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„A Synoptic Visualization Framework for Artwork Collection Data and Artist Biographies“

verfasst von / submitted by

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Abstract

This thesis surveys, synthesizes and develops visualization methods for the support of knowledge creation and communication in two historiographic subject areas. On the one hand, it explores visualization approaches to artwork collections. On the other hand, it investigates visualization approaches to biography data with specific regard to artist biographies. While both fields of study have seen a substantial increase of digital research endeavors lately, they arguably require a systematic development effort on multiple levels. Firstly, a documentation of visualization options is needed to assemble and critically assess available representation techniques. Secondly, the existing multitude of techniques have to be connected by productive syntheses, to create domain-specific visualization systems supporting scholarly inquiry with multiple analytical perspectives. Thirdly, the thesis argues for the relevance of representing historiographical context. It develops designs to mutually contextualize the works and lives of historical cultural actors—and to situate both in the polycontextual environments of bigger historiographic pictures.

Kurzfassung

Diese Arbeit entwickelt und synthetisiert Visualisierungsmethoden zur Unterstützung der Wissensgenerierung und Wissenskommunikation in zwei historiografischen Themenfeldern. Zum einen werden Visualisierungsansätze für Kunstsammlungen untersucht. Zum anderen werden Visualisierungsansätze für Biografiedaten unter besonderer Berücksichtigung von Künstlerbiografien studiert. Während beide Themenfelder in letzter Zeit eine deutliche Zunahme von digitalen Forschungsanstrengungen zu verzeichnen haben, so erfordern sie darüber hinaus eine systematische Entwicklung auf mehreren Ebenen. Erstens ist eine Dokumentation von Visualisierungsoptionen erforderlich, um verfügbare Darstellungsmöglichkeiten zu versammeln und kritisch zu bewerten. Zweitens sollte die vorhandene Vielzahl von visuell-analytischen Techniken durch produktive Synthesen verbunden werden, um feldspezifische Visualisierungssysteme zu schaffen, die entsprechende Arbeiten mit multiplen analytischen Perspektiven unterstützen. Drittens argumentiert diese Arbeit für die Relevanz der Darstellung von historiografischem Kontext. Sie entwickelt zu diesem Zweck Entwürfe, um die Werke und Biografien von kulturellen Akteuren in Beziehung zu setzen – und beide in die polykontextuellen Umgebungen von größeren historiografischen Bildern zu integrieren.

Preface

For the better and for the worse—the revolution has been sufficiently sermonized. Digital times have found us, and they keep changing our lives and works. Many parts are moving fast—forward, sideways, through the webs. Things are breaking, others assemble, while most are just transforming one way or the other. Immersed in translations, we rarely see clearly, yet we move and make do.

Digital times have also found the humanities, and the critical reception has been mixed. Without dismissing any reasons for discontent, this thesis will reflect on the apparent changes as a chance. As for a working hypothesis, it assumes that the digital transformation profoundly affects how cultures can perceive, reason with, or know about themselves and their complex archives and histories. Together with new aggregate states of information, digital times also bring about new extensions and augmentations for human cognition (Arias-Hernandez et al., 2012; Hayles, 2012). While opening a yawning abyss of data—wherein the mundane content streams of restless populations, economies and cultural industries, but also from galleries, libraries, archives and museums converge—they also provide new means to cope with the data deluge. As such, this thesis is fascinated by new options to contemplate, analyze, explore, and make sense of the accumulated riches of our late-modern culture. More specifically, it will contend, that *visualization technologies* deserve our close attention, when it comes to art-historical sensemaking in changing, digital times.

As a wanderer between historical layers, I've been formally trained in traditional humanities fields only, yet I also had the luck to work my way into some of their digital and visual modalities. The thesis at hand documents a part of this journey, and it connects and contextualizes four segments of its trajectory. However—to state the obvious—no part of it would have been possible without contemporary travelers and benefactors, who joined forces along the way, who supported, enabled, or resonated with this endeavor. Some of the most indispensable actors are documented in the co-author line-ups of this cumulative work. Most relevant others conveyed their supportive magic out of adjacent institutional, scholarly, critical, familial and friendship spheres. To all of them, I want to convey my sincere thanks. I consider myself lucky to share your ways.

1 Introduction

The digital transformation has created new research and teaching practices in the whole ecosystem of academia (Meyer & Schroeder, 2013; Pearce et al., 2011). The datafication of societal and cultural practices also influences knowledge production and mediation in the arts and humanities, where subject matters are rarely digital by nature (Schäfer & Van Es, 2017). As a result, numerous humanities disciplines have seen a growth of digital peripheries, which complement the traditional methodological cores with dynamic areas of scholarly activity (Gold, 2012; Gold & Klein, 2019; Schreibman et al., 2004). This thesis locates itself in this nascent area of development, and it is motivated by the impression that humanities domains will only benefit from the flurry of computational offers and imports if digital tools and methods will be critically assessed, consciously adopted, and epistemologically re-appropriated. Arguably, this endeavor requires a substantial amount of attention and guidance from every specific knowledge domain in the humanities, including history, where the research questions and research aims of this thesis are situated.

Among the most salient methodological innovations discussed in Digital Humanities (DH) fields of study are technologies that aim to support human analysis and interpretation of data and information sources—and which utilize techniques of *visualization* for that end (Benito-Santos & Sánchez, 2020; Bradley et al., 2018; Jessop, 2008). Going beyond the use of well-established realistic imaging procedures (such as photographs or 3D scans), methods of *data* or *information visualization* provide a whole spectrum of novel representation options for topics usually processed by academic prose only.[1] The visual encoding of data enables scholars to explore and analyze var-

[1] For recent efforts to provide interactive overviews on visualization methods and techniques, see https://datavizcatalogue.com/, http://visualizationuniverse.com/, or https://datavizproject.com/.

ious aspects of their subject matters also visually (thus also ‘visual analytics’ technologies) from various viewpoints and perspectives.[2] As such, these methods can support laborious and complex tasks of information processing across different levels of scale in the context of research and teaching.[3]

Research Aims

This thesis is dedicated to the assessment and further development of such DH visualization methods, with a specific focus on the *history of the arts*. It aims to explore and examine visualization methods in order to consolidate their future use in a historiographic context. From a technical and methodological perspective, it is a tools and methods development project in a digital history realm. Works in this area do not directly contribute to the body of historiographical knowledge but aim to substantially support future endeavors of historians’ knowledge creation and communication. The epistemological interest thus shifts from guiding questions such as “*What happened?”*, *“How?”* and *“Why*?” to “*How can we best possibly support future research and teaching efforts (dedicated to answering these questions) with novel means?*” (Galey & Ruecker, 2010).

More specifically, this thesis focuses on the visual representation of two subject matters in the area of art history: On the one hand, it will center on options to visualize *artwork collections* (A). On the other hand, it will investigate methods to visualize the *lives and biographies of artists* (B). While the project will thus develop new methods in a subfield of history, it expects its findings and results to be of relevance for the representation of numerous other time-oriented phenomena and topics from general history later on (see ch. 5).

[2] As they essentially depend on the existence and availability of structured data, visualization methods can be directly applied to analysis or mediation on humanities topics where metadata (e.g. on cultural objects, actors, or source collections) is directly available. For all other scenarios, the pre-processing of natural information sources (i.e., mostly texts or images) and the corresponding extraction or creation of data is a precondition to proceed digitally and visually.

[3] Concerning the analysis of *text*, visualization methods have been prominently discussed as novel options enabling the “macroanalysis” (Jockers, 2013) or “distant reading” (Moretti, 2013; Underwood, 2017) of complex corpora. Yet also the support of micro-level interpretation (i.e. of “close reading” activities) and of navigation between macro and micro levels of text analysis are seen as essential development aims (Jänicke et al., 2017; Jänicke et al., 2015; Kucher & Kerren, 2015). Similarly, the analysis of images and image collections is a rich and growing research field, where visualizations frequently play a substantial role to support analyses on a large scale (Klinke & Surkemper, 2016).

Research Questions

The study of artwork collections and biography data has seen a vivid increase in digitization endeavors lately. These developments have already spurred a multitude of corresponding computation and visualization initiatives, which would benefit from a critical assessment and further development on multiple levels:

i. While many interesting visualization techniques have been developed in parallel, the corresponding research fields are nowhere close to well-structured or consolidated. Both tool developers and users cannot rely on conceptual orientation or synoptic overviews up to now. As such, there is a specific need to survey the state of the art, and to collect existing visualization options. Going beyond documentation, there is a specific need to critically assess the strengths and limitations of existing techniques, to derive domain-specific development challenges for each field, and to initiate the participatory design of future DH visualization systems.

ii. Amounting to a cross-domain challenge, the multitude of existing visualization techniques has not been addressed with efforts to create meaningful synergies and syntheses up to now. To pave the way for the development of more integrated visual research environments, there is a need for a synthetic and synoptic approach to the areas of artwork and artist biography visualization. Relevant representation techniques have to been drawn together into tailored and coherent visualization systems, combining and mediating multiple interpretive perspectives.

iii. As for traditional descriptions of historical subject matters, *contextualization* is also essential for scholarly visualizations. Yet works and lives of cultural actors are commonly treated as two separate data collections, which cannot complement or contextualize each other. To change this state of affairs, a synthesis of both areas is needed, and further options are required to visualize artists' lives and works in larger historical contexts and on various levels of temporal, spatial and structural granularity.

This thesis addresses these challenges (i. survey, ii. synthesis and iii. contextualization) with regard to artwork collections and artist biography data. For this purpose, it will work along a two-pronged roadmap, which results from the parallel arrangement of its guiding research questions (see Table 1).

For both areas of artwork collections (A) and biography data (B), it will i) explore which visualization methods are available in general, to assess their strengths and weaknesses, and to derive future development options. Building on this assessment it will ii) explore ways to combine and connect these representations into more tailored and coherent visual analytics environments. Finally, it will iii) explore how to connect and combine both topic areas, which show the potential to complement and mutually contextualize each other. Furthermore, an argument will be developed that the resulting representations will substantially benefit from additional techniques to visualize macrohistorical contextual information. This will lead to novel contextual visualization strategies, which will be sketched out for future implementations.

Table 1: Research questions and intended thesis architecture

	i)	ii)	iii)
A	What is the state of the art of artwork collection visualization?	How to synthesize artwork collection visualization methods into a coherent framework?	How can we draw together methods of biography and artwork collection visualization for their mutual contextualization?
B	What is the state of the art of narrative and biography data visualization?	How to synthesize biography visualization methods into a coherent framework?	How can we situate the resulting representations in environments of macro-historical context?

Cumulative Writing Approach

This thesis builds on a cumulative architecture to integrate and connect four publications accepted for scholarly journals in 2017 and 2018. These papers develop answers to the first four research questions. While questions A1 and A2 are addressed in chapter 3, responses to questions B1 and B2 are tied into chapter 4. These two main components will be conceptually integrated and contextualized by chapter 5, which also develops synoptic answers and design strategies concerning question (A+B) 3, as sketched out in more detail below.

A (1+2) On Visualization of Artwork Collections (Chapter 3)

- Windhager, F., Federico, P., Schreder, G., Glinka, K., Dörk, M., Miksch, S., & Mayr, E. (2018). Visualization of Cultural Heritage Collection Data: State of the Art and Future Challenges. *IEEE Transactions on Visualization and Computer Graphics 25*(6), 2311–2330. DOI: https://doi.org/10.1109/TVCG.2018.2830759 ▸▸▸ With regard to research question A1, this study surveys the state of the art of artwork and cultural collection visualizations and discusses future research challenges. The publication also developed an online browser for scholarly and public audiences to access and compare all the surveyed visualization systems. It is available at: http://collectionvis.org.

- Windhager, F., Salisu, S., Schreder, G., & Mayr, E. (2018). Orchestrating Overviews. A Synoptic Approach to the Visualization of Cultural Collections. *Remaking Collections. Special Issue of the Open Library of the Humanities*, *4*(2), 1–39. DOI: https://doi.org/10.16995/olh.276 ▸▸▸ This publication answers to the question A2, how to draw together multiple visualization techniques. It summarizes multiple visualization perspectives on artwork collections and develops an integrated and synoptic approach to cultural collection visualization.

B (1+2) On Visualization of Biography Data (Chapter 4)

- Mayr, E., & Windhager, F. (2018). Once upon a Spacetime: Visual Storytelling in Cognitive and Geotemporal Information Spaces. *ISPRS International Journal of Geo-Information*, *7*(3), 96. DOI: https://doi.org/10.3390/ijgi7030096 ▸▸▸ This publication answers to question B1, collecting and discussing multiple options how to represent narratively structured data in geo-temporal information spaces. It then puts a focus on visualization of biographies, as historiographic accounts, based on methods of narration and storytelling.

- Windhager, F., Schlögl, M., Kaiser, M., Bernad, Á., Salisu, S., & E. Mayr (2018). Beyond One-dimensional Portraits: A Synoptic Approach to the Visual Analysis of Biography Data. In A. Fokkens, et al. (eds.) *Proceedings of BD-2017 - Biographical Data in a Digital World*, CEUR-Proceedings, Linz, Austria. Available at: http://ceur-ws.org/Vol-2119/paper11.pdf ▶▶▶ This publication answers to both question B1 and B2: It summarizes state of the art methods and synthesizes a multi-perspective visualization framework for biography data. In its second part it discusses future research challenges.

A+B (3) Contextual Visualization of Collection and Biography Data (Chapter 5)

Chapter 5 will reflect on the two core topics (A and B) from a wider, contextual point of view. Thus, it shifts the focus to *research question 3* and develops synoptic options to bring together visualization perspectives on biography data and artwork collections data. Despite obvious interdependencies—both genres have remained virtually unconnected up to now. Thus chapter 5 explores how an integrated visualization framework for both DH data types could be achieved, so that representation of artists' lives and works can actively contextualize each other. Furthermore, this part will stress the relevance of representing additional *historiographical context*, when engaging in scholarly information visualization. Chapter 6 will develop an outlook, and discuss various research aims, which we consider worth pursuing.

2 Methodology and State of Research

With their focus on digital and visualization technologies, the central research questions of this thesis open a fairly recent, but also a quite diversified and patchy field of investigation. Thus the articles, which respond to the first four research questions (i.e., on the state of the art in collection and biography visualization (A1 and B1), and on developing synoptic visualization frameworks (A2 and B2)), will assemble sources from rather scattered and hitherto unconnected fields of work. The corresponding state of research will be assessed by each publication for itself with a specific focus on their respective research questions. Taken together, their bibliographies include more than 300 contributions, which bring together large parts of the international state of the art, as seen from four specific perspectives. This cumulative architecture—bundling the readers' attention into four focal points—requires an initial exposition and contextualization. This chapter will do so with specific regard to so-called 'humanities approaches' to visualization, and it will lay out relevant methodological choices thereafter.

Visualization in the Context of the Arts and Humanities

Visualization techniques are generally developed to support human cognition activities and to accelerate sensemaking processes in face of abstract data (Arias-Hernandez et al., 2012; Card et al., 1999). They aim to foster and amplify mental procedures of analytical reasoning, the synthesis of information, and the creation of insights with regard to "*massive, dynamic, ambiguous, and often conflicting data*" (Cook & Thomas, 2005).[4]

[4] As such, most visualization projects are predominantly aiming for the function of *intelligence amplification* (IA), as opposed to the development of *artificial intelligence* (AI). Brooks (1996) introduced this distinction to emphasize the indispensable value of human intelligence for a whole variety of application domains, where the full automation of information processing and analysis is no option, but intelligence-amplifying techniques can make a big difference (AI > IA). Digital humanities fields are in dire need of many such techniques, while also the interconnection of AI and IA technologies currently emerges as an imminently relevant field of study (Endert et al., 2017).

Since the advent of high-performance browsers, a multitude of web-based visualization tools and libraries have been developed and made available, which allow the quick creation of standard representations (Bostock et al., 2011). Yet, visualization design for humanities data and topics is known to bring along genuine challenges: If only visualization 'hammers' are available or easily accessible, many interfaces to humanities data are in danger to end up as nail beds, featuring off-the-shelf standard techniques such as pinpointed maps and sparse network graphs (Bradley et al., 2018). Against this background, it is necessary to critically assess and re-appropriate existing techniques and to derive domain-specific development agendas. Many contributions stress the need of humanities scholars to substantially participate in the design of future visualization technology to overcome a technology and tool-driven approach to DH research, and to enable a new generation of 'ecologically validated' interfaces through critical or post-digital approaches (Andrews & van Zundert, 2018; Berry, 2014; Bishop, 2018; Correll, 2019; D'Ignazio & Klein, 2016; Dörk et al., 2013; Drucker, 2011a, 2013b; Hinrichs & Forlini, 2017; Jänicke, 2016; Kohle, 2013; Lamqaddam et al., 2018; Meister et al., 2017; Wiencek, 2018; Windhager et al., 2018b; Wrisley, 2018; Zorich, 2013). The proposed thesis will contribute to these developments and make specific use of *two guiding principles*, which have been introduced and discussed by various intersectional humanities and visualization proponents.

Designing for a Plurality of Interpretive Perspectives

The first principle—which I will refer to as "*multiperspectivity*"—aims for the "*generous*" implementation of representation techniques to "honor complexity and represent diversity" (Whitelaw, 2015). To mirror interpretive richness and diversity in the arts and humanities, this design principle strives to provide a "*plurality*" of perspectives and access points for the interpretation of complex data collections (Dörk et al., 2013). As an essential interface design strategy—what Drucker (2013a) terms "*parallax*"—the principle of multiperspectivity will be guiding the work in phase II of this thesis (see Table 1). Drawing from the multiple perspectives documented in phase I, it will inform the conceptualization (and prototypical implementation) of multi-perspective visualization systems for artwork collection and biography data.

However, this thesis will also place a special emphasis on overcoming a cognitive side effect of multiperspectivity. Visualization tools that utilize a plurality of perspectives select different ways to ‘cut’ into the complexity of any given data, to highlight particular aspects of the data, and to merge them into ‘complementary composites’ (Whitelaw, 2015). The standard technique to do so is *coordinated multiple views* (Dörk et al., 2017; Roberts, 2007, Roberts et al., 2019), yet they come with a variety of downsides on their own. These include the splitting of users’ attention (Ayres & Cierniak, 2012), a significant amount of visual complexity (Baldonado et al., 2000), and arguably the prevention of the construction of a coherent and functionally integrated ‘bigger pictures’ of a complex subject matter (Windhager et al., 2019c). Figuratively speaking, multiple views allow us to grasp, see, and sample vital parts of the proverbial elephant while hindering us to see the whole, dynamic organism in its particular context. If users want to overcome this state of affairs, they commonly have to (re)connect and (re)assemble the partial impressions from multiple views for themselves, which turns out to be a demanding cognitive task (Windhager et al., 2019c).

Against this background, this thesis makes use of the “PolyCube” visualization framework, which has been steadily developed over time (Federico et al., 2011, 2012; Mayr et al., 2019; Salisu et al., 2019; Smuc et al., 2012, 2015; Windhager & Mayr, 2011, 2012; Windhager, 2013, 2019; Windhager et al., 2008, 2011, 2016a, 2017, 2019a, 2019c, 2020).

Its main aim is to flexibly combine a plurality of synchronic and diachronic perspectives, while deliberately supporting cognitive information integration with a variety of ‘coherence techniques’ (Schreder et al., 2016; Windhager et al., 2019c, 2020;). These techniques include the coordination of views (Baldonado et al., 2000), various perspectives for integrated encoding of time (Kriglstein et al., 2014), and animated canvas transitions (Bach et al., 2017) to ensure the analysts preservation of mental maps (Eades et al., 1991), and a high visual momentum during the switching of multiple perspectives (Bennett & Flach, 2012).

Designing for Context

As a second design principle emerging from the humanities-related discourse on visualization, "*contextualization*" will play a central role. Arguably, from a data modeling and computation point of view, its need has firstly been advocated by the linked (open) data movement (Bikakis & Sellis, 2016; Bizer et al., 2009). In the context of humanities approaches to interface design, the representation of context has been notably advocated for by D'Ignazio and Klein (2016, 2020), and its major implications for future interface design has been discussed across various places (Grossner & Hill, 2017; Hooland & Verborgh, 2014; Hyvönen, 2012, 2020; Oldman et al., 2015; Windhager et al., 2016a, 2018c).

With this second strategy, the dominant focus on interface design for local DH data silos should be extended and possibly transcended. To localize both topics of collection and biography visualizations in a wider cultural and historical data context, the last part of this thesis (ch. 5) develops design strategies to additionally visualize contemporaneous (as well as preceding or succeeding) phenomena. Events and developments in the larger field of art, as well as in non-artistic fields of society (such as politics, science, economy, religion, or technology), which are of frequent relevance for the sensible interpretation of biographies and cultural objects will thus become accessible (Ziemann, 2007). By also mapping the mutual influences between these fields, relational macro-contextual information can be added (including alliances and conflicts) and artists' works and lives can become visible in the environments of bigger historiographic pictures (see sec. 5.3.1 and 5.3.2).

Research Methods

This thesis develops contributions to contemporary DH research on three levels: i) It surveys and assesses existing visualization methods for two historiographic research domains (artwork collections and biographies), ii) it synthesizes selected methods into two multi-perspective visualization systems, and it iii) outlines a synthesis of these two systems within a larger framework of contextual historiographic visualization.

As a contribution to the field of DH methods and tool development, the outlined parts of the thesis can be reframed as contributions to a larger software and systems development cycle (Figure 1).

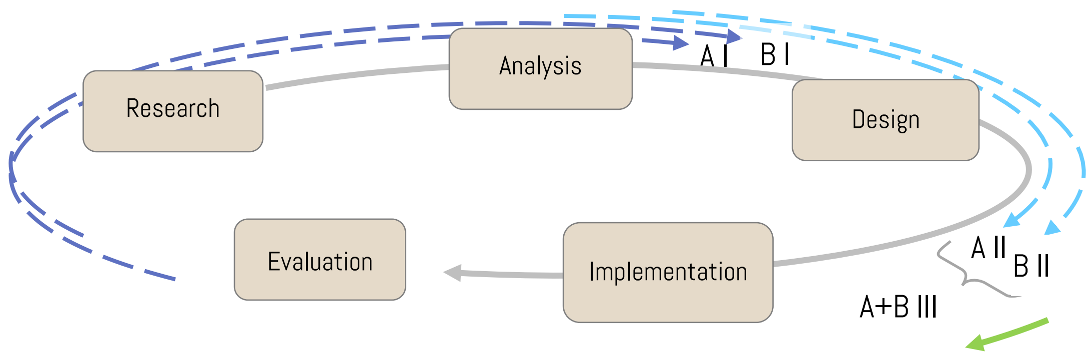

Figure 1: Standard segments of software development process cycles (beige), with the localization of main components of this thesis (arrows in dark and light blue, green).

State of the art surveys collect and organize existing visualization techniques, to assess their strengths and limitations, and to derive future research and design challenges (arrows in dark blue). Design papers are well-advised to build on surveys and results from user, data, and task analyses (Miksch & Aigner, 2014; Munzner, 2009) to develop domain-specific visualization designs (arrows in light blue).

Concerning models of information systems development, endeavors of field surveys (i) and system design (ii) thus are substantial contributions to visualization development, as they assess existing achievements, and lay ground for future stages of implementation and evaluation (Hevner & Chatterjee, 2010; Nunamaker et al., 1990; Peffers et al., 2007). All concrete efforts for the creation of system and literature surveys (i), as well as system designs (ii), then are following their own methodological procedures and guidelines.

i. **Visualization Surveys**: Literature surveys are obligatory components of research endeavors on various scales. As such, multiple methodological guidelines (such as Booth et al., 2016; Budgen & Brereton, 2006; Hart, 2018; Torraco, 2005; Webster & Watson, 2002) helped to collect, asses and organize the work for publications A1 and B1. With regard to visualization research, these paper-oriented survey methodologies have been extended to also cover interfaces, systems, and works from a non-academic context (Windhager, Federico, et al., 2018). As for the interactive presentation of systems, surveyed by publication A1 (see http://collectionvis.org), a widely used state of the art-browser has been utilized (Beck, 2014).

ii. **DH Visualization and Systems Design**: Visualization research has developed a body of general methodological guidelines for interface and information systems development, including concept and design (Miksch & Aigner, 2014; Moere & Purchase, 2011; Munzner, 2009, 2014). Recent contributions added highly relevant aspects for visualization development in the digital humanities realm, including performative prototype research and participative design (Bradley et al., 2018; Galey & Ruecker, 2010; Hinrichs & Forlini, 2017; Jänicke, 2016; Schetinger et al., 2019; Wrisley, 2018). As outlined above, systems development has been guided specifically by the two design principles of multiperspectivity (Dörk et al., 2017) and contextualization (D'Ignazio & Klein, 2016)—and all aspects of this endeavor where furthermore methodologically geared towards the maximization of visual momentum and of a coherent visual user experience (Windhager et al., 2019c, 2020).

Concerning the process cycle depicted in Figure 1, this thesis puts its emphasis on the first three stages of research, analysis and design developments. However, successful steps into the implementation stage of a visualization prototype for artwork collection data are already documented in publications A2, and partly in B1, as well as in subsequent publications (see for an updated list of publications and presentations the site of the FWF project "PolyCube" https://www.donau-uni.ac.at/en/polycube).

Evaluations of the PolyCube system, which has been prototypically developed out of the concepts from publications A2, B1, and B2, have been undertaken with a focus on cultural collection data, and the documented insights are feeding into ongoing system elaborations (Mayr et al., 2018; Salisu et al., 2019; Windhager et al., 2020; see ch. 6, p. 138 ff.).

3 Visualization of Artwork Collections (A)

What are techniques to visualize collections of artworks and cultural objects? Building on that: How can we bring some of them together into a synoptic multi-perspective interface that still provides a coherent user experience? This chapter responds to these guiding questions with a two-part answer, as developed in two publications.

The first publication (A1) provides an in-depth survey of the nascent field of collection visualization. For that matter, a team of scholars (combining their background in digital humanities, information visualization, cultural studies, and cognitive science) searched systematically for relevant contributions in the field of collection visualization, including web-based visualization interfaces and prominent tools, which are known to be frequently used for representing cultural collections. Out of 129 visualization systems, 70 interfaces were selected for a systematic review of their design space, according to a taxonomy drawing from related work in visualization and collection studies. The results grant primal insights into the design space of a nascent visualization field, and they are complemented by a thorough discussion of design challenges, which emerge from critical humanities approaches to visualization design.

The second publication (A2) takes up the thread of the former publication by zooming in on a rarely heeded follow up-challenge, deriving from the use of coordinated multiple views. While publication A1 shows that more than 80 percent of interfaces to artwork collections use multiple views (and thus follow the design principle of "multiperspectivity"), practically no interface invests additional design efforts to support the subsequent integration of information across multiple data dimensions. Against this background, publication A2 discusses the concept and partial implementation of the PolyCube visualization framework and showcases its capabilities with regard to the spatiotemporal collection data of the Charles W. Cushman photography collection. These developments are contextualized with qualitative evaluation results and a critical discussion of the balancing act between the sister threats of visualization "totalism" and "fragmentalism"—when striving for coherent interface design.

Publication A1: *Visualization of Cultural Heritage Collection Data: State of the Art and Future Challenges*

Full Bibliographical Detail of the Publication:

Windhager, F., Federico, P., Schreder, G., Glinka, K., Dörk, M., Miksch, S., & Mayr, E. (2018a). Visualization of Cultural Heritage Collection Data: State of the Art and Future Challenges. *IEEE Transactions on Visualization and Computer Graphics 25(6), 2311–2330.* DOI: https://doi.org/10.1109/TVCG.2018.2830759

Individual contribution of the author:

Co-development of the article's scope and concept, management and coordination of collaborating authors, collaborative definition of research procedure and methodology, involvement in the state of the art research of visualization articles and interfaces, analysis of corpus, contextualization, and discussion of findings and future challenges, as well as review and rework, according to the feedback from the peer-review process.

Role and position of the publication in the cumulative dissertation:

Concerning research question A1, this study surveys the state of the art of artwork collection visualization and discusses future research challenges. The publication also developed an online browser for scholarly and public audiences to access and compare all the surveyed visualization systems. It is available at http://collectionvis.org.

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Visualization of Cultural Heritage Collection Data: State of the Art and Future Challenges

Florian Windhager, Paolo Federico, Günther Schreder, Katrin Glinka, Marian Dörk, Silvia Miksch, *Member, IEEE*, and Eva Mayr

Abstract—After decades of digitization, large cultural heritage collections have emerged on the web, which contain massive stocks of content from galleries, libraries, archives, and museums. This increase in digital cultural heritage data promises new modes of analysis and increased levels of access for academic scholars and casual users alike. Going beyond the standard representations of search-centric and grid-based interfaces, a multitude of approaches has recently started to enable visual access to cultural collections, and to explore them as complex and comprehensive information spaces by the means of interactive visualizations. In contrast to conventional web interfaces, we witness a widening spectrum of innovative visualization types specially designed for rich collections from the cultural heritage sector. This new class of information visualizations gives rise to a notable diversity of interaction and representation techniques while lending currency and urgency to a discussion about principles such as serendipity, generosity, and criticality in connection with visualization design. With this survey, we review information visualization approaches to digital cultural heritage collections and reflect on the state of the art in techniques and design choices. We contextualize our survey with humanist perspectives on the field and point out opportunities for future research.

Index Terms—Information visualization, introductory and survey, digital libraries, arts and humanities

1 Introduction

Arguably, it is cultural expression and exchange that distinguish humans from other animals. Devising and sharing objects, ideas, and practices enrich behavioral options, facilitates problem-solving, and thus drives the evolution of human collectives [1], [2]. From physical tools and information artifacts to arts and entertainment—cultures create and collect things and pass them on across space and time. While doing so, cultures are changing, and so are the means of transmitting their assets [3]. Digitization has expanded the means for representing and transmitting cultural collections, which makes large stocks of cultural content available, in principle for everyone and everywhere. Against the background of these large data collections, new types of typically web-based interfaces are assuming a role similar to galleries, libraries, archives, and museums as the 'places', where cultural heritage (CH) can be experienced [4], [5], [6], [7].

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In this report, we collect recent developments of interfaces, which leverage methods of information visualization (InfoVis) to enhance access to cultural collections in order to support their scholarly analysis and casual appreciation. The survey sheds light on this emerging field, and aims to assess the state of the art for a diverse group of readers and audiences. We assume the findings and discussions to be of relevance for InfoVis researchers and practitioners, cultural scientists and digital humanities scholars, as well as owners, curators and custodians of CH collections. The general purpose of this paper is to explore and consolidate this new field by summarizing recent achievements and by reflecting on future challenges. To do so, we will discuss the background of CH data (Section 1) and describe our survey methodology (Section 2). On this basis we introduce the categories of the survey (Section 3), analyze existing visualization systems (Section 4), and discuss the findings in relation to a range of contemporary humanities perspectives to derive directions for future research (Sections 5 and 6).

1.1 Concepts of Culture

The concept of "culture" has seen a multitude of definitions [8], [9], [10]. While everyday language often uses "culture" to refer to *artful* things and emphasizes aesthetic or exceptional aspects ("the best that has been thought and known" [11]), many discourses and domains use the term in a much broader and pragmatic way. As such, culture also includes the whole portfolio of *useful* things and thoughts, including the everyday customs and practices that make up how we live as a society, "that complex whole which includes knowledge, belief, art, morals, law, custom, and any other capabilities and habits" [12]. From a functionalist perspective,

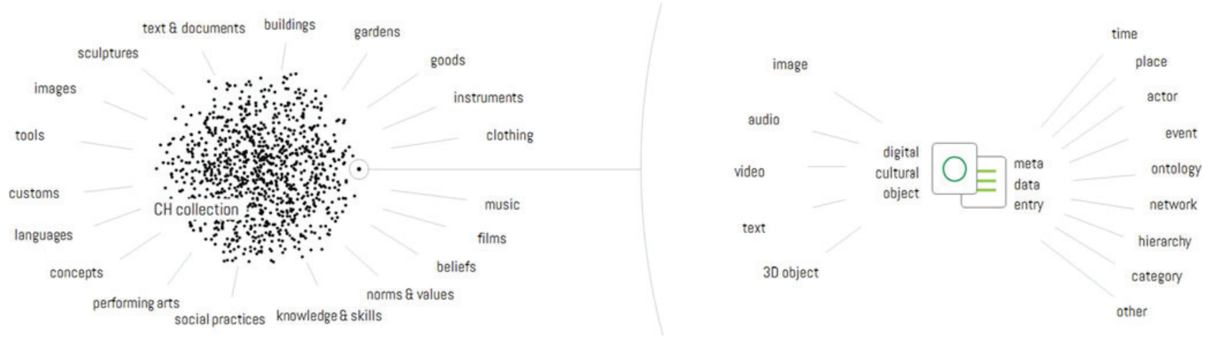

Fig. 1. Types of cultural objects and assets (left-hand side), with tangible CH at the top and intangible CH at the bottom. The right-hand side shows a closeup of the structure of CH object data, consisting of a digital cultural object (left) and related metadata entries (right).

CH thus comprises the whole arsenal of artful and useful assets that enable and refine collective reproduction. From a more critical perspective, CH objects and contents also always deserve a second look at their implicit functions and motivations (see Section 5.3). Seen from such perspectives, CH objects also reveal the functions of social and cultural demarcation or symbolic distinction [13], as they are also frequently (re)produced under competitive, exploitative, or hegemonic conditions and circumstances [14].

While early definitions of CH have mainly focused on tangible assets (e.g., objects, tools, artworks, or buildings), more recent conceptions also emphasize the relevance of intangible assets, such as performing arts, crafts, expressions, customs, rites, or any set of practices [15] deemed worthy of intergenerational transmission due to their *"aesthetic, historic, scientific, or social value"* [16] (see Fig. 1, left).

While cultural heritage is assembled by every collective—from prehistoric tribes and families to modern organizations and nations—its professional preservation in contemporary times is organized by institutions such as galleries, libraries, archives, and museums (often abbreviated as GLAM institutions). Besides preservation, these institutions work on their assets' documentation and availability for research, their mediation to the public, and the modernization of conservation technologies. In this context, digitization has proven to be one of the most consequential innovations. As CH institutions are gradually making their collections available online, the web is becoming a large-scale collection of cultural assets and objects itself. Bringing together the entities of countless local collections, large meta-aggregators like Europeana[1] or the Digital Public Library of America[2] are hosting millions of digital cultural objects, which can be accessed by interested visitors anytime and anywhere.

Yet to grant more generous access to these cultural riches, interface designers have to find new ways of representation beyond the common keyword search approach. They have to recreate ways and means to experience collections on large and small screens and to translate successful solutions and strategies of collection curators, custodians, cultural guides, and museum architects to these new information spaces [17], [18], [19]. To address a variety of these challenges, CH institutions and designers increasingly utilize InfoVis methods. We consider these approaches to showcase novel and noteworthy approaches to visualization design, and to be of relevance for academic, cultural and societal actors, and institutions alike.

1.2 Relevance

From a *visualization perspective*, the relevance of CH data arises from the specific challenges they pose to the design of visualization and interaction methods. Data of CH collections are set apart from other datasets by their rich and often heterogeneous metadata, which are associated with a wide variety of object types (e.g., images, texts, artifacts, music, and films, see Fig. 1). These objects often feature perceptually rich content (e.g., as realistically encoded images or object representations), and are often linked to further contextual information and historical knowledge [20]. These rich and heterogeneous data meet diverse user types [21], who pursue a variety of tasks [22]. In recent years, this complex scenario sparked a wave of InfoVis developments and approaches within and beyond the confines of academic research (see Fig. 2). We consider this field of application to deserve closer and more systematic attention, and want to analyze and consolidate its technological achievements from the InfoVis research point of view.

From a wider *societal perspective*, culture is the collective expression and transmission of valuable contents and practices to ensure their continued existence. As such, we consider reflections on the technical aspects and challenges of this endeavor to have relevance from multiple perspectives:

- As a critical process of socio-epistemic reproduction, transmission of culture always requires supportive measures in terms of a culture's most advanced methods and technologies (pedagogic perspective).
- The advancement of methods seems even more essential for individuals with different cultural or educational backgrounds, whose cognitive processes are already challenged by mediating cultural and linguistic boundaries (intercultural perspective).
- Eventually, given the continuously growing collections of assets across all areas, new means for analysis, synthesis, and sensemaking with complex corpora are required (macrocognitive perspective).

Guided by these motivations, we assemble existing visualization approaches to CH data, review them from an InfoVis perspective and discuss associated challenges.

1. Europeana: http://www.europeana.eu
2. DPLA: https://dp.la/

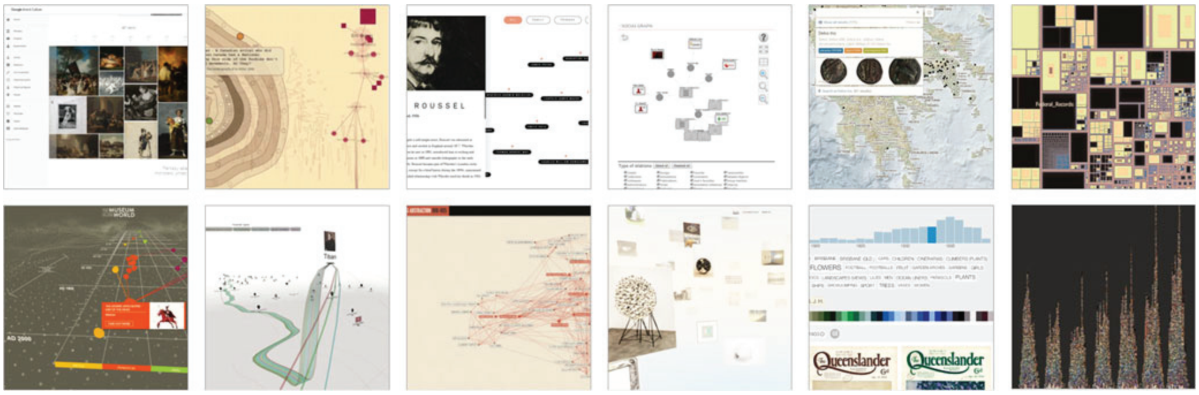

Fig. 2. A selection of InfoVis interfaces to cultural heritage data, including [23], [24], [25], [26], [27], [28] (top row), and [18], [29], [30], [31], [32], [33] (bottom row, from left to right).

2 METHODOLOGY

The survey focuses on visualizations of CH collections without restriction to a specific object type (Fig. 1, left). As such, we equally considered interfaces to collections of visual artifacts such as paintings, drawings, and sculptures, but also to text, audio, or video data that document tangible or intangible CH assets—as long as they could be represented by visual surrogates or graphical abstractions. To control this extensive search space, three criteria narrowed down our research field:

- We focused on approaches and interface designs that utilize *InfoVis techniques* for the representation of collections. Although many scientific visualization techniques for CH objects (aiming at the realistic rendering of 3D objects) exist, we included them only in the case of a hybrid use of SciVis and InfoVis methods.
- We focused on approaches with a documented application or relation to *cultural heritage data or institutions*. This criterion restricted the search space to the cultural sector, and led to the exclusion of InfoVis interfaces to, for example personal photo or music collections, or scientific text documents [34], but creates an intersection to visual text analysis in the digital humanities realm. In contrast to a recent survey in this area [160], our scope includes multiple other CH object types besides texts and predominantly analyzes visualizations based on object metadata.
- We focused on visualizations of CH object and asset collections, but did not include InfoVis systems that give their prime focus to other cultural-historical entities, like actors [35], [36] or events [37], [38].

