. Multiple node-link diagrams show connections between subsets of paintings from different time periods. This approach facilitated the comparison of artworks within and across movements, revealing nuanced patterns of stylistic innovation.

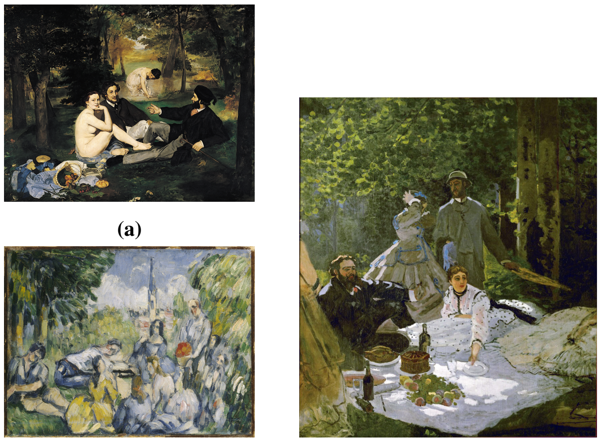
Spatial dimensions were integral to some approaches where nodes, node shape, or clusters visualized the spatial aspects. Apart from visualizing influences between artists, Isemann et al. [ITW18] visualize city-to-city influences in radial diagrams, underscoring the role of urban centers in fostering artistic collaboration. Other studies adapt existing work into digital forms. Bertens [Ber22] models Barr's seminal diagram [SB00] as an ontology, converting the hand-drawn version into a node-link diagram with nodes representing artists, movements, and cities. Edges depict relationships, while additional nodes classify the types (e.g., artist, movement), offering a structured and extensible representation of influence. Similarly, Sun [Sun14] adapted Barr's and Covarrubias' hand-drawn diagrams [SB00] into digital node-link visualizations, incorporating hexagonal nodes for cities and preserving the geographic interrelations between artists and movements.

Summary Network visualization offers a versatile and effective framework to analyze artistic influences, rivalry, and dominance. Computational techniques and traditional methodologies enable researchers to uncover hidden connections, contextualize stylistic relationships, and analyze the evolution of movements. The dynamic interplay between artists, movements, and geographic regions underscores the potential of these methods to advance both AH and VA. The reviewed works highlight several trends and actionable insights for studying influences, rivalry, and dominance:

- Node-link diagrams are the most widely used approach due to their flexibility, while radial layouts excel in visualizing egocentric networks.
- Incorporating temporal dimensions through timelines and spatial aspects via nodes, node shapes, or clusters enriches the context of influence analyses.
- Interactive systems enhance user engagement and support multi-perspective exploration.
- Visualization designs should prioritize interpretability and storytelling. The ability to overlay narratives can make tools more impactful for the target audience.
- Computational methods (e.g., machine learning, CNN), are valuable for deriving quantitative insights but benefit from validation through expert interpretation.

4.3. Similarities and Imitations

When the jury of the Paris Salon of 1863 rejected Édouard Manet's painting *Le Déjeuner sur l'herbe* (see Figure 6a), it triggered what was probably the greatest succès de scandale of its time. Its rejection, in turn, was a driving force behind the establishment of the Salon des Refusés by Napoleon III in the same year. Its presentation was ultimately met with an overwhelmingly negative response from critics, many of which described the work as vulgar and incomprehensible, ridiculing both its subject matter and its painterly execution. Nevertheless, some positive voices emerged [Kre83], and at the same time, artists began translating Manet's painting into their



(a) (b) (c)

Figure 6: *Three similar paintings by different artists. (a) Édouard Manet, Le Déjeuner sur l'herbe, 1863 [Wikc]. (b) Paul Cézanne, Le Déjeuner sur l'herbe, 1876-1877 [Wikc]. (c) Claude Monet, Detail of Le Déjeuner sur l'herbe, 1865 [Wikc].*

styles. Since then, *Le Déjeuner sur l'herbe* has established itself in AH as a threshold work of Modernism [Tuc98] and has inspired various versions of itself, including several artworks of the same name by Claude Monet (see Figure 6c), Paul Cézanne (see Figure 6b) or Pablo Picasso.

The analysis of similarities and imitations between artists and artworks highlights shared themes, stylistic parallels, and the evolution of artistic techniques over time. Various computational approaches and visualization techniques have been employed to explore these relationships, often revealing connection patterns. This section highlights significant contributions to the topic.

4.3.1. Similarities Between Artists

Table 2 presents a summary of the papers discussed in this section.

Visualization Approaches Node-link diagrams are widely used to depict artist relationships and analyze similarities between artists concerning, for example, common painting types, or thematic overlaps.

Noble et al. [NVCD22] use text mining to examine tweets from the National Gallery to link artists with common painting types, visualizing these connections in a **node-link** diagram.

Li [Li21] visualize shared themes between Dutch artists with a multi-modal node-link diagram. Artists and themes are represented as nodes, and edges link them based on thematic overlaps. Node size denotes degree, and colors represent different clusters. This approach is further refined with temporal subsets, exploring connections within specific periods.

Chord diagrams and **radial** layouts effectively handle artist relationships. Balaceanu and Takeda [BT16] present interactive radial visualizations showing similarities, like movement and location. Artists are aligned along a circle, with chords representing

Table 2: *14 papers about similarities between artists. Yellow highlights show in which part of the section the paper is discussed. Numbers in brackets denote cases in which it can be argued about the categorization.*

Vis method	**Node-link**	8	[BCP08], [Rom20], [NVCD22], [Li21], [NS21], [DCW12], [VHVW04], [Kim22]
	Tree / hierarchy	3	[LYR*15], [SMO*10], [ST12]
	Arc diagram	1	[DCW12]
	Radial	3	[Kim22], [BT16], [PCPR13]
	Chord diagram	1	[BT16]
	(Colored) adjacency matrix	1	[LSK*20]
	Ego network	1 (+1)	[Kim22], ([PCPR13])
	Other / experimental	1	[BT16]
Interaction	**Interactive**	5	[DCW12], [VHVW04], [Kim22], [PCPR13], [BT16]
Timevis	**None**	8	
	Multiple vis	1	[Li21]
	Implicit	4	[ST12], [BCP08], [Rom20], [LSK*20]
	Timeline	2	[Rom20], [DCW12]
Spacevis	**None**	12	
	Node	1	[Rom20]
	Edge (from same country)	1	[NS21]
	Total	**14 Papers**	

relationships. User interaction reveals details such as the most similar artists. In another visualization, the movements are listed in the middle of the radial visualizations, and artists are aligned along a circle and connected to their corresponding movements.

Phylogenetic **trees** (showing the evolutionary history between items) used by Shamir et al. [SMO*10] group artists by stylistic proximity, representing relationships as tree branches, with node positions indicating similarity. In another paper, Shamir and Tarakhovsky [ST12] employ neural networks to derive visual similarities among artists, visualizing the results as multiple phylogenetic trees for different art movements, painting types, or similarities of block-shaped cutouts of the paintings. Similarly, Liu et al. [LYR*15] use the feature vectors of paintings to deduce and visualize similarities between artists in a phylogenetic tree.

Lee et al. [LSK*20] apply **colored adjacency matrices** to visualize stylistic similarities between artists, clustering them based on compositional distributions (see Figure 7).

Van Ham and van Wijk [VHVW04] explore interactive **3D layouts** for visualizing stylistic connections among a large number of artists. Artists are clustered into spherical "blobs" based on shared movements, enabling dynamic exploration of artistic relationships.

Interactivity Interactive approaches support a detail-driven exploration of artist similarities and relationships. Kim [Kim22] develop a multi-view visualization system with radial ego-networks, allowing users to explore brushstroke and chroma-based similarities.

Pinos Cisneros and Pardo Rodriguez [PCPR13] also showed artists aligned around a circle in their interactive radial diagram. The ones sharing artwork types or techniques with Rembrandt are

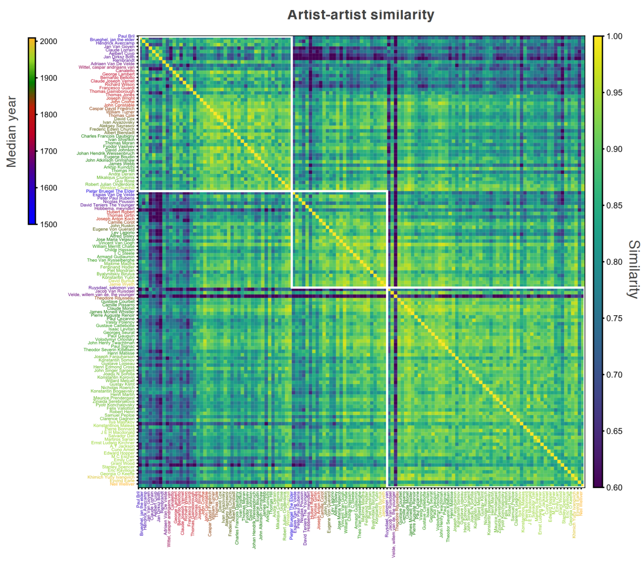


Figure 7: *Colored adjacency matrix showing similarities between artists. The colored cells denote the similarity, the color of the names the time periods the artists were active in. Lee et al. [LSK*20] CC BY-NC-ND 4.0.*

linked to him. The edges are colored according to what the artists have in common with Rembrandt (i.e., artwork type or technique).

Dörk et al. [DCW12] introduced EdgeMaps, where users could interactively explore visual similarities between artists based on movements or birth dates (see Figure 5).

Temporal and Spatial Contexts Adding temporal and spatial details can help to add context to the visualizations. Bressan et al. [BCP08] utilize feature vectors extracted from paintings to compute visual similarities between artists, translating these into network visualizations. Artists are depicted together with their corresponding movements as well as birth and death years to add further context.

Narag and Soriano [NS21] used CNN-based methods to categorize artists' shared features into relationship-driven network visualizations, including stylistic resemblance and shared country of origin. Romanova et al. [Rom20] visualized nationality-based relationships in tree-like node-link diagrams, connecting artists to their countries of origin, associated art movements, and their time periods. This layered representation captured the hierarchical and cultural dimensions of similarities.

4.3.2. Similarities Between Artworks

15 papers analyze similarities between artworks (see Table 3).

Visualization Approaches Node-link diagrams are again the choice of representation for relational data to analyze and investigate similarities between artworks. Hayn-Leichsenring et al. [HLKSC20] combine **node-link** diagrams and clustering to visualize abstract art paintings. Nodes represent artworks, colored by style, while edges denote global image property similarities, with clusters shaded to reveal stylistic groupings.