As for the specific selection of approaches, we included InfoVis systems that have been documented by research papers or publications (see Fig. 13, upper section), but also analyzed prototypical interfaces to CH collections that are publicly accessible but have not been covered by academic reflections (Fig. 13, bottom section). This allowed us to include relevant work in the field that has been done without an academic focus (e.g., [29], [32]), but also to bring in tools or prototypes that are frequently used for collection visualization (e.g., [39], [40]), yet where corresponding publications, for instance, had no direct relation to CH data or institutions (e.g., [41]).

We collected approaches and interfaces through a multi-focal research process: Primary search domains included the areas of InfoVis, Visual Analytics, HCI, Digital Humanities, Digital Art History, and Museum Studies. As such, we included works from a wide range of journals (incl. *IEEE Transactions on Visualization and Computer Graphics (TVCG)*, *Information Visualization Journal (IV)*, or *Digital Humanities Quarterly (DHQ)*) and conferences (incl. *Museum and the Web (MW)*, *International Conference on Advanced Visual Interfaces (AVI)*, or *Joint Conference on Digital Libraries (JCDL)*. Starting from a core set of search terms (i.e., combinations of *data or information visualization* and *CH or GLAM data*), we sifted through related works, keywords, and research institutions, and explored incoming and outgoing citations. In case of multiple project publications, we selected only the most recent and comprehensive paper with the highest impact. Building on the results, we extended the set of keywords and iterated the search. In case of uncertainty regarding a paper's inclusion, four authors discussed the paper or interface in question, which led to the exclusion of 59 interfaces from the initial sample (e.g., [42], [43]). The final collection of InfoVis systems included 70 prototypes, with 50 prototypes associated with a research paper, and 20 prototypes investigated as web-based standalone implementations. We provide an interactive browser to explore this collection of collection visualizations (http://collectionvis.org) and ask CH and InfoVis communities to support its future extension and enrichment.

3 CATEGORIZATION

For our assessment of InfoVis approaches to CH collection data we developed a classification schema with regard to the specific character of the field. It unifies top-down approaches of classification with inferential bottom-up categorizations that result from an open coding approach. The result provides a conceptual schema open for discussion and further consolidation. Where available, we elicit analytical categories from existing taxonomies in InfoVis and CH domains, which we adapt to the specifics of the target domain. As such, the first categories follow the three axes of data, users, and tasks [44], [45], with further categories

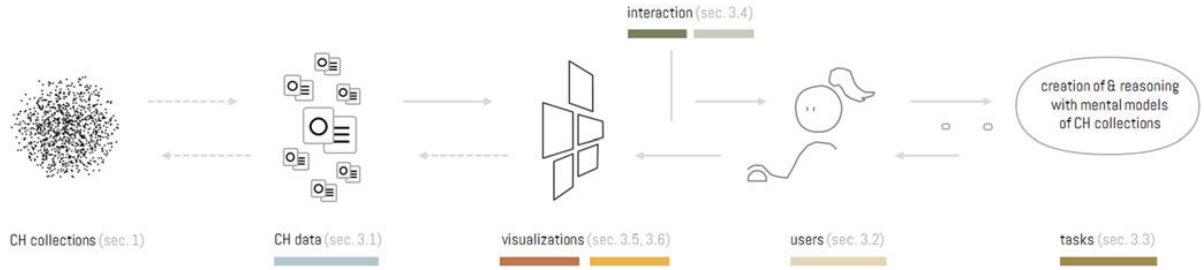

Fig. 3. Schematic lineup of a visualization system in the CH data domain with annotations and colors of the survey's main categories.

pertaining to visual granularity and information activities, as well as visual encoding techniques for temporal and non-temporal aspects of collection data. In the following, we discuss each of these categories, which have been assigned to different colors for ease of differentiation (see Fig. 3).

3.1 Data

The visualization of CH collections can involve two classes of data: the data constituting the digital cultural object, and the accompanying metadata (see Fig. 1, right). The metadata can describe a broad diversity of information associated with the CH objects and vary in scope, quality, and character across different collections, contexts, institutions, and domains. Therefore, to classify appearances of metadata, we need to resort to a unified and comprehensive metadata model. Among several standardization initiatives, the *Europeana Data Model* (EDM) [46] is one of the most mature efforts. The EDM reuses several existing Semantic Web vocabularies, such as the metadata set of the *Dublin Core Metadata Initiative* (DCMI) [47], the *Object Reuse and Exchange format* from the *Open Archives Initiative* (OAI-ORE) [48], the *Simple Knowledge Organisation System* (SKOS) [49] and the *Conceptual Reference Model* from the International Committee for Documentation of the International Council of Museums (CIDOC-CRM) [50]. Also, the *Metadata Application Profile* of the *Digital Public Library of America* (DPLA MAP) [51] is mostly built upon the EDM.

The EDM encompasses two different approaches to describe a CH object, namely an *object-centric* approach and an *event-centric* approach. The object-centric approach focuses on the static properties of the object, enabling the description of its creator, creation date, object type, and current location. However, to unlock a more comprehensive description of the object context, it might be necessary to include not only properties of the object itself, but also the properties that are associated with other object-related entities. To account for these entities, we include the following categories: *actor* (person or organization), *time*, *place*, *event*, and *ontology* (in case the visualization includes entities from knowledge organization systems).

In addition, the event-centric approach aims at building richer relational structures, such as a *network* or a *hierarchy*, by introducing contextual entities and relationships between them, including relations between objects and agents, that took part in an event at a given time at a given place. However, the two approaches are not equally distributed and established: While the object-centric approach is fully supported by most implementations and the enrichment with contextual entities partly, the event-centric approach is rarely supported. Nonetheless, relational structures can also be established in the object-centric approach by considering different types of static (i.e., non-temporal) and direct relations between objects.

In many cases, the simplest metadata assigned to an object are textual descriptions. We denote them as *text* when they are provided as free-form text, which is suitable for text visualization techniques. Conversely, when the textual description is structured as keywords or tags that can be modeled as categorical or set-typed data, we denote the textual description as *category*. Additional numerical metadata such as the number of pages of a book, the year of creation, the length of a video, or the physical dimensions of a painting are grouped under *other metadata*.

The vast majority of approaches to visualizing CH collections are built on metadata. However, many of them also integrate a visual representation of the *content* itself. In accordance with the EDM, we distinguish five *object types*: *image*, *audio*, *video*, *text*, and *3D object*. Because of the inherently visual nature of image objects, we observe that many of the surveyed approaches are tailored for image objects and display the images themselves. However, approaches focusing on other object types can likewise include a visual representation (as an example, books and newspapers can be visually represented by their cover images [18], [52], videos by a still [53], and 3D objects by a 2D rendering [54]). Moreover, the content of objects can be treated as data and processed or analyzed to derive additional metadata and better organize the visualized collection. Examples of applied techniques

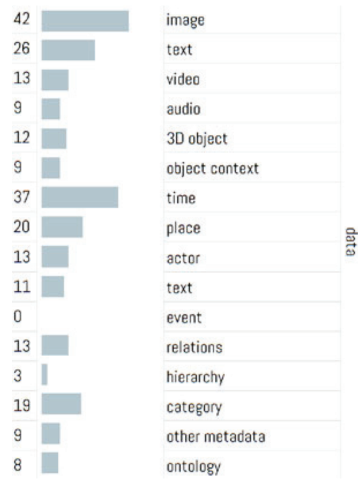

Fig. 4. Distribution of supported data types in the survey's sample.

include text mining [53], [55], [56], clustering of 3D objects based on shape similarity [54], image analysis for face recognition [57], average color abstraction [52], style, genre and artist classification [58], or clustering [59]. Fig. 4 shows the distribution of surveyed approaches according to these data categories.

3.2 Users

For the design of CH visualizations, the intended user is a critical factor: Users' prior knowledge, experiences, and interests will influence their expectations for and interactions with a visual interface. For this classification, we evaluate the InfoVis systems with respect to their intended users and the system's purpose.

3.2.1 Target Users

The target groups of digital CH collections are very diverse: From museum curators to humanities scholars and from highly interested enthusiasts to members of the general public—CH collections can provide useful and interesting information for all of them. Consequently, many different categorizations of users exist with respect to domain expertise, technical expertise, and motivation of use [21]. To classify and evaluate CH visualizations we distinguish two broad classes of users, namely (1) *experts* and (2) *casual users*. Experts encompass all people with a professional or scientific interest in CH data, whereas casual users are looking for personally meaningful information in everyday settings [60]. The users' domain expertise is an important factor for the design of InfoVis approaches. As research on the use of digital collections shows, domain expertise facilitates directed search in cultural databases [61], [62]. Knowledge of the content and structure of the collection enables experts to use relevant keywords for searching and filtering that yield more precise and satisfying results. Without this knowledge, it is difficult for casual users to retrieve meaningful results in search-based interfaces. They require an orientation phase before they can start engaging with the information [63]. Therefore, Whitelaw [18] suggests the development of more "generous interfaces" with rich overviews on the collection's structure and content and direct access to sample data objects within their context. Such interfaces can quickly serve casual users' curiosity, raise interest, and engage them in serendipitous exploratory browsing (see also Sections 5.1 and 5.2).

Within our sample of 50 visualization systems documented by a research paper, 14 are designed for expert users, 20 for casual users, and 10 for both user groups (Fig. 5). However, six publications do not include information on their target group—a highly problematic observation, as such an InfoVis system is developed without an understanding of its future use and will probably not meet the users' needs. It is also interesting to see how an InfoVis prototype can serve two highly different user groups: Some

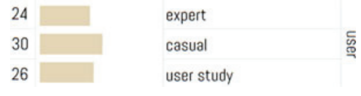

Fig. 5. Distribution of interfaces for different target groups and amount of user studies.

of the prototypes designed for expert *and* casual users have distinct interfaces for each group: For example, in *Lomen* [64] all users can use different interactive views to explore the collection. Additionally, curators can create timeline-based thematic paths to tell a story about one specific topic within the collection.

3.2.2 Evaluation

We also investigated whether a paper reported a *user study*, even if it was only briefly mentioned. The result was disappointing: Only 21 out of 50 papers reported a user study, and a further five mentioned one without reporting any results. Obviously, the papers that did not specify their intended user group also mostly did not conduct a user study (five out of six). Within the group of prototypes that were intended for expert use, 64 percent of the papers included an evaluation. In contrast, only 53 percent of the prototypes designated for casual users and 50 percent of the prototypes that were aimed at a mixed target group were evaluated. We consider these rates to be rather low, and to mirror the low level of knowledge about casual InfoVis users in general [22]. Further studies on this user group could inform and improve the design of casual InfoVis approaches in the future. For example, Hinrichs et al. [24] observed 267 interactions with *EMDialog* and found that "fancy interactions" can draw away the casual users' attention from the actual information and content. Also, evaluations with humanities researchers are needed, as their reasoning often differs from that of other practitioners using most current InfoVis systems.

3.2.3 Purpose

Additionally, we classified the purpose of the InfoVis approach: Overall, 11 InfoVis prototypes aimed for the promotion of learning or education, 19 for creating an engaging and pleasurable experience, and 20 for curating and scholarly inquiry. As expected, the purpose of the visualization correlates with the target users: Most expert approaches (93 percent) were intended to support inquiry and curation, whereas most casual approaches aimed at an engaging user experience (74 percent).

A minor amount of papers also claimed to support collaboration [54], [57], [65], [66], [67] and communication [66], [68], [69], [70]. As an early example, [54] emphasized the potential *collaboration* of different CH institutions in developing CH databases. Newer approaches furthermore argue that InfoVis opens up "opportunities for collaborations and synergies beyond academic boundaries" [65, p. 431] and that they can link the knowledge of experts and that of the public. We agree that CH databases have the inherent potential to support collaborative sensemaking and knowledge exchange, but consider further transdisciplinary approaches to be necessary to tap the full potential.

The prototypes focusing on *communication* provide easy-to-use tools for curators that enable them to visualize their own data (without advanced technical knowledge) and let the public explore their collections online. Although this might also be achieved with "general tools" for creating InfoVis (like *Silk* or *Tableau*), the reviewed InfoVis tools for CH data are better tailored to the specific needs of curators. *Neatline* [70], as an example, allows curators to enrich (historical) maps with artifacts and texts for interactive exploration, whereas *Geobrowser* [39] or *Palladio* [40] foster the spatiotemporal exploration of CH data for everyone. We regard the development of such re-usable InfoVis tools as decisive in the large-scale spread of InfoVis in the CH sector.

3.3 Tasks

The categorization of *tasks* is derived from the analytical task taxonomy by Andrienko and Andrienko [71]. A task can be understood as a question involving two parts: the known part (i.e., the reference, the task constraints) and the unknown part (i.e., the target information, the data attributes to be found). The taxonomy distinguishes two types of tasks: elementary tasks, involving individual elements of the reference sets, and synoptic tasks, involving the entire reference set or its subsets, with the corresponding characteristics as a whole (i.e., a pattern or behavior).

As for *elementary tasks*, at a finer-grained level the authors [71] distinguish lookup, comparison, and relation-seeking tasks. The vast majority of approaches, which we categorized as elementary, address only lookup tasks, both direct (e.g., find all objects created at a given time in a given place, and their attributes) and indirect (e.g., given a cultural object, find when and where it was created). These approaches support users looking for specific CH objects and their attributes and aim at assisting with visual information retrieval and searching. Given the importance of interacting with individual objects in CH databases for sensemaking, it is not surprising that this is the most frequent task category. Only a few approaches also tackle relation-seeking tasks (e.g., [56], [57]).

According to Andrienko and Andrienko [71], *synoptic tasks* play an important role in exploratory data analysis. Synoptic tasks involve finding and comparing patterns, as well as seeking relations between patterns; in the context of CH, synoptic tasks can be understood as analytic activities supporting collection understanding, which shifts the traditional focus of retrieval in large collections from locating specific artifacts to gaining a comprehensive view of the collection. In our classification, among synoptic tasks, we distinguish in particular those tasks dealing with *temporal* behaviors (i.e., behaviors involving time as the reference set), because of the well-known importance of time-oriented information in CH data [72].

For Andrienko and Andrienko "the most challenging are tasks of finding significant connections between phenomena, such as cause-effect relations or structural links, and of identifying the principles of the internal organization, functioning, and development of a single phenomenon" [71, p. 48]. Indeed, the approaches we found in our survey support only elementary tasks or descriptive synoptic tasks, while further research seems to be needed to support such *connectional tasks* in the context of CH collections. Fig. 6 shows an overview of the categorization by task.

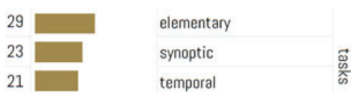

Fig. 6. Distribution of supported tasks.

3.4 Granularity and Interactivity

For digital CH collections, interface design essentially predefines how complex information spaces can be experienced. A major design decision derives from the question: which levels of object aggregation are provided? CH InfoVis systems can offer access to details of individual artifacts or overviews of entire collections—or to any other intermediate level of visual aggregation, which we refer to as *visual granularity* (Fig. 7).

3.4.1 Visual Granularity

Interaction with CH collections in a gallery or a museum mostly happens on a detail level of close-up observation or in a mode of contemplative walking from object to object. While digital collections also allow for a similar activity by the means of browsing, they also provide the option to contemplate and analyze collections from various distant perspectives [19], [72]. To conceptualize the related InfoVis design space, Greene et al. [74] introduced the distinction between previews (visual surrogates for single objects), and overviews (visual surrogates for whole collections), which we further differentiate into four types of object or collection representations:

Single Object Previews. To allow for a close-up contemplation, many systems provide detailed representations of objects, usually high-resolution photographs or 3D scans, but also video or audio encodings. These representations are often accompanied by textual object descriptions and the disclosure of object metadata and facets.

Multi-Object Previews. Above the level of singular objects, collection interfaces often aggregate previews of CH objects into multi-object arrangements, such as lists, grids, or mosaics, where thumbnails serve as object previews. As opposed to collection overviews, multi-object previews commonly represent a selection of objects and often result from searching or faceted browsing (e.g., [75], [76]).

Collection Overviews Utilizing Discrete Surrogates: At the macro level, visualization systems can provide collection overviews by using discrete abstractions for single objects such as glyphs, which keep individual objects visible and accessible for inspection while encoding metadata (e.g., temporal origin) into visual variables like position, size, color, or shape of the glyphs (cf. [33], [77]).

Collection Overviews Utilizing Abstractions. Collection overviews can also utilize all possible types of diagrammatic representations, which abstract from discrete objects and encode collection data into any other available visualization resulting in abstract geometric shapes that represent high-level patterns and structures in a collection (e.g., [28]).

In our sample of InfoVis systems, full object previews are offered by more than half of all systems, and multi-object previews are implemented by about 60 percent. 75 percent of systems offer some sort of collection overview. About half of them utilize discrete representations, and the other half use diagrammatic abstractions (Fig. 8).

3.4.2 Supported Information Activities

To engage with a digital collection and explore it across the outlined levels of granularity, visitors can pursue various information activities, which are predefined by an

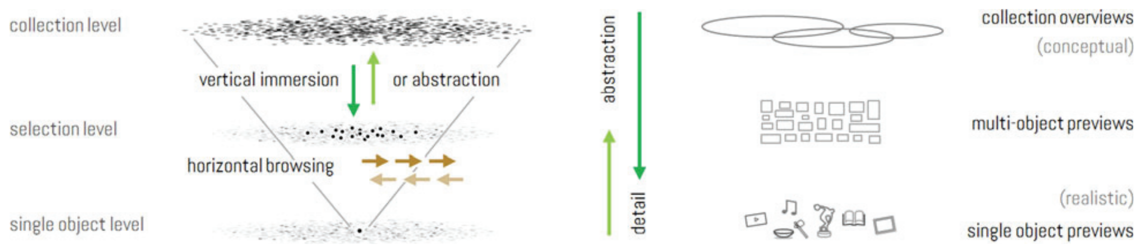

Fig. 7. Predominant information activities for CH collections, like vertical immersion or abstraction (green) and horizontal browsing (brown) (cf. [73]) and granularity levels of object collections (right), from overviews utilizing abstractions to realistically encoded object previews.

interface's interaction design. We distinguish six major types of support for different information activities [73], [78].

Object Search. As a prototypical information activity, searching is geared towards finding one or more relevant objects in an otherwise irrelevant information space. At the end of a search, which equals a funnel-like task, there tends to be the single find that ideally satisfies the information need.

Overview and Orientation. Collection overviews utilize conceptual abstractions or discrete object surrogates to visualize collections on a macro level. Thereby, they enable users to orient themselves according to various metadata dimensions and to visually analyze distributions, relations, patterns, or trends of entire collections on a high level of aggregation.

Vertical Immersion or Abstraction. Starting at a given granularity level, interfaces can support vertical movements of immersion (zoom in) or abstraction (zoom out) along the overview-detail-axis. Vertical immersion does not have to lead to the access of single objects, but can also result in the exploration of (faceted) subsets of a collection. By contrast, vertical abstraction allows the user to zoom out from the contemplation of single objects to contextualize them in their larger neighboring information space.

Accessing Object Details. The access to single object previews—often including access to object metadata and textual descriptions—equals the close-up contemplation of CH objects in physical exhibition spaces, and aims to engage users in a more detailed, profound, and in-depth object experience.

Horizontal Exploration. As opposed to vertical immersion, which narrows down the search space, horizontal browsing or exploring includes all sorts of open-ended, lateral movements, either on the object level, or along a selected level of aggregation or abstraction. This includes browsing or "strolling" along various metadata dimensions or facets, like (same) style, artist, subject, or time [78], [79].

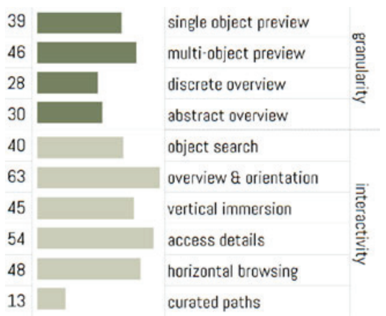

Fig. 8. The distribution of visual granularity levels (top) and supported information activities by major interaction methods (botom).

Curated Paths. One specific horizontal functionality can be achieved by curated paths, which are generated by the interface providers (curator or author-driven, e.g., [70]) and structured by additional means of narrative information design, or by the visitors' own exploration and interaction behavior (user-driven, e.g., [76]).

Of the 70 visualization systems, about 60 percent offered a search functionality, 90 percent support overview and orientation, 65 percent allowed for vertical immersion or abstraction, 70 percent support horizontal exploration, only 20 percent offer curated paths, and 75 percent enable access to object details (Fig. 8).

3.5 Temporal Visualization Methods

CH collections are assemblages inherited from the past, experienced in the present, and preserved for the future. As such, the visual representation of *temporal aspects* is a vital design dimension. In this section we survey all InfoVis approaches with regard to their choices of how to visually encode temporal data aspects, while the next Section 3.6 analyzes main methods for visualizing non-temporal data aspects. We build on existing classifications for the representation of time-oriented data [80] and distinguish six categories (Fig. 9, right).

Timelines (1D). Timelines are the simplest solution for mapping time to space in a linear, one-dimensional fashion [81]. As a method to encode the dates of origin of collection objects, timelines commonly visualize events (e.g., creation dates of objects) as marks along a line. In a more complex arrangement, they can appear as multiple, stacked, or also faceted timelines [40], [53], [82]. Also, timelines are often utilized as "linked views" in combination with other visualizations for temporal navigation [39].

Time as One of Two Spatial Dimensions (2D). By mapping time linearly to one of two spatial display dimensions (e.g., along the x-axis) and by utilizing the orthogonal display dimension (y-axis) for encoding another data aspect, interface designers frequently generate histograms [57], [83], line charts [84], (stacked) area charts [39], [85], time-oriented scatter plots [86], image plots [33], [67], or process visualizations [66]. These visualizations can again serve as linked views for temporal navigation and exploration, such as temporal selection, zooming, panning, and brushing.

Time as One of Three Spatial Dimensions (3D). When interfaces make use of three-dimensional visualization techniques, temporal data aspects can also be mapped to one of three dimensions (e.g., [29], [30]. With regard to visualizations

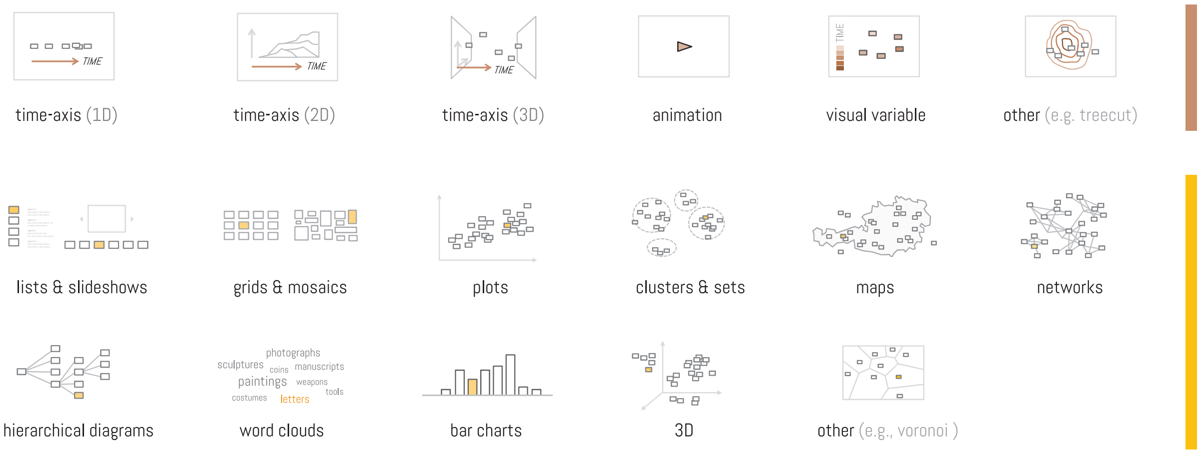

Fig. 9. Surveyed visualization methods to encode temporal data aspects (top row) and methods to visually encode non-temporal aspects of CH data collections (bottom).

based on space-time cube representations, only conceptual designs have been documented so far [87], [88].

Animation. Using animation, the temporal change of any collection aspect is represented as a temporal change of the collection visualization on the screen. CH interfaces occasionally utilize animation to make development processes accessible as moving or morphing images, often in connection with a linked timeline. This approach offers the means for user-driven temporal navigation, selection, and further exploration [39], [40], [89].

Visual Variables. By mapping time to a selected visual variable (such as color, size or texture) CH collection interfaces can transform most existing methods for non-temporal data (cf. 3.6) into time-oriented ones and add temporal information as a retinal variable (e.g., of glyphs). We found color coding to be applied mainly to collection representations on maps [40], [90], and did not identify other retinal encodings.

Other Encoding Techniques. Further surveyed solutions for the visual encoding of temporal data include ring charts [91], tree cut sections [24], or visualization of nodes within an ontology [92], [93]. Finally, date of creation often serves as the guiding arrangement principle for previews within lists, slideshows, grids, and mosaics.

As Fig. 10 shows, only a minority of interfaces (12 out of 70) encode no temporal collection information whatsoever. Among the majority of interfaces that do, the most prominent methods map time to a spatial dimension, with 30 percent of all interfaces using one-dimensional timelines, and close to 50 percent using one out of two spatial dimensions.

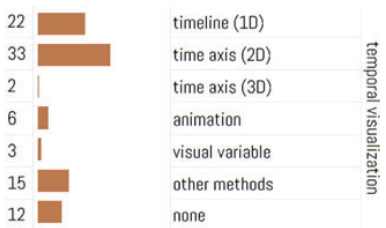

Fig. 10. The distribution of methods for the visual encoding of temporal (time-oriented, longitudinal) CH collection data aspects.

3D encoding has been used only by two interfaces, and encoding to visual variables has been applied by three. Twenty percent of all interfaces utilized other options for the visual encoding of time.

3.6 Non-Temporal Visualization Methods

Finally, we analyze all systems for visualizations of other than temporal data aspects, including *spatial*, *relational*, *distributional*, *categorical or cross-sectional* collection aspects (Fig. 9, left).

Lists & Slideshows. Horizontal slideshows or vertical lists arrange object collections in a linear sequence. While we did not consider such widely used multi-object previews (including grids & mosaics) to count as InfoVis techniques in the narrower sense, some of these arrangements encode additional data dimensions (e.g., temporal origin, dominant color or item popularity) into the previews' positions, and allow for user-driven re-arrangement, which makes them a relevant arrangement technique at the InfoVis periphery.

Grids & Mosaics. Using “line breaks”, linear arrangements turn into grids and mosaics, which arrange multi-object previews in multiple rows that raise the item-screen ratio (e.g., [23], [77]). Furthermore, grids and mosaics can be dynamized, so that tiles represent whole object categories or

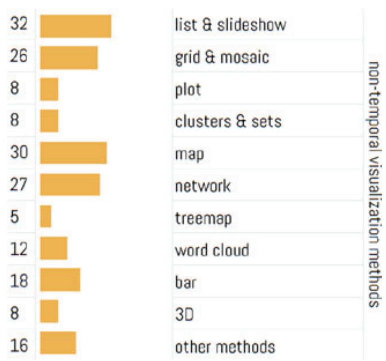

Fig. 11. The distribution of visualization methods for non-temporal (spatial, structural, relational, distributional, or cross-sectional) CH collection data aspects.

subcollections and change their content over time. Thus, also passive contemplation without clicking and scrolling is enabled [18].

Plots. Dissolving the contiguous arrangements of grids and mosaics, plots assign the two-dimensional (x and y) positions of previews or glyphs according to selected metadata dimensions in a coordinate system. Examples are image plots [33] and scatter plots [68], [94], [95], which utilize glyphs or point-like abstractions instead of object previews. As a result, distributions (clusters, outliers, gaps) appear that allow for the analysis of collection patterns or trends.

Clusters & sets. To unveil possible inter-object similarities implicit in multiple dimensions of collection data, dimensionality reduction procedures can be applied. This includes principal component analysis (PCA), multidimensional scaling (MDS) and t-distributed Stochastic Neighbor Embedding (t-SNE). With such techniques, CH collection data can then be visualized as image or glyph clusters [33], [83], [96]. If object similarities are explicitly defined (whether as group, class, or categorical object attributes), these object clusters can be visualized by set visualizations [32], [97].

Maps. As geographic origin is one of the most frequently documented metadata dimensions of cultural objects and artifacts, maps accordingly serve as a prominent visualization method to show the spatial distribution of artifacts' origins [39], [40], [90]. Likewise, CH objects' provenance histories (i.e., their spatio-temporal trajectories) can be visualized in a geographic context [89].

Networks. As for relational aspects of collection data (e.g., influences, references, inter-artifact relations, linked-data relations), network diagrams allow users to explore the proximities and distances of artifacts or cultural actors in relational or topological spaces [26], [40], [72]. While force-directed layouts often interrelate CH objects and related entities [76], graphs are also implemented to visualize relations between object metadata [56] or within metadata ontologies [91].

Hierarchical Diagrams & Maps. Given the different possible classifications of cultural artifacts, hierarchical diagrams such as treemaps are one solution to offer insights into hierarchically structured constellations of object or collection metadata [28], [97].

Word Clouds. Word or tag clouds [65], [98] are a prominent method of visualization and verbalization to represent metadata aspects of a collection. Tags or keywords can be derived either from existing object classification, mined from object titles and related textual descriptions, or generated through crowdsourcing or computer-vision methods.

Bar charts serve as another prominent visualization method for CH collection data [75], including their use as histograms to encode the temporal distribution of a collection's historical provenance (e.g., [82], [83]).

3D. Going beyond the two dimensions of flat InfoVis design, some interfaces also use a third dimension to encode CH collection data [30], [99]. This includes hybrid systems that merge the visualization of abstract data aspects as (or within) virtual spatial environments [32], [54], [92], [98].

Other Encoding Techniques. With regard to the many possible dimensions of CH collection data, a whole range of further InfoVis techniques provide insights into non-temporal patterns and distributions, including (stacked) area charts [85], ring charts [72], Voronoi maps [100], pie charts [68], Kohonen maps [101], or line charts [102].

Overall, more than half of all interfaces (55 percent) featured at least one type of a multi-object arrangement, such as lists, grids or mosaics. As for other visualization methods, geographic maps (30) and networks (27) are the most frequently utilized techniques. After that, bar charts (18), word clouds (12), cluster visualizations (8) feature prominently, followed by 3D visualizations, plots, and treemaps (Fig. 11).

4 Survey and Analysis of Interfaces

Overall, we analyzed 70 InfoVis interfaces across six main categories and 48 subcategories (Fig. 13). For all 50 prototypes documented by papers or similar publications, we were able to apply all categories and do our assessment across the full spectrum. For 20 InfoVis prototypes without a published documentation, we refrained from assessing the underlying data types, as well as intended users and supported tasks due to too large a margin of interpretative uncertainty. While the overview table discloses the structural profiles of interfaces in the general design space (rows), it also sheds light on the prominence of individual design elements and features (columns). Furthermore this table offers a documentation of design decisions for developers, who can look up the design solutions of existing visualization prototypes that deal with the same types of data. In addition to these basic functions, we highlight additional findings.

4.1 Interest in CH Visualization

An analysis of the publications by year (Fig. 12) reveals that the field of CH visualization is quite young: The first publication stems from 2004 [103] and an increased interest can be observed from 2010 onward. Since then, the publication statistics show an upward trend (with fluctuations). This trend mirrors the development of the major repositories for CH data in the last decade: The Europeana project started in 2007, and the DPLA in 2010. Both currently offer open access to huge digital CH collections, raising questions on potential use cases for these data, but also enabling their re-use in research. Also on a local scale, an increasing number of collecting institutions have invested time and money into the digitization of their collections.

This rapid growth in CH data motivated the use of InfoVis technologies, which help to make sense of massive data collections, and offer effective means to interact with these data. The development also parallels the rise of the Digital

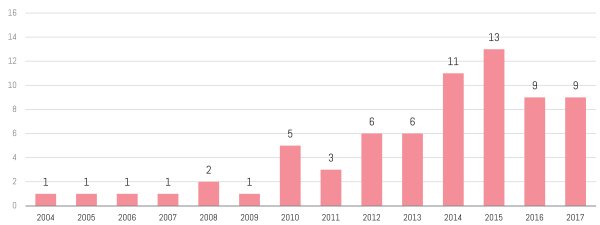

Fig. 12. The temporal development of CH InfoVis publications.

Humanities as a new research field in its own right. Consequently, with the continuous increase in available data and evolving interdisciplinary research expertise in the relevant fields, interest in applying InfoVis approaches to CH collection data grew over time and will likely continue to do so.

4.2 Observed Impact

What are the most important publications on CH visualization? To evaluate the scientific impact of the surveyed publications, we conducted a citation analysis using Google Scholar in June 2017. Six publications could not be included in this analysis as two of them were published too recently to be listed, and four were published on the *Museums & the Web* website which is not indexed in Google Scholar. From the remaining papers, most received only little attention based on the Google Scholar citation (Fig. 14). The 10 papers with the highest impact ranged from 22 to 110 citations. Nearly all early publications that were published before 2010 are found in this list (five of six), probably partly due to their extended time for reception, but also due to their pioneering status.

To understand, what distinguishes a low- from a high-impact paper, we considered the three most cited papers more closely. It becomes clear that they go well beyond the scope of describing singular InfoVis systems, but rather discuss more general concepts, which obviously proved to be useful for other researchers. The most often cited paper is by Thudt et al. on the Bohemian Bookshelf [52], in which the authors build on the theory of serendipity and delineate general design requirements for InfoVis in support of serendipity. Similarly, the second most cited paper by Hinrichs et al. [24] conducted a large user study on the use of EMDialog in an exhibition context and reported several lessons learned for the design of InfoVis. The third most cited paper by Shen et al. [93] formalizes the processes of searching and browsing and discusses how they are linked and can be integrated into the InfoVis of the ETANA digital library. These three high-impact publications illustrate how the engagement with CH data encourages visualization researchers to not only work across disciplines, but also to propose new ways of thinking about visual representation and interaction.

4.3 Casual versus Expert Use

The design of an InfoVis system strongly depends on the intended user group. As digital CH collections serve mainly two different target groups, we expected differences between interfaces for expert and casual users. However, these differences were not as fundamental as expected.

We already reported that the documented purpose of the InfoVis interface changes with the targeted user group (cf. Section 3.2.3) in that expert interfaces are intended for inquiry and curation whereas interfaces for casual users are geared towards an engaging experience. Consequently, also the supported exploration activities differ: providing an overview is important in all interfaces for all user groups and represents one of the fundamental benefits of InfoVis. In addition to this, browsing techniques were implemented more frequently for casual users, while for experts the search function was more prevalent. This observation is in line with existing research showing that experts are more skilled in searching CH databases than casual users [61], [124] and that casual users require alternative modes of access to pursue exploratory search [62].

Moreover, we observe a difference between user groups in terms of object types: Interfaces for casual users focus more on image objects than approaches for professional users, and often also display a thumbnail of the image itself; we can reasonably suppose that many interfaces for casual users are designed to engage them in browsing object reproductions rather than support exploratory analysis of object metadata.

Similarly, we observe a difference in terms of supported analytic tasks. In particular, approaches supporting elementary tasks are slightly more prevalent (60 percent) among those designed specifically for casual users; conversely, approaches supporting synoptic tasks are more prevalent (73 percent) among those designed specifically for experts. Approaches focusing on both user groups support both task types nearly equally.

With regard to multiple views, one could expect that interfaces for casual users should be simpler and provide fewer ways of visualizing data. However, no differences exist in the number of implemented visualization methods. But the kinds of visualization techniques differ: Expert interfaces use fewer lists, grids, and tag clouds than casual interfaces. As list and grid visualizations are fundamental ways for browsing a visual collection, this matches the results observed for the exploration activities that casual users more often browse than search.

4.4 Multiple Views

From a visual analytics perspective, the complexity of CH data implies that every possible encoding method can capture only so much of a collection's composition or structure. According to the design rationale "one view is not enough" [72] the survey shows that the use of *multiple non-temporal perspectives* (either as multiple-choice or multiple coordinated view systems) is a widely used technique to combine the strengths of different views—and to counterbalance possible analytical reductions of a singular technique. About 80 percent of all interfaces utilize more than one non-temporal visualization method. On average, 2.63 (SD = 1.18) different non-temporal encoding techniques were used, ranging from 1 to 6 [68]. The most frequently implemented non-temporal encoding techniques are also most often combined: lists, grids, maps, and networks.

The temporal dimension in CH data was visually encoded by 81 percent of the CH InfoVis interfaces. According to Kerracher et al. [125], offering multiple views "to maximise insight, balance the strengths and weaknesses of individual views, and avoid misinterpretation" is also highly relevant for *temporal analysis*. Visualization systems increasingly combine different visual approaches to temporal aspects to allow the user to select and switch between the most appropriate representations for the data and task at hand [125]. This trend seems to also manifest in CH collection visualization: One out of three systems (31 percent) implemented multiple encoding techniques for temporal data aspects (e.g., [40],

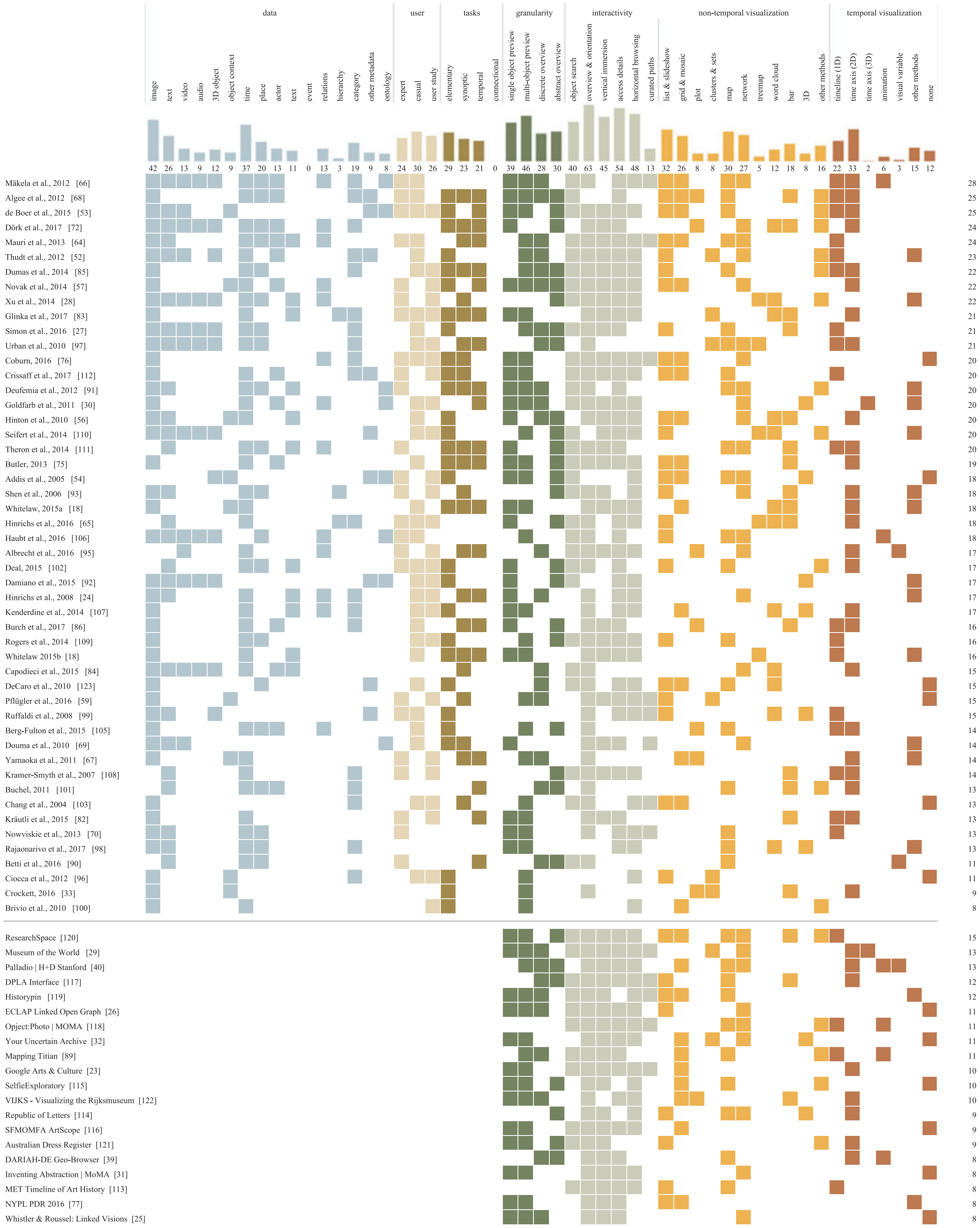

Fig. 13. Design space and categorial distribution of all surveyed InfoVis interfaces to CH collections, with paper-based prototypes at the top, and publicly accessible prototypes without associated publication at the bottom. Ranking according to number of design features.

[89]). The implementation rates of 1.16 (SD = 0.76) different temporal encoding methods per system (ranging from 0 to 3 [40][66]) are still significantly lower than for non-temporal visualizations. Given the relevance of the historical data dimension for cultural sciences and humanities scholars, we expect these rates to grow. With regard to

citations	author (year)	title
110	Thudt et al. (2012)	The Bohemian Bookshelf: Supporting Serendipitous Book Discoveries through Information Visualization
96	Hinrichs et al. (2008)	EMDialog: Bringing Information Visualization into the Museum
60	Shen et al. (2006)	Exploring Digital Libraries: Integrating Browsing, Searching, and Visualization
53	Chang et al. (2004)	Collection Understanding
45	Mäkelä et al. (2012)	How to Deal with Massively Heterogeneous Cultural Heritage Data – Lessons Learned in CultureSampo
29	Addis et al. (2005)	New Ways to Search, Navigate and Use Multimedia Museum Collections over the Web
29	Brivio et al. (2010)	Browsing Large Image Datasets through Voronoi Diagrams
27	Ciocca et al. (2012)	Browsing Museum Image Collections on a Multi-touch Table
23	Ruffaldi et al. (2008)	Design of Information Landscapes for Cultural Heritage Content
22	Whitelaw (2015)	Generous Interfaces for Digital Cultural Collections

Fig. 14. Number of citations per paper (left) and top 10 publications (right).

the combination of temporal and non-temporal encoding methods, we found that 1D timelines are most often implemented together with lists, maps, and networks. 2D-time axes are often combined with lists, grids, maps, and networks. The methods of animation and color coding are mostly combined with maps and networks.

As one remarkable result, we found practically no hybrid systems integrating InfoVis techniques with 3D rendering techniques (e.g., of real or virtual museums), even though such combinations could provide multiple insights into the connections between abstract and concrete arrangements [126]. We want to mark this as a particularly interesting unexplored possibility and emphasize its future potential (also for VR/AR guides), so that sensemaking in physical and digital information spaces can mutually amplify their potential (see Section 5.5).

4.5 Intangible Heritage

As the distribution of data types in the survey shows (Fig. 13, blue column), there is a remarkable shortage of interfaces enabling access to *intangible* objects or practices, such as music, film, performing arts, or linguistic entities (e.g., narratives, folk tales, or poems). One hypothesis to explain this absence of interfaces to intangible cultural heritage is that texts are mostly found in specific-purpose libraries. Moving images or music on the other hand might be either stored in similarly specific collections, or shared and transacted mostly on commercial and private platforms. Regardless of its origins, we consider this large structural blind spot to delineate one of the most promising areas for future developments. As countless domains of the humanities, arts, or cultural sciences have assembled itemized knowledge and data collections about their focused intangible phenomena, practices and objects of study (Fig. 1, left-hand side), most of the surveyed InfoVis approaches are also applicable to their data.

As such, intangible CH data collections (e.g., as curated by the UNESCO [127]), which include various forms of knowledge and practices, oral traditions and expressions, performing arts, social practices, rites, customs, rituals and traditional craftsmanships, could be visually explored and presented by the modern means of all the available InfoVis methods outlined so far. Likewise, humanities disciplines (such as ethnography, sociology, history, or cultural anthropology) document and collect phrases, folk songs, poems, recipes, concepts, ideas, habits, customs and practices. We assume that most of these itemized collections can also be represented on the basis of associated metadata, and that therefore related research and teaching initiatives could also benefit from most the visualization methods and techniques enlisted above.

5 Discussion

As evidenced by the survey so far, recent developments in the area of CH representation have motivated a multitude of visualization approaches, which begin to form an interconnected field of study with its own questions and challenges. These novel challenges have been answered by a discussion about newly required design principles and strategies. In the following, we discuss a selection of these perspectives, which emerge from multiple strands of discourse between digital humanities, cultural sciences, and information visualization. They are in part a response to early InfoVis developments, and we consider them to be valuable voices shedding light on possible future demands for advanced visualization design in the CH data realm.

5.1 Serendipity

The concept of serendipity originates mainly from discourses in library and information sciences. In its literal meaning, serendipity describes "the faculty or phenomenon of finding valuable or agreeable things not sought for" [128]. Although coincidence, unexpectedness, and accidental discovery are also associated with the term, in particular in the sense of "unexpected" or "accidental" scientific discoveries [129], we want to emphasize the potential to deliberately incite and encourage serendipitous information retrieval. While it is not possible to directly control serendipity, it nonetheless can be influenced [130]. It could be argued that the well-structured and curated presentation of collections in museums or libraries allow for strolling along a multitude of paths through the *information space*, and encourage serendipitous encounters. This creates the effect that visitors will likely come into contact with information (books, exhibits, objects) "that are of interest to them but that they were unaware of prior to visiting" [131].

Options for Operationalization. In the context of digital CH collections and interfaces, the question of how to support serendipity is not easily answered [130]. One approach is seen in emulating the serendipitous information space of a library or museum in digital CH interfaces [132]. Others rely on search interfaces but offer a slightly more serendipitous access in the sense that related or similar objects to the one searched for are also recommended based on existing object taxonomies or user-generated tags [131], by providing hypertext links between related entities [130], or by suggesting items that are otherwise related to the viewed entities [133].

The specific potential of InfoVis for encouraging serendipitous information retrieval was first illustrated by the Bohemian Bookshelf [52], which applies several serendipity-focused design principles, such as multiple visual access points, highlighting adjacencies, enticing curiosity, and supporting playful exploration. Another example is the Past Paths project [76], [134], where the scrolling speed controls the display of items. Slow speed shows only related items, whereas higher speed highlights seemingly random new topics. To support orientation, the users can store items of interest and explore their past paths in visualizations that highlight relations between the accessed items [134].

Being quite an elusive term and concept, there is no established recipe for designing serendipitous collection interfaces or InfoVis environments. However, the principles of serendipitous encounters, including, for example, the value of unexpected discoveries, the feeling of surprise, the challenging of familial interactions, and the enabling of unpredictable results, might offer a way to evoke corresponding experiences [135]. Still, thorough user studies have not yet been conducted that would help us to fully understand how specific design decisions influence users' perception of serendipity. Nonetheless, the intention to increase the likelihood of serendipitous encounters within a digital CH interface is likely to help create more open, more diverse, and possibly more engaging user experiences.

5.2 Generosity

Relatedly, the notion of "generous interfaces" [18], [75] revolves around the question of how digitized CH can be made accessible in a way that is also able to "reveal the scale and complexity of digital heritage collections"[18]. At its core, it is characterized by a clear contrast to what still is a default starting point in many digital interfaces: the search slot. The generous approach to collection interfaces defines five principles: i) show first, don't ask; ii) provide rich overviews; iii) provide samples; iv) provide context; and v) share high quality primary content [75]. It aims to provide rich and navigable representations that encourage exploration and browsing [18], while overviews establish context and maintain orientation during access to details at multiple scales.

Options for Operationalization. The principle of generosity explicitly confirms well-established design principles of InfoVis, which emphasize the importance of overview, orientation, and details on demand [136]. It also promotes the utilization of multiple (over)views (see Section 4.4), to form complementary composites that reveal different aspects of a collection—what Drucker terms "parallax" [137]. It also promotes more playful extensions of information seeking towards less goal-oriented information activities, such as satisfying curiosity, enjoying aesthetics, and avoiding boredom. Rather than the functional satisfaction of an information need, generosity emphasizes process, pleasure, and thoughtful engagement [18], requirements as they have been documented for casual users [60], information flaneurs [73], and humanities-based approaches to interface design [138].

In this sense, the concept of generosity—together with concepts of criticality (see Section 5.3)—can arguably help to overcome all overly narrow task- and deficiency-driven approaches to interface design that are grounded in a simplistic user-as-consumer- and problem-solver-model [137]. From this perspective, the first half of this survey's categorization schema (centered around data, users, and tasks) may appear to be a questionable choice for analyzing interfaces for "humanities-based" experiences. However, by encouraging the elicitation of humanities scholars' tasks and requirements, we consider their needs as inputs to be taken seriously for participatory system development. Only sustained and systematic collaboration might enable more reliable collections of humanities-specific requirements and conventions. We see this as a necessary step towards the design of methodically and epistemologically less "trojan horse" [139] technologies, as well as their ecologically valid evaluations.

Also, the principle of generosity goes beyond mere design implications and also includes the call for open data, open source, and open access. Last but not least, generous design aims for the deliberate generation of novel questions and critical inquiries, such as going below the surface of given assumptions (Section 5.3) and looking beyond all local confines (Section 5.7), rather than claiming to exhaustively show "what is" [18].

5.3 Criticality

With the principle of criticality we refer to reflections and design strategies, that can help to meet specific epistemic standards in various humanities, arts, and CH communities. Some of these standards mainly aim to prevent unverified or realistically naive renderings of CH topics, data, and subject matters, and instead support interpretive accounts and critical analyses of authoritative representations and their assumptions [139]. In this context, visualizations and interfaces can and should not claim the status of being inevitable technical solutions. To the contrary, they have to be addressed as cultural artifacts themselves, which require thorough reflection, critique, and appropriation [73], [140]. For this purpose, we see largely two options: encouraging the level of critical self-reflection on the side of visualization designers, and at the same time, raising the critical (data and visualization) literacy skills on the users' side.

Options for Operationalization. To raise the criticality of CH visualizations and interfaces, we promote design principles and guidelines that promote disclosure (making data and design choices transparent), plurality (offering multiple views and perspectives), contingency (acknowledging the open-ended nature of user experience), and empowerment (fostering user's self-activation and engagement) [141]. These principles can help to question interfaces, and gain a second look at their seemingly realistic demeanor [138]. Even more so, they help to have a critical look at the data and design choices, and to revise or refute (parts of) visual representations, including their rhetorical devices [142]. If these rejections can be documented together with alternative design suggestions, a multimodal version of "critical theoretical" discourse might ensue, drawing on texts and visual representations alike.

We see a specific relevance of such a critical discourse when it comes to CH collections and data, which are often heterogeneously interpreted in pluralistic humanities discourses, depend on the disclosure of sources, are intertwined into subjective histories, and relate to multiple questions of provenance, methods, and disciplinary traditions. We also see a need to include CH institutions in critical reflections, which influence collection interpretation by their ways of cultural mediation, including exhibitions, catalogues, and their overall framing of collections. Since at least the 1990s [143], critical discourses in the context of institutional critique, postcolonial studies or feminist theory have vigorously been advocating for a more nuanced, self-reflective practice of collecting and exhibiting. This has moved many institutions—in the light of public and academic scrutiny—to openly reflect their history, their entanglement in hegemonial structures and power relations, and also acknowledge the need to address these issues when engaging in a dialogue with the public. In simple standard interfaces to CH data, these discourses cannot be equally represented. Yet the understanding of CH collections as dynamic entities that can be formed, re-arranged, contextualized, and annotated through innovative forms of participation can be specifically supported [144]. Equally, InfoVis and interface design holds the potential to allow for multiple, uncertain, and sometimes even conflicting perspectives and narratives to surface (cf. Sections 5.6 and 5.4), while keeping the physical structure and "authoritarian" metadata of a collection intact.

All of these options to foster a critical utilization of visualization technologies eventually depend on the skills and intentions of users and visitors to apply them. When developing visualizations and interfaces in a CH context, the intended users' expected skills should be thoroughly reflected, as well as their prior knowledge and assumptions. Only these sorts of reflections—together with corresponding onboarding techniques and educational initiatives—can lead to the establishment of critical data and visualization literacy. As a result, a new form of "source criticism" for representations in digital environments could emerge, which is duly needed not only in the humanities.

5.4 User Guidance and Narration

Design strategies of user guidance and narration enrich the standard mode of individual and user-driven visualization reception. User guidance by *recommendation* provides suggestions for the extension and continuation of a certain viewing experience—often by clustering related material around objects or areas of focus. Existing metadata of CH collections often support faceted browsing and recommendations corresponding to data dimensions (e.g., similar style, artist, subject, or any other category). In addition to the existing records, algorithmically derived metadata and recommendations can be used when developing a visualization [133], [144]. Machine learning in combination with computer vision has shown great potential for extracting visual features that allow us to go beyond the manual annotation of large collections [58] and thus contain the potential to critical intervention [144]. Also, similarity-based layouts can be used to create visual arrangements that are based both on the objects' metadata and on the algorithmically derived similarity of the images [145]. Users can also be invited to curate and recommend their own collections and assemblies, and share as guidance with the public—and even inspire others to creatively engage with the material in artistic practice and design[146].

User guidance can also be implemented as a form of *narrative*, by offering suggested paths or sequences of sense-making. The design principle of storytelling has been intensely discussed in the InfoVis community [147], [148], [149], as it brings back author-driven techniques of sense-making into a field originally focused on user-driven analysis. For the traditional presentation of CH collections, narrative arrangements are quite usual. Museums frequently rely on curatorial expertise when they make content available. One of the purposes of curation can be regarded as "narrating the collection", i.e., telling a story by selecting and presenting objects in a purposeful manner, accompanying them with additional information, and even guiding visitors through and between exhibits. Commonly, visual interfaces to digital CH collections disrupt the pattern of search-centric interfaces and provide more generous tableaus of objects and overviews, including the means for individual vertical exploration (zooming, immersing, details on demand [136]), and for horizontal browsing and strolling [73], [78]. Going beyond these user-driven movements, narrative design offers curator-driven pathways that extend the information seeking mantra [136] with the option to "*enjoy sequential guidance on demand*". While narrative visualizations can be completely author-driven, most examples find ways to balance author- and user-driven modes of experience [147]. As such, interface designers can allow users to drive their visits to collections individually, but also to lean back, and follow a narrator's suggestions and connections.

Options for Operationalization. In the context of visual interfaces to CH collections, narrative guidance can be implemented, for example, as animated movements across a map, which may include different textual and visual source materials [70], [89]. Narration can also follow a curator's storyboard along various spatial (i.e., linear or axial) encodings of time as with timelines, flowcharts, or tree diagrams [150], or also in 3D space [151]. The guidance can be author-driven (e.g., by curators [64]), user-driven [23], [29], or even created by users with their own CH data [70]. Users can store their individual path through a collection and share it with others [76], [134], which allows the publication of alternative and critical narratives in addition to the "authoritative" narrations created by commissioned curators. With regard to balanced approaches we found a largely untapped potential to interweave storylines into visual tableaus (see also the options of martini glass structures, drill-down stories, and interactive slideshows [147]), and thus to deliberately synthesize the author- and user-driven modes of experience in the context of CH collections and data.

5.5 Remote Access versus Being There

Differences between *on-site* experiences of CH collections and modes of *remote access* to CH collection data have already been discussed with regards to a common lack of narrative guidance in traditional CH interfaces (see above). On a more general level, the idea of bridging the gap between collection visualizations on screen and their appearances in physical settings refers to a unique challenge for visualization design. Most papers in this review discuss web-based InfoVis prototypes. A minority used and evaluated mobile systems [109], which could be used both remotely or in-situ. In their study, Rogers et al. [109] observed different patterns of use in virtual and physical museum environments, in particular, the entry point depended on the interaction taking place remotely or in-situ. Also, overviews linked with individual artifacts tended to promote exploration in the remote setting, while in-situ it was the physical artifacts driving explorations. This finding alone makes it obvious that InfoVis systems developed primarily for remote use will not necessarily serve the information needs (or maybe rather expectations) of museum visitors.

Options for Operationalization. We consider the in-situ use of exploratory interfaces and collection visualizations in real CH exhibition settings to be a largely unexplored area of application. For the interconnection of on-screen and off-screen experiences at exhibition sites, multiple constellations exist, from the in-situ use of public screens [152], [153] and mobile applications [109] to immersive installations [107], to a whole spectrum of virtual, augmented or mixed reality solutions [154], [155]. These solutions can focus on the well-known requirements (from overview and orientation to providing details on demand) for the visible parts of a collection or also go beyond. Given the fact that only a small percentage of an institution's collection is usually on view in exhibitions or visible storage, visualizations can bring information about off-display objects (or even about a whole range of contextual knowledge, see Section 5.7), back into a museum's hall, to enhance the overall visitor experience.

5.6 Facets of Uncertainty

Within visualization research, the question of how to deal with uncertain data already belongs to one of the standard exercises of the field [156]. When dealing with CH data, the question of uncertainty is often discussed in the context of digital reconstruction of CH sites and 3D visualization [157]. When it comes to InfoVis of CH collections, we see a lack of discussion on the same level. One of the most prevailing but also challenging metadata entries in CH collections is "date" (Section 3.5)—as it poses not only challenges of the historically exact dating or age determination, but also in regards to different concepts of time and the question of what date should be recorded and represented. Is it the date or period of production, of public display in its original setting, or of a sale or resale of a given object—or even a combination of several dates [158]?

Options for Operationalization. Kräutli and Boyd Davis [158] suggest not to render these uncertainties invisible by creating visualizations that represent time as exact, but instead integrate visual renderings of probabilistic time descriptions. This would relate to the humanities' convention to do the same on a textual basis. However, while general visualization research has addressed the visual encoding of temporal uncertainty [159], InfoVis for CH also needs to take on the challenge of visually representing interpretation and ambiguity on a more general level. Drucker argues that the visual representation of ambiguity and uncertainty also might require a shift away from standard metrics to metrics that express interpretation [138].

For the sources that introduce uncertainty into the age determination of artifacts, Kräutli and Boyd Davis have assembled a whole list, including the "inherent imprecision of the world" and the "interpretation by curators" [158]. We consider this list of factors to influence almost all metadata dimensions (see Section 3.1), including places, actors, relations, and even more so all available ascriptions of meaning. The acknowledgment of imprecision and interpretative openness that is present in textual sources in the humanities have hardly been acknowledged in the design of CH interfaces and visualizations. As these factors also tend to be rendered invisible in visual interfaces, there is a multitude of challenges for representing uncertainty in various data dimensions for future visualization approaches.

5.7 Contextualization

Emerging standards for *linked data* (see the "event-centric" approaches to CH data in Section 3.1) provide new options of enhancing, contextualizing, linking, and reframing CH objects and collection data [161]. Linked data is a way of publishing structured data that allows metadata of different local databases to be connected and enriched, "so that different representations of the same content can be identified, and links between related resources can be made" [20]. As such it introduces new potentials for the enhancement of collection data and might eventually support the overall processes of sense-making by connecting CH data silos and allowing for cross-domain representations and reasoning [162]. By uniquely identifying entities (such as cultural artifacts, creators, institutions, places, or events) and drawing typified (e.g., temporal, spatial, contextual, and conceptual) links between them, linked data initiatives weave CH-specific knowledge graphs and relational tissues into the Semantic Web [163]. Corresponding applications can benefit from this extended data ecosystem by utilizing and visualizing connections that go far beyond the scope of any local CH database. As linked data also brings along the risk of opening too many doors of possible connections for the users' cognition, related projects always have to balance the chances with parallel risks of accelerating "museum fatigue" [164] in a digital setting.

Options for Operationalization. Linked data can help to fundamentally reframe the interface to CH collections. In this sense, we see a remarkable potential to challenge the "authoritarian" or institutional cores of metadata inventories, as well as to conceive new avenues for visualizing object and art collections in relation to various societal environments (cf. [165]). Such contextualizations can foster a more systemic understanding of the arts and their interplay with historical environments. By connecting a given collection and its visualization with relevant societal environments in their historical constellations, the arts become visible as part of a greater system (e.g., reacting to or anticipating and influencing societal developments). CH visualizations can be annotated with historical markup, and thus contextualized within the wider socio-political circumstances of the collection's past and present [83]. But also the exchange of impulses with other societal spheres, such as politics, technology, economy, religion, science, or daily life (cf. [166]) can become visible in the rich depictions of future interfaces. In this regard, contextualizing and linking data can be a step towards further widening the concept of generosity, and to merge the horizon of CH exploration and interpretation with the complex horizons of socio-cultural meaning production and their dynamics at large.

6 Conclusion and Outlook

With this paper, we investigated and analyzed the state of the art in visual interface design for CH collection data. From the InfoVis point of view, CH data collections unfold as a specifically challenging but also promising research scenario. Novel challenges emerge from the wide variety of object types and their rich and heterogeneous metadata, often associated with materially rich content and further information, which have to be made accessible to diverse users with different abilities and aspirations.

We analyzed 70 CH visualization systems across a custom-made taxonomy to capture the current state of interface and visualization design. We analyzed the structure of this design space and reflected on open challenges and emerging topics from a wider InfoVis and humanities perspective. As such, we aimed to contribute to the consolidation of a hitherto scattered but vibrant research field. From the further development of its technical standards, we expect contributions with relevance for different communities, including scholarly, educational, intercultural, casual and public fields of cultural reasoning and communication.

To provide effective and productive interface technologies, the thorough understanding of users' motives, backgrounds, and cognitive requirements seems indispensable. As such, we argue for specifically attentive approaches, where user-centered design practices are guiding the system development, and local data, user, and task diversity is fully taken into account. While conducting this survey, we—as an interdisciplinary team of researchers with roots in different epistemic cultures—experienced once more, how only a patient collective sensemaking process can establish relevant categories and connections, which foster productive reflections between experts for information technologies and humanist thinking.

We consider visualizations and interfaces to CH data to be contemporary cultural artifacts in their own right. As they become part of our present day collection of instruments to explore, interpret, and communicate the past, we consider them even more so as epistemic objects, which need to be open for interpretation and critique. We hope that the outlined categories and principles can advance this endeavor. At the same time, we want to emphasize the need for more systematic and elaborate evaluations, which have to complement the process of interpretation and critique. It is our impression that such a balanced approach offers the opportunity to further develop and deepen this field of study, and to interconnect a multitude of visualization endeavors as a transdisciplinary research domain.

Appendix A

Online browser for the exploration of CH visualization interfaces: http://collectionvis.org

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REMAKING COLLECTIONS

Orchestrating Overviews: A Synoptic Approach to the Visualization of Cultural Collections

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In addition to providing pleasant and stimulating experiences, complex cultural collections can require significant amounts of cognitive work on the part of visitors. Whether collections are situated in physical spaces or presented via web-based interfaces, the sheer richness and diversity of artefacts and their associated information can frequently lead to cognitive overload and fatigue. In this article we explore visualization methods that can be used to fend off fatigue and to support cognitive tasks such as collection exploration and conceptual comprehension. We discuss a variety of options to generate collection representations with multiple views and focus on the rarely heeded challenge of how to integrate information from these views into a bigger picture. By utilizing multiple space-time cube representations (through the PolyCube framework), we discuss an effective approach to integrating and mediating multiple perspectives on cultural collection data. We illustrate its potential by the means of a case study on the work of Charles W. Cushman and outline first insights drawn from a heuristic evaluation. Finally, we situate our approach within the larger epistemic and methodological environment of humanities approaches to visualization design.

Introduction–On Trunked and Truncated Beasts

Can we address the elephant in the room? Spaces containing complex cultural collections (CCC) pose thorough challenges to the cognitive systems of visitors. Encounters with galleries, libraries, archives, or museums require sense-making activities with a vast number of mostly unknown objects. These are frequently of high perceptual diversity and rich in detail, each one connected to many threads of further information; and are commonly arranged in physical architectures based on unfamiliar principles. Even if visitors intend only to experience leisurely pleasure, such encounters require significant amounts of perception, interpretation, and learning. In short, considerable *mental effort* is required in order to cope with objects' and topic's complexities. If visitors are not domain experts, there is a good chance that this mental effort will soon translate into a rather simple generic feeling like fatigue, exhaustion, decreased attention, and information overload, or—if they cannot connect to the matter at all—plain boredom (Robinson, Sherman & Curry, 1928).

So aside from their well-known marvelous and inspiring aspects, it is rarely made explicit that CCCs require considerable support from a perception and cognition perspective. Learning about collections–i.e. building up a mental model (Vandenbosch & Higgins, 1996)–can be strenuous and challenging. This applies when visitors simply stroll through collections but is amplified when they explore the multiple dimensions of associated information (on textual displays or in collection catalogs) in depth. This challenging side of cultural collection is well-documented and well-known, too: 'Museum fatigue' and similar effects (like early satiation, exhaustion, and distraction) have been documented and studied for a long time (Bitgood, 2009a; Bitgood, 2009b; Davey, 2005; Gilman, 1916). Combined with restricted cognitive resources, collection complexity often enforces selectivity and simplification on the observers' side. 'Simply put, complexity is limited understanding. It is the absence of information that makes full comprehension of a system impossible' (Rasch, 2000: 49). Furthermore, 'increased consciousness of complexity brings with it the realization that "total comprehension" and "absence of distortion" are unattainable' (Rasch, 2000: 51). As a practical consequence visitors often build up only a limited understanding of the collection, grasping only fragments of the cultural riches before exiting through the gift shop.

We are reminded of the parable on the elephant and the blind men.[1] As an early reflection on the cognitive and communicative woes in face of object complexity, the tale ponders on the selectivity and apparent incompatibility of truncated system descriptions. Some sort of access to complex objects is possible for everyone, yet limited cognitive resources commonly generate idiosyncratic snapshots or locally valid impressions only. As for the reconnection of these partial perspectives and observations, the fable finds a solution either in an outside observer, who provides vision and conceptual integration; or in procedures of communication between the owners of the restricted views. We will keep those suggestions in mind, while turning back to present day cultural collections, which show no signs of simplifying as media technologies evolve.

Following decades of digitization, CCCs often exist both as traditional object collections in physical spaces, and as digital collections in data and information spaces.[2] It is in these theatres of operation where GLAM professionals (i.e. the owners, curators, guides, or custodians of galleries, libraries, archives or museums) have to support activities to chase, grasp, and reassemble elephants on a daily basis. It is their challenge to make collections comprehensible in face of limited vision and finite attention spans. Even if there is a strong belief among museum professionals that museum fatigue cannot be stopped, 'much like death and taxes' (Bitgood, 2009b: 195) the fight against it (diminishing, struggling, wrestling with it) is part of their daily work. Numerous approaches also show that fatigue is in fact not inevitable, 'if we design the visitor experience [more] effectively' (ibid.: 196).

1 The fable, which has been traced back to Buddhist, Hindu and Jain texts around the 1st millennium BCE tells the story of a group of blind men, who learn and conceptualize what an elephant is by touching it. Each blind man feels a different part of the elephant body, such as the side, the tusk or the trunk. They then describe the elephant based on their partial experience. Their descriptions lead to disagreement on what the object essentially is.

2 Concerning the scope of contemporary 'crowd-curated' CCCs consisting of native digital objects, estimates approach hilarious numbers: 70 million Instagram uploads a day (Yi-Frazier et al., 2015), 350 million Facebook images a day (Feinleib, 2014) and an estimated 180 billion images across platforms in 2014 (Meeker, 2014).

Looking around, we find numerous design strategies which help visitors to grasp the elephant while shunning, minimizing, or ameliorating fatigue. Many of them have been applied both in physical museum spaces, as well as in digital information spaces. Prominent methods include storytelling (Bedford, 2001; Boyd Davis, Vane & Kräutli, 2016), audio guides (Kuflik et al., 2011), gamification (Champion, 2014; Rowe, Lobene, Mott, & Lester, 2014), personalization and customization (Huang, Liu, Lee & Huang, 2012), participation (Ridge, 2013), and making curatorial concepts and arrangement principles transparent (e.g. onboarding techniques or 'advance organizers', as described by Anderson & Lucas, 1997).

In the following section, we zoom in on approaches which utilize methods of visualization to support the understanding of complex cultural collections. A synoptic approach is outlined by section three, its exemplary implementation in the fourth section, and its evaluation in the context of a case study in section five.

Visualization of Complex Cultural Collections

Visualization creates graphical representations from complex data allowing visitors to explore them interactively, and to acquire insights that unaided perception would not allow for (Ferreira & Levkowitz, 2003). The purpose of such representations is thus the amplification and augmentation of human cognition. This includes the acceleration of users' understanding; and the support of their analysis, reasoning, and sense-making activities in face of enormous, heterogeneous, abstract, and often time-oriented data (Arias-Hernandez et al., 2012; Thomas & Cook, 2005).

Digital collections commonly integrate digitized object representations of artefacts (such as images, text, audio, videos, or 3D models) and associated metadata entries, such as place of origin, date of origin, creator, style, or inter-object relations (see **Figure 1**).

In some cases the databases of GLAM institutions already mirror the complexity of their physical collections, constituting a prototypical example of massive, heterogeneous, abstract, and often time-oriented data. Such digital databases are often even less amenable to human sense-making than their physical counterparts, a problem exacerbated by the fact that visitors to digital collections are often treated as

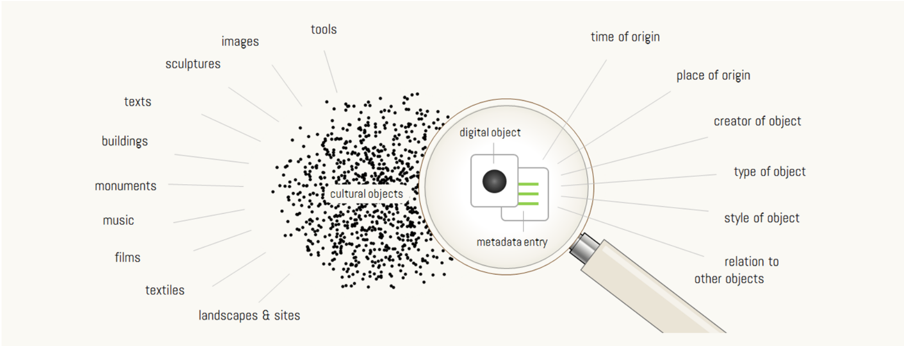

Figure 1: Cultural collections comprise a diversity of object types (left). As digitized collections, they are commonly translated into a digital object (image, text, audio, video, or 3D model), and enriched with multiple dimensions of metadata (right).

if common information seekers on the web, and so are provided with only the most basic (search-centered) access technologies. Such search-based interfaces require a thorough understanding of the collection's structure and available metadata to retrieve meaningful results (Goodale et al., 2014). It is this dire background against which several novel visualization-based approaches to data complexity have been developed. As the characteristics of CCC data differ to other collections of data in various ways, these works also expanded the understanding of ways in which users' cognition could be supported more adequately. In addition to the task-driven and deficit-oriented conception of visitors as information seekers, they provide new facets of understanding by utililizing methods to support visitors as playful, curiosity-driven, strolling, critical and exploratory subjects.[3]

Generosity, Serendipity and the Autotelic Reframing of Data Complexity

Let's imagine a visitor arriving at the landing page of an art gallery, an archive or a museum, with a collection he doesn't know well (cf. Whitelaw, 2015). We consider this visitor lucky if the website developers have already taken on board recent work reconsidering how visualizations can help visitors engage with the elephant ahead.

[3] For an investigation of the state of the art and future challenges for information visualization approaches to cultural heritage collections, see Windhager, Federico, Schreder et al. (2018).

In the following, we explore a selection of the basic ideas and design strategies they might have employed.

As a powerful paradigm for interaction with abundant information, the 'search box' approach to information retrieval has dominated interface and interaction design since the emergence of the web. Search boxes still are often chosen as the main method of access and are used even by the largest cultural collections such as Europeana, which, as of June 2018, contained more than 50 million artworks (europeana.eu). Exemplarily implemented by our everyday search engines, the search box paradigm builds on two assumptions: that visitors at least vaguely know what they are looking for, and that visitors do not want to engage with the complexity of the search space, which stays hidden from their perception until query algorithms have done their mediating work. However, this only works if users are able to state their needs (i.e. their information deficit), after which ten blue links to further data or information artifacts are wheeled out for closer inspection (Broder et al., 2010).

Dörk et al. (2011) reject these assumptions. Building on studies of non-experts (or 'casual users', as per Pousman et al., 2007), they firstly take issue with the paradoxical manner in which search engines require visitors to search for things they commonly know little or nothing about. Against this unjustified assumption, they call for methods that enable direct access and exploration, such as directly entering a data collection and strolling through its riches. Secondly, they revise the operating metaphor on data complexity. If massive data collections are not conceived as tiresome deserts or dusty archives, but for instance as vital landscapes or vibrant cities, then movement through them becomes an 'autotelic' activity, providing aesthetic value in and of itself. Here, the shortening of search paths and times is no longer front-and-centre to the visitor experience, but rather the provision of vertical immersion and horizontal exploration in and through datasets. The visitor is no longer positioned as a deficit-driven information seeker, but as an open-minded urban flâneur. In order to facilitate the desires of this browsing subject, interfaces should extend beyond the search-box and become 'generous', enabling hedonistic, open-ended, curiosity-driven and multi-perspective data engagement endeavors (Whitelaw, 2015).

This 'generous design' avoids starting with questions but prefers to directly show: it aims to offer rich overviews and context, as well as high quality primary content and detail on demand (Butler, 2013). Because it has the privilege to deal with data that does not have to be hidden it can throw the doors of collections wide open and so transform databases into giving and sharing visual repositories, which represent scale and richness; but also allow multiple ways to focus on specific details. To honor the complexity and diversity of a collection, generous design offers multiple access or vantage points, and encourages multiple perspectives on the assembled riches. Understanding that any given visualization method can capture only certain aspects of a collection's composition or structure, it calls for multiple views to be used in the presentation of objects, combining the strengths of different methods and forming complementary composites to reveal different aspects of a collection. Such a multi-perspective interface enables the 'open-ended proliferation of partial views, rather than a single total or definitive representation' (Whitelaw, 2015: n.pag.), an approach which, as Drucker (2013) argues, better match the open-ended dynamics of human interpretative processes.

Another key facet of human information acquisition that visitors can utilize in such interfaces is 'serendipitous' engagement. In museums, libraries and other open object collections, visitors frequently find interesting and inspiring information by chance. Several studies on everyday information practices show that serendipitous encounters constitute a key component of information acquisition (Ross, 1999). Thudt et al. (2012) thus reflected on interface design methods which create options for serendipitous learning and for encountering unexpected information of interest. Based on their study, they recommend following a playful approach to information exploration and to entice curiosity through visually distinct representations of single objects. Furthermore, they recommend to highlight adjacencies between objects but also to provide flexible visual pathways for exploring a collection, and to grant multiple visual perspectives and access points.

Advantages and Challenges of Multiple Views

As a standard technique for fostering multiple entry points and a plurality of perspectives and interpretations, the method of 'multiple views', or 'coordinated multiple views' (Andrienko & Andrienko, 2007; Roberts, 2007) has been established. Offering multiple views has the advantage to 'maximise insight, balance the strengths and weaknesses of individual views, and avoid misinterpretation' and 'allow the user to select and switch between the most appropriate representations for the data and task at hand' (Kerracher et al., 2014: 3). Instead of betting all analytical capacities on singular implementations of visualization methods like maps, networks, or treemaps (see **Figure 2**, left hand side), advanced interface design builds on the understanding that *one view is not enough* (Dörk et al., 2017)—bountiful combinations of views are the way to go. As a recent review of visualization approaches to cultural collections shows, existing visual collection interfaces frequently make use of this principle, and implement on average 2.6 different spatial, structural, or cross-sectional visualization methods (Windhager et al., 2018).

However, offering multiple views can also be a way to cover a specifically interesting data dimension in a more diverse or in-depth fashion. For the cultural heritage domain, *time* is such a crucial data dimension (Dörk et al., 2017). Accordingly, the temporal origins of individual objects or collection parts should not only be visualized by the means of simple timelines, but also by utilizing animation, layer superimposition, layer juxtaposition or space-time cube representations (see **Figure 2**, right hand side). Using these options in tandem can help to maximize insights and balance the strengths and weaknesses of individual views for the temporal data dimension in particular (Kerracher et al., 2014). Although analysts of cultural collections could arguably benefit from such a rich depiction of the temporal dimension, we found collection interfaces to only use a modest number of 1.2 time-oriented views on average (Windhager et al., 2018), which shows a huge potential for future designs.

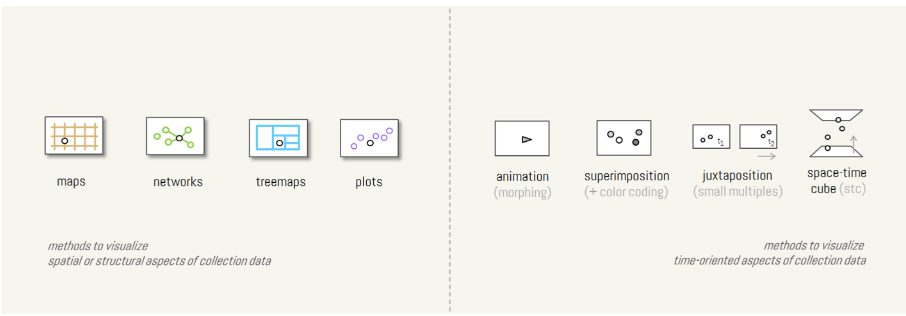

Figure 2: Multiple spatial or structural visualization methods (left) and multiple methods to visualize time (right).

While we consider this generous provision of multiple (spatial, structural, and temporal) perspectives as a strength of novel interfaces, their implementation also comes with a notable downside, which has been barely mentioned or problematized up to now: multiple perspectives recreate perceptual complexity and diversity on the overview level on our screens. The resulting challenge has various consequences for macrocognitive reasoning operations (Klein & Hoffman, 2008), i.e. for sense-making in the context of complex data and tasks. We call this challenge the 'split-attention challenge' of complex interfaces with multiple views—and consider it to be a second-order problem of visual reasoning, and a fundamental challenge for future visualization system design (cf. Schreder et al., 2016).[4]

From Visual Analytics to Visual Synthetics

Split-attention challenges arise when observers of multiple views start to wonder about the bigger picture of a collection—or what the whole elephant looks like—yet their diverse information sources appear spatially or perceptually separated, and do not easily merge.[5] Visual-analytical interfaces mostly focus on taking complex subject matters or data apart, separating them into their constituent elements and providing cross-sectional or longitudinal cuts with different techniques through complex objects of study.[6] **Figure 3** shows two screenshots taken from prominent visualization interfaces, which are frequently applied to the analysis of cultural heritage collections (Coleman et al., 2017; Jänicke et al., 2013). In the selected arrangements, they both combine the map-based representation of a collection with a time-oriented representation (i.e. a histogram and a line chart).