Schneider and Kohle [SK17] leverage user-assigned tags to compute stylistic similarities, clustering paintings by common descriptors and visualizing the similarity network in a node-link diagram. Seguin [Seg18] refines CNN models to identify visual similarities between artworks, creating node-link similarity graphs that facilitate the grouping and retrieval of related paintings.

Text-based analyses contribute to relationship mapping by leveraging co-occurrences in descriptive data. Arends et al. [AFG*12] and Noble et al. [NVCD22] analyze tag data to identify shared descriptors, representing these relationships as node-link diagrams. By capturing common descriptors, such approaches reveal thematic trends across datasets.

Garcia et al. [GRN20] put contextual information about paintings and relationships between artistic attributes into a network to improve the performance of art classification and art retrieval. An example of the knowledge graph they use for the context embeddings is visualized showing paintings, painting type, artists, and their nationalities as nodes of different colors. Further node-link diagrams display clusters of paintings per different embedding showing artists, nationality, timeframe, painting size, painting type, and other properties as nodes.

Klinke [Kli18] uses computational methods to analyze tag-based relationships across hundreds of artworks, creating **ego-networks** to compare shared descriptors. Tags are connected based on co-occurrence, providing insights into thematic overlap across paintings. These computationally derived relationships are then visualized in node-link diagrams and scatterplots to highlight patterns in brightness and other features.

Baroncini et al. [BSvT*23] created an interactive approach for art historians to answer questions about paintings. The painting is displayed in the middle with edges leading to questions (e.g., who, when, where). Who, for example, reveals nodes for the author or the patron. The user can click on questions to reveal others or to retrieve the corresponding information from various sources, for example, other artworks created by the same artist. Depending on the interests of the user various paths can be explored.

Shamir et al. [SMO*10] employ machine learning techniques to compute visual similarities between paintings, leveraging features derived from color, texture, and other stylistic elements. The resulting relationships are visualized as phylogenetic **trees**, where proximity between nodes denotes stylistic similarity.

Weinstein et al. [WVS19] utilize **dendrograms** to cluster Cézanne's works hierarchically based on visual parameters such as saturation and complexity. They further visualize which painting is most similar to one of Veronese's paintings. Paintings serve as nodes, with hierarchical branches denoting similarity degrees. This approach also incorporates **adjacency matrices** for a tabular representation of artwork relationships.

Adjacency matrices are also employed by Schich and Ebert-Schifferer [SES08] to represent hand gesture frequencies across paintings. Paintings and gestures form the matrix axes, with cells showing co-occurrences. Visual clusters highlight stylistic trends across artists.

Figure 8: *3D visualization of similarities between artworks, showing their images, titles, artists, and year of creation. Tsjornaja et al. [TWB22] CC BY 4.0.*

Interactivity Interactive systems offer significant potential for exploring artwork relationships. Tsjornaja et al. [TWB22] develop a virtual reality platform for navigating 3D similarity graphs, where nodes are paintings and edges depict visual similarities (see Figure 8). This immersive approach enables an intuitive exploration of complex relationships.

Feng et al. [FCH*22] created an interactive co-occurrence graph where nodes are objects in paintings that occur together. This was intended to inspire users with ideas for writing a poem about the painting. Users can annotate or edit object connections, enhancing the system's adaptability and accuracy.

Temporal and Spatial Contexts Similarities between artworks need to be explored according to their temporal and spatial context.

Table 3: *15 papers about similarities between artworks. Yellow highlights show in which part of the section the paper is discussed.*

Vis method	Node-link	12	[Seg18], [SK17], [HLKSC20], [Hon18], [FCH*22], [SSCO*13], [AFG*12], [NVCD22], [Kli18], [TWB22], [BSvT*23], [GRN20]
	Tree / hierarchy	2	[SMO*10], [WVS19]
	(Colored) adjacency matrix	2	[WVS19], [SES08]
	Ego network	2	[Kli18], [BSvT*23]
	Multiple coordinated views	1	[FCH*22]
Interaction	Interactive	3	[FCH*22], [TWB22], [BSvT*23]
Timevis	None	9	
	Multiple vis	1	[SSCO*13]
	Implicit	5	[WVS19], [Hon18], [TWB22], [BSvT*23], [GRN20]
Spacevis	None	11	
	Node	2	[BSvT*23], [GRN20]
	Nodeproperty	1	[Hon18]
	Clusters	1	[SSCO*13]
	Total	**15 Papers**	

Honig [Hon18] used network analysis for teaching in AH. The students analyzed similarities between paintings and visualized them in two node-link diagrams. The graphs also include the locations and sometimes the years of the paintings.

Suarez et al.'s paper about Hispanic Baroque Art [SSCO*13] shows multiple node-link diagrams depicting similarities between descriptors of paintings for different time periods. Node colors denote the clusters, which roughly correspond to different countries. Further node-link diagrams visualize the evolution of the similarity clusters over three centuries.

4.3.3. Similarities Between Art Styles

A summary of the five papers discussed in this section can be seen in Table 4.

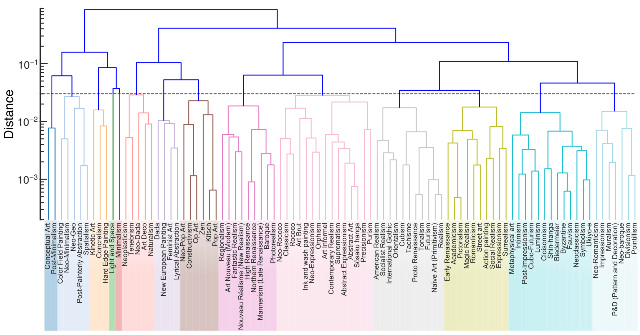


Figure 9: *Dendrogram showing similarity clusterings of art styles. Courtesy of Sigaki et al. [SPR18].*

Visualization Approaches Rebollar and Grana [RG22] utilize **node-link** diagrams to visualize similarities derived from a confusion matrix of art style predictions using a CNN. Directed edges represent similarities between art styles, and the nodes are positioned temporally (e.g., earlier styles appear higher in the diagram). This layout provides an overview of how art styles evolve and influence one another over time.

An interesting approach to visualizing stylistic similarities and relationships are **dendrograms** and **colored adjacency matrices**. These techniques are particularly effective for representing hierarchical relationships between art styles. For instance, Sigaki et al. [SPR18] analyzed permutation entropy and statistical complexity within paintings, quantifying the complexity of the artwork. This served as the basis for hierarchically clustering art styles and the results are visualized in dendrograms and adjacency matrices. The former can be seen in Figure 9. Here, art styles are represented as nodes and edges denote the similarities between them. Node colors provide visual cues about clusters (i.e., similar styles), while edge lengths or colors represent the distance or strength of the similarity between styles.

Similarly, Lee et al. [LSK*20] effectively employ colored adjacency matrices to visualize stylistic similarities based on the distribution of compositional proportions within paintings. The node colors represent time periods and edge colors indicate the degree of similarity between styles. This approach allows for a dynamic and visually engaging exploration of how compositional elements evolve and change across different art historical periods.

Temporal and Spatial Contexts Considering the temporal and spatial context eases the contextualization and exploration. Yang [YCZ*18] visualize the origins of art styles on a map with an accompanying timeline. Nodes represent art styles, and links connect them to their countries of origin, providing spatial and temporal context for understanding the development and dissemination of art styles across different regions and time periods. Romanova et al. [Rom20] utilize a tree-like node-link diagram to visualize con-

Table 4: *5 papers about similarities between art styles. Yellow highlights show in which part of the section the paper is discussed.*

Vis method	Node-link	2	[Rom20], [RG22]
	Tree / hierarchy	1	[SPR18]
	Map with edges	1	[YCZ*18]
	(Colored) adjacency matrix	2	[SPR18], [LSK*20]
	Colored adjacency matrix + dendrogram mix	1 (in supplement)	[SPR18]
Interaction	Interactive	0	
Timevis	None	1	
	Implicit	3	[Rom20], [LSK*20], [RG22]
	Timeline	2	[Rom20], [YCZ*18]
Spacevis	None	3	
	Node	1	[Rom20]
	Map	1	[YCZ*18]
	Total	**5 Papers**	

nections between art movements, time periods, artists, and nationalities. This approach effectively illustrates the multifaceted relationships that shape the art historical landscape.

Summary Analyzing similarities between artists, artworks, and art styles employs diverse methods to understand connections within the art world. These methods provide valuable insights into the evolution of artistic expression, the interplay of historical and cultural contexts, and creative practices. Common approaches include:

- Node-link diagrams, adjacency matrices, and radial layouts are frequently used to represent similarities and relationships between different types of entities.
- (Colored) adjacency matrices, dendrograms (sometimes together with other visualization techniques) and phylogenetic trees were used more often to visualize similarities than they were used to depict other relationships in this survey. This suggests that they can be especially helpful for this task.
- Machine learning (CNNs) and text mining are frequently utilized methods to analyze data and identify similarity patterns.
- Interactive systems enhance exploration, allowing users to dynamically navigate and analyze relationships.

4.4. Travel and Movement

In 1937, the Spanish Republican government commissioned Pablo Picasso to paint a contribution for the Paris World's Fair of the same year. When Guernica, a village in Basque Country, was bombed by the German Nazis and Italian Fascists on April 26, Picasso, living in Paris then and not having visited Spain since 1934, created a 3.5 by 7.8 meters monochrome oil painting portraying the suffering and chaos triggered by this war. After the World's Fair, rolled up and packed in a tube for transport, the painting went touring several European and North American cities per the request of the artist and its commissioners [VH07], only coming to a preliminary halt in the MoMA during the 1950s, when its physical condition forcibly stopped its tour [Att17]. In the process, the painting's journey not only disseminated anti-war concepts but also Picasso's visual language, and with it, a kind of artistic strategy for addressing realities of extreme violence and agony [Puc20].

Travel and movement of artists and artworks is an interesting topic for art historians. It helps to explain the relations between artists and artworks: the diffusion and adoption of content, form, and style.

4.4.1. Artists' Travels

A summary of the papers discussed in this section can be found in Table 5.

Visualization Approaches As this section focuses on travel, it is unsurprising that the most popular visualization method was maps since they help determine spatial context. Other visualization methods were also used, sometimes in combination with maps.

Kaiser's paper [Kai14] is about the Hagenbund, an Austrian artist association between 1900 and 1938 with its principal exhibition place at Zedlitzhalle in Vienna. A **radial ego-network-like map** visualization shows Vienna at the center and directed edges to other cities (see Figure 10). They denote all group exhibitions in Zedlitzhalle between 1900 and 1938 by artist associations not from Vienna, all participations in Austria and abroad, and venues of traveling exhibitions. Concentric circles around Vienna show the distances to the other cities. Further visualizations give an in-depth view of Hagenbund's exhibition activities and its members.