[4] 'Split attention effect' is the name for a phenomenon where learners are offered multiple descriptions or depictions of the same topic, and thus have to integrate these representations mentally. This forced integration process stresses the learner's working memory and can negatively impact learning if the mutually dependent or complementary sources are designed poorly or cannot easily be synthesized. To create effective learning environments, it is recommended that designers avoid split-attention by externally integrating the different sources of information together into a single integrated source of information (Ayres & Cierniak, 2012), or implement other integration-supporting techniques.

[5] Due to their unique visual syntax and data spatialization principles, information visualizations are specifically challenging components for top level-integration. Yet also with each visualization type itself, the challenge to mentally merge cross-sectional and temporal perspectives ranks high.

[6] See the etymological origins from the Greek *analusis* and *analuein*, referring to 'unloosing, 'unraveling' or 'dissecting'.

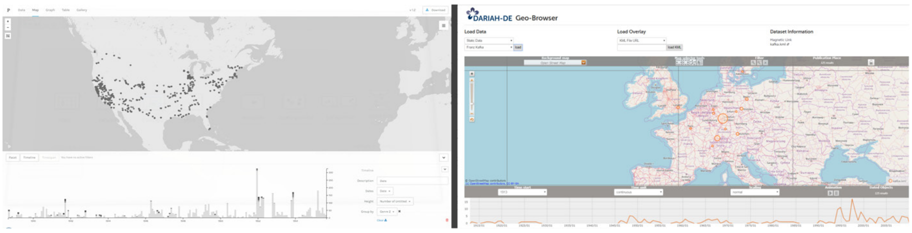

Figure 3: Screenshots taken from Palladio (cf. Coleman et al., 2017) and the DARIAH-DE Geobrowser (cf. Jänicke et al., 2013), with both displays combining coordinated views on spatial and temporal collection data aspects.

For a synoptic integration of the displayed data, users have to combine information from both views (i.e. from the spatial and temporal perspective at the same time) and build up a mental model that integrates both data dimensions. Cognitive science researchers have called attention to the fact that such synthetic operations are cognitively demanding in general, but require even higher cognitive effort when the aim is to construct a coherent and consistent mental model rather than a sketchy 'cognitive collage' (Tversky, 1993). We contend that this challenge becomes aggravated where visual-analytical systems are designed without additional 'coherence techniques', or in the absence of a macrocognition-supporting visual-synthetical framework (Schreder et al., 2016).

With regard to the synthesis of bigger pictures, we distinguish between possible results along a quality gradient of construction. According to Tversky's distinction (1993), 'cognitive collages' equal a distorted mix-up of partial information, differing perspectives and reference points that characterize fragmentary internal representations. 'Snippets of information are stored in memory but are not systematically or only loosely related to one another. Though this information can be recalled, it is difficult to use such ill-structured information to solve more complex problems' (Schreder et al., 2016: 82). In contrast to cognitive collages, mental models integrate different aspects and perspectives and 'capture the categorical or spatial relations among elements coherently, allowing perspective-taking, reorientation, and spatial inferences' (Tversky, 1993: 15). **Figure 4** illustrates the distinction with figurative regard to the CCC elephant.

While it is relatively easy to synthesize jumbled and fragmented collages from multiple views, their coherent assembly requires either more mental effort by the

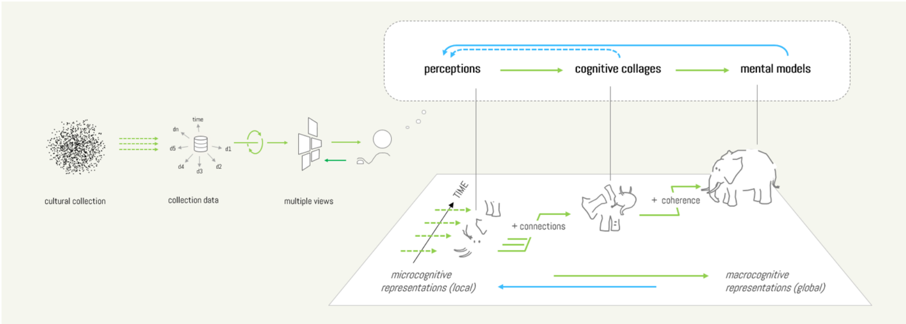

Figure 4: The visual-synthetical continuum from microcognitive representations (single perceptions) to macrocognitive representations, that are either cognitive collages or mental models.

user—or the development of more effective techniques of visual-synthetical design on the visualization side.[7]

With regard to 'coherence techniques', which support cognition by connecting insights from different views to larger units of sense-making, we find two basic approaches: the use of consistent visual variables or design choices across multiple views (Qu & Hullman, 2018); and the use of coordinated interaction methods like coordinated selecting and highlighting or linking and brushing, as well as synchronized panning, scrolling or zooming (North & Shneiderman, 2000). Yet even if both techniques are exemplarily implemented—as in the two interfaces shown in **Figure 3**—cognitive challenges remain. On the one hand, significant visual work is needed to bridge the distance of separated views, while conflicting design choices must be disambiguated. One of these conflicts is created by the simultaneous use of the horizontal axis as an west-east axis of the map view, while simultaneously representing the temporal data dimension in the other view.

As Funtowicz and Ravetz (2013: 8) put it in their reflection on the elephant, '[e]ach perceives his or her own elephant as it were. The task of the facilitator is to see those partial systems from a broader perspective, and to find or create some overlap

[7] Cognitive science research points to the significant payoffs that coherent representations can have on local visual sense-making (cf. Figure 4, arrows in blue). Users with more coherent mental models can better organize their local perceptions and recall information better (McNamara, et al., 1996). They can better navigate the information space (Tversky, 2011) and thus are assumed to generate more inferences and novel insights into the data (Schreder et al., 2016).

among them all, so that there can be agreement or at least acquiescence'. Accordingly, we think that the facilitation and orchestration of inter-perspective agreement is a challenge worth a systematic research effort of its own. The development of future visual analytics interfaces deserves special attention from a *visual synthetics* perspective in order to cope with the downsides that the multiplication of perspectives brings. We do not think that 'multiple view-fatigue'—which can hit viewers when trying to synthesize everything on their own—is inevitable, if visualization designers put the synthetical challenge on their agenda. This should not be done to the detriment of the hermeneutic richness of single views, but for their mutual amplification. As such, we want to explore options to better organize visual complexity, and to do so in a *coherent, consistent* and *interoperable* manner. Guided by these targets, we introduce an approach that we consider to significantly help with the challenge to facilitate perspective overlap, integrate information and insights, and mediate between multiple views on complex cultural collections.

PolyCubism–A New Approach to Information Integration

The research project *PolyCube*—Towards Integrated Mental Models of Cultural Heritage Data (PolyCube, 2016; Windhager et al., 2016) addresses this challenge by developing a visually integrated interface for CCCs. The interface will work as a web-based platform for collection visualization, but could also be implemented as an (interactive, screen-based) data sculpture (Zhao & Van der More, 2008), which can serve as a three-dimensional 'advance organizer' (Ausubel, 1960; Anderson & Lucas, 1997) in the entrance hall of a gallery, library, archive, or museum.

The PolyCube emerges from the space-time cube representation (STC), first developed and utilized in human geography to support the visual analysis of human movement patterns and the spatial diffusion of innovation (Hägerstrand, 1970). The operating principle of this method is to orthogonally blend cross-sectional views (horizontal plane) and temporal view (vertical axis) together, allowing the mapping of the spatiotemporal origins of objects. Every event distribution in space and time thus translates into the unique shape of a point cloud, disclosing further spatiotemporal patterns to the gestalt perception of CCC visitors and analysts.

By the means of a space-time cube representation, the PolyCube scaffold can arrange CCC objects as point clouds according to multiple spatio-temporal arrangement principles. On the bottom, a data plane initially features a geographic map, and each object's place-of-origin determines its horizontal position. The vertical axis of the cube represents time–and thus date-of-origin assigns an individual altitude to each cultural object above the ground (**Figure 5**).

Contemplated from a distance, this framework rearranges every corpus as a characteristically shaped 'hyperobject', which invites on-demand probing, zooming and close-up display. Further visual structures are *sets* which can delineate aggregations of objects, and *links* displaying relations between them. Together with possible alternative layouts for the data plane (like force-directed graphs, set diagrams or treemaps), the PolyCube approach can morph the corpora of large cultural collections into a wide range of expressive, data-driven shapes or patterns, with each constellation allowing different insights into a collection's rich conceptual anatomy (see **Figures 6** and **7**).

A New Kind of Pattern Language

Figure 6 shows a lineup of basic available patterns. While basic distribution plots (left) unveil the spatiotemporal extension of a cultural collection's origins for the visitors' contemplation, inter-object links can provide the means to visualize narrative or curatorial pathways, as well as genealogical or inter- and intragenerational relations between artifacts (second from left and center).

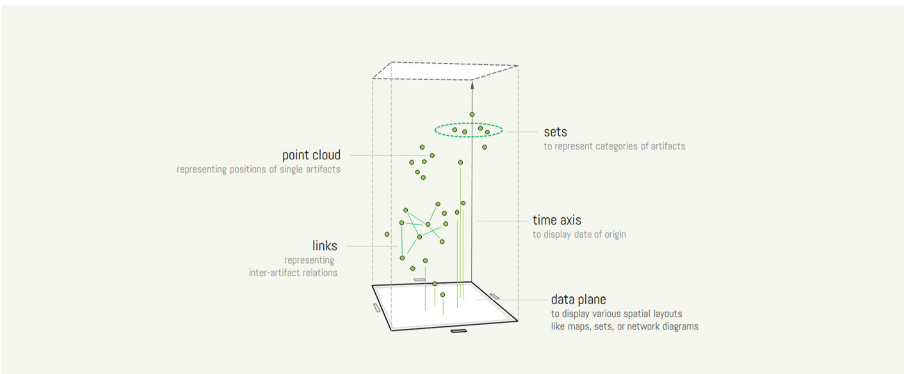

Figure 5: The space-time cube as an integrated visualization method for collection data.

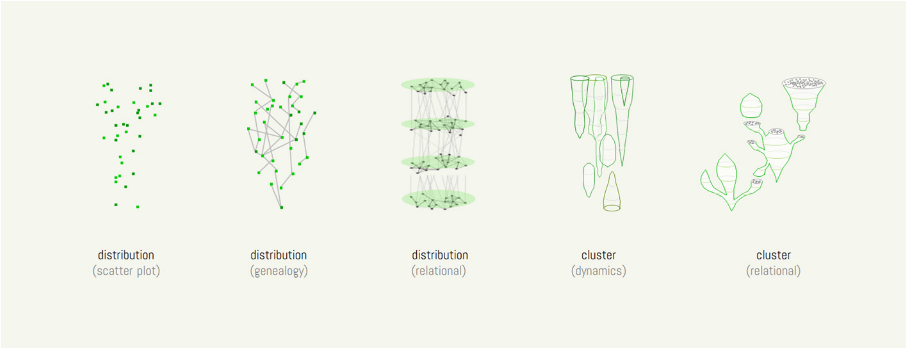

Figure 6: Different spatiotemporal patterns and expressions within the space-time cube, which can be generated from rich CCC data to show distributional, relational and categorial (set-like) shapes of a CCC in parallel.

Figure 7: Basic flow patterns to visually parse and analyze the evolution of CCC developments.

For categories of objects—accumulated and delineated by sets—the framework generates expressive flow patterns (second from right and far right), which exemplarily can disclose the parallel evolution of cultural styles or schools, or their mutual genealogical influences. For these accumulating perspectives—which can also indirectly visualize the associated development of cultural organizations, art schools, religions, fashions, disciplines, or any other collective entities—a simple pattern language helps users visually parse complex developments as composites of basic temporal patterns (**Figure 7**). Styles or schools emerge in time, and either grow, split, or differentiate into multiple subcultures (left hand side). On the other side they can merge, de-differentiate, shrink, and cease to inspire collective reproduction or variation.

Excursus on two versus three dimensions in visualization design

When utilizing the third dimension in InfoVis, one should prepare for some additional explaining. As Munzner (2014) puts it: '[i]n brief, 3D is easy to justify when the user's tasks involve shape understanding of inherently 3D structures … In all other contexts, the use of 3D needs to be carefully justified'. In light of this stance, we should check whether cultural collection data is inherently 3D, which—in a trivial sense—it is obviously not. Yet, on the other hand, the relevance of time has been already stated for the cultural heritage context, which technically adds a further dimension to any plain visualization technique, already utilizing two display dimensions.[8] Following this perspective, hybrid 3D data (i.e. spatio-temporal or structural-temporal data) is omnipresent in the cultural heritage domain, which requires integrated representation solutions as provided by the STC. More specifically, a number of further arguments support the use of an STC.

Firstly, the STC achieves the integration of spatio-and-temporal in a fair and balanced manner by distributing the strongest and most effective visual variable (i.e. position, cf. Mackinlay, 1986) equally to all sides: x- and y-axis to spatial data, z-axis to temporal data.

Secondly, this unfolds a whole new visual-analytical morphology as an expressive and technically open-ended, time-oriented pattern language that could be parsed and read by highly trained faculties of 3D gestalt perception (see below), and which synoptically encodes time like no other method we know (see **Figures 6** and **7**).

Thirdly, as Bach et al. (2016) note, STC representations can act as translational hubs or as operational cognitive scaffolds. They can mediate between the temporal visualization methods mentioned above (see **Figure 2**); and translate from temporal to spatial perspectives, while supporting visual analysts' navigation by seamless transitions (see **Figures 8** and **10**). To the best of our knowledge no other visualization method can do this.

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8 As Dörk et al. (2017: 46) conclude from their evaluation of a multiple view-system under the subject matter '*Primacy of time*': 'While time was only considered in two of the four views, the feedback indicated that it is a dimension that could be expanded across all views'.

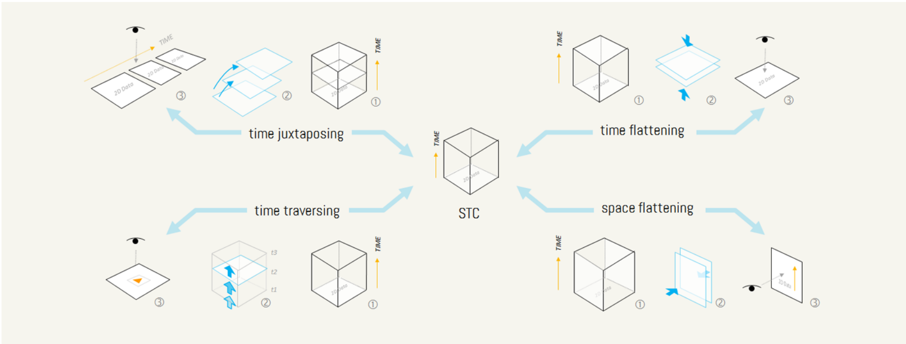

Figure 8: Seamlessly traceable transitions on the space-time cube allow to derive various alternative visualization perspectives on a collection's spacetime (from Windhager et al., 2017) (see. also Figure 12).

Fourthly, empirical studies on casual users (Amini et al., 2015; Kristensson et al., 2009, Kveladze, Kraak & van Elzakker, 2015) show that they can identify spatiotemporal patterns more quickly and more accurately with STC than with 2D visualization. While the STC is less suited for identifying detailed data properties on one dimension, it can unfold its full power when users want to see multidimensional patterns.

Fifthly, studies show that STC representations are liked because they are 'cool' (Amini et al., 2015; Kristensson et al., 2009). This should not be dismissed given the importance of drawing casual users and accidental visitors into an in-depth exploration process.[9]

Sixthly, Sorger et al. (2015) provide a conciliatory frame for the mediation of 2D and 3D representations, which resonates with recommendations of generous design and cherishes the benefits of representational syntheses: Integrating 2D and 3D visualization methods in a single interface provides users with complementary composites, which can add to the method's mutual contextualization and comprehension.

[9] As for the visitor group of visualization experts, who are expected to rather feel provoked by the use of 3D representations, we agree with Bitgood (2009b: 200, emphasis in original), who implores designers to '*[b]e provocative*! Stimulating exhibits are the best preventive medicine for 'museum fatigue'. Once interest is 'hooked', visitors are likely to be more engaged with the experience; boredom and tiredness are then minimized'.

Drawing these arguments together, we consider STC representations to provide a powerful and largely untapped potential for visual-synthetical mediation—not in spite of but due to their use of an additional display dimension. While this also increases visual clutter and interaction costs (e.g., due to additional rotating, zooming and panning, cf. Munzner, 2014), some of the standard complaints from plain design advocates could also be returned to the sender: pleas for the minimization of interaction costs will remain acceptable only if they find alternative ways to cover the significant cognitive costs of information integration that pile up for unaided macrocognition in between multiple views. There is a final argument to be made about cognitive economics—one that strives for a balance between open-minded, pro-plurality approaches (Dörk et al., 2011; Drucker, 2013; Thudt et al., 2012; Whitelaw, 2015) and a vital defense of cognitive ergonomics. The latter could encourage a re-thinking of Ockham's razor for the visual reasoning domain (views and entities should not be multiplied beyond necessity) and drive the orchestration of already existing perspectives (see also Section Six).

Case Study–The Charles W. Cushman Collection

To consolidate the outlined design principles, we present first patterns and insights from a digital collection case study, reshaped by the first implementation of the PolyCube framework as a visual-analytical research prototype.

PolyCube–Technical Implementation and Case Study Data

Three main considerations guided the technical implementation of the PolyCube concept: reusability; modularity for ease of reading and extension; and compatibility with DOM selection in order to accommodate various document object model (DOM)-related libraries such as data driven documents (D3.js). We aimed to build the PolyCube 3D rendering environment on CSS3D, doing without the WebGL engine as much as possible, as this is still not supported by browsers and older devices with limited exposure and instability of the current HTML5 canvas.

To ensure modularity, the code was built in a modular fashion using the popular JavaScript framework to support easy integration and creation components by creating a PolyCube object as a function with properties such as *drawMap*, *drawElement*, *Render*, and *superImpose*, which can be called and used on the fly. To achieve compatibility with DOM-related libraries such as d3.js, known for its powerful data exploration focus, we made all major components in the DOM accessible by drawing them using the CSS3D renderer as opposed to the webGL renderer with the help of the three.js 3D library.

As for the data, we make use of the Cushman Collection (Indiana University, 2004), as it has already been developed, prepared and geo-referenced by Miriam Posner (2014) for the use with the Palladio interface (Coleman et al., 2017; Edelstein et al., 2017), which also serves as a reference for comparison.[10] Charles Weever Cushman was an amateur photographer and alumnus from Indiana University. The collection he bequeathed to the university encompasses 14,500 photographs, taken between the years 1938 and 1969. As our system prototype is still awaiting optimization for processing speed and visual occlusion management (Elmqvist & Tsigas, 2008), we took a closer look at a randomized sub-selection of 800 photographs dating from 1938 to 1955.

PolyCubistic Perspectives on the Cushman Collection

For the case study, a geographic map and a set-diagrammatic visualization were implemented as cross-sectional visualization methods. These views have been transferred to an STC, which also offers a juxtaposition and a superimposition perspective on demand. **Figure 9** shows the first representation of collection data from a space-time cube perspective. The screenshot shows the origins of Cushman's photographs as spatiotemporally located events along the trails of his travels.

The representation allows for rotation, zooming and panning, and access to previews of photographs (see **Figure 11**, left hand side). Space-time cube representations provide an integrated perspective on spatiotemporal distributions (Kristensson et al., 2009), but also serve as a cognitive scaffold, which helps to create other spatial, temporal, or spatiotemporal perspectives by visual manipulations (Bach et al., 2016; see **Figure 8**). To support the navigation of users between different views, and to keep their spatiotemporal orientation intact, the prototype features seamlessly animated canvas transitions (cf. Federico et al., 2012) as a mediating

[10] The cultural collection visualized with the Palladio toolkit in Figure 3 (left hand side) shows this data selection from the Cushman Collection.

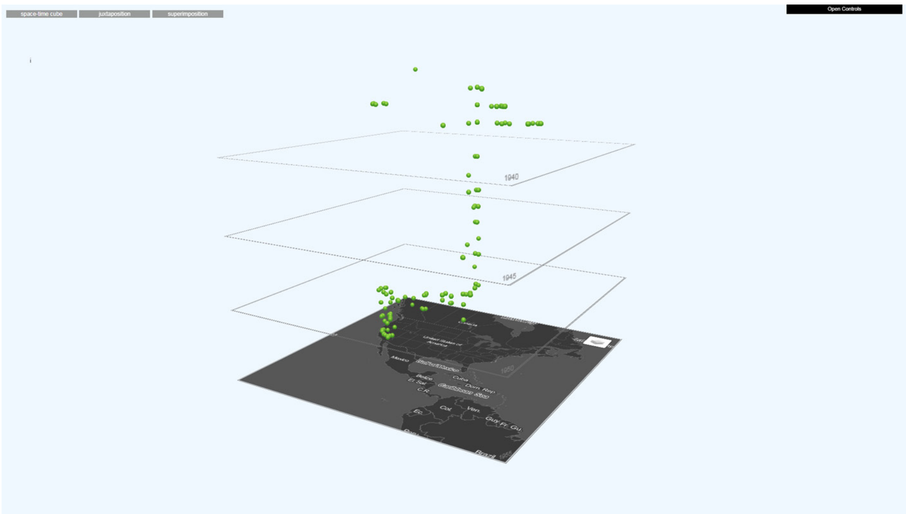

Figure 9: Space-time cube representation of a sub-selection of Charles W. Cushman's work, comprising 800 images between the years 1938 and 1955.

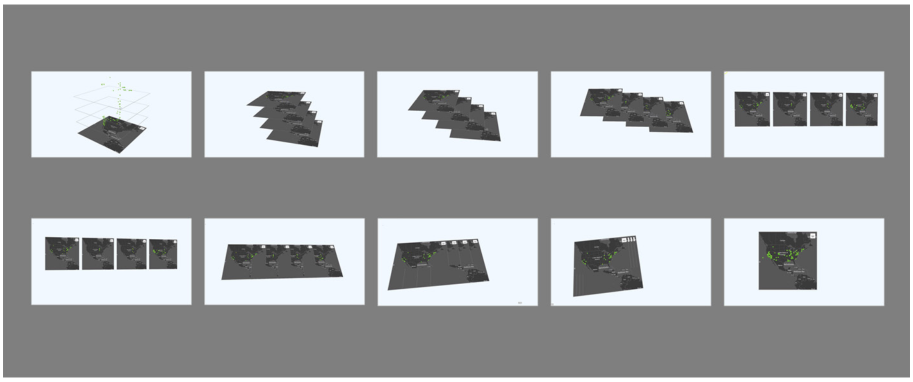

Figure 10: Animated canvas transitions, seamlessly translating an STC representation into a juxtaposition perspective (top row) and from a juxtaposition into a layer superimposition perspective (bottom row).

coherence technique. **Figure 10** shows how these seamless transitions visually guide the user's perception from an STC representation to a layer juxtaposition perspective (top row), and from a juxtaposition to a superimposition perspective (bottom).

From a model-based reasoning perspective, these transitions strengthen the visual momentum of the visualization system (Bennett & Flach, 2012), and support the maintenance of the spatiotemporal mental model. Exemplarily, starting from an STC representation allows to seamlessly flatten the vertical time axis, so as to arrive at an aggregated superimposition perspective (see **Figure 11**).

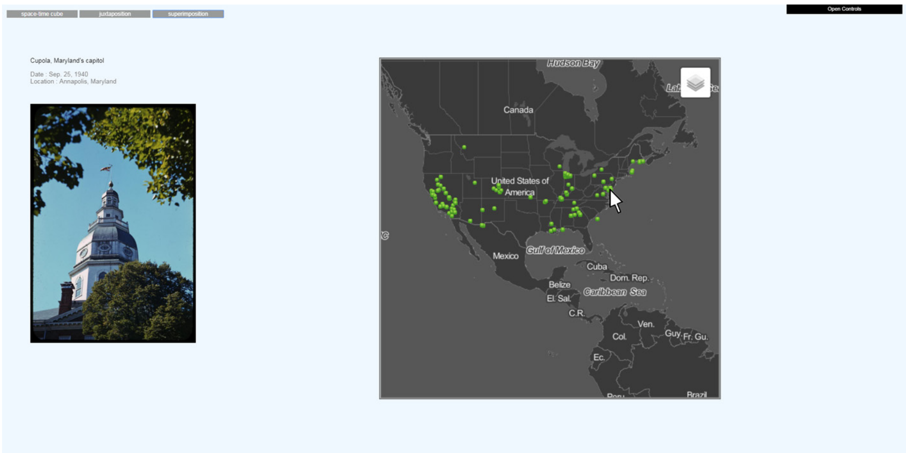

Figure 11: The 'time flattened' superimposition perspective on a subselection of the Cushman Collection, with a highlighted picture from Annapolis, MD, 1940, on the left hand side.

Figure 12: The layer juxtaposition (or small multiple) perspective on the Cushman Collection, visualizing photographs taken from 1938–40, 1940–45, 1945–50, 1950–55 (from left to right).

The flat superimposition layout allows for inspection of the overall spatial distribution of objects, and the precise reading of spatial positions from an orthogonal point of view. As the time-axis has been shortened, it is possible to encode time into another retinal variable like the color of the data points to allow for a balanced comparison of different spatiotemporally integrated perspectives.

Figure 12 shows the prototype's third major perspective, arranging temporal layers in a juxtaposed position. The strength of this position is the disaggregation

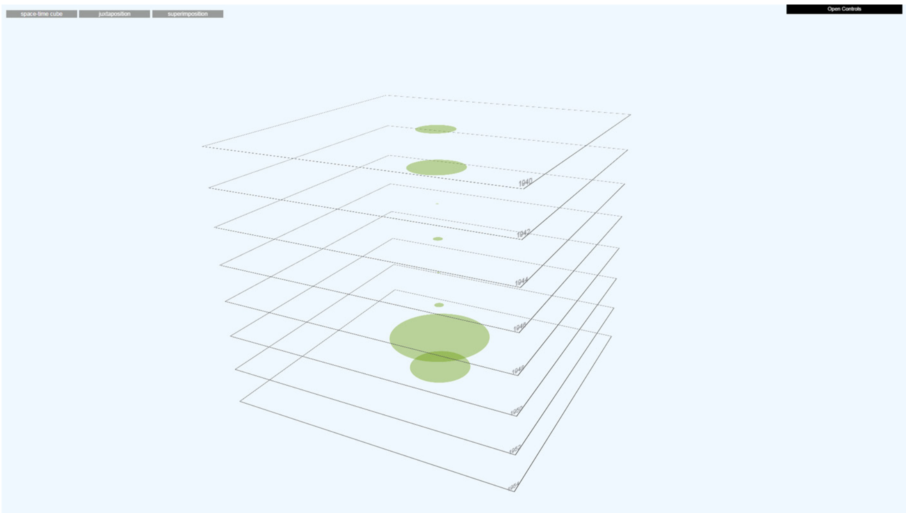

Figure 13: The set-diagrammatic STC perspective on the Cushman collection.

of the superimposed view into multiple temporal panels, and the conventional reading direction from left to right. We consider this constantly available plurality of perspectives to provide an added value to the visual analysts, so that they are always able to balance the strengths and weaknesses of individual views by switching 'between the most appropriate representations for the data and task at hand' (Kerracher et al., 2014).

Figure 13 finally shows how the PolyCube framework is open for the implementation of various further spatial, structural, or in general 'cross-sectional' visualization methods (cf. **Figure 2**, left hand side). Using a simple set visualization, it allows to aggregate objects per temporal segment, and to convey an integrated view on the development of every (sub)collection.

If such set-diagrammatic cuts through the longitudinal development of a collection are further enriched (for instance by differentiating subsets), the flow-patterns of **Figure 7** will emerge, supporting the cognition and sense-making of collection visitors and analysts. Due to the openness of this imaging framework, we consider its emerging 'data sculptures' to provide a multi-faceted but orchestrated approach to the visualization of complex cultural collections. Exhibitions can utilize it by providing interactive 3D models on large or small screens, but also by implementing them as physical visualizations (Zhao & Vande Moere, 2008) in the entrance halls of libraries, archives and museums.

Whether for online or offline collections, such data sculptures can serve as prime exhibits among others, featuring as a bigger picture of the whole elephant, and as a novel interpretation of the advance organizer concept (Anderson & Lucas, 1997). Whilst we are aware that visitors will be required to put in a degree of work to become familiar with such models, studies point out that once someone is 'hooked' by a (meta-)exhibit, it becomes more likely that they will engage with subsequent experiences, while 'boredom and tiredness are then minimized' (Bitgood, 2009b).

Evaluation

We conducted a qualitative evaluation of the PolyCube prototype with three casual users: two female and one male. None of them had prior knowledge about the Cushman collection, nor any expertise in the field of information visualization. They participated voluntarily in this study without any remuneration besides some complimentary chocolates.

Evaluation Procedure

Following a short introduction to the Cushman Collection and the interaction techniques offered within the prototype (rotate, zoom, pan, select), participants were left to freely explore the prototype on a 24'' screen while thinking aloud. The visual structure of the STC was not further explained as we sought to understand how casual users make sense out of the unfamiliar PolyCube system (similar to the procedure in Smuc et al., 2008). Having gained an understanding of the prototype's visual structure, they were asked some task-like questions about the Cushman Collection (e.g. can you guess from the visualization, where Cushman lived in which periods?). For the selection of questions, we oriented ourselves on prior research (e.g., Amini et al., 2015), showing that the STC is more powerful for gaining spatiotemporal knowledge related to broader patterns than about individual data points. In a final interview, participants were asked to compare different variants of the STC (number of layers, set-diagrammatic vs. geographic data plane), as well as the STC against the juxtaposition and superimposition views with respect to user experience and to its informative value. They were encouraged to name improvements and describe problems they encountered. Overall, the evaluation procedure took between 20 and 35 minutes per participant. While the experimenter guided the evaluation, two observers noted down the most important statements and observations. Audio recordings were used to validate these protocols.

Evaluation Results

During the free exploration, Participant 1 started with an extensive phase of close reading—viewing and evaluating the different photographs—before she was encouraged to explore the arrangement of the data points (7') and slowly gained an understanding of the visual structure (15'). The other two participants explored and understood the visual structure right from the beginning. Participant 3 rightly observed that significantly fewer than 800 data points became visible in the various perspectives, which was caused by the merging of spatiotemporally adjacent data points on the chosen scale.

Participants reported no significant problems while answering our questions. They could identify spatiotemporal patterns efficiently with the STC. All three participants were able to describe where Cushman lived or travelled during each period. Participant 1 was the only one to show initial difficulties in relating the data points to the correct geographic regions, but came to grips with the task after rotating the STC. Confronted with the task to identify the time periods when Cushman was the most active or inactive, all three participants could instantaneously point out the corresponding time periods. When asked to describe the collection to someone else, they focused on their (mostly emotional) evaluation of the explored photographs rather than on the collection's spatiotemporal characteristics. As Participant 2 phrased it: 'a number of uninteresting photographs, but in a nice toy to play with'.

During the final interview, all three participants preferred the STC over the juxtaposition and superimposition visualizations. As Participant 1 stated: 'you can't feel the logic at once, but then it is becoming clear … You can compare period, territory, the main objects. This is nice'. All participants highlighted the STC's potential to support an integrated understanding of the geographic and temporal distribution and interdependencies of the data, which cannot be as easily derived from the other views. They also highlighted the attraction and user experience of the

STC. As Participant 2 put it: 'if I have something boring [the photographs] and fun [the STC]—and something boring and no fun—I'll take the former, obviously'.

The participants suggested numerous improvements. With respect to the visual design, Participant 2 would stated they would have found the STC more logical or natural if the time-axis were inverted. For the juxtaposition perspective, all participants missed labels specifying the temporal periods. Participant 3 suggested improving the labeling on the time axis so that it can be easily read regardless of rotation. We also collected some design suggestions, such as the ability to enlarge selected photographs on demand and the addition of data layers of related (historical or political) events, so that the artworks of the collection could be contextualized in a broader space-time context.

As for the set-diagrammatic visualization (**Figure 13**), the participants easily understood the focus on the total amount of pictures per period, but also remarked that the abstraction from the geo-temporal details reduced the visual-analytical value. However, they recognized a potential for this perspective when dealing with the analysis of larger (or also categorically differentiated) collections.

Conclusion and Outlook

In this article, we have reflected on both the curiosity and openness that drives people to explore cultural collections and on the well-known limitations of their cognitive resources. Information visualization offers a powerful spectrum of methods to provide visitors to complex collections with facets of a bigger picture. Interaction with such representations can add to the visitor's sense of overview and orientation–and thus facilitate conceptual understanding. Following our discussion of recent achievements of generous interface design, we focused on a second-order problem that arises from one of its central design strategies: multiple views allow visitors to inspect CCC data from diverse perspectives and support the investigation of spatial, structural, and temporal data aspects. Yet, most of these interfaces leave users to themselves when it comes to the integration or mediation of these perspectives.

We introduced the PolyCube framework as a method to mediate and integrate a diversity of local views on a global level of representation. Analogous to the provision of overviews on a local level, this enhances the ease of global cognitive syntheses and reduces cognitive efforts to integrate various perspectives without sacrificing any of the benefits offered by plain local 'standard' views. In particular, the options provided by seamless transitions appear as a promising technique to support visual macrocognition and as a noteworthy strategy for strengthening the visual momentum of advanced interfaces for use with and by cultural collections (Bennett & Flach, 2012). While preparing for the necessary evaluations to more thoroughly investigate and substantiate our arguments, we look forward to a discussion which needs to be had on a more fundamental basis, where methodological and epistemic positions of humanities-related research are negotiated.

Towards New Kinds of Elephants

Revolving around an organismic metaphor of complexity, we have discussed a specific combination of techniques to reassemble elephants as a whole. Towards the end of this endeavor it seems necessary to look into one of the most obvious limitations of this metaphor: cultural collections—like so many other complex phenomena—have no original (spatial or visual) superstructure that can be visually reconstructed in an isomorphic fashion. Diagrams and information visualizations are indispensable techniques because they successfully create *new* arrangements of abstract data, optimized for human perception by rule-driven layouts. Unfortunately, these rules have been mostly devised as independent procedures, with each visualization technique imposing its own structure and logic on the pictorial spaces of canvasses or screens. When zooming out from a multitude of such local (body part) images, they do not easily connect like pieces of an animal puzzle. Unlike naturalistic images, they cannot be directly traced back to a common 3D space, to which they hold an isomorphic part-whole relationship. And unlike words or sentences, they also cannot easily be connected to more complex descriptions because no diagrammatical 'macrosyntax' for the assembly of macro-pictures has been developed (Windhager et al., 2019). In the present, then, this requires designers of visualization systems to engage in the non-trivial practice of elephant creation *ex nihilo*. To bring the body parts of abstract and complex topics together, their anatomies and connective tissues have to be invented first. If macrocognitive syntheses should be supported, new kinds of elephants await their creation and cultivation—an objective obviously allowing multiple solutions for each topic too. While our concept of 'coordinated multiple cubes' offers such an orchestrated draft, we hope for a whole branch of visual synthetics research to emerge, to bring new kinds of bigger pictures into being in the material and mental 'white spaces' in between multiple views.

Mapping and Tapping into Humanities Controversies about Interface Design

If we aligned a good part of this article's argumentation with the blind men's quest for information integration, we know that other observers of the scenery can see things differently. To also bring in their perspectives, we close with a reflection on expected reservations about our holistic approach. Regarding various humanities approaches to interface design (Drucker, 2011, 2013) we even expect our initial problematization to be inverted: if reflections do not start from the cognitive costs of reasoning with a diversity of incoherent information, but from all-too simple and counterproductive suggestions for unification—of which are many—the momentum can shift to the defense of interpretive diversity.[11] It is in this context that we consider the calls for even multiplying 'fragmentation and partial presentations of knowledge' to originate (Drucker, 2013, n.pag.).

If interpretation is a central operation underlying the thinking and working of the humanities, then interface design has to support this activity, conceived as an open-ended, critical and constantly self-challenging endeavor. Related approaches thus sometimes question traditional HCI objectives like ergonomic efficiency, but strive to foster elaborate evaluation and reframing activities like critical reflection, intellectual argument and rhetorical engagement. To this end flow, or pleasure-driven

[11] Known issues for poor holistic elephant paintings or system designs commonly include a lack of interpretive plurality; a lack of declared positionality; a lack of openness for critique, modification, or revision; a lack of transparency on data and visualization methods' provenance; a lack of system performativity or procedurality; and last but not least, claims for impartiality and objectivity. We consider all these problematizations of bigger pictures to be frequently justified and want to foster their systematic discussion for future visualization system developments (e.g. Dörk et al., 2013; Glinka et al., 2015; Hinrichs et al., 2017).

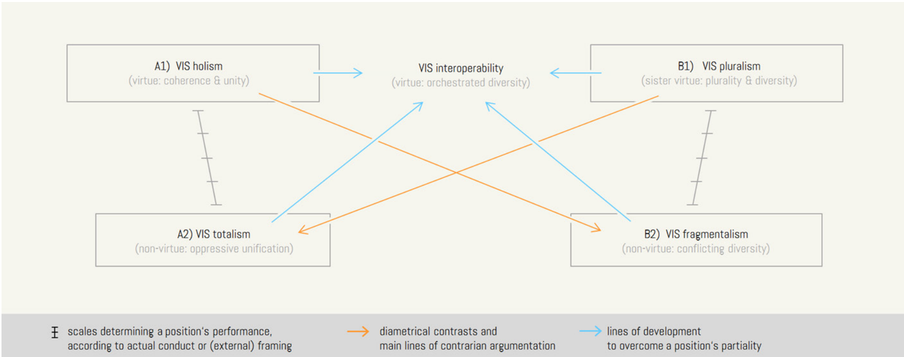

Figure 14: Square of opposition, showing lines of contrarian argumentation (orange) between humanities design positions together with possible lines of development (blue).

engagement with data is also deemed essential; as well as the acknowledgement of the subjective, situated, and partial character of every emerging result (Drucker, 2013). Interpretive approaches deliberately call for perspectival pluralism and the disaggregation of asserted totalities, while embracing 'ambiguity and uncertainty, contradictions and the lack of fixity or singularity' (Drucker, 2013: n.pag.). As such we are aware of positions which seemingly invert this article's rationale, and which ask designers to create interfaces 'which can tolerate inconsistency among [different] types of knowledge representation and organization'. From this point of view, inconsistencies and contradictions between multiple views are not only acceptable, but they ultimately also help to expose 'the illusion of seamless wholeness' as a useless or even counterproductive idea (Drucker, 2013: n.pag.).

As with many controversies, it is possible to tap into such lines of contrarian argumentation by mapping them within a 'square of opposition' (**Figure 14**). This notation has evolved from its Aristotelian origins to support the mediation of polarizing discussions or tensions between seemingly incompatible values or positions (Hartmann, 1926; Schulz von Thun, 2007). As a visualization technique it represents two positions (A and B) as polar opposites on the left and right hand side of a canvas. We map our advocacy for holistic or integrated representations as position A, to oppose it with the endorsement of visualization plurality and diversity at position B. Furthermore, two possible manifestations of each side are distinguished, putting the ideal conceptions (A1 and B1) at the top, while adding their less than ideal versions (A2 and B2) below, which arise either from their poor implementation (e.g., from malpractice or exaggeration) or from their external misinterpretation (including negative framing or deliberate misconstruction). As for the ongoing debate about the proper visualization of cultural complexity, we know holistic representations to be at constant risk to devolve into forced schemata of unification. On the other hand, the strive for perspectival plurality can lead to the fragmentation of any coherent picture, substituting the non-virtue of forced integration with the non-virtue of conflicting diversity.

In a reliable fashion, contrarian arguments emerge from a diagonal polarization, where charges (arrows in orange) are directed from the upper corners of a position (A1 and B1) to the opposite corners at the bottom (B2 and A2). Corresponding controversies thrive on the common self-idealization of a position in combination with the devaluation of the opposite value. Yet the square can also show ways for mediating tensions by developing dynamically balanced or hybrid positions in between (arrows in blue). While not being especially popular in the academic context, pragmatic approaches to the mediation of controversies can move both sides forward.[12] While our position started close to a holistic stance (A1) motivated by problems of perceptual fragmentation (B2) we acknowledged methods of generous design (B1) but focused on the challenges of renewed fragmentation by multiple overviews (B2) to finally mediate them with an interoperable design of 'orchestrated diversity', dynamically balancing between A1 and B1. On the other hand, pro-plurality approaches to interface design follow a mirror-inverted pattern to problematize totalizing representations (A2), which frequently offer even less than the sum of their parts (Latour et al., 2012). As such, they plausibly argue for designs fostering plurality and diversity (B1), but to avoid the descent into conflicting diversity they

[12] To a certain extent, we can even consider the visual information-seeking mantra ('overview first, then zoom and filter, details on demand', Shneiderman 2003) to form such a mediating bridge, which guides countless visualization projects to pragmatically combine holistic overviews with pluralistic detail views day by day.

also have to reflect on strategies of coordination across views so that they 'can be integrated in various ways' (Dörk et al., 2017: 46).[13]

Connectivity is key. While it is possible to enjoy many humanities controversies as explication of competing and contrarian positions, advanced interface design is well-advised to read them in a complementary fashion and to bring their best arguments into a dynamic balance. This will also allow us to take care of a more informed development of bigger pictures in the realm of the humanities, despite the damage that approaches concerned with these big pictures suffered from poststructuralist decrees. As has been stated with regard to ambitious accounts of culture and history in general: '[i]f the grand narratives known so far … have been seen through as unsuitable attempts to seize power over the world's complexity, this critical realization neither delegitimizes the narration of things past nor exempts thought from striving to cast an intense light on the comprehensible details of the elusive whole' (Sloterdijk, 2013: loc. 847).

To remake and refine visual representations of cultural collections and other complex humanities topics, we advocate synoptic visualization approaches which coordinate the best knowledge representation strategies of multiple communities. Such hybrid endeavors will generate more effective approaches to the support of macrocognition in face of data diversity, and the facilitation of switching between multiple perspectives and sense-making frames. This seems to us to be not only a design task worth strengthening, but also a cognition technique which comes close to a civic meta-competence for these times, arguably not only needed in digital humanities' and cultural sciences' research domains.

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[13] Furthermore, pro-plurality approaches rarely want to be read as 'argument in favor of bad, inefficient, or obstructive design', nor provide a 'perverse justification for the ways in which under-resourced projects create confusion, as if that were a value for humanists' (Drucker, 2013: n.pag.).

Competing Interests

The authors have no competing interests to declare.

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4 Visualization of Artist Biography Data (B)

Which techniques are available to visualize the narrative accounts of the lives of artists and other historical actors? Building on that: How can we bring a prolific selection and combination of multiple views together, to arrive at a synoptic multi-perspective interface that still provides a coherent user experience? This chapter answers these guiding questions with two publications, dedicated to the biographical extension of the PolyCube framework, introduced by publication A2 (sec. 3.2).

Publication B1 investigates ways and means to visually analyze narrative information. Building on a reflection of the cognitive aspects of storytelling, it investigates options to transfer the venerable genre of narrative accounts (e.g. on the lives of historical actors) into the visual realm. In a comparative discussion, five different visualization techniques are taken into consideration. Coordinated multiple views, animation, superimposition, juxtaposition, and space-time cube representations are assessed for their strengths and limitations and examined with regard to geo-temporal narratives. In the second part of the publication, the PolyCube concept is discussed as an integrated visualization system, which can mediate multiple geo-temporal perspectives through animated canvas transitions. An outlook is dedicated to the visualization of narrative threads in the context of non-geographic spacetimes.

Publication B2 continues this endeavor and asks with a more specific focus on historical biography data, how the PolyCube framework can support historians in their efforts of data analysis, visualization, and knowledge communication. As for a conceptual case study, the authors join forces with a digital prosopography project, which transformed the Austrian national bibliographical dictionary (ÖBL) into a structured database. Making use of selected biographies, this publication shows how the PolyCube system can provide a multi-perspective account for spatio-temporal, categorical-temporal, and relational-temporal biographical data dimensions in parallel. The corresponding conceptual overview is complemented with a discussion of open research and development challenges.

Publication B1: *Once upon a Spacetime: Visual Storytelling in Cognitive and Geotemporal Information Spaces*

Full bibliographical detail:

Mayr, E., & Windhager, F. (2018). Once upon a Spacetime: Visual Storytelling in Cognitive and Geotemporal Information Spaces. *ISPRS International Journal of Geo-Information*, *7*(3), 96. DOI: https://doi.org/10.3390/ijgi7030096

Individual contributions of the author:

This publication was collaboratively conceived with Eva Mayr (lead author). The article's background and visualization framework were developed in constant interaction. All of the content—as well as the underlying PolyCube project—derived from collaborative designs and discussions of both authors. Eva Mayr developed the cognitive foundation of this article and contributed the first drafts of the corresponding textual descriptions in all sections. I conceived the visualization foundations and wrote the first drafts of the corresponding textual parts of all sections and devised the figures. Revision according to peer review proceedings by Eva Mayr.

Role and position of the publication in the cumulative dissertation:

This publication answers to question B1, collecting and discussing multiple options on how to represent narrative and biographical data in geo-temporal information spaces with a focus on visualization-based methods of narration and storytelling. Partly, it also already responds to question B2—how to synthesize multiple visualization methods into a coherent framework.

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Concept Paper

Once upon a Spacetime: Visual Storytelling in Cognitive and Geotemporal Information Spaces

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Abstract: Stories are an essential mode, not only of human communication—but also of thinking. This paper reflects on the internalization of stories from a cognitive perspective and outlines a visualization framework for supporting the analysis of narrative geotemporal data. We discuss the strengths and limitations of standard techniques for representing spatiotemporal data (coordinated views, animation or slideshow, layer superimposition, juxtaposition, and space-time cube representation) and think about their effects on mental representations of a story. Many current visualization systems offer multiple views and allow the user to investigate different aspects of a story. From a cognitive point of view, it is important to assist users in reconnecting these multiple perspectives into a coherent picture—e.g., by utilizing coherence techniques like seamless transitions. A case study involving visualizing biographical narratives illustrates how the design of advanced visualization systems can be cognitively and conceptually grounded to support the construction of an integrated internal representation.

Keywords: geotemporal data; information visualization; narrative information processing; storytelling; multiple views; space-time cube

1. Introduction

Stories surround us in many aspects of our daily lives—conversations, news reports, series, films, and books are only some of the most obvious examples. Cultures are flush with thousands of narratives, whether real, fictional, or hybrid; they organize knowledge about our collective past, document our contemporary experiences, emotions, hopes, fears, and visions, and sketch out possible ways into intended futures. Cultures inherit stories and invent new ones, which are collected and shared in everyday communities; they are studied and interpreted by arts, humanities, and history scholars. Stories are used to communicate and present complex contents effectively, and are taught in journalism, media training, and rhetoric seminars.

Geotemporal stories that more or less centrally tell a protagonist's movement through a geographic space can be found in many different narrative genres. Prototypical examples are travel reports, quest narratives, or biographies. One historical case where movement is highly central in the story is Homer's Odyssey, as the geographic positioning and the timespan of Odysseus' stops during his journey are still a topic of discussion (Appendix A). Visualization (cp. Figure 1) can help readers to connect the plot to familiar places and to better understand the time course of the events.

Figure 1. Homer's Odyssey visualized on a map (adapted from [1]) and as a timeline.

It is not surprising that storytelling has also become a topic of interest in information visualization. The corresponding crossover genre of "narrative visualization" or "visual storytelling" has been explored and elaborated extensively during the last years [2–10].

These works developed and discussed a whole panoply of solutions, such as how to bring the framing methods of diagrammatic pictures and stories together—to the mutual benefit of both. Visualization designers reconsidered "author-driven" design elements and strategies (like sequential guidance, ordering, or messaging), which can enrich the usually "reader-driven" reception of visualizations to varying degrees [5]. Since this "narrative turn," developers of visualization systems have been able to choose more consciously whether complex information should be designed as open installments to be freely explored by the users, or whether they should be guided through these worlds by predefined sequences and narrative paths [11]. However, these reflections were mostly restricted to narrative communication patterns and the visual design space, and did not address the cognitive foundations of storytelling.

What is it that makes storytelling such a powerful mode for processing information and communicating it to experts or general audiences? This paper approaches this question first from a cognitive science perspective, to better understand how narratives are processed and internalized (Section 2). In a second step, it turns to the question of how to support the visual analysis and comprehension of stories by different methods of spatiotemporal information visualization (Section 3). Building on these options, we introduce a case study and a visualization framework that puts emphasis on the cognitive integration and on the coupling of multiple perspectives (Section 4), and we outline options regarding how to further advance this visual storytelling environment (Section 5).

2. Cognitive-Scientific Foundation

The main reason for the cultural prominence and omnipresence of stories is that narration is not only a mode of presentation, but "a fundamental way of organizing human experience and a tool for constructing models of reality" [12] (p. 345) in everyday life. Bruner [13] proposed a "narrative mode of thought" (p. 97) that helps one to construct internal representations about events, human intentions, and actions in the world. The events and actions described in stories closely correspond to everyday sequences and experiences and, therefore, their representation and comprehension is more natural than of other types of information (e.g., descriptive) [14]. Questioning the causes of events and the intentions of actors and organizing incoming information within such chains of events is central to human thinking and sensemaking.

How can we define a story—or rather, a narrative—as it is termed in cognitive science? Wilkens et al. [15] (p. 324) define a narrative as "a chain of events related by cause and effect occurring in time and space and involving some agency." Following this definition, a story consists of five central information elements: (1) multiple events, (2) a time frame, (3) a space, (4) involved actors or objects, and (5) causal relations between them (Appendix B).

On a cognitive level, story schemata are available concerning how a story is built, how it progresses, and what its constituents are [16], which reduce cognitive load and allow stories to be processed fast and efficiently. Guided by these schemata, the recipient of a story picks up narrative cues, relates the information to scripts and prior knowledge, and actively builds up an internal representation of the events and the involved actors, which results in the so-called "situation model" [17]. How this situation model is actually constructed and what its cognitive constituents are comprise a matter of complex discussions, which will be elaborated further down (see also Figure 3). The situation model is relational and multidimensional in nature and is continuously updated as the story unfolds (Event-indexing model, [18]): Each new *event* occurring within a story becomes cognitively assigned or connected to a *time frame* of the narrative, to a *space* (the scene or location where it happens), to one or multiple *causes* (the prior event(s) that influence(s) the event), the *protagonist(s)* actively or passively involved, and to the way the event relates to the protagonists' goals or *intentions*. Figure 2 shows a conceptual draft of the event-indexing model, visualized as a time-oriented semantic graph (from left to right).

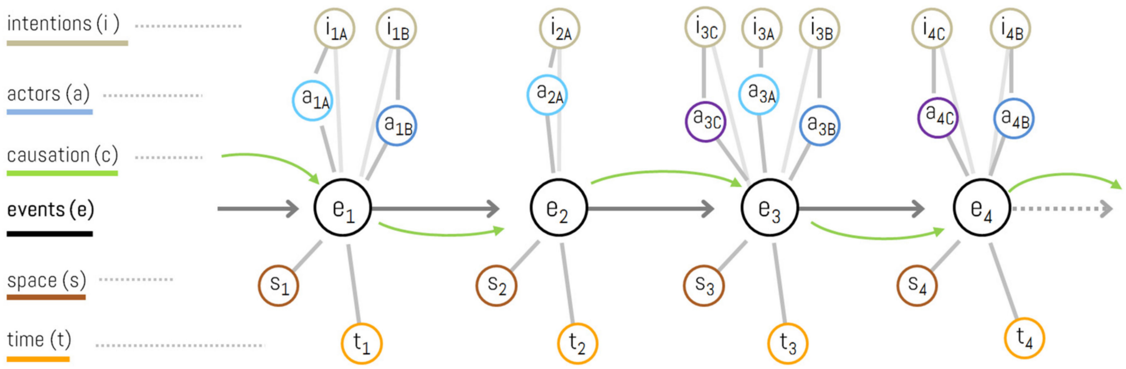

Figure 2. The comprehension of stories is said to result from the cognitive interconnection of narrated facts or events (**e**) according to five situative indices or data dimensions. Comprehension ensues if a recipient can situate events meaningfully in a developing situation or scenario that has been caused (**c**) by preceding events and interconnects specific actors (**a**) and their intentions (**i**) at a certain time (**t**), and in a certain place or space (**s**).

Depending on how much of these situative indices an event shares with prior events, it can be integrated into the situation model relatively easily [19]. During the construction of a situation model, story recipients try to establish coherence on a local level (no inconsistencies and contradictions between two following events) and on a global level (within the whole story [14]). The recipient aims to close existing coherence gaps or breaks (inconsistencies within one or multiple dimensions) within the story by not only drawing inferences between the pieces of information, but also with prior knowledge. A story can be better understood if it is coherently designed; that is, if it is told consistently, does not contradict itself or miss information within the chain of events, and if its global architecture is plausible with regard to the interplay of the five threads.

But, how are stories (or narrative data in general) internally represented? For multimodal information processing and learning in general, a bi-modal model has been developed by Schnotz [20]. Its basic assumption is a dual layer architecture: Based on Paivio's dual-coding theory, Schnotz suggested that multimodal information is processed in parallel in (1) a verbal–propositional and (2) a visual–spatial system and leads to the construction and elaboration of multiple internal representations, which can be transferred to one another and are closely connected in an active process that generates a coherent knowledge structure (see Figure 3). Building on this model, we assume that stories—as information in general—are internalized and represented somewhere in these different modes: either verbal or visual, but mostly in a bi- or multimodal fashion. Visual–spatial and verbal–propositional information are drawn together to construct a coherent situation model of the story.

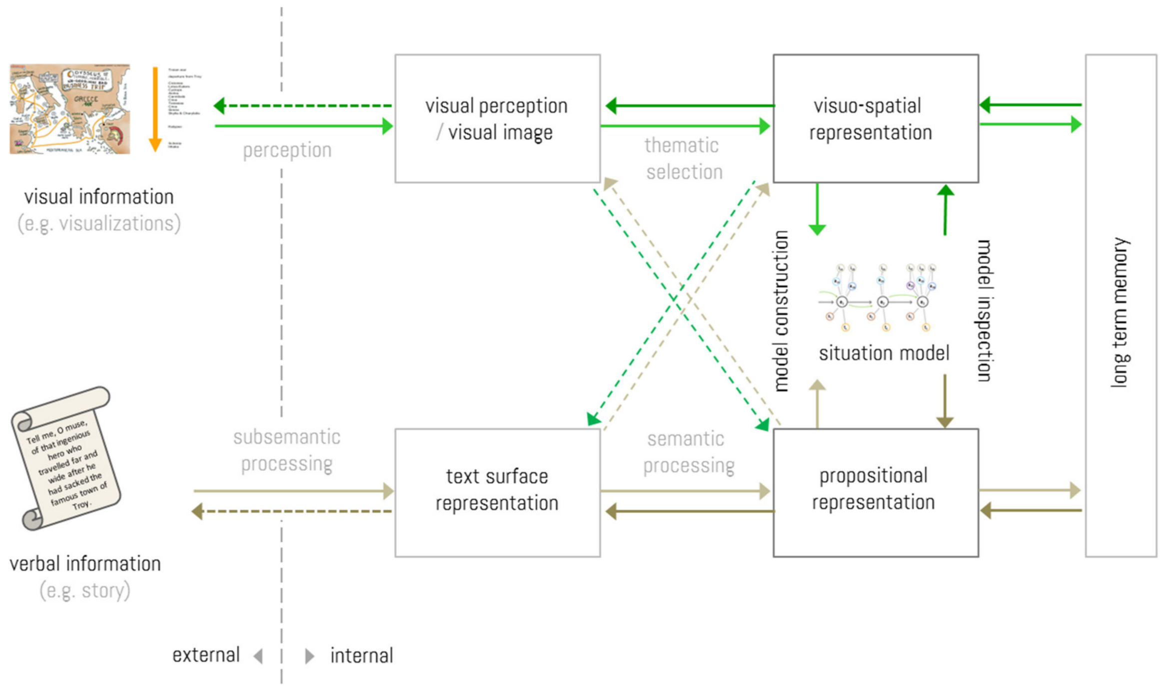

Figure 3. Model of multimodal cognition (Schnotz, 2014) adapted for the internalization of storytelling visualizations.

For the geotemporal visualization of stories, two story indices are of specific interest for us: space and time. Though the other indices (intentions, actors, causation, and events) are also highly relevant, they are not the focus of our paper. We will shortly elaborate on them in Section 5.1.

2.1. Space

Space is regarded a difficult dimension of stories, as its nonlinear nature does not match the linear sequence of events [19]. A map-based representation of a story can assist the construction of a spatially structured situation model, which integrates details about a story's locations [21]. Still, the typical mental representations generated from maps and from stories differ. Tversky [22] postulated that the internal representation of a spatial environment is not a coherent image of the external representation. Rather, recipients only selectively internalize information cues that are relevant to them (and the current task), which may or may not be related to other pieces of information, and which are likely to contain different perspectives. These "cognitive collages" are not coherently organized and, therefore, do not allow perspective-taking, reorientation, and spatial inferences, compared to a fully integrated cognitive map. Rather, the information pieces are related by the spatial relations between them and to larger units or landmarks [23], to personal experiences, and to frames of reference [24]. In contrast to situation models, a cognitive map (or collage) is nonlinear (except maybe for the representation of a spatial path), noncausal, less coherent and less structured.

Therefore, an important question for storytelling with maps is how stories are internally constructed and represented on a cognitive level. Kosara [25] (para 1), emphasized that "pictures don't tell stories, people do. An image, a visualization, data, etc., can only be the material the story is made from." The recipient of a narrative visualization plus his or her prior knowledge, intentions, and interests decide what information is attended to and what is internalized. Whether he or she generates a sequential situation model, a cognitive map, or some partial or hybrid form cannot be prescribed by the geovisualization, even though some design cues can help recipients to generate a better integrated, more coherent internal representation.

2.2. Time

Time is one of the most important dimensions of a situation model, as temporal information helps the recipient to establish causal and motivational links between events [19]. Similarly, Kosara and MacKinlay [8] argued that the temporal structure of stories is a fundamental feature for storytelling with visualizations. Therefore, we may assume that sequential and chronological aspects dominate (or strongly structure) the mental representations of stories (or situation models), which goes together perfectly well with the time-oriented nature of speech or reading text.

Yet, if the comprehension of the chronological character of complex stories should also be supported visually, time must be visually encoded and represented, which requires design choices that are far from trivial. "Time presents specific challenges for the representation of data because time is a complex and highly abstract concept" [26] (p. 203). One of the most frequently used solutions is to map time to a spatial (i.e., linear or sequential) dimension of the pictorial space, which often results in timelines [27–30], or also in linearly juxtaposed representations of sequential art [31–33].

Visual cognition support for the comprehension of stories and narrative data often leads to the utilization of either timelines or maps (or a combination of both), which organize the pictorial space—and, thus, the users' modes of thought—quite differently [34]. Maps represent data that are already spatial, while timelines "spatialize" the abstract concept of time, utilizing the pictorial space in a radically different way [35]. This presumably leads to the construction of two different internal representations, which require additional mental effort to synthesize. To help the recipients generate a situation model of the story that integrates geographic and temporal data more closely and supports cross-dimensional reasoning and perspective taking, a combined or hybrid visualization method is required. Therefore, in the following section, we discuss hybrid visualization techniques that integrate geographical and temporal data aspects—and thereby, facilitate visual storytelling in a spatiotemporally synoptic fashion.

3. Spatiotemporal Visualization Methods

How can we represent narrative data visually on the screens of visualization systems that aim to augment and amplify reasoning with these kinds of data? Numerous solutions to visualize spatiotemporal aspects of narrative data have already been studied and analyzed in the literature. To illustrate some of these techniques, we will zoom in on the example of individual movement data, which consists of "recording the location of a moving point object through time" [36] (p.183). Such data have also been called a "mobile trajectory," "world line," "life path," "space–time path," or "spatial history" [36]. The benefit of focusing on individual movement data is its elementary nature, which allows the construction of a great variety of story types or narrative forms by combinatory means. Even if individual biographies or space–time paths of objects and actors are only one basic type of spatiotemporal data, almost every other type of narrative utilizes them to draw them as brush strokes into a more complex and intertwined choreography.

With regard to individual movement data, cartographers have introduced multiple methods and means for representing movement, dynamism, and change [37,38], including static and animated maps, space–time cubes, and coordinated linked views (e.g., maps with timelines). In the following section, we take a closer look at a selection of five of these standard techniques, which have been widely discussed and are available in various visualization tools and geo-analytical packages (for a video demonstrating these visualization techniques in the PolyCube system, see https://youtu.be/PTsk-NROJhU). Figure 4 lists these common perspectives, each visualizing spatial and temporal data aspects in a hybrid fashion.

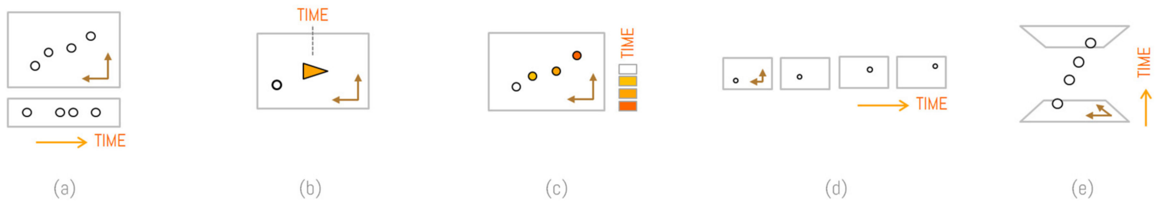

Figure 4. Hybrid views for visualizing spatial (brown) and temporal (orange) data dimensions in combination: (**a**) multiple coordinated views, (**b**) animation or slideshow, (**c**) color-coded layer superimposition, (**d**) layer juxtaposition and (**e**) space–time cube representation.

Each of these spatiotemporal representation techniques requires different affordances for the construction of a corresponding internal representation (see also [26]) and, thus, also for the construction of the story situation model. In the following section, we are going to discuss each of them from a cognitive perspective and what they mean for the integrated perception and understanding of a story's spatial and temporal dimensions.

(a) **Multiple coordinated views** combine a standard map with a time graph to visualize spatial and temporal data aspects in parallel [39]. This method utilizes separate representations for the locational and temporal distributions of story events and usually coordinates these views via linked interaction methods, e.g., allowing for linked brushing [40]. For multiple coordinated views, it is likely that users generate two separate internal representations (one for each view) with some links to one another. Depending on the visual work and interaction a user invests to bridge this split of attention [41], these links can be relatively densely knit.

(b) **Animation or slideshows** (also "dynamic representations" [42], p. 6) map narrative time orientation to the time dimension of the visual representation [26]. As such, they can represent the movement of objects or actors as a continuous dynamic (i.e., as smooth animation) or as a discrete sequence of steps, which we refer to as a slideshow. These techniques can further be implemented as non-interactive or interactive representations [43] (p. 1588), allowing users to go back and forth in time. It is well known that animation can foster the perception of even subtle changes or display dynamics, but also that the user's working memory is easily overwhelmed when too much information changes too fast [26]. If the visualization is more complex, a slideshow might be better suited, which reduces the temporal continuum to discrete intervals. Users then can interactively go back and forth from one story event to the next. Still, considering one's visual view and comparing it to the next one is very demanding for the working memory and increases interaction costs by repeatedly going back and forth.

(c) **Layer superimposition** techniques merge multiple temporal positions—or temporal layers—into one integrated representation, while using transparency to see all positions at once [32]. Time is mostly encoded with an additional retinal variable, like color, or with the annotation of temporal values or vectorial references, signifying a temporal sequence of positions in space. In Figure 1, the map on the left-hand side uses a numerical sequence and arrows to encode the time orientation of the narrative. By using such a technique, users can build up a spatiotemporally integrated internal representation of the story. Aside from the expected challenges posed by visual clutter and occlusion, a concern regarding this technique is whether time (e.g., encoded by a color scale) is visually salient enough to be as well integrated into the story situation model as geographic space.

(d) **Layer juxtaposition** separates spatiotemporal data into multiple temporal layers, to arrange these layers in parallel—mostly along a spatial reading dimension. This results either in "small multiple" maps [43] or, more generally, in the hybrid genre of data comics [33,44]. In face of juxtaposed views, the user must sequentially read and compare multiple adjacent views to detect the visual changes and comprehend how the story unfolds over time. Though a lot of visual work is required to compare the different views, the user does not need to remember them like in a slideshow; thereby, the interaction costs are lower.

(e) **Space–time cube** representations merge maps and timelines orthogonally within a cubic space, which allows one to map every space–time path as a three-dimensional trajectory [45–48]. Aside from providing such a direct integration of spatiotemporal coordinates, space–time cubes also come with the specific functionality of supporting the cognitive translation and navigation among all other spatiotemporal views [49] (see Section 4). From a cognitive perspective, space–time cube representations offer one perceptually integrated view in which the story can unfold. In contrast to a superimposition view, time is also mapped to space, making the temporal and geographic information of movement paths similarly salient. Therefore, the user can more easily build up a spatiotemporally integrated situation model of a story. However, in such a three-dimensional visualization, visual clutter—and increased interaction costs—are a constant challenge [50]. Still, evaluations confirm that space–time cube visualizations are easy to use and are especially suited for the exploration of spatiotemporal patterns [51,52].

In comparison, these well-established representation techniques find distinctly different solutions to represent spatial and temporal data aspects in an integrated or hybrid fashion. Table 1 summarizes their visual–analytical strengths and limitations and illustrates that every method comes with a specific profile, combining analytical benefits with particular costs.

Obviously, among these different options, there is no ideal view—but rather, multiple perspectives and methods exist to represent narrative data in a spatiotemporally hybrid way. For this reason, advanced visualization systems provide multiple spatiotemporal views as a "solomonic" design strategy—not to sacrifice the benefits of alternative perspectives, but to offer multiple ones. This allows one to "maximise insight, balance the strengths and weaknesses of individual views, and avoid misinterpretation" [53] (p. 9), and enables the user to select and switch between the most appropriate representations for the data and task at hand (ibidem, p. 10). For storytelling visualizations, multiple views offer different perspectives on a story, highlight different event indices, and let the user construct a more elaborated internal representation.

Table 1. Visual–analytical strengths and limitations of spatiotemporal representation techniques.

	Coordinated Views	Animation/Slideshow	Layer Superimposition	Layer Juxtaposition	Space–Time Cube
Strengths	+ Plain 2D views + Connected by linking & brushing	+ Salient detection of change + Small screen occupancy + "Quasi-integration" in working memory	+ Spatiotemporally integrated and aggregated vis + Small screen occupancy	+ Parallel visualization + High visual literacy to be expected (comics)	+ Spatiotemporally integrated view + Metashape + Attraction power + Cognitive & conceptual mediator
Limitations	- Split attention effect - High visual work - No spatiotemporal integration	- Memory overload - High interaction costs - Interpolation of animation can create data artifacts - Slideshow can reduced continuous temporal data to an ordinal variable	- Visual clutter - Design too flat, generates little attraction - Time needs to be mapped to an additional visual cue (like color)	- Large occupancy of display space - Temporal data is reduced to an ordinal variable - Split attention effect - High visual work	- Visual clutter - High interaction costs - Medium occupancy of display space

As time orientation plays a central role in the narrative data domain, we recommend to follow best practices of visualization system design and to deliberately implement multiple views for the complementary and flexible combinations of analytical perspectives. Yet, we also recommend deliberately addressing a neuralgic cognitive challenge, which emerges from using multiple views with their corresponding design strategies. Simply put, the utilization of multiple perspectives allows users to avoid analytical reductions, blind spots, and simplifications. However, multiple perspectives also challenge users' coherent understanding: How do these different perspectives relate to each other? How do users not only perceptually integrate spatial and temporal perspectives (as all five abovementioned techniques assist them to do), but also cognitively integrate, couple, or synthesize these different spatiotemporal perspectives? This challenge is of special importance in narrative visualizations, as the coherence of the external representation is relevant for the construction of a coherent situation model. Coherence breaks have been shown to interrupt the construction of the internal representation and the recipient's engagement with the story [14,54]. Similarly, for the design of visualization systems, coherence is an important factor to be considered, since it eases the construction, maintenance, and cognitive utilization of the internal representation [55]. Building on conceptual work, we report on the development of a web-based visualization environment, which emphasizes these exact development gaps that have remained largely unresolved by interface design so far.

4. Towards a Multi-Perspective Interface for Narrative Visualization

The PolyCube framework (PolyCube project: https://www.donau-uni.ac.at/en/polycube) has been developed to offer multiple temporal views on spatiotemporal data, while putting a focus on the overall ease of use, enhanced navigation, and on supporting the cognitive integration of insights from multiple views. Its central operating perspective is provided by a space–time cube representation and also offers access to perspectives of layer juxtaposition, layer superimposition, multiple coordinated views, and animation. One of its main design strategies is to translate or mediate these different perspectives by seamless layout transitions, which are illustrated further down (Figures 7 and 8). The visualization system is currently developed as a web-based visual analytics environment and has been explored with regard to two application scenarios, including a case study on cultural heritage collection data [56] and another on biography data [57].

4.1. Visualizing Biography Data and Historical Narratives

Digitization initiatives are transforming historiographical knowledge collections into semantically structured data and knowledge graphs [58,59]. This translation also involves large biographical lexica, which have been assembled to document the life stories of national cultural heroes—as well as many thousands of other figures that have influenced domains such as the arts, politics, or natural sciences—in a standardized manner. By the means of natural language processing techniques (Appendix C), a variety of entities and relations are extracted from thousands of life path narratives, including actors, organizations, social relations, and geographic places, which are all interwoven by the pathways of individual trajectories and temporally structured according to documented events and dates.

With regard to historical and cultural figures of Austria, the APIS project (https://www.oeaw.ac.at/acdh/projects/apis/) has developed a digital prosopographical information system out of the National Biographical Lexicon [60]. To explore the visual–analytical framework outlined so far, we extracted documented locations and corresponding time stamps for a dozen biographical narratives, which we injected into spatiotemporal visualization systems for further exploration. Figure 5 exemplarily shows the biographical trajectory of Joszef Szabo—an Austro-Hungarian opera singer and actor—visualized as a space–time path by the means of a commercial package (left-hand side, [61]) and by the prototypical PolyCube system, utilizing web technologies, such as d3.js, CSS3D and three.js (right-hand side).

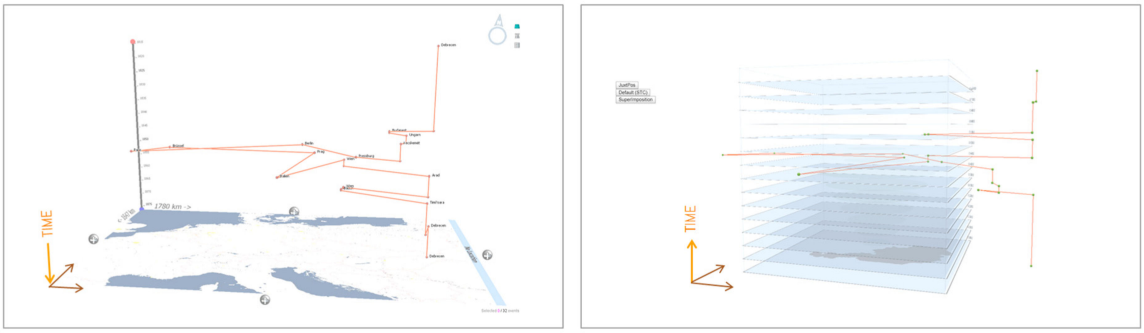

Figure 5. Space–time cube representation of the life-path of the Austro-Hungarian opera singer and director, Joszef Szabo (1816–1875) by the GeoTime suite (**left**) and by the web-based PolyCube system (**right**).

We chose a space–time cube representation as a preferential entry point into narrative visualization because it immediately discloses a variety of spatiotemporal patterns (such as horizontal movements or vertical "stations") to the highly skilled faculties of 3D gestalt perception (see Figures 5 and 6). Furthermore, it allows on demands switching to all other spatiotemporal perspectives—while maintaining the orientation of analysts in a unique way (see Section 4.2).

With regard to the basic pattern language, three elements define individual choreographies: "The basic concepts in time geography are paths, stations, and prisms. Paths show movement behavior of objects through space and time [...]. The stations indicate locations where people stay for longer moments [...], and prisms representing space reachable within a given time budget" [62] (p. 57). Therefore, the meandering curves of historic actors disclose their spatiotemporal profile, consisting of their main biographical stations and connected by their movements and travels. As each historical character starts from different spatiotemporal coordinates—and behaves differently until his or her death—their space–time paths can be read and interpreted like a unique diagram. As soon as a minimum amount of familiarity (or visual literacy) with this visualization technique emerges, historians or humanists can utilize it for the purpose of close reading or viewing spatiotemporal story aspects—or zoom out for distant reading of multiple biographies or narratives in a mutual context, connection, or comparison (see Figure 6).

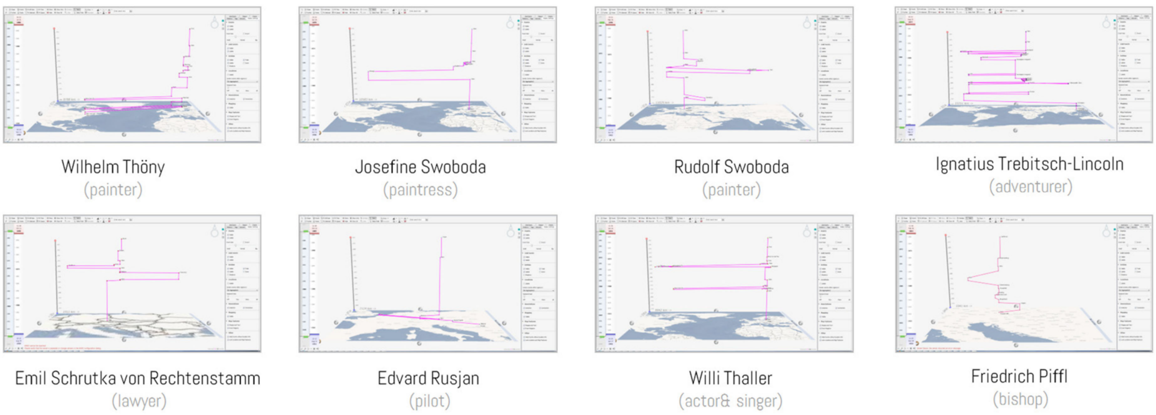

Figure 6. Comparatistic visualization of eight biographical narratives, as extracted from the APIS project.

Space–time cube representations allow the direct construction of a model of a historic actor's behavior and visual analysis of a multitude of movement patterns [63,64], but they also have some analytical limitations (see Table 1). Therefore, if visualization systems want to offer multiple alternative perspectives on spatiotemporal data—how can we maintain their orientation when switching from one perspective to another?

4.2. Supporting the Cognitive Integration of Multiple Perspectives

Bennett and Flach [65] define the extent to which an interface supports the users' transitions between different perspectives or information activities as "visual momentum." One of the most effective design strategies to increase visual momentum and enhance the "cognitive coupling" between different views is traceable transformations of arrangement principles, which work like movements of perspective-taking and changing in natural environments.

These seamless transitions work like a coherence technique [55] that connects one view with another by making explicit changes—but also constancies—between different perspectives. Various forms of morphing visually translate from one spatialization principle to another and, thus, help to build up a coherent representation of both views [30]. By changing layouts incrementally—as opposed to abrupt changes or hard cuts between views—the spatial rearrangement of the story-relevant elements into new constellations can be perceptually traced. These techniques correspond to the idea of preserving the mental map [66], the effort of keeping the number of changing elements to a suitable minimum, and the notion of making the new arrangement principles transparent.

With specific regard to the translation between spatiotemporal visualizations, Bach et al. [49] provide a conceptual key element: Space–time cube representations can transform into different spatiotemporal visualizations (including spatial or temporal perspectives only) by quasi-physical operations of flattening, cutting, traversing, or stretching (see Figure 7).

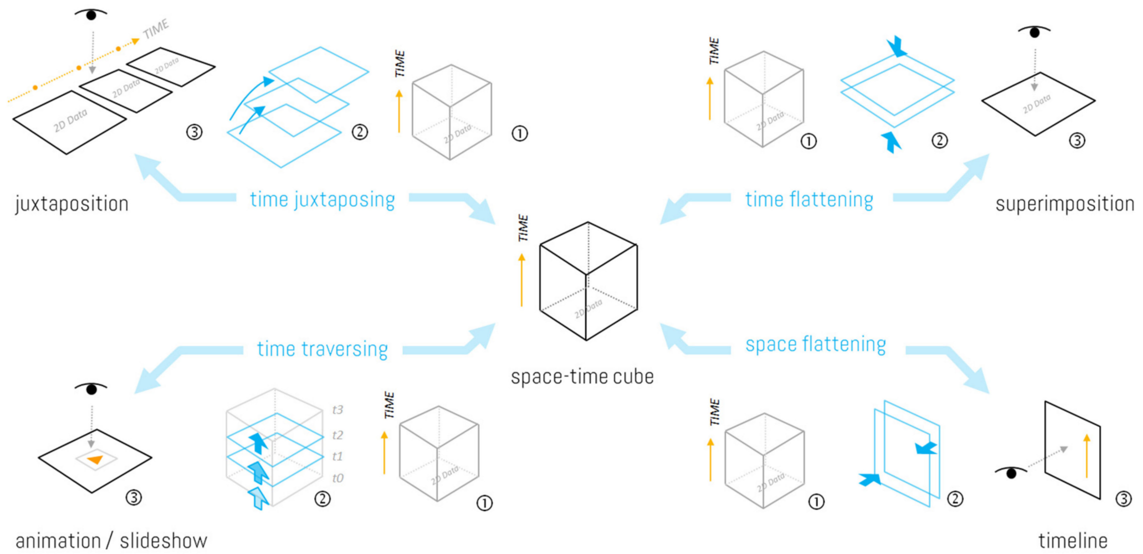

Figure 7. Space–time cube operations (in blue), seamlessly translating a space–time cube representation into four other perspectives [49,57] relevant for narrative visualization.

The PolyCube system supports these operations of alternative spatiotemporal perspective taking and cognitive coupling by seamless canvas transitions (for a video demonstration, see https://youtu.be/PTsk-NROJhU) [56,67]. Figure 8 illustrates two of these transitions, leading from space–time cube to layer juxtaposition, and from juxtaposition to a superimposition perspective. The expected cognitive effects on the macrocognitive integration and synthesis of insights, the orientation of the narrative analyst, and overall ease of use are currently being evaluated. In line with this endeavor, we see the development of coherence techniques (including hybrid views and seamless transitions) to be a research and design task of its own for complex interfaces, in order to better support cross-dimensional inferences and versatile model-based visual reasoning with narrative data [68].