Dzialek [Dzi24] analyzed migrations of Polish artists from 1770 to 1939 to determine important cities for the art world. Multiple **node-link** diagrams for different periods display the migration of artists between cities. Edge color and width denote the number of migrations to visualize popular migration routes. The node size depends on the number of incoming or outgoing artists marking popular cities. Multiple other map-like visualizations show the percentage of prominent painters per city, artist colonies, and study places for different periods.

Interactivity Adding interactivity to visualizations can further help with exploring the trajectories of artists. ECARTICO (Ni-

Table 5: *6 papers about travels of artists. Yellow highlights show in which part of the section the paper is discussed.*

Vis method	**Node-link**	3	[KLSR18], [KR20], [Dzi24]
	Radial	1	[Kai14]
	Map with edges	5	[Kai14], [KLSR18], [KR20], [SSA*14], [NB*13]
	Ego network	1	[Kai14]
	Sankey diagram	1	[KLSR18]
Interaction	**Interactive**	1	[NB*13]
Timevis	**None**	0	
	Multiple vis	1	[Dzi24]
	Edges on map	4	[KLSR18], [KR20], [SSA*14], [NB*13]
	Animation/video	1	[SSA*14]
	Implicit	1	[NB*13]
Spacevis	**None**	0	
	Nodeshape	1	[KLSR18]
	Node	3	[KLSR18], [KR20], [Dzi24]
	Map	5	[Kai14], [KLSR18], [KR20], [SSA*14], [NB*13]
	Total	**6 papers**	

jboer et al.) [NB*13, ECA] is a website containing multiple interactive visualizations about painters and other artists from the Low Countries—modern Belgium, Netherlands, and Luxembourg. Different tools for analysis are available. One of them is an interactive map visualization that shows the migration of painters who were active in Amsterdam between 1600 and 1700. Different filters for cities, time periods, artwork types, etc., can be applied. Circle sizes and popups on the map denote how many painters lived in a city. Other views show line charts with the number of active painters or painters entering the market over time, where different time periods, occupations, etc., can be filtered. Further hotspot maps and animations show places of birth and the number of active painters over time.

Temporal and Spatial Contexts All papers in this section use spatial aspects to analyze the data. Additionally, temporal elements can help to gain insights about travels in different time periods.

Schich et al. [SSA*14] show various artists' and other notable individuals' birth and death places spanning 2000 years on a map with edges between them, where node colors highlight places with more births than deaths and vice versa. Multiple visualizations and an animated video show migration movements over the years and for different countries. A colored adjacency matrix denotes over- and under-representation of migration data between regions. Multiple other visualizations further explore world populations over different periods, cities, or regions.

Another paper by Kaiser et al. [KLSR18] is about the travels of artists who were members of the Austrian artist association Künstlerhaus, founded in 1861 in Vienna. Two node-link diagrams show artists' trajectories between birth and death places, with edge widths highlighting popular routes. Further, the trajectories are also visualized on a map with links between cities similar to the one by Schich et al. [SSA*14]. Multiple Sankey diagrams

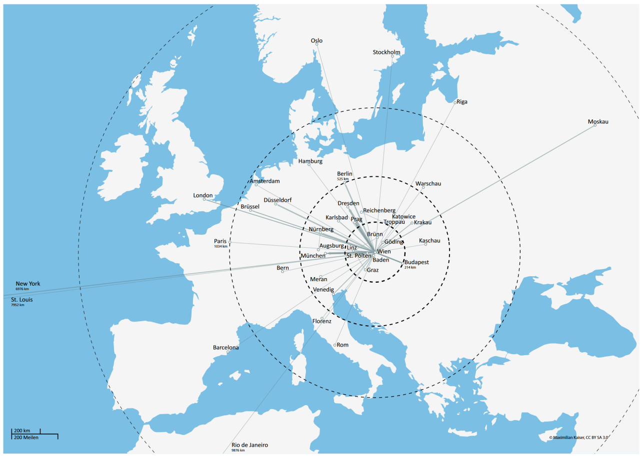


Figure 10: *Map showing the group exhibitions by artist associations not from Vienna and their participants from abroad. Courtesy of Kaiser [Kai14] CC BY-SA 3.0.*

display migration streams of members from Künstlerhaus between different cities and countries over time. They also include places where the artists studied or worked. In a book chapter, Kaiser and Rumpolt [KR20] further investigate the mobility of members of Künstlerhaus in node-link diagrams showing travels between cities or countries and maps with links showing where artists traveled for their education. Colored nodes help to identify communities.

4.4.2. Travel of Artworks

A summary of the five papers analyzing the travels of artworks is given in Table 6.

Table 6: *5 papers about travels of artworks. Yellow highlights show in which part of the section the paper is discussed. Numbers in brackets denote cases in which it can be argued about the categorization.*

Vis method	**Node-link**	3	[SRM19], [CDSV22], [Gin15]
	Map with edges	3 (+1)	[SRM19], [SSCO*13], [Cra20], ([Gin15])
Interaction	**Interactive**	1	[Cra20]
Timevis	**None**	2	
	Edges on map	3	[SRM19], [SSCO*13], [Cra20]
	Timeline	1	[Cra20]
Spacevis	**None**	0	
	Node	2	[CDSV22], [Gin15]
	Map	3	[SRM19], [SSCO*13], [Cra20]
	Total	**5 papers**	

Visualization Approaches For visualizing travels of artworks, only node-link diagrams and maps were used. Castellano et al. [CDSV22] provide two **node-link** diagrams identifying artworks that are stored in a different country than the one they were created in and all artworks kept at certain institutions (e.g., a museum) displaying connections between countries, cities, and institutions.

Ginhoven [Gin15] wrote about Forchondt, a Flemish painter and art dealer from the 17th century, and how paintings were distributed from the Netherlands to Spain and Latin America. Two node-link diagrams with cities as nodes show Antwerp as the source destination and the intermediate and end destinations of the paintings sold by Forchondt in total and to the Iberian Peninsula. The nodes are roughly positioned relative to their geographic positions and are colored by country. Edge widths denote popular routes for painting sales. An additional map with pie charts in different sizes shows the number of paintings Forchondt sold in a city. The segments of the pie charts denote the percent of material they were painted on (e.g., canvas, linen). A bubble chart shows which descriptors were mainly used for paintings exported to the Iberian Peninsula.

Suarez et al.'s paper [SSCO*13] about Hispanic Baroque art also provides a **map** visualization with links that show how artworks traveled from their place of creation to the place they are currently kept at (e.g., museums, galleries).

Interactivity Interactive approaches can help to track the travels of artworks and compare them. Mapping Paintings (Cranston) [Cra20, Cra] is a website that shows the travels of one or multiple paintings with hotspots and markers, as can be seen in Figure 11. Different maps with paintings have been created, some by users. Edges show the routes of artworks in different colors per painting. When clicking on a hotspot, the map zooms in to reveal all aggregated markers. Information, including the owner, location, and time frame, is displayed for different locations on the map. Additionally, the user can search for artists, paintings, and owners to get more information about them or contribute by starting a new project and adding the travels of a painting on a map. For projects, an additional timeline is shown below the map, which visualizes the different stops of the painting and their duration.

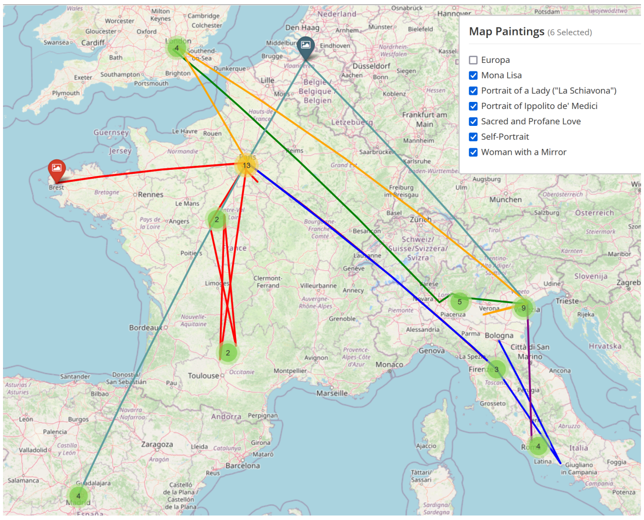


Figure 11: *Map showing the travels of different artworks with markers and edges. Screenshot taken from the website. Cranston [Cra20].*

Temporal and Spatial Contexts Since many papers in this section use maps, most of the temporal contexts are visualized by edges on a map showing, e.g., stops of artworks or exhibitions over time. Saint-Raymond and Métraux [SRM19]'s paper is about the Matsukata collection that was confiscated in 1944 by France as an "enemy asset". Its artworks were exhibited from 1946 to 1958 in various cities worldwide before most were given back in 1959 to Japan. A map visualization shows in which cities the artworks from the collection were exhibited (see Figure 12). Circle sizes denote the number of exhibitions or exhibited artworks, and the colors show if the Matsukata collection was mentioned in the exhibition catalog. Directed edges denote the stops of traveling exhibitions over time. A node-link diagram displays the network of exhibition organizers where paintings from the Matsukata collection were featured.

Summary Visualizing artists' and artworks' travel can facilitate getting insights into their lives and provenance. Adding temporal aspects and interactivity can further help to analyze the data.

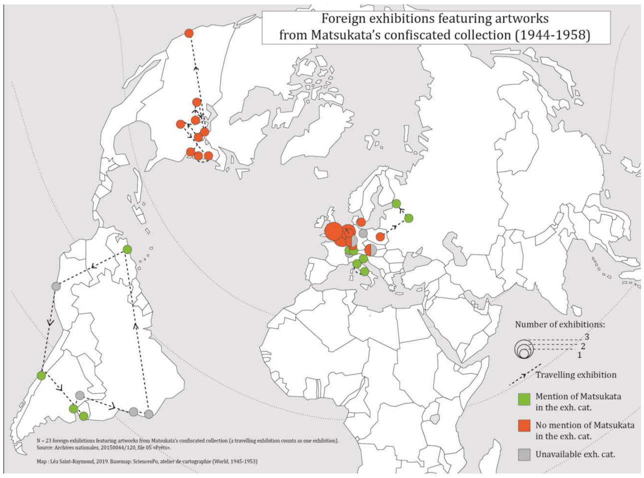
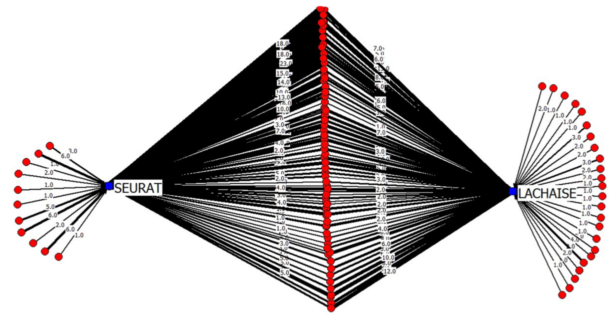


Figure 12: *Exhibitions that showcased artworks from Matsukata's collection. The node color depicts if the Matsukata collection was mentioned in the exhibition catalog. Edges show traveling exhibitions, node sizes, and the number of exhibitions in one location. Saint-Raymond and Métraux [SRM19] CC BY-NC-SA 4.0.*



Seurat overlaps Lachaise's connections by 78%.

	Number of MoMA exhibit connections with other Armory artists.	Percent of repeat connections.	Percent of exhibit connections with prestigious artists (MoMA solo show).	Number of artist's MoMA solo shows.	Number of textbook pages given to artist across three modern textbooks.
LACHAISE	83	75%	33%	2	0
SEURAT	83	86%	38%	1	6

Figure 13: *Artists co-exhibiting with Seurat and Lachaise. Numbers on the edges show the numbers of co-exhibitions. Braden [Bra21] CC BY 4.0.*

- Most papers used maps, followed by node-link diagrams to visualize the travels of paintings, artworks, or stops of traveling exhibitions.
- Similarly, temporal aspects were mostly depicted with edges on a map.
- A vast majority of approaches are from the AH domain, suggesting that this is an important research topic for art historians.

4.5. Exhibitions and Art Markets

"I wish we could have a show like this" read a note allegedly added to the catalog of the 1912 Sonderbund exhibition in Cologne by American painter Arthur Bowen Davies, who then sent it to his colleague Walt Kuhn [Bro88]. Sharing Davie's enthusiasm, Kuhn immediately took the next ship and traveled to Cologne to see the show, coming into contact with avant-garde European art developments that were only vaguely known in the USA. In the same year, the Association of American Painters and Sculptors was founded, with Davies as its first president, aiming at exhibiting "the best contemporary work that can be secured" [Bro88]. Davies and Kuhn then spent a year in Europe, assembling over 400 works of art [Alt94] before, on February 15 1913, they opened the exhibition they had dreamed of, unofficially called the *Armory Show*. By bringing together foreign and local artists, this exhibition exposed artists to new techniques and audiences to new ideas and ultimately contributed greatly to the development of modern art in the USA.

Analyzing relationships in the art world is essential to better understand the history of art—connections between artists, patrons, and collectors, such as co-exhibitions and auction networks.

4.5.1. Exhibition Activity

A sumary of the papers discussed in this section can be found in Table 7.

Visualization Approaches All papers visualizing exhibition activities used node-link diagrams, suggesting that they remain the most versatile tool, supporting detailed exploration of co-exhibition data.

Braden and Teekens [BT20] use a **node-link** diagram to explore Dutch museum exhibitions between 1946 and 1955. Nodes represent artists, colored by cohort (past, present, future), while edges indicate co-exhibitions. Labels such as "A" or "H" reveal the extent of collaboration across cohorts, highlighting individual artists' network positions. Expanding on this, Braden [Bra21] examines MoMA exhibitions between 1929 and 1968. A node-link diagram features Seurat and Lachaise as focal points, linking them to other artists based on co-exhibitions (see Figure 13). Shared connections are positioned centrally, with edge widths and labels denoting co-exhibition frequencies.

Joyeux-Prunel [JP19] adopts a straightforward node-link visualization to map the circulation of art through exhibitions. Artists and exhibitions are nodes, with edges representing artist participation in exhibitions. Artist node colors encode participation frequencies.

In contrast, Krasevac and Slosel [KŠ18] explore early 20th-century exhibitions of the artist associations Mánes and Sztuka. Their visualizations include node-link diagrams where nodes represent artist associations, institutions, exhibitions, and artists. Edge colors encode connections based on node types. Separate diagrams highlight differences between male and female participation or focus on specific Slovenian exhibitions in 1900.

Kolesnik [Kol18] investigates neo-avant-garde exhibitions. Node-link diagrams categorize venues (museums, galleries, artist-run spaces) and show connections between artists and exhibitions. Node colors denote types, while edge widths represent shared participation or roles like organizer and catalog editor.

Dendrograms provide hierarchical insights, capturing clusters of

Table 7: *13 papers discussing exhibition activity. Yellow highlights show in which part of the section the paper is discussed. Numbers in brackets denote cases in which it can be argued about the categorization.*

Vis method	**Node-link**	13	[BT20], [JP19], [Kol18], [KBŠ16], [KŠ18], [PS11], [Kai20], [Kai14], [FSR*18], [Sas22], [Bra21], [HABK14], [SRC17]
	Tree / hierarchy	1	[PS11]
	Map with edges	1	[KBŠ16]
	(Colored) adjacency matrix	1 (in supplement)	[FSR*18]
	Sankey diagram	1	[FSR*18]
Interaction	**Interactive**	0	
Timevis	**None**	5	
	Multiple vis	5	[Kol18], [PS11], [Kai20], [Sas22], [HABK14]
	Implicit	4	[BT20], [KBŠ16], [Kai14], [HABK14]
Spacevis	**None**	7	
	Nodeproperty	1 (+1)	[KŠ18], ([Kai20])
	Nodecolor	2	[FSR*18], [SRC17]
	Clusters	0 (+1)	([PS11])
	Map	1	[KBŠ16]
	Total	**13 Papers**	

shared exhibitions and their temporal or geographic evolution. Papenbrock and Scharloth [PS11] use node-link diagrams and **dendrograms** to analyze German co-exhibition networks during the 1930s and 1940s. These hierarchical structures emphasize localized art scenes, such as those in Berlin and Munich, and allow for temporal comparisons across decades. Temporal clustering techniques add a dynamic layer to these analyses.

Kolesnik et al. [KBŠ16, KBŠP21] overlay exhibition data on a **map** to depict the spread of New Tendencies art movement participants (see Figure 14). This map highlights the geographic interplay between exhibitions and the evolving cultural centers that shaped the movement. Additional node-link diagrams depict Mavignier's personal network and artist participation in multiple exhibitions, using color and size to encode roles, centrality, and network clusters.

Fraiberger et al. [FSR*18] analyze 36 years of co-exhibition data across 143 countries. Venues are nodes colored by country, and edges represent shared exhibitions, with weights indicating the number of artists connecting venues. Additional visualizations include community clusters, **Sankey diagrams** showing career trajectories, and **colored adjacency matrices** depicting co-exhibitions between artists belonging to different communities.

Temporal and Spatial Contexts Exhibition activity captures temporal and spatial dimensions, which need to be investigated in detail. Kaiser [Kai20] visualizes artist participation in different yearly exhibitions with multiple node-link diagrams. Nodes vary by type (artist, exhibition), and sizes indicate the number of exhibitions. Filters allow detailed views based on factors like education, travel, or city connections. In another study [Kai14], Kaiser examines the

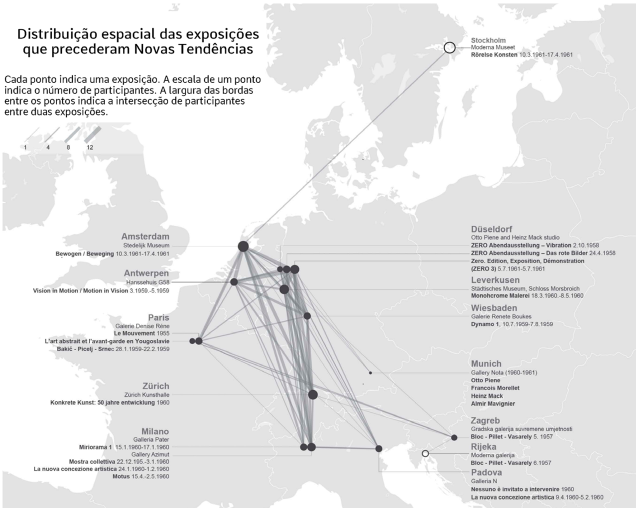


Figure 14: *Artists' co-exhibitions displayed on a map. Nodes denote cities and the exhibitions that took place there. Edge widths correspond to the number of co-exhibiting artists. Kolesnik et al. [KBŠ16, KBŠP21] CC BY-NC-SA 4.0.*

Hagenbund artist association, visualizing artist and exhibition networks over time, where exhibition nodes are colored by time period. Artists are differentiated by membership status and exhibition frequency, with node size and centrality reflecting prominence. Husslein-Arco et al. [HABK14], while expanding on Kaiser's analysis of Hagenbund, incorporate multiple node-link diagrams in an exhibition catalog. These diagrams focus on top-exhibiting artists during specific periods, like 1900–1938 or 1930–1938, and their exhibition participation. Further node-link diagrams for different exhibitions link artists and reviewers through edges that encode positive or negative feedback. This layer provides insights into critical reception, expanding the analysis beyond participation metrics.

Sasajima [Sas22] explores New York's art venues between 1940 and 1969, with multiple node-link diagrams, mapping the evolution of avant-garde exhibition venues in New York. This approach enables comparative analysis of art scenes over distinct decades, revealing the rise and fall of pivotal networks.

Saint-Raymond and Courtin [SRC17] introduce auction sale networks into the computational space. By analyzing shared buyers, artists, their nationalities, and auction patterns, they reveal a previously underexplored link between co-exhibition networks and market dynamics, shedding light on how exhibition exposure impacts commercial success.

4.5.2. Art Market Networks

A summary of the papers visualizing art market relationships can be seen in Table 8.

Visualization Approaches Kaiser [Kai20] broadens the visualization scope by combining collectors, artists, and institutions in a unified **node-link** diagram. This layered visualization reveals not only transactional relationships but also the influence of educational institutions on artists' careers and collector preferences, encapsulating the intersection of education, patronage, and market dynamics.