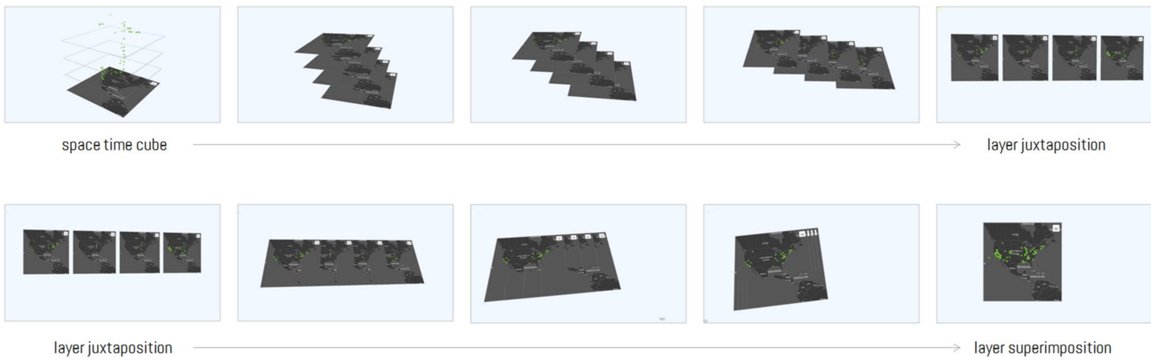

Figure 8. Animated canvas transitions of the PolyCube system, seamlessly translating a space-time cube representation into a juxtaposition perspective (**top row**) and from a juxtaposition into a layer superimposition perspective (**bottom row**).

5. Discussion

In this paper, we presented some basic assumptions about narrative cognitive processing and their implications for the design of narrative spatiotemporal visualizations. We outlined a novel design guideline and strategy to tackle the "representation challenge" of geovisualization: "To develop new forms of representation that support the understanding of geospatial phenomena and space-time processes. There is a need to take full advantage of technological advances that make it possible to [...] generate complex multidimensional and dynamically linked views, merge representation with reality, and [...] to develop methods that help users navigate within complex representations" [69] (p. 7). In the following section, we want to shortly discuss different related questions and challenges that mostly go beyond the core topic of this special issue, yet seem to be relevant for us, as they expand fields for further research.

5.1. Going beyond Space and Time

In this paper, we focused on the visualization of two event indices: space and time. However, what role do actors, events, intentions, and causation play in storytelling with geographic visualizations? On one hand, the displayed information content of the story here comes into play; in our case study of life stories, the protagonists pre-defined the main actors and we visualized their life events (as data points in the temporal and spatial information space). While the temporal chain of events already gives the recipient important cues on causes and intentions [19], the actual verbal description of these events will help the recipient to understand these further. On the other hand, we can also go beyond spatiotemporal data and visualize other aspects of a story: Persons or organizations (as collective actors), their relationships, as well as emotions and sentiments (Appendix D) are essential elements of a story, where established visualization techniques can assist recipients in gaining a broader picture of the story. Current reviews on text visualization [70] provide interesting resources for storytelling visualizations, going beyond space and time. In the following section, we will discuss different visualization techniques supporting distant reading on a story macro level (Section 5.2) and close reading on a story micro level (Section 5.3).

5.2. Distant Reading: Combining Geovisualization with Non-Geographic Visualization Techniques

What seems to be of utmost interest, from a more general visualization point of view, is the openness of the PolyCube approach to going beyond the geovisualization frontier and connecting with non-geographic information visualization methods [35]. This allows not only the maintenance of the visualization of geo-spatiotemporal movements as an analytical backbone for the investigation of narrative data, but also the ability to combine this perspective with other relevant imaging procedures. Figure 9 shows how biographical narratives can also be told and visualized against the background of non-geographic information spaces. Exemplarily, the left-hand side illustrates the path of an individual through the social–relational spacetime, generated by interaction, collaboration, or conflict [67], whereas the right-hand side shows how the same system can also visualize trajectories through a knowledge or topic space of a cultural domain [71]. In both cases, the spatiotemporal scaffold is maintained, while the geographic map on the data plane is substituted by a force-directed network graph or a hierarchically structured treemap. With regard to the event-indexing model (cp. Section 2), these methods also allow the development of visualization systems that support the comprehension and connection of other event indices than space or time, like actors and their interactions, as well as the development of sentiments and intentions, as long as they can be categorized and visually encoded into a non-geographic or structural topology.

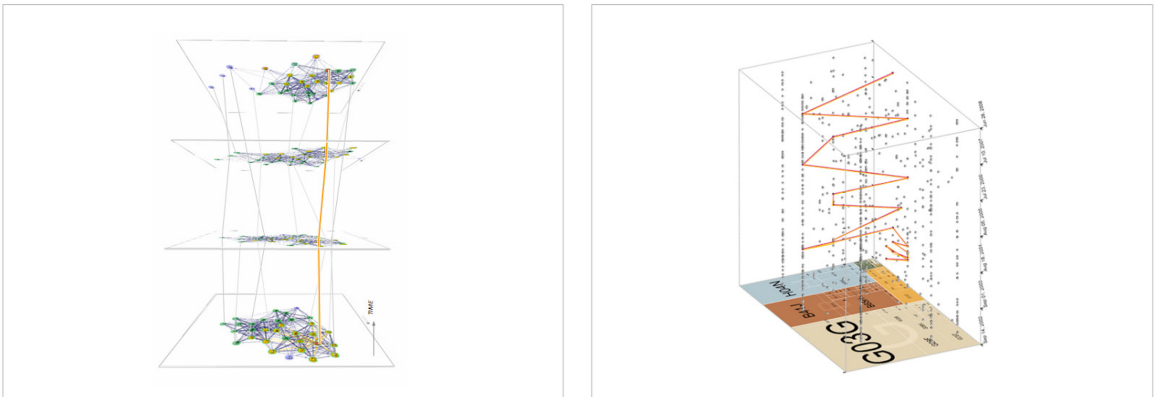

Figure 9. Illustration of the openness of the PolyCube framework to non-geographic visualization methods, like time-oriented network graphs (**left**) or cultural–categorial treemaps (**right**).

5.3. Close Reading: Combining Visual Analysis with Textual Analysis

What also seems to be essential in the context of narrative visualizations is to offer optional access to textual representations of narrative data in parallel to graphic representations. This allows the analysis and "close-read" of a source text (or a visualization description or annotation), in comparison to diagrammatic representation, possibly including further supportive text visualization measures, such as coordinated highlighting or colored mark-up of textual entities (cp. [69]). Eccles et al. [3] showed how a system of coordinated multiple views can do this for space–time cube representations and, thus, provided one of many recent instances for the desideratum of a visualization system "*that does not destroy the original text in the process*" [72]. Another option for combining textual data with a graphic representation is to tell a story sequentially and incrementally on a textual basis, while zooming and panning to selections of a space–time path—as is already offered by tools like StoryMapJS (https://storymap.knightlab.com/) or ESRI storyteller (https://storymaps.arcgis.com/).

5.4. Visualizing Non-Linear Stories

What also becomes possible in the context of parallel views is the visual analysis of (non)linear story structures. Biographies are often told as chronological and linear stories in which the narrative order preserves and mirrors the story order of historical events [73]. In contrast, advanced storytelling frequently mixes things up and works with nonlinear narrative sequencing to create artful or surprising narrative arcs to convey a sense of mystery and tension and elevate the readers' entertainment. As this narration technique also adds to overall sensemaking challenges, any combined depiction of story order and narrative order (e.g., by the use of dual timelines or the inclusion of textual data) allows the visualization of such nonlinearity of story development—and further adds to the users' orientation and comprehension [74,75].

5.5. Going beyond the Situation Model—Narrative Effects and Drawbacks

As indicated in Section 2, the processing of narrative information is highly structured by cognitive schemata. Until now, we have only discussed the nature of the internal representation (situation model) and how it is constructed (event indexing). However, many further cognitive and motivational effects of narrative processing can be found in the literature, which are of interest for better understanding the effects of storytelling—positive and negative alike. On the positive side, existing story schemata reduce cognitive load and free cognitive resources, allowing us to process information more deeply and understand more complex information [76]. On an emotional–motivational level, identification with the story is a powerful mechanism, which can also result in narrative engagement, flow, and positive attitudes towards the topic [54]. On the negative side, incoming story information is checked only for plausibility and coherence, but not necessarily for truth [54], nor is it critically reflected. Therefore, it poses the risk of being misused for persuasive effects [77].

5.6. Evaluation Challenge

In their paper on cognitive and usability issues in geovisualization, Slocum et al. [42] emphasized that a usable interface should be built on a metaphor well-known by its users. Story schemata are similar to these metaphors in assisting the user (if activated) to process the information in a quick and efficient manner. But, how do we know that a story schema was activated? How can we know how well the user integrated geotemporal information in the story situation model?

A final, but nevertheless important, challenge is how to survey and evaluate situation models and whether they integrate spatial and temporal data. It is difficult to use the evaluation methods of narrative text comprehension research, as they often use relatively simple stories to single out the effects of interests (see also [78] on the relationship between psychological and cartographical research). When it comes to more complex visual stories, it is important to further develop these methods and combine them with qualitative methods (like the think-aloud technique) to develop a better understanding of the construction and enrichment of situation models from visual stories. Within the PolyCube project, we collected and reviewed a set of methodologies to assess internal representations resulting from the interaction with information visualizations [79]. Further research is needed to empirically evaluate these methodologies and identify the most suitable ones for the study of information visualization, in general, and of story situation models, in particular.

6. Conclusions

This special issue called for design guidelines and best practices for the development and deployment of expressive, perceptually salient, and cognitively supportive online geographic information stories. In this paper, we approached this question from a cognitive perspective and reviewed research on how stories are internally represented and cognitively constructed. The event-indexing model by Zwaan et al. [18] served as a reference for our discussion of geotemporal visualizations for storytelling: Each event of a story is indexed according to actors, their intentions, space, and time, and linked to prior events by causation. This model stems from research on narrative texts; although it was already transferred to other types of media (like films), we are not aware of publications that have transferred the event-indexing model to narrative visualizations. This model can serve as a reference for—and can provide guidance to—future empirical studies on this topic.

The event-indexing model suggests that the spatial and temporal information in a story can serve as a framework for the construction of the story situation model. We explored the design space in which (a) spatial and geographic information can be visually represented in an integrated fashion and (b) multiple perspectives can be coupled in a coherent manner. Standard techniques for visually representing spatiotemporal data (coordinated linked views, animation or slideshows, layer superimposition, juxtaposition, and space–time cube representations) all have different drawbacks and benefits from a cognitive perspective. To develop design guidelines, assisting visualization scholars and professionals in determining the representations that are best suited to supporting the smooth and synoptic construction of situation models (i.e., for which specific kinds of stories and users) is a topic for future research.

In absence of such guidelines and for more complex stories, we suggested offering multiple spatiotemporal representation techniques within one visualization system. We discussed techniques increasing the coherence between multiple views, e.g., by seamless transitions, and assisting users to cognitively integrate these visualizations and construct a coherent internal representation of the story from multiple analytical perspectives. As an outlook, we illustrated options to extend the geovisualization perspective and integrate non-geographic space-time cartographies to a synoptic visual-analytical environment of multiple coordinated cubes.

In a case study, we showed how this kind of visual analytics framework can support storytelling in history and biography contexts. As for further areas of application, we aim to explore how this framework also proves to be useful for visual storytelling in other (digital) humanities and social sciences domains, in order to shed light on a wide range of actor networks and their dynamics throughout the evolution of the human web [80].

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Appendix A

Even if scholarly attempts to match the semi-fictional locations of the Odyssey with real geographic places have been mocked since the early days of classical philology, the seminal ancient narrative provides a valuable case. With its nonlinear spatiotemporal storyline, it has not only challenged its recipients' faculties of imagination since ancient times, but has also been said to be the archetypical narrative portraying the relentless striving of modern human subjectivity [81], thus influencing the self-conceptions and expectations of countless subjects, readers, and writers (from Virgil to James Joyce) for centuries to come.

Appendix B

Frequently, a certain amount of drama—caused by an inciting incident, a conflict or a desire—is also said to be an integral part of a story definition, which raises recipients' interests, fosters engagement and, thus, drives and motivates the sequential progress of a narrative [82].

Appendix C

The use of natural language processing (NLP) for the automatic detection of events, persons, etc., out of biographical texts is an ongoing research endeavor [83]. Though NLP techniques progress fast, "it is a well-known fact that automatic text analyses do not yield perfect results" (p. 210).

Appendix D

Recent approaches additionally extract emotions and sentiments from (narrative) texts via natural language processing and visualize them [84,85].

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This publication answers to the question B1 and B2: It summarizes state of the art methods and synthesizes a multi-perspective visualization framework for biography data. In its second part, it discusses future research challenges for biographical data visualization and related knowledge communication.

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Beyond One-Dimensional Portraits: A Synoptic Approach to the Visual Analysis of Biography Data

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Abstract

The study of biography data – and the reasoning with it – can be supported by multiple visualization techniques. Biographical databases contain massive amounts of temporally structured biographical entries, connecting events, places, institutions and actors with a variety of relations between them. We present a synoptic visualization concept for multi-dimensional biographical analyses, to go beyond well-established techniques to portray one-dimensional data aspects. We discuss synergies arising from the combination of multiple synchronic and diachronic views into a more coherent visual analytics environment. Possible synchronic views include geographic, relational and categorial perspectives on biography data (e.g., maps, network and treemap diagrams), while multiple diachronic perspectives are provided by coordinated multiple views, animation, layer superimposition, layer juxtaposition, and space-time cube representations. By closely intertwining these visualization methods we aim to support the creation of more integrated and connected mental models of biographical data. This visual framework is open for other fields of application like prosopographical research, digital history, or many other time-oriented arts and humanities data domains.

Keywords: biography data, prosopography data, information visualization, visual analytics, information integration, mental model

1. Introduction

Digital biographical databases are a rich resource for historical research: They provide a massive amount of information, which used to be scattered in different text collections or local archives, and make it possible to technically connect them to bigger pictures of the life patterns of historic individuals and groups. Yet, analyzing, as well as reasoning and sensemaking with these multi-dimensional data remains challenging, especially for non-experts in digital methods. In this paper we present how an integrated visualization framework (PolyCube project, 2018) addresses these challenges by developing a synoptic visualization approach for the study of biography data.

Information visualizations "use computer- supported, interactive, visual representations of abstract data to amplify cognition" (Card et al., 1999). Visual representations help to explore and analyze data distributions and patterns immediately, and to reason on them interactively. Some biographical databases already offer such supportive measures in form of basic visual representations like maps, networks or timelines (cf. APIS project, 2018). These techniques allow to analyze single data-dimensions, such as geographical, relational or temporal aspects of individual biographies. However, such selective or one-dimensional visualizations do not allow to investigate cross-dimensional questions like "*How does the movement of actors affect their social networks, institutional affiliations, or their means and rhythms of cultural production?*".

Going beyond the use of multiple but unconnected views, visualization research already provides various synoptic design strategies, which require a careful adaptation to the biography research realm. Against this background, we consider the integration of one-dimensional data portraits into bigger pictures to be a novel and noteworthy objective for advanced visualization system design.

To do so, we will look at the initial state of textual biography data (e.g., as given by biographical lexica) and how it is currently transformed into structured digital data (Section 2). A discussion of related work in visualization research (Section 3) will be followed by reflections on challenges posed by the utilization of multiple but separated perspectives (Section 4). To effectively tackle these challenges with a novel visualization system design we introduce the PolyCube framework (Section 5) and outline options for its future elaboration (Section 6).

2. Textual biography data

Collecting, documenting and sharing facts and stories about the lives of relevant individuals is a core activity of human cultures, and the essential objective for biography researchers since centuries (Roberts, 2002).


ÖBL

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Österreichisches Biographisches Lexikon

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Piffl, Friedrich (Gustav) (1864-1932), Erzbischof

Piffl Friedrich (Gustav), Erzbischof. * Landskron (Lanškroun, Böhmen), 15. 10. 1864; † Wien, 21. 4. 1932. Sohn eines Papier- und Buchhändlers; trat 1883 in das Augustiner Chorherrenstift Klosterneuburg ein, stud. Phil. und Theol. an der Hauslehranstalt des Stiftes, 1887 Profeß, 1888 Priesterweihe. War dann in der Seelsorge in Wien-Floridsdorf und Wien-Heiligenstadt tätig, ab 1892 Prof. der Moraltheol. und Soziol. an der Hauslehranstalt (1894/95 studienhalber in Rom), 1898 auch Sekretär des Propstes, 1902 wurde er Verwalter von Stiftsgütern in Ungarn, 1906 Kanzleidir., 1907 Propst des Stiftes Klosterneuburg. P. erwarb sich Verdienste u. a. um die Vereinigung der österr. Chorherrenstifte zu einer Kongregation, gründete 1908 das „Jahrbuch des Stiftes Klosterneuburg", ließ die ehemalige Chorfrauenkirche St. Magdalena zu einem Ver.Heim umbauen und leitete den Neubau der dem Stift inkorporierten Kirchen von Donaufeld und Kierling. 1913 wurde er auf Vorschlag des Erzh.-Thronfolgers Franz Ferdinand (s. d.) zum Fürsterzbischof von Wien ernannt, 1914 zum Kardinal kreiert. P. wurde zum Mittelpunkt der Organisation der Jugendbewegung (1917), der kath. Presse (u. a. „Zeitung für Stadt und Land", 1891, „Wiener Kirchenblatt", 1918, „Kleines Volksblatt", 1919), der Förderung des kath. Volksbundes, der Kath. Aktion in allen Zweigen (1927) und der christlichen Arbeiter- und Gewerkschaftsbewegung (Zentralpräses der kath. Gesellenver.), für die er sich seit seiner Kaplanszeit in Wien-Floridsdorf engagiert hatte. Er gründete 1910 die Akad. für kirchliche Musik, unterstützte zur Behebung des akuten Priestermangels das Canisiuswerk (Präs.) und widmete sich nach 1918 intensiv der Caritashilfe. Neben 42 Notgottesdienststätten (ab 1918) konnten in Wien zehn, in NÖ acht und im Burgenland fünf neue Kirchen erbaut werden, um deren einheitliche künstler. Ausgestaltung er sich bemühte. Ab 1922 war ihm mit der Apostol. Administratur des Burgenlandes noch die mühevolle kirchliche Organisation dieses neuen Bundeslandes übertragen. P. war auch ein faszinierender Kanzelredner, der in aufrüttelnden Hirtenschreiben allein und mit dem Episkopat Österr. zu den Problemen und Strömungen in und außerhalb der Kirche klare Stellung bezog.

W.: Ansprachen und Hirtenbriefe in Wr. Diözesanbl., Wr. Kirchenbl., RP, Kleines Volksbl.

L.: Bohemia vom 13. 3. 1937; Sudetendt. Ztg. (München) vom 6. 11., Volksbote (München) vom 21. 11. 1964; Ecclesiastica, 1932, n. 20 (Bibliographie); Feierl. Inauguration, 1932/33; Ostsudetenland, 1957, S. 506; Wr. Kirchenztg. vom 18. 10. 1964; Wr. Diözesanbl. vom 1. 9. 1968 und 1. 7. 1970 (= Beitr. zur Wr. Diözesangeschichte); Buchberger; Groner; Kosch, Das kath. Deutschland; N. Österr. Biogr. 9, 1956, S. 175 ff.; B. O. Cernik, Die Schriftsteller der noch bestehenden Augustiner-Chorherrenstifte Österr. von 1600 bis auf den heutigen Tag, 1905, S. 270; R. Hellmer, Kardinal P., 1931; S. J. Tzöbl, Kardinal P., 1932; A. Loris, Der Volksbischof Kardinal F. G. P., 1933; St. Leopold. Festschrift des Augustiner Chorherrenstiftes Klosterneuburg . . ., hrsg. von S. Wintermayr, 1936, S. 236; R. Prantner, Kath. Kirche und christliche Parteipolitik in Österr. . . . unter der Regierung Kardinal P.s . . ., kath. theolog. Diss. Wien, 1955, s. Reg.; M. Liebmann, Die Rolle Kardinal P.s in der österr. Kirchenpolitik seiner Zeit, theolog. Diss. Graz, 1960; F. Rennhofer, F. G. Kardinal P., 1967; Ch. Muckenhuber, Kardinal P. und die Christlichsoziale Partei, 1964/65, Manuskript, Inst. für Zeitgeschichte, Univ. Wien.

(F. Loidl)

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Figure 1: Biographical lexica collect textual data and images about historically relevant individuals. Screenshot from the ÖBL (Österreichisches Biographisches Lexikon, 2018).

As a result, hundreds of thousands of textual descriptions have been accumulated into biographical libraries and dictionaries, which are recently transformed into structured data collections by digital humanities initiatives (Bernád, Gruber & Kaiser, 2017).

2.1 Digital biography projects

While traditional written collections have largely appeared as meaningless textual "strings" to digital research approaches before, methods of natural language processing (NLP) allow to transform these texts into structured, semantically enriched data. Several research groups throughout Europe are currently working on creating enriched linked open datasets (LOD) based on national biographical dictionaries (e.g.. Fokkens et al., 2014; Reinert et al., 2015; APIS project, 2018). Starting from textual entries on historic individuals - see Figure 1 for an exemplary entry on the bishop Friedrich Piffl (1864–1932) from the Austrian Biographical Dictionary 1815-1950 (ÖBL)[1] – NLP methods enable the extraction of structured entities, including (names of) actors, places, institutions, or events, all featuring different attributes and interrelations, which are changing due to actions and developments over time (Reinert et al., 2015; Reznik & Shatalov 2016; Schlögl & Lejtovicz, 2017). The resulting data collections are often modeled as time-oriented knowledge graphs, which are accessible for novel data and text-analytical procedures, including methods of visual analysis and communication (see sec. 3).

While the future promises of such technologies for historic research are striking – in terms of openly accessible databases containing millions of actors and relations - there are still a lot of problems to solve. Most of the biographical dictionaries started several decades ago when printing books was still expensive and therefore make extensive use of abbreviations. Most of modern NLP tools on the other hand are trained on digital born texts and perform very bad on these abbreviations. Even when the NLP part (mainly named entity extraction) works well, the automatic linking of entities - finding the real world expression of a string - is still a merely unsolved problem. This is especially true for biographies where we often miss additional information on the entities found in the text. Visual analytics is not only important for analyzing the final data, but can also play a crucial role in detecting errors in this unsteady process.

2.2 The APIS system

The APIS system was developed in the course of the identically named digitization project (APIS, 2018). The APIS project deals with semantically enriching the Austrian Biographical Dictionary (Österreichisches Biographisches Lexikon 1815–1950, ÖBL), which is a supranational work of reference covering courses of life and career of about 20.000 historical figures of the former Austro-Hungarian monarchy and the First and Second Republics of Austria.

[1] Austrian Biographical Dictionary entry accessible online at http://www.biographien.ac.at/.

For the project, a custom relation-based data-model was developed. It covers persons, places, institutions, works and events and allows for interrelating all of these entities. While entities also contain easy to adapt attributes, relations only consist of a time frame and a type. Attributes of entities and the relation type are SKOS (Simple Knowledge Organization System) based vocabularies. The data model also allows for keeping a complete edit log.

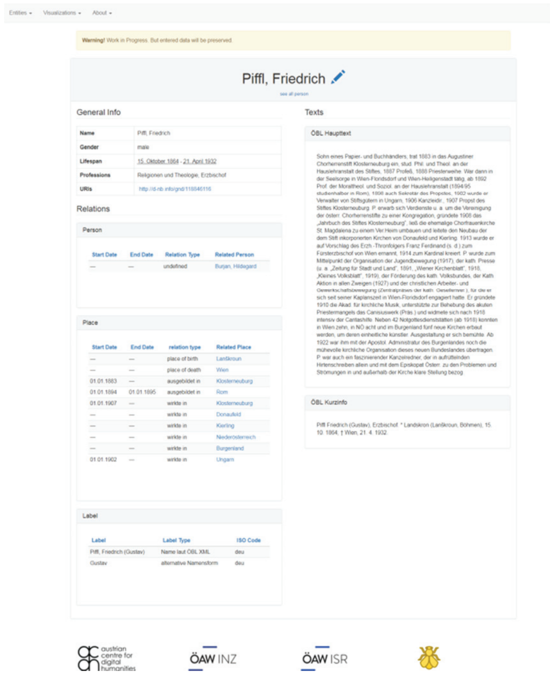

Figure 2: Digital biography projects extract entities (such as places, persons, institutions, events and works) and their interrelations as time-oriented, structured data. Screenshot from APIS project (2018).

For a smooth and easy editing process, a web application was developed (see Fig. 2). Amongst others, it features autocompletes, automatic links to reference resources (such as Geonames and GND), the possibility to highlight or annotate entities directly in the biography, a basic mapping and network visualization component with export functionality (Schlögl & Lejtovicz, 2017).

Similar to other biography digitization projects, the APIS system aggregates large amounts of structured data to support historians and humanities scholars' research activities. Yet to make these large amounts of data more accessible and to efficiently support the corresponding reasoning and sensemaking processes, advanced (visual) analysis methods are required.

3. Visualization of biography data

Recent work in the visualization realm has documented multiple options to support the visual analysis of biographical data from various synchronic (i.e. geographic, relational or structural) and diachronic (i.e., time-oriented) perspectives. The table in figure 3 shows different *synchronic* (i.e., not primarily time-oriented but structure or distribution-oriented) perspectives as rows. Due to their general prominence, maps have already been widely adapted for the visualization of biography data (APIS project, 2018), and methods for the geo-temporal visualization of actor movements are under constant development (Ellegaard et al., 2004; Kapler & Wright, 2005; Kwan et al., 2005; Goncalvez et al., 2015). For the visualization of relations between different actors, network frameworks (Schich et al., 2014; Kaiser, 2017), and mixed method approaches (Armitage, 2016) have been proposed. Attributes of historic individuals (such as professions or fields of activity) have been visualized by treemaps (Hidalgo et al, 2014), whereas other approaches engaged in multi-method investigations and visualizations (Gergaud et al., 2017).

For *diachronic* perspectives, various approaches have been developed to map time linearly as *timelines* (Hiller, 2011; Brehmer, 2017). Other hybrid methods to visually encode time in addition to synchronic data aspects include *animation*, *layer juxtaposition*, *layer superimposition*, and *space-time cube* representations, which are represented as columns in figure 3.

Despite the growing amount of visualization techniques, which are technically available to analyze selected dimensions of biographical data collections, their orchestrated use has not been advocated and investigated so far. Also the challenge of integrating multiple views on different data dimensions has not been addressed systematically so far. With regard to both of these research gaps, we consider the development of multi-perspective interfaces, which support the integration of different perspectives, to be a next level design objective. Such a multiple-perspective interface would also improve the chances to detect fundamental errors in NLP-based data creation pipelines early on.

4. Combining multiple visualization perspectives

Given the complex and multidimensional nature of biography data, every single visualization technique can reveal only a rather one-sided or one-dimensional data portrait. Specific visualization methods (such as maps, networks or timelines) provide analytical benefits with regard to certain data and tasks, but are limited or useless with regard to others. Advanced visual interfaces aim to overcome these limitations by combining and utilizing multiple visualization techniques synchronously, which cover multiple data dimensions and aspects either by an interface of parallel views (often as *coordinated multiple views*, Scherr, 2008) or as perspectives to be chosen in a serial manner. With regard to the distinction between synchronic and diachronic visualization techniques, we argue that advanced visual-analytical interfaces to biography data are well-advised to integrate multiple views and instances from both categories, also to cover the relevance of the temporal dimension for biographies.

Implemented within multiple coordinated views, *synchronic perspectives* (showing cross-sectional, structural, or distributional data aspects, see fig. 1, first column) can combine their analytical features, but commonly have to be complemented by at least one analytical perspective on temporal aspects of data organization. These *diachronic perspectives* can be added as linear representations (e.g., as timelines in coordinated multiple views, see fig. 3, second column), or as various hybrid techniques to encode time as joint projections together with synchronic representations (see Figure 3, third to sixth column).

Figure 3: A cross tabulation of synchronic (including geographic, relational, and categorial visualizations; rows) and diachronic visualization methods (split screen, animation, superimposition, juxtaposition, and space-time cube perspective; columns) for biography data.

Multiple views are a design principle of general relevance for complex data, "in order to maximise insight, balance the strengths and weaknesses of individual views, and avoid misinterpretation" (Kerracher et al., 2014). This applies for both synchronic and diachronic perspectives: Given the importance of the temporal dimension in biography research, it seems obvious that multiple solutions to represent time can increase the analytical diversity and capacity of a visualization system. Multiple views allow researchers to select and switch between the most appropriate representations for the data and task at hand.

Figure 3 cross-tabulates the various synchronic and diachronic visualization techniques mentioned so far, and depicts a basic design space for biography data visualization, which remains also open for the addition of novel methods (see section 6). It offers well-established options for the visualization of biographic pathways through multiple "space-times" - as orthogonal combinations of synchronic (rows) and diachronic perspectives (columns) on the data. While single methods have already been implemented separately by various interfaces to biographical data collections (cf. Section 2), their well-composed *combination* and *integration* is a next-level design challenge not tackled up to now.

Yet, especially for interfaces with multiple views, a new problem of visual-analytical complexity emerges: When historians aim to answers questions combining multiple data dimensions (such as "*How did the migration of an individual affect her/his social network, institutional* *affiliations, or means and motivations of cultural production*?") they commonly have to combine information from multiple views. This requires to build up a mental model bridging and integrating different data dimensions, which is a task high in cognitive effort (Trafton et al., 2000). Attention is commonly split between multiple views and linked data have to be identified and related, before they can be integrated into one mental model. Yet, different visualization techniques (which we refer to as "*coherence techniques*", Schreder et al., 2016) can support researchers in assembling their local insights into a bigger picture. Well-established techniques for such a support derive from the visual integration of different data dimension into a multidimensional visualization, and among those, *space-time cube representations* show a significant potential to mediate across the different splits and separations of usually unconnected and particularistic perspectives.

In the following we introduce a framework revolving around space-time cube representations. While this framework initially demonstrates what one specific diachronic perspective (i.e. the space-time cube) can do for the visual analysis of biography data, we also show how this perspective can play a crucial role for the cognitive integration and mutual translation of multiple other diachronic perspectives (Bach et al., 2016).

5. A synoptic visualization framework utilizing multiple space-time representations

The PolyCube framework has been set up to support synoptic visual data analysis with regard to cultural collection data (Windhager et al., 2016; 2018). With regard to history and biography data, it provides even richer options to support visual investigation and information integration between multiple views. We outline its main perspective by tracing its geo-temporal origins, and move on to demonstrate its analytical potential also for non-geographic aspects of biography data. For this purpose we combine prototype visualizations developed across three different research projects (Federico et al., 2011; Smuc et al., 2015; Mayr & Windhager, 2018), and showcase an exploratory study conducted with biography data (cf. Windhager et al., 2017).

5.1 Geographic space-time

The visual notation of the space-time cube originated in human geography to allow for the visual analysis of human movement patterns and of the diffusion of innovation. This visualization method blends synchronic views like maps (as horizontal plane) and a diachronic timeline (vertical z-axis) in an orthogonal fashion, which allows to model spatiotemporal data points (like events of historic travels) as a three-dimensional shape. Any spatiotemporal behavior thus translates into a unique space-time trajectory and enables historians to interpret biographic movements as visual patterns.

Figure 4 illustrates this option for biography research by taking on the geo-temporal movements of the Austrian archbishop Friedrich Piffl (1864-1932), which were extracted from the textual data shown in figures 1 and 2 (APIS project, 2018). The trajectory shows the main stations (from top to bottom) of his life, including Lanskroun (Czech Republic), Vienna, Rome, and Hungary.

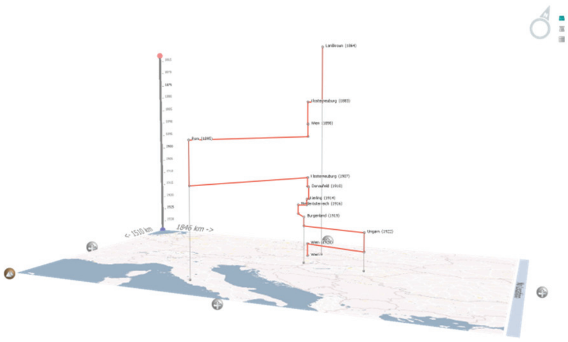

Figure 4: Visualization of the biographical trajectory of Friedrich Piffl (1864–1932) from a geo-temporal perspective, created with GeoTime (Kapler et al., 2005).

For the purpose of comparative and combinatory research, composite visualizations (such as juxtaposed or superimposed space-time paths) enable the visual comparison and combination of biographical life patterns, including the study of similarities and differences of patterns among different actors. Figure 5 illustrates this option by displaying the pathways of the Austrian artists and siblings Josefine and Rudolf Swoboda, whose careers as portrait painters led them into opposite directions and to different royal courts spread across the world map.

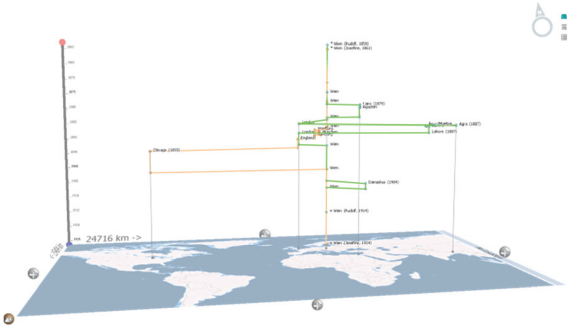

Figure 5: The trajectories of the Austrian artists and siblings Josefine (1861-1924, orange) and Rudolf (1959-1915, green) Swoboda, seen from a geotemporal perspective.

Analyzing and visualizing exemplary entries from the APIS data collection also made the problem of incomplete and implicit information obvious: Biographical articles contain a lot of implicit information that is hard to extract and visualize: Exemplarily, an entry stating "*1922 X moved to Rome and became a professor at the University of Vienna in 1928*" makes clear that X moved to Rome in 1922, but says only implicitly that he moved to Vienna in

1928. Similar is the problem of incomplete data: Piffl was known to have managed monastery estates in Hungary. However, his biography does not mention the exact locations of these monasteries. By proxy, the visualization in Figure shows a point where Piffl most certainly never was (i.e., the middle of Hungary). We consider data aspects and issues like these to be drivers for the future development and necessary implementation of methods of uncertainty visualization in the historical research and visualization realm (sec. 6.4).

5.2 Relational space-time

Going beyond the geo-temporal data domain, space-time cube representations can also offer insights into the dynamics and developments of different other non-geographic data dimensions. The resulting trajectories then represent the movements of individuals through further space-times of analytical value, like social-relational space-times, generated by interaction patterns of collaboration or conflict.

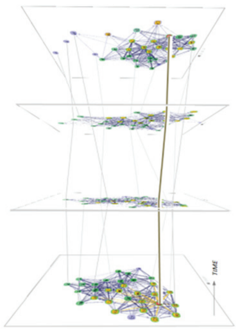

Figure 6: Visualization of an individual movement through social-relational space-time, as demonstrated by Federico et al. (2011).

Figure 6 conceptually illustrates this option by the highlighted movement of an actor through an evolving social-relational structure, as defined by a group of other actors (Federico et al., 2011). Depending on the richness of relational and temporal data, such visualizations can enable historians to study the interactions of individuals of interest and to track their careers as movements, which often lead them from the socio-cultural peripheries of larger network graphs or clusters to their structural cores. These visualization thus can show macro patterns and also detailed interactions of individuals, including their relative positions and the development of their network centrality measures (Weingart, 2013; Bernád et al., 2017).

5.3 Categorial space-time

As a third variation of space-time cube representation we outline the option to visualize the pathways of individuals through any other space defined by categories, which historians use for classifying activities. With regard to all possible activity spaces, in which historical individuals have been active (such as social-structural fields of production, professions, cultural domains, or knowledge areas), visualizations like treemaps can provide a valuable synchronic perspective (cf. Hidalgo et al., 2014). Thus, by implementing treemaps into categorial-temporal cubes (see Fig. 7), a diachronic perspective unfolds, which discloses novel patterns of movement or persistence through categorial spaces (Smuc et al., 2015).

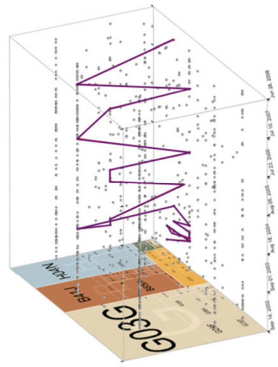

Figure 7: Individual movement through categorial space-time, as demonstrated with regard to the knowledge space of a patent classification by Smuc et al. (2015).

5.4 Linking multiple space-time cubes

In analogy to multiple coordinated views (Scherr, 2008), we promote the connection of multiple space-time cubes to synoptic ensembles. This enables the visual exploration of biographies in multiple relevant space-times in parallel (Figure 8). The specific line up of space-time-cubes - which could include various further methods - naturally depends on available data (and data dimensions), and the intended analytical tasks. We consider such a synoptic setup to provide an effective visualization environment, which could be explored by the means of different interaction techniques (such as brushing and linking), but which could also serve as a versatile scaffold for the selection of more detailed analytical perspectives, including well-established methods of flat visualization design, as will be discussed in the next section.

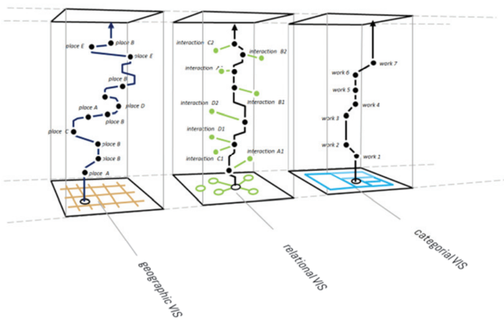

Figure 8: The PolyCube visualization environment for biography data using multiple coordinated cubes, based on space-time cube representations utilizing maps, network diagrams and treemaps (from left to right).

5.5 Mediating multiple synchronic and diachronic views

Bach et al. (2016) have shown, that space-time cube representations also support the (cognitive) translation and mediation of the working principles of multiple diachronic and synchronic views - also by the means of seamless canvas transitions and the smooth adaptation of the perspective on the visualization (figure 9). Given the outlined (linked) visualization of the outer right column of figure 3, the other temporal visualizations (i.e. layer juxtaposition, layer superimposition, or animation - as well as all possible "space-flattened or time-flattened" standard perspectives - could be seamlessly generated out of the different space-time cubes. We contend that such seamless translations will have a positive effect on the preservation of mental models of complex time-oriented data, and as such for the navigation and visual reasoning - especially in the early stage of an exploration process.

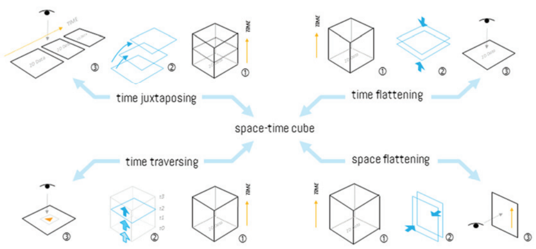

Figure 9: Space-time cube representations can help to preserve and translate mental maps and visualization perspectives (adapted from Bach et al., 2016).

6. Discussion

With regard to the visualization framework outlined so far, we discuss interesting options for further development.

6.1 Prosopographical data visualization

Going beyond single trajectories, the outlined framework is open for more complex analyses to be undertaken with bigger prosopographical datasets. *Prosopography* is the domain for studying biographies as seen from a collective perspective (Keats-Rohan, 2007). Historians deal with a wide variety of social collectives – such as organizations, religions, art schools, political entities, conflicts, or movements of innovation. For their analyses, the proposed framework can also be adapted to map the temporal development of groups as *sets*.

Figure 10 enumerates different visual patterns, which - in combination - can map all the complex developments of historical groups or collective entities. As a method for aggregated representation, prosopographical or collective set visualizations can complement the display of line-like, individual trajectories in geographic or relational space-times.

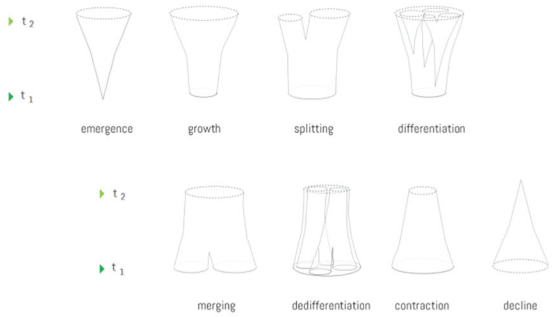

Figure 10: Visualization of the temporal development patterns of groups or organizations, as seen from a set-typed prosopographical research perspective.

6.2 Process and project visualization

While actor trajectories have been featured and visualized as consistent lines so far, these life paths can obviously also be parsed and segmented according to biographically meaningful units of a finer temporal granularity. This allows to visualize and annotate single processes or projects, whose pursuit is strongly structuring and guiding individual behavior - also if nothing else (e.g. no movement or interaction) is visible from another visualization perspective. Practical means to visualize projects or processes derive from the separation of (colored) segments, tick marks, or annotations, which could be applied in a nested temporal structure, signifying long-term work or life phases, mid-range projects or procedures, and basic actions or events (Figure 11).

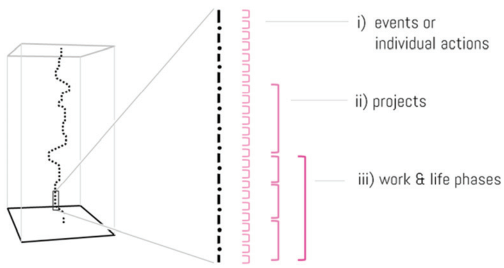

Figure 11: Options of process and project visualization, building on temporal activity patterns.

6.3 Sentiment visualization

Along with the visualization of biographical project and work cycles, we consider the visualization of sentiment data (whether of individual actors or within actor networks) to be of high interest for future approaches. With increasing options to also extract sentiment data from textual sources, rich and qualitative biographical accounts will allow the visualization of emotional stages phases, or chapters of life, related to critical events, like success or defeat, as well as stages of illness, recovery, thriving, and many more (cf. Kucher et al., 2017).

6.4 Uncertainty visualization

In the more general context of history and humanities data collections, we see a specific need to handle questions of *data quality* and *uncertainty* in a reflected manner. Critical questions of data provenance and quality necessarily arise from the investigation of historically fragmented and often disputed data sources. In this context, the deliberate representation of uncertainty measures can help to bring transparency, awareness and trust into the collective interpretation process (Sacha et al., 2016).

6.5 Mapping controversies

Differences and debates about data, sources and representations are all the more likely when experts and scholars are working in distributed or even competing settings of multilateral data curation and interpretation. Aside from the options to collaboratively and consensually enrich visual representations of historical figures, we consider it relevant to also make different scholarly standpoints and interpretations available and visible. This would allow to utilize the outlined framework not only to communicate agreed-upon results, but also to motivate and support the collective critical editing, revising and annotating of biographical knowledge graphs. As such, competing interpretations could be studied, compared and taught on a visual basis, and historiographical controversies could be made productive (Marres, 2015).

6.5 Visual storytelling

Given the increasingly advanced options for the largely user-driven exploration of biography data by the means of multi-perspective visualizations, we consider it specifically interesting to merge these representation techniques with narrative or author-driven representation techniques (Segel & Heer, 2010) to tell life stories, e.g. of national cultural heroes. Storytelling then could enrich the analytical systems with sequential guidance for the purpose of scholarly communication, the pedagogy and teaching realm, but also for data-driven journalism and public knowledge communication (Mayr & Windhager, 2018).

6.6 Integrating close & distant reading

As for its application, the outlined framework can be productively used as an interface connected to structured data collections, or as an interface visualizing textual data via automated natural language processing pipelines. In this context it seems essential, to offer access to textual source data in parallel to visual representations. This allows to study and "close-read" a source text in comparison to a visualization, possibly including further supportive text visualization techniques, such as colored mark-up of textual entities, connection to various layers of annotation, or coordinated highlighting (Jänicke et al., 2017). Eccles et al. (2008) show how a system of coordinated multiple views can link back to textual data representations. As such, space-time cube representations can provide overview and orientation, while still keeping the original textual data accessible. Another option to combine textual data with a graphic representation is to actually tell a story sequentially and incrementally on a textual basis, while zooming and panning to selections of a space-time path, as it is already offered for two-dimensional representations by tools like StoryMapJS[2] or ESRI storyteller.[3]

6.7 Automated vs. qualitative visualization

To further foster and enable control and curation of largely automated natural language processing endeavors – but also for the means of a qualitative complementation of these highly complex procedures – we consider options for manual input and data curation to be an essential future feature. This will aid to the existing options for data development and enrichment, but also enable shorter modelling cycles by starting to generate structured biography data from scratch. For this purpose, we consider either options for manual data creation (e.g., by a simple event-based spreadsheet notation), or direct spatiotemporal drawing functionalities to be of high practical value, which will allow to generate biography visualization – and quantitative or structured data – from existing expert knowledge, which has not been codified or formalized in any other context so far.

7. Conclusion

With this paper we discuss the creation of structured data from biographical texts, and advanced options of their visual analysis. The outlined visualization framework firstly provides visual-analytical access to complex biography data, as well as visual reasoning support on an overview and detail level. Secondly, it offers multiple perspectives to generate richer and non-reductionist portraits of the available data. Finally, it aims to considerately support scholar's information integration by utilizing space-time cube representations. In addition to challenges arising from the ongoing effort of implementation and evaluation, we suggest to focus on a number of objectives for future research (see sec. 6) to enable a more complex and synoptic understanding of the life and work of historical individuals.

8. Acknowledgements

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[2] StoryMapJS: https://storymap.knightlab.com/

[3] ESRI storyteller: https://storymaps.arcgis.com/

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5 Contextual Visualization of Collection and Biography Data (AB3)

After investigating two types of humanities research topics and data from a visualization point of view, this chapter reflects on questions of their mutual contextualization. Formally speaking, these considerations probe possible relations between object collections (artworks) and event collections (i.e. lives of artists) (see Figure 2). In both areas, the collections themselves do already contextualize single entities (objects or events), yet visualizations of both types of subject matters frequently refrain from further possible contextualizations—but not least due to their dependence on "siloed" data collections. This comes also from the historical fact, that information collections often are organized in the form of specialized knowledge silos first (i.e. either as object-oriented archives or as biographical knowledge collections)—which also translates into siloed digital data collections during contemporary datafication endeavors.

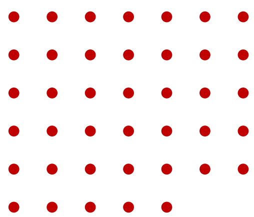
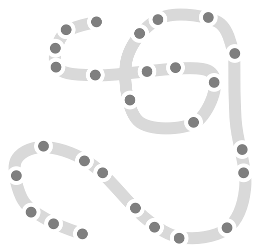
a)  b) 

Figure 2. Art-historical data frequently are organized around a) *object collections* (symbolized with a grid layout, left) or b) as *event collections*, which are commonly organized chronologically, for instance as artists' biographies or histories of art movements (arbitrary timeline layout, right).

By contrast, the following reflections will assume that endeavors of *data linking* (i.e. initiatives of opening, standardizing, and exchanging humanities data) will proceed, and that interface developers are well-advised, to also consider the actual linking of local visual representations for the sake of bigger contextual pictures (Windhager et al, 2019c). As such, this chapter conceptually explores questions of how representations of artworks and artists' lives can be visually drawn together by selected encoding techniques.

5.1 Reassembling Work and Life

Studying the works and lives of artists in parallel has a venerable history (Vasari, 1550/2008), and is considered a standard practice in arts and history-related domains. Also, the following reflections are guided by the idea that such a synoptic perspective can help to understand a variety of data, objects, and developments in more depth. In parallel to the well-established "ergo-biographical" tradition of art-historical inquiry, we may expect various effects of mutual illumination—for specific types and kinds of scholarly tasks and investigations.[5] For instance, scholars can search for clues and patterns about how biographical developments (such as geographic movements, encounters, or changes in their social networks or institutional affiliations) affected their overall productivity, or more specifically the contents, styles, and frequencies of their cultural (object) production. Vice versa, it might be interesting to examine how the creation and publication of artworks affected biographical trajectories, as the reception of objects is known to open certain biographical pathways (such as invitations to institutions, exhibitions, communities), or foreclosing others.

It is this background of higher-level analysis tasks and combinatorial questions, against which it seems important to care about connections between biography and artwork visualizations, and against which this chapter will probe the conceptual design space of bigger, ergo-biographical pictures.

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[5] Well documented counter-arguments against the synoptic study of life and work—for instance along the lines of New Criticism (Hickman & McIntyre, 2012)—can still be fully respected: On the one hand, the exploration of synoptic visualization strategies does not preclude possible preferences for (the use of) isolated, unconnected representations—we can rather consider them to be the current state of the art. On the other hand, the preference for the 'non-biographic' or 'non-historical' study of artworks is commonly not founded in a "non-contextual" approach to investigation or interpretation, but rather in the preference for *alternative* contextualizations. New criticists, for instance, do not look at artists' lives, beliefs, or intentions for the purpose of interpretation, but rather at whole corpora of other artworks, or positions within universes of discourse, and at the general principles, which they find on a structural level. Thus from a visualization point of view, we can image these scholarly preferences to also require novel strategies for contextual representations, even though these challenges will not be discussed in the current (con)text.

So given the two data domains and their separated representations (see Figure 2) - *How do we bring them in touch?* In general, visualization designers can count on a substantial link: Object collections arguably are born out of the event collections or sequences of artist activities and biographies. During their creative periods, a major part of artists' life events and actions serve the assembly of cultural objects. Whether those objects are photographs, paintings, performances, songs, sculptures, stage plays, novels, operas, movies—whole chains of operations (with characteristic lengths) contribute and condense into the creations of objects (see Figure 3).

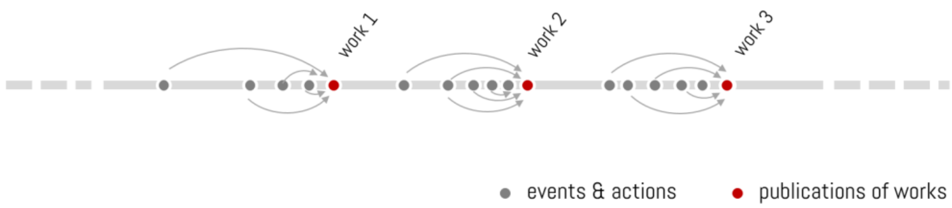


Figure 3. Event-based timelines as carriers of events and actions (grey), including creations and publications of artworks (red).

Sometimes artworks emerge or result from a handful of events or actions only (e.g. photographs), sometimes they require the interconnection and orchestration of staggering numbers of actions from scores of actors: In case of complex art forms (e.g. movies, architecture), a large number of biographies interweave temporarily like supply chains into the creation of a complex compound object.

Regarding a common denominator for biographical event collections and object collections, we can rely on *events* as mediating entities: Biographies consist of them, objects are created by them, and commonly objects are also formally published with certain events, such as (first) release, publication, exhibition opening, or premiere events—to unspool an 'object biography' thereafter (Joy, 2009).[6] This allows us to

[6] At the object-biography level, a relevant conceptual and visual bifurcation has to be mentioned regarding the common practice to *reproduce* successful artworks. While this thesis focuses on the "original assembly" of artworks only, all cultural object types (such as paintings, sculptures, plays, films,

follow an event-based approach to contextual visualization—and to develop a variety of corresponding visualization strategies.

5.2 Contextual Visualization Strategies

Regarding a whole spectrum of possible representation techniques (also reflected upon in chapters 3 and 4), two contextual design strategies commend themselves for closer consideration: On the one hand, the next section will elaborate on a purely diachronic visualization approach utilizing *faceted timelines* (5.2.1). On the other hand, a syndiachronic visualization approach, utilizing the *PolyCube design space* will be discussed (5.2.2).

5.2.1 Faceted Timelines

Timelines count among the simplest—yet most effective—visualizations for time-oriented data, whose diagrammatic strengths (utilizing space to symbolize the abstract notion of time) are known and made use of for centuries (Brehmer et al., 2017; Priestley, 1765). When used in parallel combination, the resulting multi-line ensembles are commonly referred to as *faceted timelines*—or sometimes also *stacked timelines* (cf. Fanelli, 2013). As opposed to unified timelines, a faceted timeline is “one that has been partitioned according to some categorical attribute, effectively resulting in multiple timelines”, which “prompts the audience to compare these timelines” (Brehmer et al., 2017, p. 5). The most relevant partition in the context of this thesis obviously is one between *biographical* and work-related (or *ergographical*) events. Drawn up in parallel, we arrive at an “ergo-biographic” visualization, where both lines contextualize each other—and which is illustrated by Figure 4 in its most basic form.

songs) could also be investigated for instances of their subsequent reproduction. As such, the reenactment of event-like artworks (such as operas, symphonies, plays) could be mapped with (second-order) point clouds, while reproductions or duplications of tangible objects (paintings, sculptures, storage media) opens multiple object trajectories, which could be represented both with (branching or faceted) timelines, or with (spatio-temporal) filiation trajectories in the PolyCube framework.

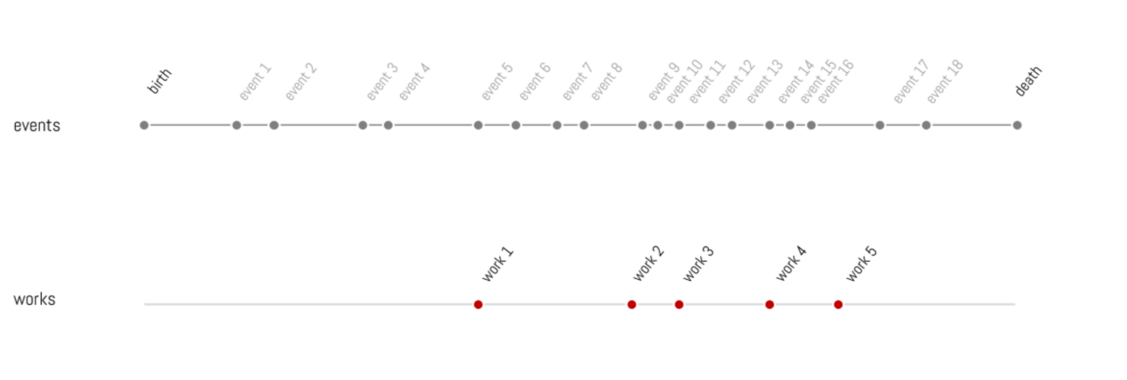


Figure 4. Visualization of a biographical event collection (top) and of an object collection (bottom) via two data-specific timelines, which contextualize each other.

Regarding interactive versions of such a design, only a handful of similar visualizations have been implemented up to now, for instance by the art-historical information website "The Art Story" (The Art Story, 2009), where selected artworks from prominent artists are shown as a juxtaposed sequence, pointing to their dates of origins on the lifelines of the respective artists (see Figure 5).

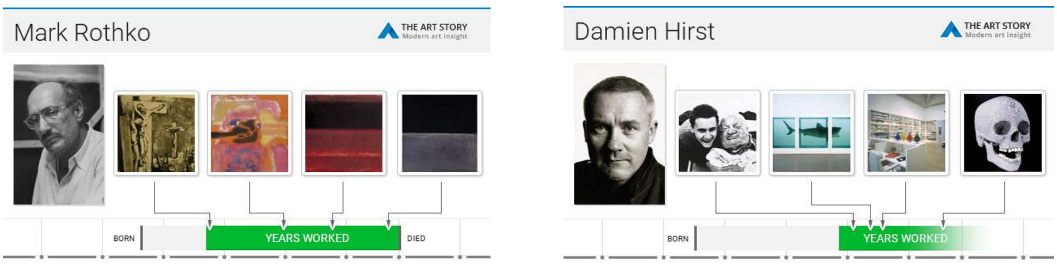


Figure 5. Two contextual visualizations of selected artworks (top), placed above the biographical timelines of artists (bottom), by theartstory.org.

Going beyond the most simple designs of ergo-biographical timelines, faceted timelines can differentiate their main threads into more detailed diagrammatic representations: Biographical timelines can be faceted according to different types of events (such as spatial shifts, social threads, relationships, focus of work or attention), and ergographical timelines can be further distinguished according to different types of works, topics, styles, or phases of artistic productivity.

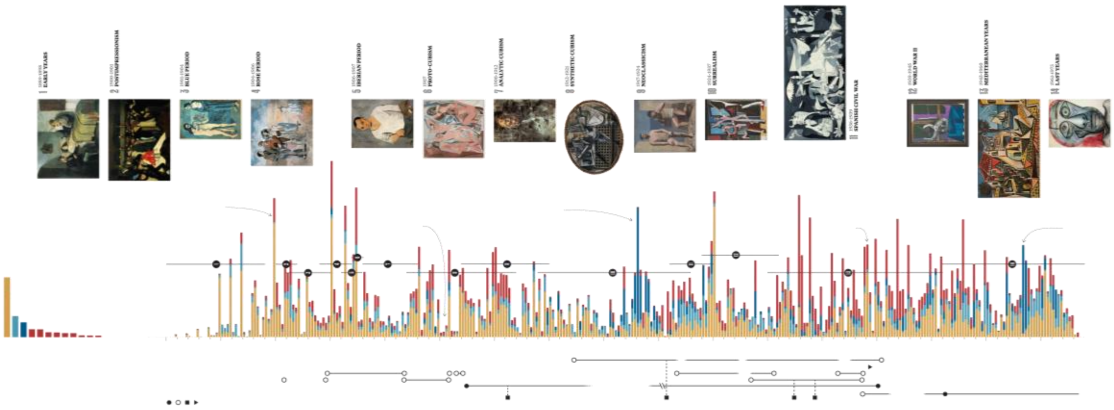


Figure 6. Contextual Timeline "Strokes of Genius. Deconstructing Picasso", juxtaposing biographical lifelines of relationships (bottom), with work and artistic periods (center), and individual artworks (top) (Morris et al., 2018).

A more complex and elaborated example (Figure 6) visualizes objects and works of Pablo Picasso (top) in parallel to the faceted depiction of types of works by the means of a color-coded histogram (center) and the lifelines of the artist's social relationships (bottom) (Morris et al., 2018). Such rich and faceted diagrammatic representations of an artist's life and work can help to visually organize multiple lines and threads of art-historical investigation and reasoning, and provide synoptic insights into the parallel processes of artistic work and periods of productivity.

However, both unified and faceted timelines have also been criticized for cutting complex dynamics things apart into seemingly unrelated tracks, which misses their essentially interwoven nature and their multiple causal interrelations. Frank (2019) notes, that a first approach to a 'visual historiography' can be easily established via the temporal, spatial, and thematic context of information about historical events, "*but without explicitly stated relations between events it is questionable how useful that could be in supporting historical research. […] The problem with such a 'visual historiography' is that it cannot support visual contextualization done by the historian during conceptualizing complex interrelations of historical events—including not only temporal, spatial, and thematic relations, but also causal relations (incl. the motivation and roles of historical actors involved in the events), mereological, and constitutive relations of complex (e.g. composite) events.*"

In the current context, the assessments and admonishments of this short quote provide valuable pointers to major future challenges for the genre of "visual historiography", without requiring us to address all of their complex implications. From a faceted timeline-point of view, the most relevant notion is that of *relations*, which are commonly missing between individual lines, but which can be easily added, given the knowledge about corresponding influences. By the means of relationally enriched designs, all possible events in unified or faceted arrangements can have effects on each other.

An illustration for a *relational unified timeline* (depicting both causal and mereological relations between actions and artworks) can be already found in Figure 3. An illustrative example for a *relational faceted timeline* design can be found in "Britten's poets" (Kräutli, 2016a), where the works of Benjamin Britten are contextualized by—and connected to—the lives of other artists, which have influenced his compositions and which are referenced by the collection of his works (Figure 7).

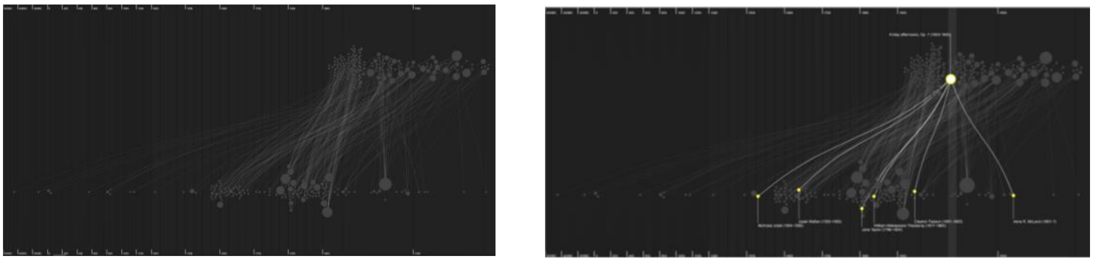


Figure 7. "Britten's poets" (Kräutli, 2016a), showing Benjamin Britten's works (upper timeline) and referenced works or writers (lower timeline), with the contextual reference network of a single object, highlighted on the right-hand side.

Similarly, every faceted object and biography-oriented timeline could be contextualized with—and connected to—relevant historical events, and the shapes, bundles, directions, and density of references can make relations, impacts, and historical influences visible.

An instructive example for such a design is given by the digital interface to "Peters' Synchronoptische Weltgeschichte" (Behrendt et al., 2010), which (amongst other views) features a complex faceted timeline, developed and printed for the first time in the middle of the 20th century (Peters & Peters, 1952). The digital interface allows to transform the faceted visualization into a relational representation on demand, to show the relations between events and related historical actors (see Figure 8)—which can be translated to ergographical timelines too.

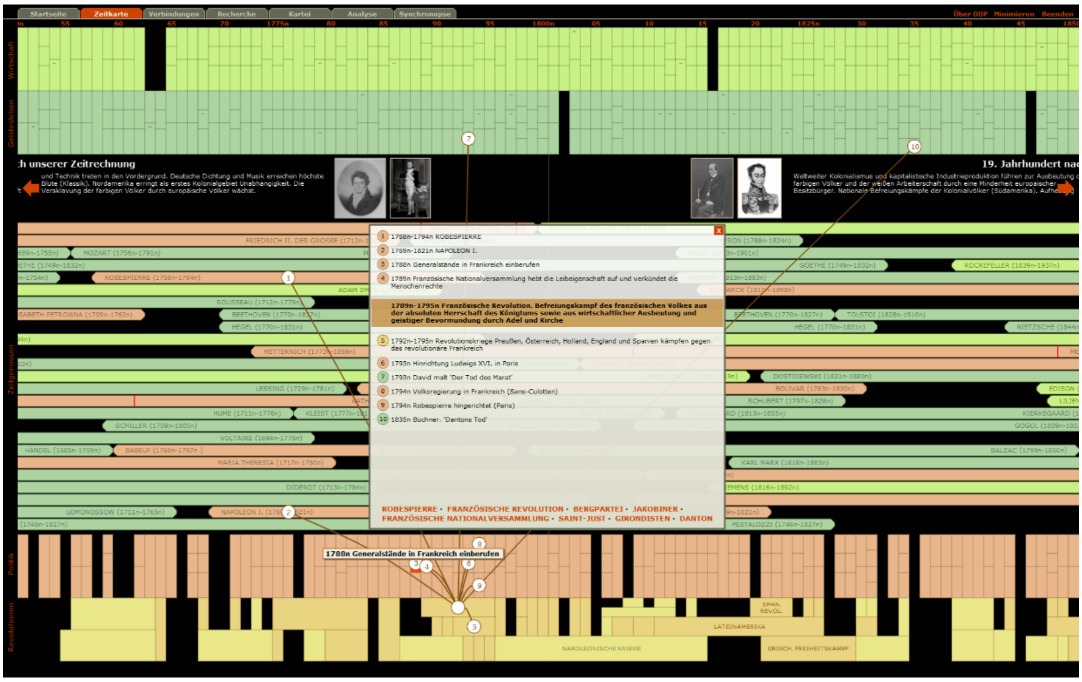


Figure 8. A relational overlay, drawn on top of the massively faceted timeline of the digital version of "Peters' Synchroptic World History" (Behrendt et al., 2010).

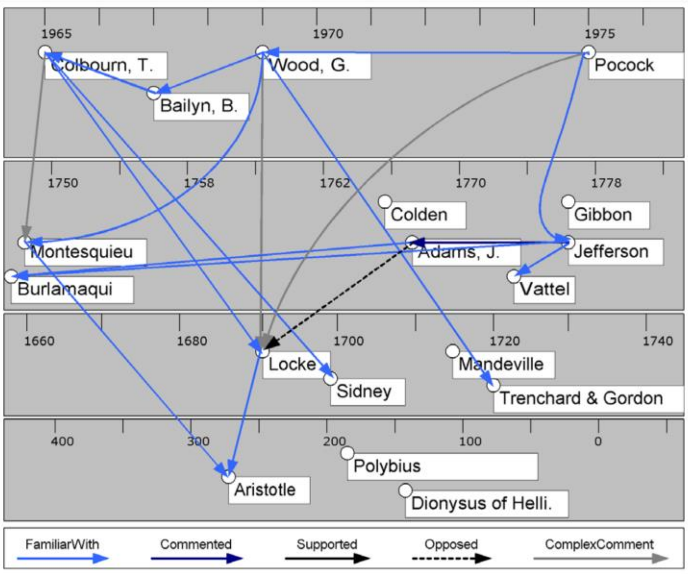


Figure 9. Faceted timelines showing references among publications dealing with republican theory (Jensen, 2003).

As for the diversity of possible relations between events, an instructive design could be found in Jensen (2003), who shows how a faceted timeline can expressively visualize the complex network of relationships between writers (see Figure 9), by representing multiple types of relations, including *familiarity, support*, *opposition* or different types of *commentary*. Similarly, relational, ergobiographical timelines can visualize different types of beneficial or adversarial relations between the life and work (phases or events) of artists.[7]

How far such relational data models and representations for beneficial or detrimental, but also "causal, mereological and constitutive relations" (Frank, 2019) between historical data points can be advanced, will depend on multiple constraining factors: On the one side, a decisive constraint is given by the (lack of) density, quality, reliability, and degree of data or detail, that can be found in historical and archival information. What can enrich any kind of naturally sparse information, on the other side, is the *linking* of data. If historical and archival knowledge collections can be semantically enriched and linked to existing data about objects and actors, these knowledge collections also can be exploited for extraction and enrichment of relations, attributes, or any other aspect of data. Finally, an additional kind of information can arise from what can be plausibly derived, hypothesized or claimed in the context of academic arguments or discourses, as shortly elaborated further down (see ch. 6.2).

As for a takeaway from this section, it seems worth noting that contextual visualization strategies based on timelines recommend themselves as simple but powerful solutions with near-universal applicability. They put their focus predominantly on chronological positions on a spatialized or axial depiction of time, thus they are effective, easy to generate, and practically endlessly combinable: What makes timelines one of the most interesting solutions for contextual visualization, is that they can be easily stacked and concatenated so that the assembly of bigger pictures is doable with moderate efforts (see section 3). What constrains contextual visualizations of these kinds, obviously is the lack of alternative views.

[7] As with many types of relational diagrams, various challenges for these types of relational diagrams are expected to arise with regard to necessary (de-)clutter management, readability, and graph comprehension, arising from their multi-layered and multi-logic (i.e. not only force-directed) nature (Bennett et al., 2007).

5.2.2 Coordinated Multiple Views

Coordinated multiple views arguably are the standard technique for the *visual synthesis* of distinct visual-analytical perspectives (Roberts et al., 2019; Roberts, 2007). Multiple views are considered to be the standard technique to deal with—and cope with the analytical risks of—complex datasets. Regarding their dimensional richness, observers frequently encounter that "*one view is not enough*" (Dörk et al., 2017). As single visualization techniques can only utilize a limited amount of visual variables, analysts are required to selectively 'cut' into the complexity of the data to highlight and project particular aspects, while neglecting other facets and data dimensions. Coordinated multiple views, by contrast, allow establishing a plurality of perspectives side by side. By forming *complementary composites* (Whitelaw, 2015), they help to "maximize insights and balance the strengths and weaknesses of individual views" (Kerracher et al., 2014, p. 9).

Multiple views are also a standard technique to upgrade synchronic (i.e. non-temporal) views to "syndiachronic" (i.e. time-oriented) compound views. As purely diachronic perspectives, (faceted) timelines thus can be connected to most other structural, spatial or relational perspectives to enrich them with temporal information. For instance, the Palladio interface (http://hdlab.stanford.edu/palladio-app/) allows users to combine timelines with maps, with network graphs, with image grids, or with a data table—so that other than temporal data aspects of events (e.g. their geographic position or relational characteristics) can be inspected in a juxtaposed manner (see Figure 10, left).

Figure 10. Coordinated multiple views, as utilized by the Palladio interface (left), which allows combining the components (right) of geographic maps, timelines, networks, and image grids.

However, the Palladio interface allows only to combine one synchronic (i.e. non-temporal) view (e.g. a map) with a diachronic (time-oriented) view on the same screen. By contrast, if users want to compare geo-temporal and graph-temporal data structures, they have to switch between different tabs, which comes with high cognitive costs to memorize the perceived information in between. Against this background, this thesis is interested in visualization designs, which allow to integrate time as a diachronic dimension into every synchronic perspective (i.e. into syndiachronic perspectives)—and still allow to combine multiple syndiachronic views side by side. The "PolyCube" visualization framework, which has been elaborated in publication A2 (Orchestrating Overviews), B1 (Once Upon a Space-Time) and B2 (Beyond One-Dimensional Views) provides one possible design for this purpose. By utilizing this framework, the following section will reflect on further aspects of mutual contextualization of object and biography data, which would be impossible to visualize with faceted timelines alone.

5.2.3 Multiple Space-Time Cubes

Timelines as linear, spatial representations are well-suited to represent and connect chronological sequences of events. As "ergo-biographical" timelines (see Figure 3, p.108), they also provide an excellent basis for further contextualization within geographic and non-geographic visualizations. Chapter 4 already described, how the PolyCube environment allows to visualize biography data, by transforming linear biographic timelines into space-time cube trajectories—and into three other types of syndiachronic representations (superimposition, juxtaposition, and animation) on demand.

Figure 11 shows how this framework can also integrate 'ergobiographical' trajectories. In such representations, hybrid diachronic trajectories—in which work and life events already contextualize each other—can be re-contextualized in technically unlimited further syndiachronic environments. Firstly, both work events (red) and life events (black) are represented as data points along an individual life path (see Figure 3, p.108). After a transformation into a space-time cube environment, the vertical (temporal or diachronic) position of these data points derives from the time stamp of each event. Their horizontal coordinates, on the other hand, derive from various synchronic (non-temporal) layouts, such as geographic, force-directed, set-diagrammatic or hierarchical mapping techniques. Obviously, the choice of contextualizing cubes will also depend on the richness of available information and the data dimensions given in any particular cultural dataset.

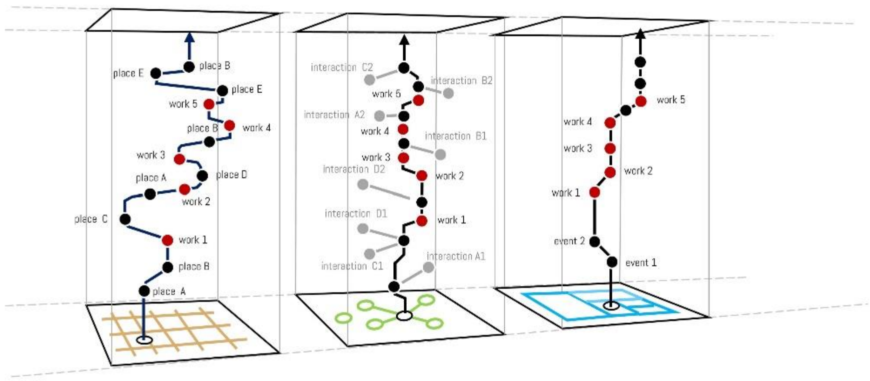


Figure 11. Visualization of cultural objects (red) in a hybrid combination with biographical events (black) within the PolyCube framework (cf. Publication B2).

Sometimes, also the lack of historical information can be compensated by other data dimensions. Figure 12 (left) shows the biographical trajectory of Charles W. Cushman, the photographer whose work is also represented in publication A2 (Windhager et al., 2018b). The specifics of Cushman's biography have been described in a recent case study (Mayr et al., 2019): For two large segments in Cushman's biography (visible as two gaps in the pink trajectory in Figure 12a), the curators of his photography collection declare a complete lack of biographical knowledge and point to his photographs instead: "*with the exception of what may be gleaned from his images, virtually nothing is known about Charles' career and life*".[8] By looking not only at the individual pictures (Figure 12c) but at their spatiotemporal metadata, which Cushman documented in a travelogue, biographical data points for a detailed biographical trajectory can be 're-engineered' (Figure 12b).[9]

[8] Online at: https://webapp1.dlib.indiana.edu/cushman/overview/cushmanBio.jsp

[9] This metadata has been prepared and geo-referenced for spatiotemporal analysis by Posner (2014).

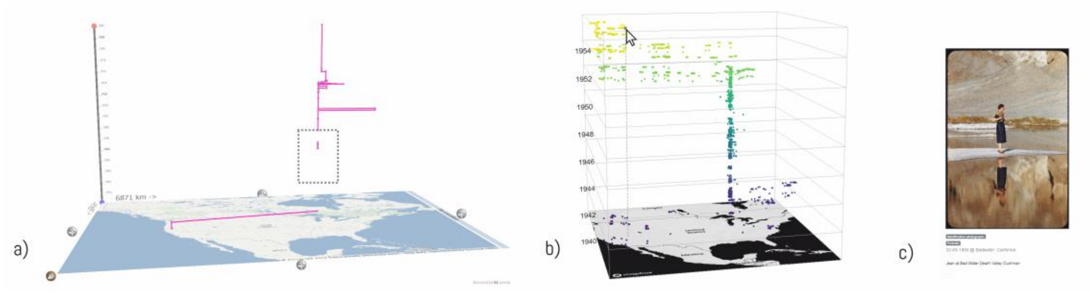


Figure 12. Visualization of the fragmentary biography of Charles W. Cushman, as it has been known to the curators of his photography collection due to written accounts (a), for which data points could be filled in by object metadata of his work (b), comprising 14.500 individual photographs (c), e.g. of his wife Jean (Mayr et al., 2019).

In his travelogue, Cushman did not only document the places and dates of his photographs but also their content—both with short descriptions and with self-assigned keywords. This categorical classification allows creating another syndiachronic view, which provides a set-typed perspective on his work—and on the biographical development of his photographic interests over time. Figure 13 (right) shows how such a time-oriented set-time visualization can contextualize the geographic space-time visualization (left) of historic individuals. The vertical structures in the picture at the right represent the main categories of the photographs (such as "landscape", "architectural", "city", or "identification photographs") and the gray-colored hull structure shows the growth or decrease of the number of photographs per category over time (Salisu et al., 2019).

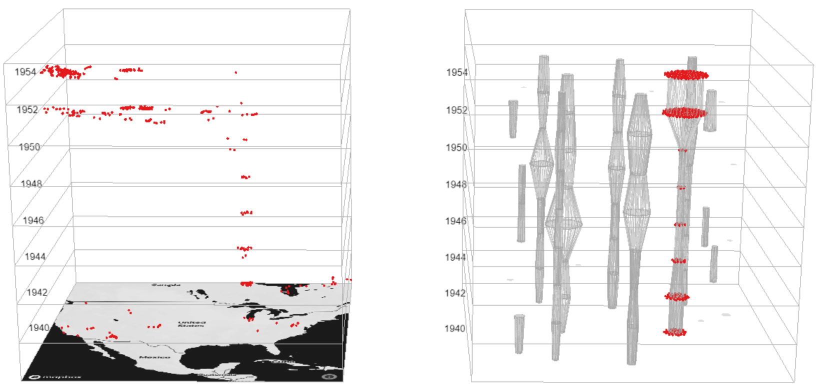


Figure 13. Coordinated geo- and set-time cube, depicting the development of one selected genre (i.e. landscape photographs) over time.

For the works of Charles W. Cushman, the combination of a geo-temporal and a categorical-temporal visualization has been the available maximum of perspectives. Without sufficient information on his collaborators, acquaintances, or social contacts, a relational-temporal visualization (see the ‘graph-time cube’ in the center of Figure 11) cannot be meaningfully generated. However, the flexible nature of the PolyCube framework allows for each investigation to select appropriate analytical perspectives and to combine the corresponding modules into a polycontextual line-up (Mayr & Windhager, 2019; Windhager et al., 2020).[10]

While the PolyCube visualization framework derives its name from its initial setup, which utilizes multiple space-time cube representations, it does not offer this specific syndiachronic view only. In visualization research, multiple techniques have been developed to represent time (Aigner et al., 2011; Kriglstein et al., 2014), and each technique is known to have both specific visual-analytical strengths and limitations. For instance, space-time cube representations have been appreciated for their spatiotemporally integrated nature, their three-dimensional pattern language, their consumption of medium display space, their attraction power for casual users, and their ability to act as a cognitive and conceptual mediator (Bach et al., 2017; Kriglstein et al., 2014; Mayr & Windhager, 2018; Windhager, Salisu, et al., 2018; Windhager et al., 2020). On the negative side, space-time cube representations are known to generate occlusion of objects, depth ambiguity, perspective distortion of distances and angles, and to raise interaction costs for analysts trying to compensate these effects (Munzner, 2014; Sedlmair et al., 2013; Windhager et al., 2020).

Due to the relevance of the temporal data dimension for both cultural collection and biography data, the PolyCube framework does not place all its analytical bets on one syndiachronic view only but integrates and provides *four* time-oriented views. The matrix of Figure 14 shows a possible selection of synchronic views as rows (in this case maps, sets, and graphs)—and the blue arrows show how three additional syndiachronic views can be activated to represent the temporal data dimension across all the rows.

[10] At the current point in time, the PolyCube framework only allows to visualize the point clouds of cultural object collections. The connected visualization of data points as *biographical trajectories* is the main objective of a subsequent project proposal, focusing on the visual analysis of biographical information, which has been created out of national prosopography projects.

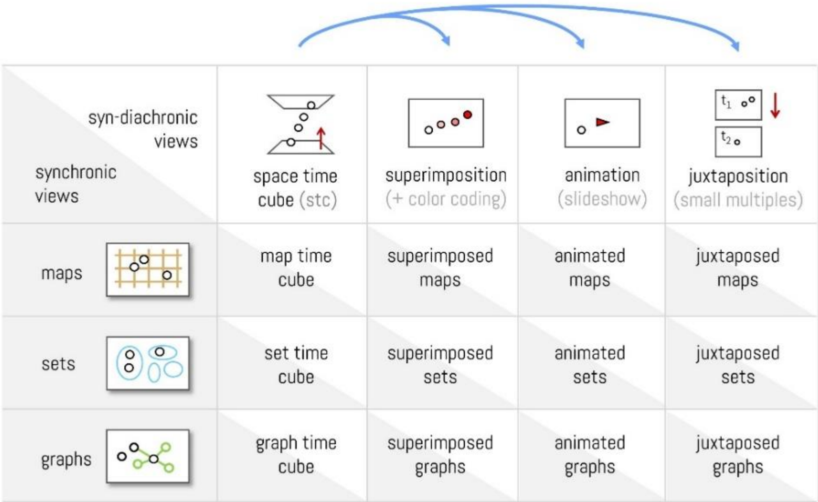


Figure 14. A matrix of syndiachronic views, as integrated by the PolyCube framework.