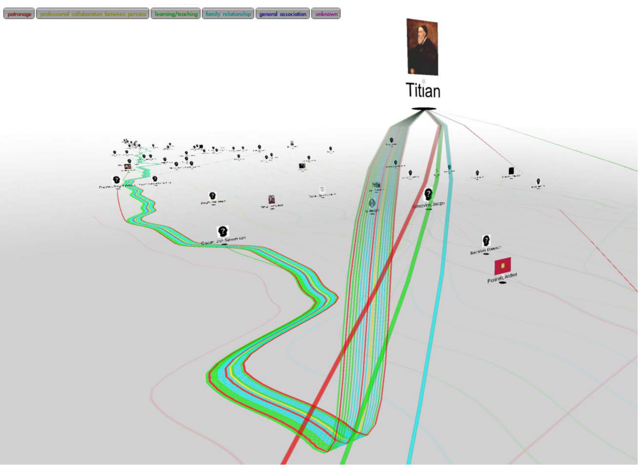


Figure 15: *3D interactive information landscape showing different relationship types (e.g., patrons or influences) with differently colored edges. The height of a node denotes its degree. Courtesy of Goldfarb et al. [GAFM11, GAF*11].*

Fletcher and Helmreich [FHIE12] use node-link diagrams to depict the trading network of Goupil & Cie, a 19th-century auction house. Artists, buyers, and Goupil branches form the nodes, with their colors distinguishing entity types. Edges denote transactions, encoding transaction volumes in edge widths. By including multiple diagrams for different years, the approach illustrates temporal shifts in trading patterns. The accompanying interactive map enriches the visualization by showing the spatial distribution of art-related entities, such as galleries and retail locations, offering users a geographically contextualized view of the market. By computing metrics such as betweenness centrality, they identify influential nodes (i.e., key buyers or auction houses), that served as intermediaries within the art market.

Interactivity Goldfarb et al. [GAFM11, GAF*11] introduce an immersive experience with their 3D information landscape, where users can navigate artist-patron relationships in a time-aligned spatial environment which can be seen in Figure 15. By interacting with specific nodes, users can explore connections, access additional metadata, and uncover hidden relationships within the network.

Temporal and Spatial Contexts The study of art market relationships leverages a variety of computational techniques to quantify, cluster, and analyze networks of patrons, collectors, and ownership changes. These approaches often integrate temporal, spatial, and network-based analyses to uncover hidden trends and patterns. The Mapping Paintings project by Cranston [Cra20, Cra] adopts a novel approach by using interactive maps to track the provenance of artworks. These maps display ownership transitions as spatial and temporal trajectories, linking specific locations to periods of ownership (see Figure 11). By visualizing the geographic and chronological journey of individual paintings, this approach provides a rich narrative of art circulation and historical movement.

McCabe [McC19] employs both static and geospatial visualizations to study the copper painting market. A node-link diagram captures Rottenhammer's network of patrons and collectors, with cities represented as nodes and edges indicating the flow of artworks. Node sizes reflect transaction volumes and edge width denotes relational strength. Maps complement these diagrams, providing a geographical perspective on the distribution of Rottenhammer's collectors and patrons, showcasing the far-reaching influence of his work across cities.

Summary Each of these approaches demonstrates the versatility of visualization techniques in capturing art market dynamics. While node-link diagrams dominate, integrating spatial maps, adjacency matrices, and 3D representations highlights the multifaceted nature of these relationships. Together, they provide a comprehensive toolkit for exploring how artworks, patrons, and collectors shaped the art market. Analyzing relationships in the art world, including co-exhibitions and auction networks, offers insights into the dynamics that shape artistic movements and market behaviors. Common approaches include:

- Node-link diagrams are widely used to visualize co-exhibition networks, artist interactions, and market dynamics. Other approaches were also used, employing a range of visualizations tailored to provide multiple perspectives and support different analysis needs.
- Community detection algorithms, network centrality measures, and temporal clustering can identify patterns in co-exhibition and auction networks. These techniques uncover latent relationships and shifts in artistic movements or market activity over time.

Table 8: *6 papers about art market networks. Yellow highlights show in which part of the section the paper is discussed. Numbers in brackets denote cases in which it can be argued about the categorization.*

Vis method	**Node-link**	3	[McC19], [Kai20], [FHIE12]
	Map with edges	1	[Cra20]
	Ego network	0 (+1)	([McC19])
	Information landscape	2	[GAFM11, GAF*11]
	Multiple coordinated views	2	[GAFM11, GAF*11]
Interaction	**Interactive**	3 (+1)	[GAFM11, GAF*11], [Cra20], ([FHIE12])
Timevis	**None**	2	
	Multiple vis	1	[FHIE12]
	Edges on map	1	[Cra20]
	Implicit	2	[GAFM11, GAF*11]
	Timeline	3	[GAFM11, GAF*11], [Cra20]
Spacevis	**None**	3	
	Node	2	[McC19], [FHIE12]
	Map	1	[Cra20]
	Total	**6 Papers**	

- Integrating data from different domains (e.g., critical reception, auction patterns, and artist mobility) enriches the analysis. Provenance tracking can add valuable context to understand the broader impact of exhibitions or art market transactions.

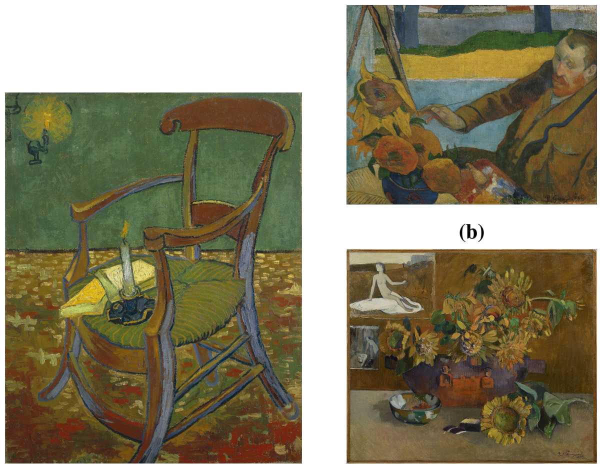
4.6. Social Relationships

In October 1888, Paul Gauguin moved into his friend Vincent Van Gogh's house in Arles. The artists lived, painted and planned a future together, trying to establish some kind of association of painters (letter 716). However, due to an acute episode of Van Gogh's psychic illness, Gauguin moved back to Paris on December 23, 1888 [Vel08]. The final failure of their relationship, which artistic differences had already strained, left Van Gogh alone in a fit of madness, which led him to cut off part of his ear the same day [Lub61]. Gauguin did not visit him in the hospital (letter 736). A series of artworks, made in the short time of their cohabitation, bear witness to their intimate friendship: Van Gogh's painting of Gauguin's chair (see Figure 16a) or a portrait of Van Gogh by Gauguin (see Figure 16b). In the following year, they started to get in touch again, somewhat cautiously at first, but then more familiarly. In 1901, thirteen years after the incident and eleven years after Van Gogh's death, Gauguin still paid tribute to his friend by painting his favorite subject: Sunflowers (see Figure 16c).

Art historians analyze the social relationships of artists to figure out in which circles they are active and how ideas and inspirations spread. The relationships between students and their masters are decisive since they might adopt the master's style or themes. Sometimes, artists have an artist as a spouse or other family member, which is also how ideas can diffuse. Further, social relationships can help artists get into certain circles, making them more popular or more likely to get into an exhibition.

4.6.1. Work, Student, Teacher

A summary of the papers discussed in this section can be seen in Table 9.



(b)

(a) (c)

Figure 16: *(a) Vincent Van Gogh, Gauguin's Armchair, 1888 [Wikc]. (b) Paul Gauguin, Vincent Van Gogh Painting Sunflowers, 1888 [Wikc]. (c) Paul Gauguin, Still Life with Sunflowers, 1901 [Wikc].*

Visualization Approaches Node-link diagrams are especially popular for visualizing social relationships. This is also clear from the number of papers that use them. Narag and Soriano [NS21] visualize which artists were from the same art school, friends, or co-workers in three **node-link** diagrams where each one represents a different art movement. Artists are displayed as nodes, and the edge colors show the type of relationship.

A paper by Bernád and Kaiser [BK17] visualizes Austrian artists and the institutions where they studied in node-link diagrams either showing artists and institutions as nodes or only institutions, connected if an artist attended both. Further, multiple small node-link

Table 9: *16 papers visualizing work-related relationships. Yellow highlights show in which part of the section the paper is discussed. Numbers in brackets denote cases in which it can be argued about the categorization.*

Vis method	**Node-link**	12 (+1)	[LW22], [NB*13], [ES18], [BK17], [Kai20], [Kai17], [NS21], [DA12], [MHR12, HMK*09], [BAA*19, LABV18], ([ZHF*22]),
	Tree / hierarchy	3	[Kai20], [BAA*19, LABV18]
	Radial	3	[PCPR13], [MHR12, HMK*09]
	Map with edges	1	[ZHF*22]
	Ego network	3 (+1)	[DA12], [MHR12, HMK*09], ([PCPR13])
	Information landscape	2	[GAFM11, GAF*11]
	Multiple coordinated views	4	[GAFM11, GAF*11], [BAA*19, LABV18]
Interaction	**Interactive**	10	[LW22], [PCPR13], [NB*13], [GAFM11, GAF*11], [BAA*19, LABV18], [DA12], [MHR12, HMK*09]
Timevis	**None**	10	
	Multiple vis	2	[ZHF*22], [Kai20]
	Implicit	2	[GAFM11, GAF*11]
	Timeline	4	[GAFM11, GAF*11], [BAA*19, LABV18]
Spacevis	**None**	13	
	Nodeproperty	1	[BK17]
	Nodecolor	1	[ES18]
	Clusters	0 (+1)	([ZHF*22])
	Map	1	[ZHF*22]
	Total	**16 papers**	

diagrams show student-teacher and different family relations (parent, spouse, relative) between artists.

Similarly, a paper by Kaiser [Kai17] shows a node-link diagram with different social relationships (e.g., student-teacher, colleagues, friendships) between Makart and Defregger, two Austrian painters. The paper further contains a node-link diagram of various members from Künstlerhaus artist association and their connections (education or career) and connection strengths (e.g., an artist was student and later also teacher in the same institution) to institutions (universities, schools, etc.). A bar chart visualizes the evolution of further Austrian artist associations.

In another paper, Kaiser [Kai20] further analyzed members of the Künstlerhaus artist association. In a node-link diagram, student-teacher relationships between these artists are visualized highlighting which artists had especially many students by node size. Multiple node-link diagrams show artist-institution relationships for different artist cohorts (artists born in different decades) denoted by different colors and connections between schools, artists, and collectors. A **tree** shows the hierarchy of a school of three artists and their students through positions and node sizes.

Mäkelä et al. [MHR12] and Hyvönen et al. [HMK*09] created CultureSampo [Cul], an online platform for Finnish culture. Different relationships of painters and other people are considered (e.g., student-teacher, spouse, family relationships). An artists' social network is shown as a **radial** node-link diagram with the artist in the middle. It is possible to click on any node in the graph to show their social network and get more information about them. Additionally, there is a map view that shows object locations and close cultural sites. Further, objects (e.g., paintings) can be seen on a timeline.

Pinos Cisneros and Pardo Rodriguez [PCPR13] visualize student and teacher relationships of Rembrandt and other artists in an interactive radial visualization with artists aligned around a circle and edges in the middle. Edge colors denote the relationship types.

Goldfarb et al.'s **information landscapes** [GAFM11, GAF*11] also contain multiple social relationships (e.g., student-teacher, collaborators, patrons, family) between the artists and other people (see Figure 15).

Interactivity Interactive approaches enable a thorough analysis of vast relationship networks, e.g., by highlighting connections or nodes or displaying different people's networks. Li and Wang [LW22] visualize student-teacher relationships between Chinese painters of all dynasties in an interactive 3D augmented reality (AR) node-link diagram. Clicking on a node highlights all nodes directly connected to it. Due to the fact that it is AR, the user can move in the room to see the graph from different angles.

Inventing Abstraction [DA12, MoM] is a website about an exhibition at MoMA featuring abstract artists (the visualizations are due to Paul Ingram and Mitali Banerjee). The interactive node-link diagram contains artists from the exhibition as nodes and their productive connections as links between them. Hovering over an artist highlights their connections in bold. The node color and size determine whether an artist has more or less than 24 connections within the network. By clicking on an artist, only the network between them and their acquaintances is shown, displaying the se-

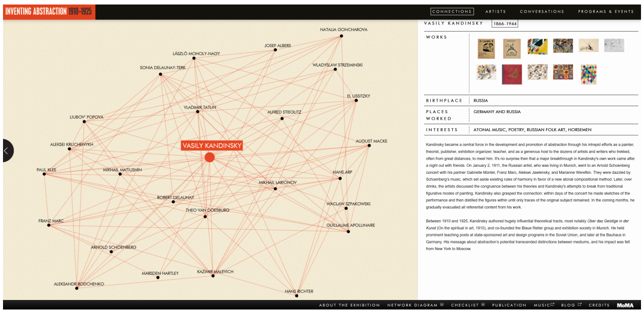


Figure 17: *MoMA Inventing Abstraction showing relationships between different abstract artists. Screenshot taken from the website [DA12, MoM].*

lected artist in the middle, as well as example paintings and additional information (see Figure 17).

Apart from ECARTICO's (Nijboer et al.) [NB*13, ECA] visualizations about artists' travels, the user can display all relationships (e.g., student-teacher, co-workers, family) and other information of an artist as a list, but it is also possible to view a three-step network of all relationships of an artist. The node colors denote the gender of the people. Another interactive node-link diagram displays the network of the painter's relatives.

Temporal and Spatial Contexts Taking into account spatial and temporal contexts can be helpful to analyze relationships according to proximity (e.g., neighborhood), nationality, different time periods, or cohorts.

Zheng et al. [ZHF*22] analyze different social relationships (e.g., student-teacher, colleague, friendships, relatives) between artists living in Shanghai in the early to mid-20th century to find the most influential art districts. Multiple maps for different years show artists' connections over time. Colored circles around groups of nodes show spatial clusters. Additionally, a stacked bar chart shows the percentages of artists' contacts from various relationship types (e.g., friends or family). Various other maps display hotspots of artists' locations or where exactly which artist lived in a main cluster.

Etro and Stepanova [ES18] investigated the distribution of talent over time. In a node-link diagram, they visualize the student-teacher relationships, distinguishing between Dutch and Flemish painters. Additionally, the numbers of students per master are visualized in a scatter plot.

Project Cornelia [BTVDS*] is an online research engine about Flemish painting and tapestry from the 17th century. Brosens et al. [BAA*19] present the project more with a focus on AH, while Lamqaddam et al. [LABV18] focus on VA (visualization and encodings). A horizontal ancestry tree displays painters, merchants, tapestry producers, and other people and their relationships (e.g., professional, godparenthood, or family). Filled bars denote the life spans of the people and their current age depending on the user selection of a year. A timeline next to the tree facilitates temporal analysis of the relationships and events.

4.6.2. Family, Friends, and Various Social Relationships

A summary of the papers about social relationships can be seen in Table 10.

Visualization Approaches Again, most of the papers used node-link diagrams to display relationships between artists and their social contacts, but there were also some other approaches. Kovacs [Kov16] visualizes various relationships between Parisian artists in the 19th century, among them friendships, acquaintances, and collaborations in **node-link** diagrams. Another node-link diagram with directed edges shows Degas' network of letter communication with his acquaintances.

Ross [Ros13] analyzed gender bias in art history with her students. They created a visualization containing female artists and their social connections to other male and female artists. Fifteen female artists and social connections are displayed in a node-link diagram where the artists are the nodes, and the node color denotes if the artist is one of the fifteen researched ones or not. A small colored mark on the nodes shows the gender of the artist and a letter their sexuality. There is also a detailed view of the network, only showing one of the 15 artists and their connections in an **ego-network**.

In their paper, Srakar et al. [SGV16] investigated the social network of Slovenian artists, most of them painters. They constructed a node-link diagram where the biggest connected component shows artists aligned in a **radial** layout around a circle with the edges in the middle. Smaller components are not necessarily radial. They are clustered by art movement and edges denote social relationships. A second network contains the same people and links in a node-link diagram.

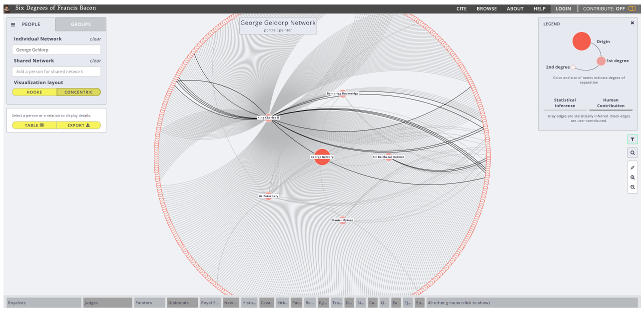


Figure 18: *Six Degrees of Francis Bacon visualizing the radial network of relationships between painters. Screenshot taken from the website. Finegold et al. [FOS*16].*

El Zant et al. [EZJRFS18] analyzed direct and indirect relationships of top painters from seven Wikipedia language versions. Three **colored adjacency matrices** with artists as nodes and all links, indirect links, and direct links between them as edges are provided. Node-link diagrams show friendship networks of artists for the French Wikipedia and the average of all Wikipedia versions highlighting the top friends per artist. Further node-link diagrams compare artists' relationships in different Wikipedia language versions, including art styles and highlighting top painters per style as well as friends of friends. Further node-link diagrams show edges from a painter to the countries their top three friends come from.

Table 10: *11 papers about various social relationships. Yellow highlights show in which part of this section the paper is discussed. Numbers in brackets denote cases in which it can be argued about the categorization.*

Vis method	**Node-link**	11	[EZJRFS18], [GAFM13], [GM19], [GM18], [FOS*16], [Kov16], [SGV16], [Ros13], [ZKKC*24], [LKB*23], [GKWV20]
	Radial	3	[FOS*16], [SGV16], [ZKKC*24]
	(Colored) adjacency matrix	2	[EZJRFS18], [ZKKC*24]
	Map with edges	1	[LKB*23]
	Ego network	3	[FOS*16], [Ros13], [ZKKC*24], [LKB*23]
	Timeline with links	2	[ZKKC*24]
	Multiple coordinated views	2	[ZKKC*24], [LKB*23]
Interaction	**Interactive**	5	[FOS*16], [Ros13], [ZKKC*24], [LKB*23], [GKWV20]
Timevis	**None**	6	
	Edges on map	1	[LKB*23]
	Implicit	4	[GAFM13], [GM19], [GM18], [ZKKC*24]
	Timeline	2 (+1)	[ZKKC*24], [LKB*23] ([GAFM13])
Spacevis	**None**	4	
	Nodecolor	3	[GAFM13], [GM19], [GM18]
	Node property	1	[ZKKC*24]
	Node	3	[EZJRFS18], [GM19], [GKWV20]
	Map	1	[LKB*23]
	Different vis per country	1	[EZJRFS18]
	Total	**11 papers**	

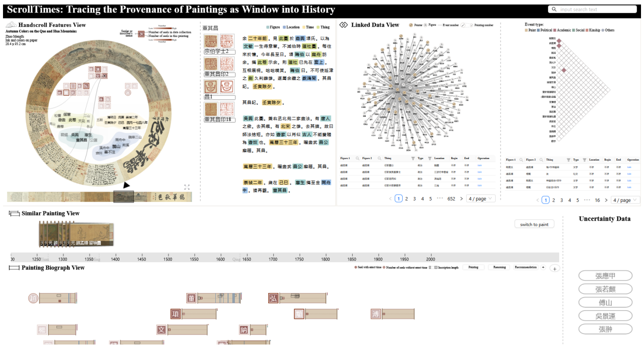


Figure 19: *Seals linked to their positions on the handscrolls and to words in the word cloud (top left), ego-network and colored adjacency matrix showing shared events between people (top right), and the linked timeline (bottom). Screenshot taken from the website. Zhang et al. [ZKKC*24].*

Interactivity Six Degrees of Francis Bacon [FOS*16,Six] interactively visualizes the social network of Francis Bacon. It is possible to only show painters (or other professions) and their relationships in the network (see Figure 18). Node size shows the degree of separation, where the origin node is the largest one, and with each step, the nodes get smaller. Its color denotes if the person is a painter. Clicking on a node shows further information and highlights links to other nodes. Two artists can be chosen, showing the people connecting them colored according to the fact that they are direct acquaintances or not. The artists can also be displayed on a timeline with bars for their life spans.

Zhang et al. [ZKKC*24, ZKKC*] created an online interactive multiple-view approach to analyze handscrolls that contain paintings, text about the painting, as well as seals of the artist and owners (see Figure 19). The scroll is visualized as a ring. When clicking on a seal, edges to its positions on the scroll are drawn. There are word clouds for time, location, figure (person), and thing. Dashed edges from the seal to words in the word clouds indicate which person wrote which words on the scroll. An ego network and colored adjacency matrix show shared events between people from the seals and those mentioned in the texts with their types (e.g., family, political, academic). A timeline shows the life spans of the artist, owners, and people who wrote or were mentioned in a text on it. Common events link the persons on the time line to each other. Further, similar paintings are displayed and there is also a view about uncertainty in the data (e.g., missing artist names or dates).

APIS [GKWV20,API] is an online database that contains biographies of famous Austrians. The user can choose a source entity type (e.g., person, place, institution), a relationship type (e.g., was artist, participated in exhibition, was student), or a target entity type, and a node-link diagram will show the selected node types and relationships. Different node colors denote their type. A click on a node displays additional information and how many connections it has to other node types (see Figure 20).

Temporal and Spatial Contexts Goldfarb et al. [GAFM13, GM18, GM19] visualized artists' connections through links be-

Figure 20: *A node-link diagram in APIS [GKWV20,API] highlighting exhibitions in which Griepenkerl exhibited. Screenshot taken from the website.*

tween their Wikipedia pages. A node-link diagram displays painters and their links with a maximum distance of 75 years between them. The node colors correspond to the painters' nationalities and also denote the clusters. Nodes are positioned according to time periods from left to right. Their other paper visualizes the same Wikipedia graph as before but with nodes colored by birth dates of the artists, as well as comparisons of the networks from eight different Wikipedia language versions. Further, the ULAN network (see Section 5 and Table 11) colored in two different visualizations by nationality and relationship type (e.g., family or teaching) is displayed, and a network linking artists to art styles, including the nationality of the artists as node colors. Another network links nationalities of the artists. Additionally, a jittered scatterplot timeline shows the temporal distribution of artists linked to art styles.

In/Tangible European Heritage (InTaVia) [LKB*23, Int] is a website where it is, among other things, possible to display a painter and their connections in an ego-network. Linked to the painter are different people, paintings, events, places, and groups (e.g., artist associations). A map with birth and death places, production sites, and event locations (e.g., workplaces) adds spatial context, while a timeline with birth and death dates and dates of the creation of paintings and other events adds a temporal one. The views are interactive and linked. A further map visualization displays stops of an artists' journey with links between them.

Summary Many papers visualized social relationships between artists, either work related or personal, highlighting the significant amount of interest in this topic.

- A huge majority of papers used node-link diagrams for visualizing social relationships, which suggests that they are useful for this purpose.
- Papers about social relationships contained most of the ego-network visualizations compared to the other relationship types we surveyed.
- Half of the approaches were interactive, facilitating the detection of connected nodes by highlighting them or enabling users to further explore networks of people connected to selected artists.
- A majority of papers included work related relationships into their approaches, highlighting the interest in interconnections between artists.

5. Digital Resources & Databases

In this section, we will discuss the datasets that were used for the papers presented in Section 4 and the online approaches from the supplementary material [TFK*25]. It is by far not a complete collection of art related datasets, but we think that it might still be helpful to see what already exists or to find a fitting dataset for the next project.

All in all over 70 different data sources were used in the 95 discussed papers and 28 online approaches (see supplementary material [TFK*25] for a thorough discussion of the online approaches). As the numbers suggest, many of the data sources were only used in one paper. On average 1.8 data sources were used per paper or online approach. The source that was used most often was Getty Union List of Artist Names (ULAN) [Getd], followed by Wikipedia [Wikd], Wikidata [Wikb], and DBpedia [DBp]. It is no surprise that Getty ULAN was very popular since it provides standardization for artist names, which can help to gather information from multiple resources and offers different kinds of relationships (e.g., student-teacher, patrons, family members) between artists and other people that can be very interesting for network analysis. There are also several cases with multiple papers by the same author or co-authors using the same dataset(s). This results in a higher count for specific datasets.

In the following, we focus on datasets available online, as we think that they might be especially interesting for the readers. They are listed in Table 11 and in the supplementary material [TFK*25]. Most are online catalogs of various museum collections. The majority focuses on artworks and often provide images and additional information, such as the artist, art style, size, date of creation, or provenance. Some collections also include extensive information about the artists or exhibitions. Another type of source are websites with online biographies and, as for ULAN, websites providing norm data (e.g., alternative names) for people, places, etc. Another big group are image datasets with different specializations, e.g., specific objects in the paintings, specific types of paintings (e.g., landscape), paintings by specific artists, in specific styles, or from certain times. There are also datasets focusing on particular artists or artists from certain countries. Some of these specialized painting or artist datasets were created using subsets of the other datasets or, for example, by crawling Wikipedia and links between its pages. The data sources also included household inventories and art market-related data, as well as two image search engines.

6. Discussion

We identified five relationship types the surveyed papers can be categorized into, which can be seen as the main topics of interest for art historians (i.e., influences, similarities, travels, art market and co-exhibition, and social relationships). This survey highlights the wide range of VA techniques used to analyze relationships in AH. The findings reveal recurring patterns, significant challenges, and opportunities for further research, advancing interdisciplinary research in these fields.

The visualization tool that was used most often in the papers was Gephi (22% of papers). Artists were the most represented subject (83% of papers), followed by artworks (25%). There were a total

Table 11: *Online available datasets used in the papers.*

DB name	Includes images	**Entries**	Time	Space
7 Topical catalogues of Venus artworks [Ben07, Ben]	yes	19,300 works from 6,648 artists	500 years	Europe
APIS database [GKWV20, API]	no	ca. 20,000 historical figures	since 1815	Austria-(Hungary)
ARC Ukiyo-e Face Dataset [TCSK21, ROI]	yes	> 11,000 paintings and > 20,000 faces		
Artemis Image Database [Ins]	yes	55,590 entries	< 1000 - 19XX	
ARTigo [WBBL13, Lud]	yes	55,590 entries?	< 1000 - 19XX	
Artl@s database [JPSRDS16]	no	> 5,000 exhibitions, > 71,000 artists, > 183,000 artworks	1673 - now	global
Artnews list of art collectors [ARTa]	no			
Brooklyn Museum Collection [Bro]	yes	> 93,000 objects, > 12,600 artists, > 2,700 exhibitions		global
Brueghel family database [Hon]	yes			
Carnegie Museum Collection dataset [Car]	no	28269 objects		
Collections from the INHA Library [Bib]	yes	> 38,000 resources in different categories	16th - 20th century	focus on French people, but also others
DBPedia [LIJ*15, DBp]	yes			
DoME Database [BMB*20, DoM]	no	> 1,300 exhibitions from > 13,200 artists, > 207,000 catalogue entries	1905-1915	mostly Europe, but also other countries worldwide
ECARTICO [NB*13, ECA]	no	65 755 persons (9706 painters)	1475 - 1725	Low Countries
Europeana [IH13, Eur]	yes	> 50 million objects		
Getty Art and Architecture Thesaurus (AAT) [Har10, Geta]	no	> 34 000 terms		
Getty Museum Collection [J.]	yes	> 110,000 artworks	BCE - present	global
Getty provenance index [Getb]	no	in total > 2,3 mio records	1520 - 1970	various European countries
Getty Thesaurus of Geographic Names (TGN) [Har10, Getc]	no	> 3 mio place records		global
Getty ULAN [Har10, Getd]	no	> 500,000 records		global
Giorgio Cini Foundation Venice [Fon]	yes	> 300,000 photos		
Google Image Search [Goo]	yes			
Integrated Authority File (GND) (WebGND) [Webb]	no	> 11 mio entries		global
Kaggle Art Challenge Dataset [Kag]	yes	50 artists, 24 - 877 paintings per artist, 8355 images in total		
kaggle Museum of Modern Art Collection [Musa]	no	> 15,000 artists and > 130,000 artworks		
Kitromilidis et al.'s painter network dataset [Kit]	no	2,113 painters		
Lee et al.'s Landscape and Abstract painting dataset [LSK*20]	links	Landscape: 14,912 paintings, 1,476 artists, Abstract: 5,780 paintings, 175 artists	Western Renaissance - Contemporary	global
LTFC online art collection [LTF]	yes			China
MoMA exhibitions dataset [Musb]	no	1,788 exhibitions, 11,550 constituents	1929 - 1989	
MoMA Inventing Abstraction [DA12, MoM]	no	> 80 artists and their connections	1910 - 1925	
Musée d'Orsay Collection [Musc]	yes	> 150,000 artworks	19th and 20th century	global
Musée du Louvre Collections database [Musd]	yes	> 500,000 artworks		global
National Gallery of Art (Washington D.C.) open dataset [Natb]	links	> 130,000 artworks and their artists		
National Palace Museum Open Data [Natc]	yes	228 exhibitions, > 25,000 artworks (3,824 paintings), 204 nominal + numerical datasets	different dynasties and periods	China
Österreichisches Biographisches Lexikon (ÖBL) [Ö22, Ö]	no	> 18,000 historical figures	1815-2010	Austria(-Hungary)
Oxford Dictionary of National Biography [Oxf]	no	> 63,000 biographies		focus on British people
Painting91 dataset [KBVdWF14, KBVdWF]	yes	91 artists, 4,266 paintings		
RKD artists database [RKDa, RKDc]	yes	> 350,000 artists etc.		global (but focus on Dutch and Flemish people)
RKD image database [RKDb, RKDc]	yes	> 250,000 artworks		global (but focus on Dutch and Flemish art)
Schich's dataset [SSA*14]	no	> 150.000 people	> 2,000 years	global
SemArt Dataset [GV18a, GV18b]	yes	21,384 paintings		
Slovenska Biografija dataset [Slo]	no	> 5,000 people	1500 - now	global, but focus on Slovenia
Smithsonian American Art Museum collection [Smi]	yes	46,485 artworks, 8,716 artists, multiple current, past, and traveling exhibitions		global, but focus on american art
Song Dynasty Paintings Database [Men]	no	1463 paintings and their artists etc.	960 - 1279	China
Tate Gallery Collection Dataset [Tat]	link	about 70,000 artworks, 3,532 artists		
The British Museum [Bri]	yes	nearly 4.5 mio objects		global
The Met Museum Open Access dataset [Met]	yes	> 490,000 artworks	5,000 years	global
The National Gallery, London [Nata]	yes	> 2,600 paintings and other artworks		global
The Rembrandt Database (part of RKD images) [RKDd]	yes	700 paintings		
VIAF (Virtual International Authority File) [VIA]	no			
Web Gallery of Art (WGA) [Weba]	yes	> 52,800 objects, > 6,300 artists	3rd - 19th century	focus on Europe
WikiArt [Wika]	yes	> 100,000 artworks, > 4,000 artists	32nd century BC - now	global
Wikidata [Wikb]	yes	> 114.8 mio entries		global
Wikipedia [Wikd]	yes	> 64 mio articles across languages		global
Yahoo Image Search [Yah]	yes			global
Young Joon Oh's dataset [Oh17]	no	173 people	Renaissance	global

of 28% of papers with interactive approaches, which were most often used for conveying social relationships as compared to the other surveyed relationship types. Most papers used 2D approaches (97%), followed by 3D (5%) and 1D (2%), where all of the 1D approaches and some 3D ones were used together with 2D ones. While 23% of papers used only networks with no additional views. 21% of papers had bar charts as a supportive visualization. Temporal aspects appeared in 53% of papers and spatial ones in 44%, with time often shown implicitly (28%, e.g., node color) and space as nodes (18%) or on maps (13% of papers). Temporal aspects were used across all the different relationship types we surveyed, spatial ones especially for conveying the travels of artists and artworks, but also across all other relationships. The most popular topic for comparisons were different time periods (17%), multiple visualizations for comparisons were used by 46% of papers. Node-link diagrams were the most popular (83%), followed by tree visualization (18%).

For visualizing the travels of artworks or artists, the spatial aspects are especially important. As they can be best displayed on maps, it is no surprise that this was the prevalent visualization method in this case. (Colored) adjacency matrices, Dendrograms, and phylogenetic trees were most often used by papers visualizing similarity relationships as compared to other relationship types. This could be due to their characteristics, which make it possible to group similar objects together or create hierarchies. Other tree visualization types were most often used for visualizing influences compared to other relationship types, partly due to the fact that some of them tried to remodel two of the tree visualizations presented in the section about hand-drawn visualizations. In comparison to other relationship types, ego-networks were most often used for displaying social relationships. Their layout, which typically places one node in the middle (ego) and aligns nodes connected to it in a circle often reduces clutter caused by overlapping nodes or edges and thereby facilitates the analysis of relationships of an object of interest. However, 2D node-link diagrams dominate the visualization approaches of networks in AH across all surveyed relationship types except travels of artworks and artists. While effective for straightforward connections, like influences or co-exhibitions, they become increasingly difficult to interpret with the network's density. This makes extracting insights challenging. In contrast, VA offers diverse network representations and analysis techniques beyond node-link diagrams, such as adjacency matrices, radial layouts, and hybrid approaches. This broad range of techniques presents valuable opportunities for art historians to explore and communicate complex relational data more effectively. For instance, adjacency matrices by Lee et al. [LSK*20] and radial layouts by Balaceanu and Takeda [BT16] provide clean, structured views of dense networks. Combining these with node-link diagrams or timelines, as Fraiberger et al. [FSR*18] demonstrated in their analysis of global art exhibitions, highlights multiple perspectives. In the following, we discuss observations and insights gained while conducting this survey.

Beauty or Clarity A recurring challenge in network visualization lies in balancing visual appeal with an analytical utility. This is the trade-off between the aesthetics, computational complexity, and the ability to effectively represent the underlying network structure clearly. Dense networks represented as node-link diagrams often result in "hairball"-like visualizations and obscure meaningful patterns. For example, Kolesnik et al. [KBŠ16] employed eigenvector centrality to emphasize key figures within Mavignier's network, achieving clarity while maintaining aesthetics and appeal. Similarly, Goldfarb et al. [GAFM11] used 3D information landscapes to cluster entities intuitively, providing beauty and interpretability.

Balancing aesthetics and clarity within network visualization is a major challenge also relevant for AH. Visually communicating and presenting research insights are often as important as the analysis itself. Ensuring that the output is not only informative but also compelling is a non-trivial challenge that is also central to VA. In this sense, alternative or hybrid network representations present a pressing topic for future research [FAM23]. Visualization approaches such as layered networks, radial layouts, or even hybrid approaches (i.e., combining adjacency matrices with node-link diagrams) could provide new ways to manage complexity while preserving a sense of visual appeal. Such approaches offer flexibility and allow for the prioritization of specific aspects of the data or design.

Shades of Truth Art historical data is often ambiguous or incomplete and needs a careful and thoughtful representation of this *uncertainty*. Recent advancements suggest using mathematical and logical models to represent uncertainty as a range of values in network visualizations [CGH*24]. This approach offers a nuanced way to depict uncertain relationships, effectively addressing ambiguities often found in humanities data. In practice, uncertainty can be represented visually through varying edge opacities, dashed lines, or gradient colors to indicate levels of confidence or ambiguity. For example, Schikora and Isemann [SI17] tackled this by varying edge transparency and thickness to denote the confidence of influence relationships. El Zant et al. [EZJRFS18] analyzed painter networks from multiple Wikipedia language versions, differentiating direct and indirect relationships. They encoded probabilities with edge colors, capturing uncertainties in relational strength and enabling comparisons across language versions.

Integrating uncertainty representation into narrative-driven visualizations represents an ongoing challenge. VA approaches and tools that combine visualization methods with storytelling techniques and consider uncertainty could make the data more transparent, accessible, and engaging. Additionally, establishing visual standards for depicting uncertainty—whether through edge or node visual markers or dedicated uncertainty visualizations—could provide transparency and clarity about the data quality and completeness. This is especially important in interdisciplinary settings where art historians and visualization experts collaborate.

The Art of the Story Transforming static network visualizations into compelling narratives presents a novel research direction. Unlike linear stories, networks are intricate webs of interconnected relationships, making it challenging to weave coherent narratives. Interactive approaches like EdgeMaps [DCW12, DCW] offer a starting point. Allowing users to explore relationships dynamically, zoom into specific areas of interest, and filter information can empower them to construct narratives from networks. However, simply providing interactivity is not enough. We must develop more sophisticated strategies for guiding toward insightful and engaging story-driven interpretations. Guiding viewers with questions like

"Who are the key influencers?" or "How did this art style spread?" encourages to explore specific storylines. Animating the network to show how relationships evolve over time can reveal dynamic narratives and highlight key turning points. Research has explored innovative approaches, such as graph comics [BKH*16] to effectively communicate dynamic network changes to a general audience. Streamlining the creation of comics [KLN*25] makes it easier to transform dynamic graph data into engaging visual narratives.

This presents a notable direction for future research: augmenting network visualizations for storytelling, which would provide a deeper understanding and inspire new insights. Developing intuitive and user-friendly interfaces and seamlessly integrating these techniques would empower researchers and the general public to communicate and share their network-based narratives effectively.

Computational Frontiers Computational techniques are transforming art historical research, empowering scholars to delve deeper than ever before. Network analysis, employing methods like centrality measures [FHIE12, McC19] and community detection [FSR*18] have become indispensable. It allows to uncover hidden patterns, identify key players, and understand the evolution of art scenes in ways that were previously not possible. Today, machine learning algorithms and models are crucial to analyzing visual features, identifying stylistic similarities [Seg18,RG22,NS21], and inferring artistic influences [CDSV22]. Furthermore, text mining techniques, as exemplified by Arends et al. [AFG*12] and Noble et al. [NVCD22], extract valuable insights from textual data, such as artwork tags, exhibition catalogs, and artist biographies, mapping relationships and understanding critical reception.

These computational approaches are not only tools—they offer art historians a new perspective on their data and enable them to generate new hypotheses, challenge existing theories, and present their findings in more engaging and accessible ways. Moving forward, research should focus on developing more sophisticated algorithms to uncover nuanced relationships, such as subtle forms of influence and conceptual or stylistic affinities. Advancements here will improve our understanding of AH and open new avenues for research and collaboration between disciplines.

The Best of Both Worlds The true potential of VA and AH lies in fostering interdisciplinary collaborations between art historians and visualization researchers. While art historians possess deep domain expertise in AH, their knowledge of cutting-edge visualization techniques may be limited. Conversely, VA researchers often lack the understanding of art historical concepts and research questions necessary to develop effective and insightful visualizations. By bridging this gap, interdisciplinary collaborations can lead to transformative outcomes. AH can provide crucial context, guiding the development of visualizations to address specific research questions and reflect the complexities of art historical data. In turn, VA researchers can introduce novel techniques to enable art historians to see and explore data in new and insightful ways.

This exchange is not a one-way street. AH can also contribute to the VA field. The rich historical and cultural context in AH can inspire new visualization idioms and metaphors, challenge existing assumptions about data representation, and design more human-centered and culturally sensitive visualizations. A genuinely interdisciplinary approach requires a shared understanding of each field's unique challenges and opportunities. Open communication and collaborative research projects provide the foundation for this interdisciplinary research. Future work should focus on developing frameworks and methodologies for interdisciplinary collaboration.

Limitations We recognize that there exists a substantial body of work dedicated explicitly to other types of data visualization—such as visualizations of stylistic similarity, geographic diffusion without explicit links, or temporal trends in isolation. These are, however, out of our present scope. For example, scatterplots may show clusters of similar artworks but lack the explicit links needed to represent relationships such as artistic influence, collaboration, or exhibition co-occurrence. Similarly, timelines or geographic maps without links are limited in their ability to convey how nodes (e.g., artists or artworks) interact or are related across time or space. We also decided to focus on paintings and exclude contemporary art. We assume that contemporary art with its diverse range of media, forms, and practices, offers exciting opportunities to extend the present exploration. Finally, since our literature research primarily focused on digital resources, analog sources are not considered.

7. Conclusion

In this survey, we investigated the impact of network visualization on art historical research, showcasing its ability to bridge the gap between traditional qualitative methods and modern computational approaches. We identified five relationship types the surveyed papers can be categorized into and concluded that these indicate especially interesting research directions for art historians. By focusing on the main subjects and their relationships, we illustrate how network visualization enables the exploration and analysis of the complex and intricate relationships in art historical networks. The increasing integration of VA in AH (as well as AH in VA) presents new directions for analyzing artistic influence, stylistic transitions, and social networks. Dynamic, interactive visualizations and computational methods provide novel perspectives, complementing traditional qualitative narratives. Maps were predominantly used to visualize travels of artists and artworks and in comparison to their usage for visualizing other relationship types, (colored) adjacency matrices, dendrograms, and phylogenetic trees were most often used for depicting similarity relationships, while other tree visualizations were used more often for showing influences, and ego-networks for social relationships. However, the field remains primarily dominated by 2D, node-link-centric approaches, underscoring the need for alternative or hybrid approaches to represent and explore complex relationships. While network visualization has advanced our understanding of historical and social dynamics, there are also challenges in effectively visualizing ambiguity, uncertainty, incompleteness, and temporal evolution. The trade-off between aesthetic appeal and interpretability remains a central consideration, particularly given the communicative priorities of AH. Addressing these challenges requires interdisciplinary collaboration to design techniques that meet both the analytical and interpretative needs in both fields. For future research, network visualization for sub-domains within AH that include other time frames or art forms could be surveyed and compared to the results of our survey.

In conclusion, this survey highlights the growing importance of network visualization in advancing AH research. By bridging VA with AH inquiry, these approaches provide a better understanding of complex historical relationships and open the door to innovative, interdisciplinary collaborations that can reshape the field.

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