With this design strategy, we ensure the advantages of multiple views for one (specifically relevant) data dimension: to maximize insights and to compensate drawbacks of individual syndiachronic views (cf. Kerracher et al., 2014).

However, by switching between different representations, analysts have to reorient themselves, and adapt their already acquired knowledge to a new perspective, which puts an additional amount of cognitive load on their reasoning systems. To counter this effect, the PolyCube framework utilizes animated canvas transitions (see Figure 15) relying on space-time cube transformations (Bach et al., 2017), which help to preserve the users' mental map and to ensure a high amount of visual momentum (Bennett & Flach, 2012).

When looking at the first column of Figure 14, it becomes clear that the PolyCube system is also 'just' a system design utilizing coordinated multiple views (cf. sec. 5.2.2 Coordinated Multiple Views), which allows combining various synchronic views (such as maps, sets, and graphs) in a modular fashion. As a distinctive feature, however, it 'upgrades' the chosen plurality of synchronic views into a plurality of syndiachronic views, to specifically support the frequently history-oriented tasks of cultural scholars, curators, biographers, historians, and other interested audiences.

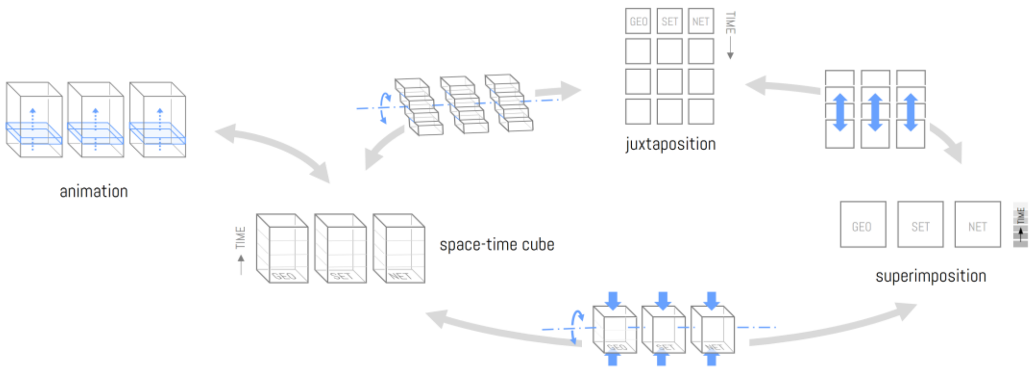


Figure 15. Animated canvas transitions can support the seamless motion between different syndiachronic views, based on space-time cube operations.

Given this multitude of syndiachronic views, the remaining reflections of this chapter will focus on the space-time perspective—yet they will rely on the outlined strategy, that this type of 3D representation—with its known limitations—can always be translated into a plurality of alternative syndiachronic perspectives on demand.

Figure 16 thus summarizes why and how the PolyCube framework seems specifically interesting for contextual visualization. On the one hand, it allows to directly integrate hybrid ('ergo-biographical') timelines, where life and work events already contextualize each other (a), into multiple syndiachronic views, which contextualize each other with different data and information selections (b). On the other hand, the free scalability of this framework allows to draw up bigger views around each selected view, so that each "local" perspective can again be embedded into a larger context—from all kinds of *mesoscopic* context, up to technically "globally" extended space-time cubes.

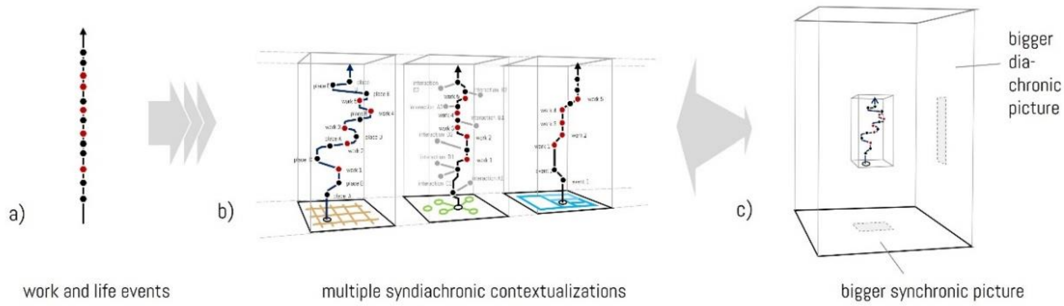


Figure 16. Contextual constellations, which are available in the PolyCube framework include a) ergo-biographical trajectories, b) coordinated contextualized syndiachronic trajectories, and c) bigger contextual pictures, which extend the synchronic and diachronic scales to visualize macro-contextual data of selected dimensions.

The diachronic boundaries of these biggest possible *macroscopic* frames of reference coincide temporally with the totality of anthropological or planetary time. As for the biggest possible synchronic boundaries, the maximum frame of geographic reference practically matches the well-established scaffold of a world map, which allows to contextually visualize all kinds of relevant actors, objects, materials in a life paths environment.[11] For other types of synchronic macro-context, network diagrams, set diagrams, or any other type of categorical or statistical visualizations could be added according to relevant contextual data.

[11] As a notable limitation, geographic space-time cubes are not well-suited to represent places significantly above or outside the planetary surface. Extraterrestrial sceneries for human (or other) activities thus would require a visualization that is juxtaposed to the planetary frame of reference, similarly to the dislocated depictions of Alaska and Hawaii on U.S. maps.

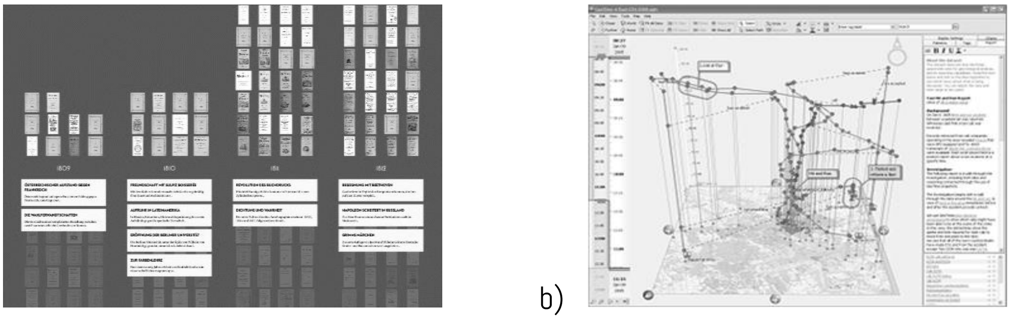
5.3 Bigger Pictures

For many types of sensemaking with both *cultural object collections* and *biographies*, contextual information and knowledge are of indispensable relevance. A majority of object or artwork collections have to be considered as “semiotically active” ensembles. Artworks, to begin with—whether they are paintings, sculptures, texts, or films—frequently match the definition of *symbols* as “something that someone intends to represent something other than itself” (DeLoache, 2004, p. 66). Artworks are not only influenced by other “things” (i.e. depicting, mirroring, reacting, transforming, questioning, or responding to other objects, actors, or events in their environment), but they also frequently influence “other” entities (e.g. other artists, actors, communities, institutions, understandings, self-conceptions). This kind of relational-contextual meshwork and exchange between cultural object collections and their material and socio-historical environments is frequently part of the interpretive, explanatory, evaluative, or critical sensemaking procedures. Thus, visualization design in the arts and humanities context is well advised to also explore strategies to represent these kinds of contextual metabolism.

Human activities, on the other side, are frequently driven by external developments, and furthermore understood as *intentional* or goal-oriented undertakings, which are directed to something outside of themselves or their immediate horizon. Biographies thus can be analyzed by their self-established context, i.e. with regard to what actors perceived as relevant influences, and what they aimed to achieve in their environment. But going far beyond these direct networks of causal and intentional relations, biographers and historians are used to embed and analyze their subject matters in the context of larger conceptual frames, where diachronic long-term trends and developments are of equal relevance as the interplay of large-scale synchronic (social, political, technological, or structural) forces.

Against this background, it is slightly irritating, that representation of context is largely missing across state-of-the-art systems for biography and collection visualization (see also publication A1 / Windhager, et al., 2018a).

While a few exceptions manage to overcome the restrictions of local data silos, they mostly utilize textual annotations, to point out relevant contextual aspects. Exemplarily, the VIKUS viewer allows to add textual information for each column of its seamlessly zoomable histogram which adds context for parallel life events or larger historical events (Figure 17a). Spatiotemporal visualizations (such as space-time cube representations of biographies), on the other hand, can be contextualized with narrative reports on the depicted events (Eccles et al., 2007), and both modalities (text and visualization) can be linked, so that highlighting of individual elements emphasizes correlated entities in a coordinated fashion (Figure 17b).



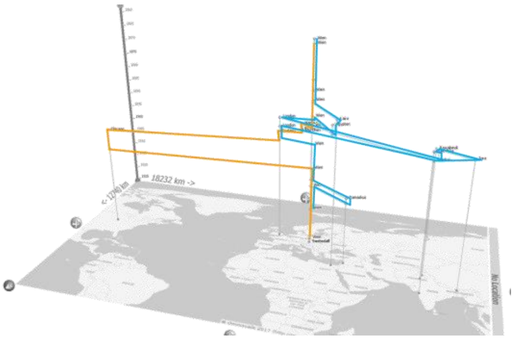
a) b)

Figure 17. Textual annotations providing context in the VIKUS viewer for the works of J.W. Goethe (Glinka et al., 2017), as well as textual information contextualizing the visualization of a space-time path (Eccles et al., 2007).

Arguably, there is a specific need to follow these leads, and to further develop and advance visualization strategies which go beyond textual annotation in this area, to make visualizations of arts and humanities topics more contextually and ecologically valid. To that end, this chapter will look into related work, and draw together visualization options on a meso-level (i.e. contextualization in the field of art history) and on a macro-level of contextual affairs (i.e., going beyond the field of art).

5.3.1 Meso-level Contextualization

On a *meso-level* of contextualization, individual biographies are known to be substantially interwoven with other biographies. As for a basic example, Figure 18a depicts a pair of artist siblings, whose trajectories strongly influenced each other, even though their career paths temporarily led into opposite continental directions (Windhager et al., 2017).

a) 

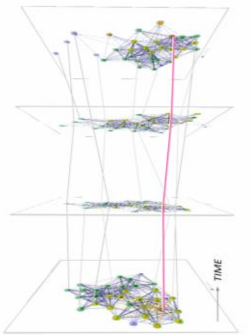
b) 

Figure 18. a) Mutual contextualization of the geo-temporal trajectories of Josefine Swoboda (1861–1924, orange) and Rudolph Swoboda (1859–1914, blue). b) Socio-contextual visualization of the trajectory of a single researcher over one year.

On a higher level of abstraction, art historians often group individual artists into categories like schools, styles, genres, or movements, which again can be visualized in parallel (see Figure 20). Figure 18b illustrates how such aggregates could be modeled and represented based on social and topical relations—e.g. as a network between individual artists, who influence each other by mimetic, collegial or competitive relations.

Harking back to section 5.2.1 Faceted Timelines also faceted timelines can be used to visualize individual biographies in the context of other biographies. Figure 19a shows how the famous “Chart of Biography” by Joseph Priestley already provides such a contextual ensemble of biographies (Davis et al., 2013; Priestley, 1765). About 200 years later—and with a notably bigger diachronic and synchronic bandwidth—we again find historical individuals visualized in the central swim lane section of each page of Peters’ “Synchronoptic World History” (Figure 19b), spanning a period from the 30th century BCE to 1950 CE (Peters & Peters, 1952).

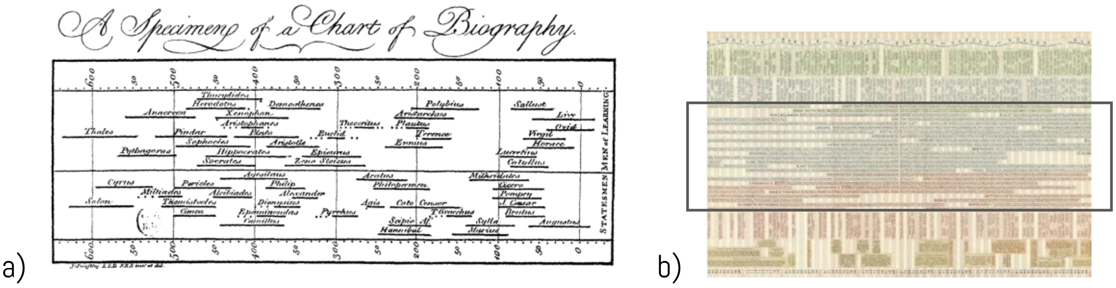


Figure 19. (a) Priestley's Chart of Biography (1765) and (b) Peters' Synchronoptic World History (1952) both utilize faceted timelines for contextual biography visualization.

It seems noteworthy, that despite the digitization of this work (Behrendt et al., 2010, see Figure 8), no large-scale synchronoptic history visualization is available as a web-based interface until today, short-lived attempts for big history data notwithstanding (Walter et al., 2013). As a consequence, the following sections will draw their visual examples predominantly from non-interactive, printed works. By proceeding from an individual level of visualization to a conceptual aggregate level the trajectories of individual artists commonly merge into the abovementioned historical strands of art schools, styles, genres, or movements. As for a prominent example, Figure 20 depicts a segment of the faceted "Tate Artist Timeline" for the 20th century (Fanelli, 2013).

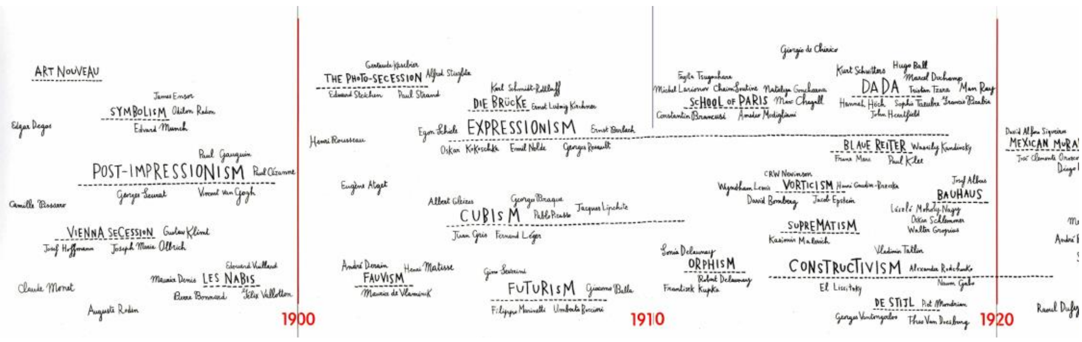


Figure 20. A Segment of the "Tate Artist Timeline: 20th Century" (Fanelli, 2013).

Still on a meso-level of contextualization (i.e. including developments in the field of art only), this foldable representation visualizes the multiple strands of art movements, which developed in cascading and parallel patterns, while competing for attention, admirers, and buyers in a steadily diversifying art market. As a background canvas, such a timeline could be utilized to localize and contextualize either individual artist biographies, or also the thumbnail previews for individual objects of whole exhibitions and object collections.

As for a notable limitation, it has already been stated above, that faceted timelines rarely take (inter)relations between their parallel lines into account (Frank, 2019). However, especially art movements are known to constantly observe each other and their environments, and to influence each other via complex inspirational, mimetic, antagonistic or adversarial dynamics. A prominent historical attempt to visualize such a time-oriented network of influences has been hand-drawn by Alfred Barr (1936) and wrapped around the catalog on the MoMA's founding exhibition on Cubism and Abstract Art (Figure 21). This graph drawing illustrates, how non-geometric and geometric abstract art (bottom) arose from an influential interplay of preceding art-historical and pop-cultural movements after the turn of the 20th century (top).

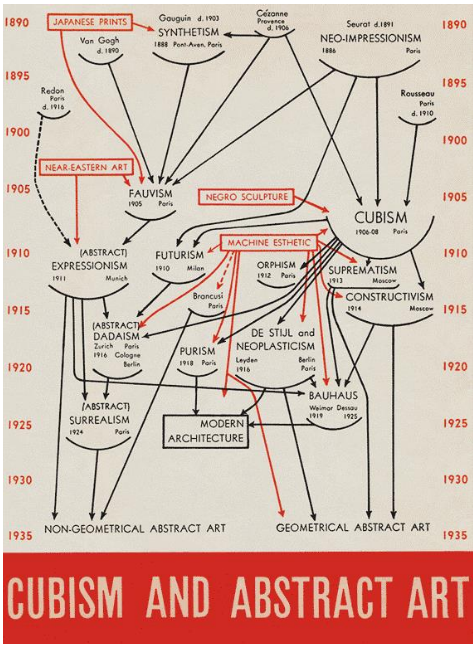


Figure 21. Jacket of the Catalogue on "Cubism and Abstract Art" by Alfred Barr (1936).

As for an artful contextualization of this historical example, Figure 22 shows an extended, relational-faceted timeline (Shelley, 2009). The painting integrates the central parts of the 1936 diagram and deepens the historical background to represent preceding and subsequent developments between 1800 and 2000 CE.

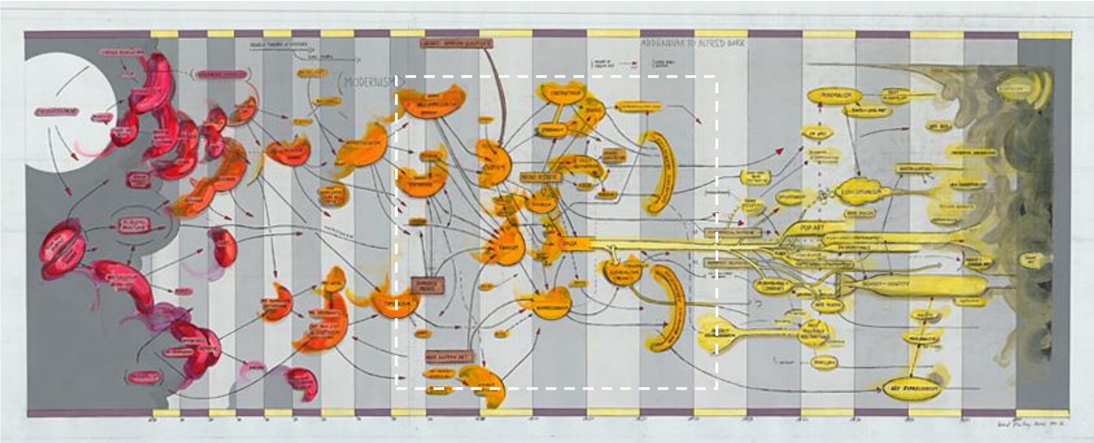


Figure 22. “Addendum to Alfred Barr, ver. 2” by Ward Shelley (2009), which contextualizes the relational timeline of Barr (original area outlined by the author). Image (c) W. Shelley.

By taking their cues from such contextual-relational self-depictions from the field of art, future visualization systems for biography and artwork collection data could strive to make the preceding, parallel, and succeeding events and developments visible, which are relevant for an ‘ecologically valid’ understanding of objects and biographies alike. This includes the depiction of the exemplified art-historical epochs and styles, with their constant competition, their mutual influences, and their memetic-metabolic interplay, which is governed by collective allied, adversarial and distinctive forces.

The (re-)situation of cultural objects or actors in such contextual landscapes can help to make their relational and contextual “footprints” visible. Figure 23 shows how the lives and works of artists could be localized and situated in the vicinity of the most relevant events and developments, by which they have been influenced, with which they interacted, and which have been influenced by them.

“*The point is that we could situate a work within the many networks from which it gains meaning and value, and then present the results within complex visual arguments - the kind that were elaborately constructed on slide tables before being reduced to side-by-side comparisons for lectures or standard print publications*” (Drucker, 2013b, p. 6).

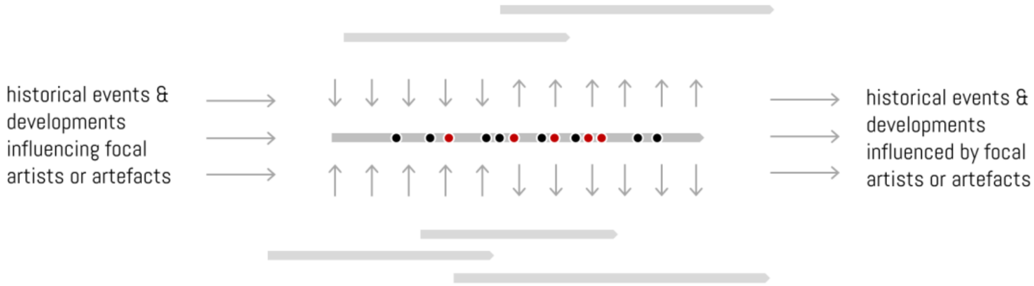


Figure 23. The basic structure of (visual) contextualization patterns of preceding, contemporary, and subsequent influences, references, interactions, and interconnections.

As a stand-in example for the possible future visualization of time-oriented, relational footprints of cultural objects or actors, Matejka et al. (2012) demonstrated how scholarly papers can be contextualized in their own historical networks of references (Figure 24) against the background of a research corpus.

In such visualizations, a unique pattern of incoming and outgoing ties shows for each object, how it relies on research published in the past (blue ties)—and how this object influenced the creation of other texts (auburn ties).

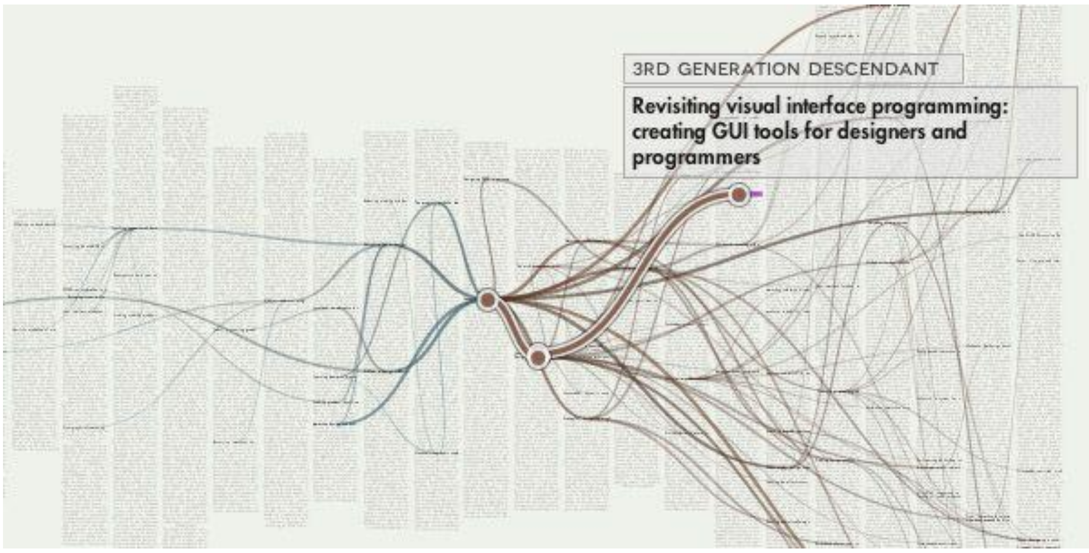


Figure 24. Visualization example of the relational and contextual footprints of research papers: *Citeology. Visualizing paper genealogy* (Matejka et al., 2012).

A cautionary note though can be derived from the fact that relations in the area of scholarly papers and scientometrics are easy to track and to analyze, as each object has to disclose its relevant influences by the rules of good scholarly conduct. Influences and relations in the field of art—however substantive and plausible—are not available on a comparable level of explicitness and standardization. Yet it is not only the linking of (meta)data which is on the rise for CH databases and projects (Hyvönen, 2012, 2020), but as Drucker (2013b, p. 12) notes, a "huge critical corpus of primary and secondary materials in the field of art history will come online over the next decade". Arguably, it is mainly in those primary and secondary sources of art-historical discourse, where the substantial interrelations and contextualizations of cultural objects and actors are studied, documented, argued, contested, and continuously (re)negotiated. When taking future developments of natural language processing into account, we might expect a wealth of linked data and linked entities to become available 'around' various art-historical subject matters soon. What's more, we may expect these links not only to point to events and developments in the field of art but basically into all other fields of culture and cosmos, which artists could ever meaningfully relate to.

5.3.2 Macro-level Contextualization

Only in the rarest of cases, it makes sense to look at artwork collections and artists' lives as secluded and sealed-off occurrences or to assume that the field of art and culture is a closed and self-contained sphere. When cultural scholars and historians investigate and interpret the relevance, meaning, motivation, or impacts of their subject matters, they naturally look at the countless (incoming and outgoing) relations, by which artists and objects refer to their wider environments and by which they have been influenced or motivated. The specific nature and character of these rich referential networks practically define all objects and make them distinct, relational constellations within a larger cultural and historical context. It can be argued, that traditional humanist approaches to interpretation naturally do nothing else than following such semiotic and contextual leads (Frank, 2019). As such, they deliberately transcend the mere material or formal analysis of objects and their metadata, to trace and reconstruct their nested (micro-, meso-, and macro-)contextual embeddings. Humanistic inquiry and interpretation probably coincide largely with such tracing activities, to recover constellations of the original cultural and historical context in artefacts—and obviously also to evaluate their relevance from a critical point of view.

Digital activities have differed from this practice because they frequently have to work with local and limited data collections only—also termed 'silo-typed' data—which are sealed off installments regarding their own interpretive discourse. Linked data initiatives are making a difference in this respect, and digitization is not only bringing a plethora of objects and biographies online but also "the primary and secondary materials of cultural historiography and art history" (Drucker, 2013b, p. 12). Transformed into structured knowledge graphs, these materials will also bring about new kinds of relational tissues for context-preserving information collections, which will branch and reach far beyond the "field of art". Cultural collections and prosopographical databases thus will be able to not only represent objects and actors as embedded into their micro and meso-contexts—but also indispensably interwoven into larger fields of cultural and societal reproduction.[12]

To get a conceptual grip on this ultimate macro-level of contextualization, sociological distinctions and terminologies are of interest, which demarcate relevant *societal fields*, surrounding and contextualizing the 'field of art'. Various theories of differentiation allow to distinguish major societal components, which result from the collective division of labor and responsibilities—for instance by systems-theoretical sociologists (Schimank, 2015; Ziemann, 2007) or field theorists (Hilgers & Mangez, 2014). Largely following the terminological suggestions of the former, we can consider modern society to contextualize the field of art with about a dozen functional systems (or social fields), such as economy, law, science, politics, education, healthcare, military, and media. Figure 25 shows a simple, conceptual depiction of such a differentiated system, with the field of art at its focal center.[13]

[12] However, left to themselves, these contextual constellations tend to convolute into infamous 'hairballs', when put into network visualization tools without further plan. It is the working hypothesis of this thesis, that the most effective measure to counter this risk, is the self-conscious development of synoptic and coherent macro-designs—similar to the PolyCube framework—which have to guide "vis4dh" endeavors from an early stage.

[13] As theories rarely conceive modern society to be monocentric, this topology is by definition polymorphic and transformative, i.e. each field could be analyzed as its focal point.

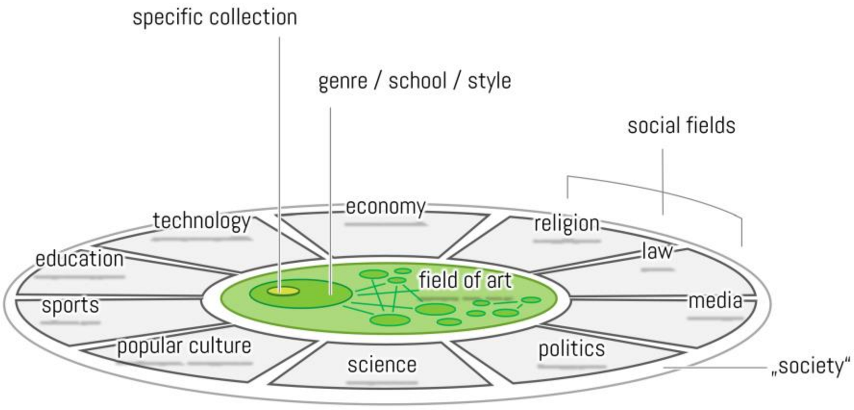


Figure 25. A field- or systems-theoretical conception of society from a synchronic perspective, with the field of art selected as the focal field of reference.

Given such a macro-sociological conception, most of the contextual reflections so far fit into the green field of art and cultural production: By definition, the production and reception of artworks are located in this field, as are (large parts of) the lives of artists. Depending on the specific practices of art-historical discourses and interpretations, cultural objects and collections are localized there, and organized into specific genres and art schools, with all their complex interconnections. All the bigger, contextual pictures, which have been outlined and documented so far, arguably are situated in this area—and it just takes a diachronic 'historicization' of this synchronic view, to arrive at a syndiachronic representation, which can integrate most of the meso-contextual timelines collected above (Figure 26, lower half).

However, societal fields are not conceived as closed areas, but as functional macro-units, which are engaged in a complex interchange of information, decisions, and services and which provide problem-solving strategies, as well as adaptive and communicative functionalities for each other (Schimank, 2015). The field of art, for instance, has been analyzed as a provider of various functions for other fields throughout its complex history including the sublime, beauty, meaning, distinction, distraction, disruption of expectations and so on (cf. Luhmann, 2000; Van den Braembussche, 2009). The modern art field provides its society with a constant stream of stimuli, ranging from realistic depictions to abstract creations, bold provocations, and hermetic inventions. Most of the field-related objects, events, and dynamics are either connected to each other (internal relations), reacting to outer happenings (incoming relations) or affecting external developments again (outgoing relations).

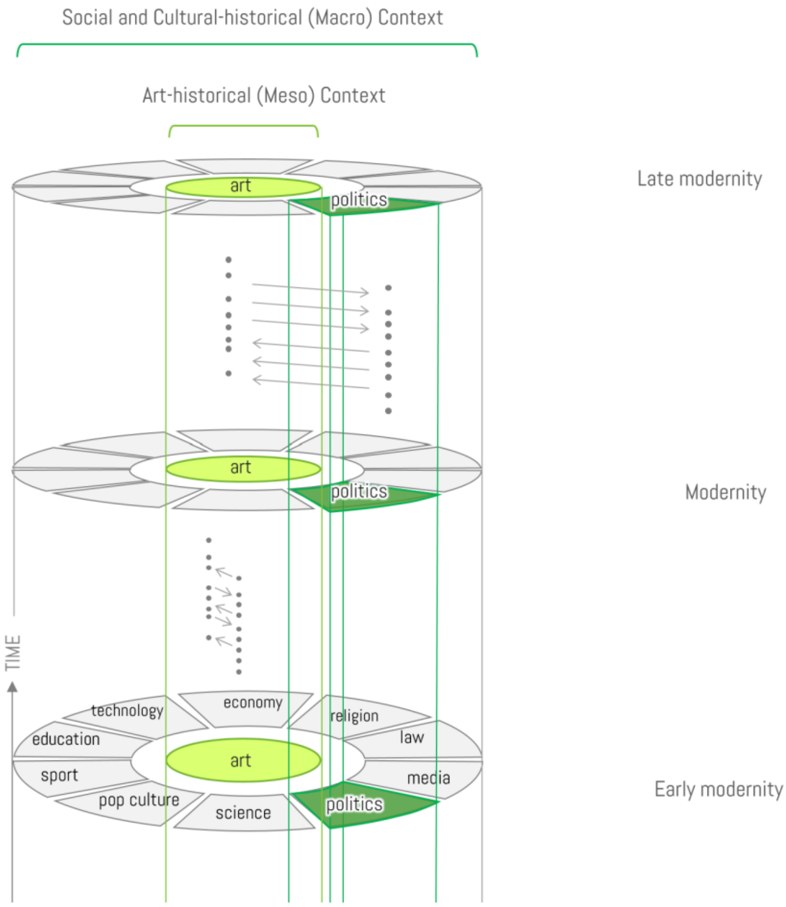


Figure 26. A syndiachronic projection of the macro-contextual topology, highlighting the co-evolving societal fields of art and politics, incl. intra- and inter-field dynamics.

In this context, the field is known to have current macro-patterns—and art historians are known to know about whole histories, which detail these evolving relations to all other societal fields. In line with Figure 26 (upper half), art history can study specific interactions or long-term relations between art and politics (highlighted in light and dark green). Simultaneously, also the changing relations and power dynamics between art and religion, art and technology, art and economy, art and media, etc. are of indispensable relevance when a bigger picture of an (art-)historical situation has to be generated and communicated.

Thus, with utilizing such syndiachronic visual scaffolds, the rich contextual (hi)story of art and society can also be told on a visual basis. From a 'polycubistic' point of view, this is the maximum contextual extension—technically offering space for the localization and representation of all conceivable cultural objects, subjects, ties, and tissues. The sketchy nature of these figures testifies to their conceptual status. Arguably, for the time being, they are relevant mostly from a didactical point of view. However, nothing speaks against their spontaneous utilization, as hand-drawn outlines on the blackboards of classes and seminar rooms. Also non-interactive visualizations can help to better understand—and mentally model—the cornucopia of influences between art and complex other fields of reference, all evolving over time.

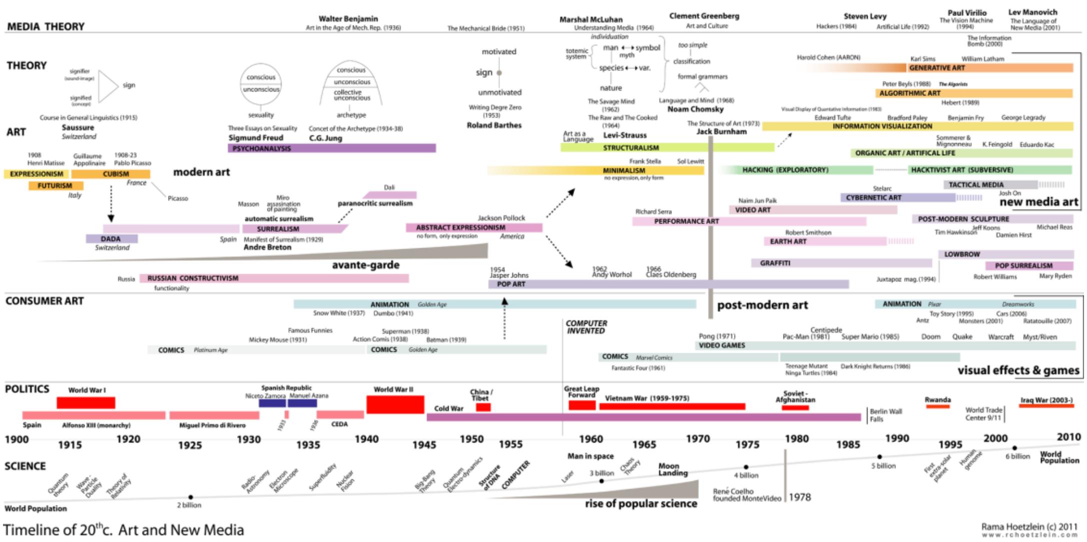


Figure 27. The “Timeline of 20th Century Art and New Media” by Hoetzlein (2009b), which provides an example for a valuable macro-contextual canvas to support art-historical (re)situation, mediation, and (knowledge) communication. Image (c) Rama Hoetzlein.

Figure 27 shows how also faceted timelines (sec. 5.2.1 Faceted Timelines) can serve the same goal. Depending on the specific art-historical scenario in question, macro-contextual pictures can be assembled in a faceted fashion. Exemplarily, Hoetzlein (2009a) contextualizes art-related developments within the dynamics of politics, consumer art, science, theory, and media theory throughout the 20th century. Given any specific artist biography or artwork collection, such macro-contextual canvasses then allow to highlight their relational and interpretive ecology in a salient fashion (see Figure 28).

With a nifty, self-referential gesture, this picture also includes the endeavor of information visualization as a yellow time bar in its top-right corner. Rarely has “Visualization-ism” (Staley, 2002) as the late-emerging practice and “*science of analytical reasoning, facilitated with interactive visual interfaces*” (Thomas & Cook, 2006, p.

10) been more productively contextualized. Given its complex and nested data constellations, which have been outlined in this chapter, it seems obvious, that the field of art history definitely qualifies as a valid subject matter, which deserves a whole spectrum of visual interfaces of its own.

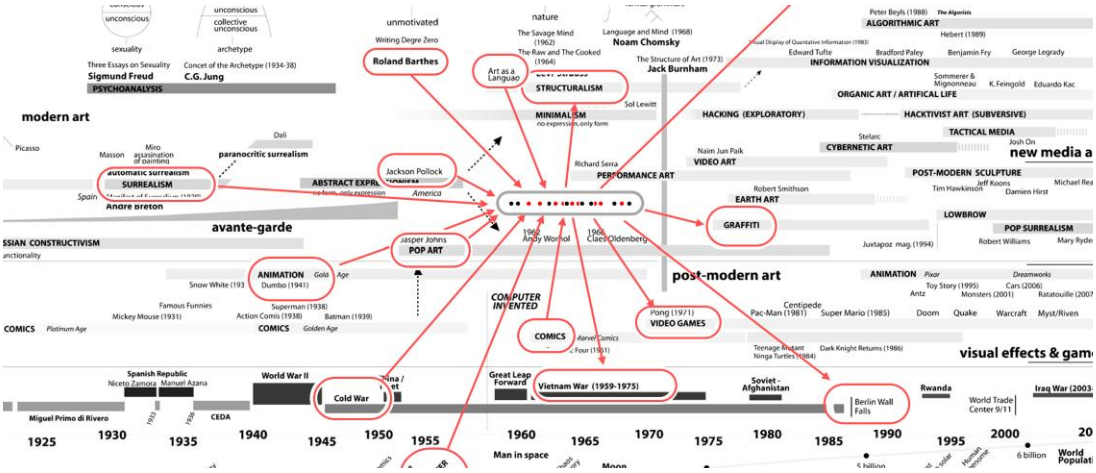


Figure 28. Symbol image, suggesting the use of visualizations (such as Figure 27), to contextualize the lives and works of artists within bigger historiographical pictures.

Similar to—but sufficiently different from—big data analysts in the national security context, art historians are also immersed into scores of *"massive, dynamic, ambiguous, and often conflicting data"*, as a techno-military visualization manifesto prominently put it (Cook & Thomas, 2005, p. 4). Guided by this operational analogy, the basic argument for visual analytics technologies can be safely decoupled from the security context, and productively re-appropriated within the arts and humanities realm. Given their well-known critical prowess, humanists seem well equipped to domesticate the "Trojan horse" (Drucker, 2011a). Arguably, the intended benefits, i.e. enhanced capabilities "*to synthesize information and derive insight*", to "*detect the expected and discover the unexpected; provide timely, defensible, and understandable assessments; and communicate assessment effectively for action*" also find themselves better resituated in an ethically and aesthetically less dismal context. Whether for research scenarios, pedagogic purposes, for the promotion of cultural heritage or for the purpose intercultural communication—it seems obvious that the essential self-reflecting tasks of every culture—to perceive, reason with, or know about itself—deserves the best technologies, that this culture has to offer.

6 Discussion and Outlook

This thesis set out to pursue three strands of work: Firstly, it aimed to collect visualization options and developments with specific regard to artwork collections and artist biographies (ch. 3.1 and 4.1). Secondly, it synthesized multiple visualization techniques for both subject matters, to arrive at a synoptic visualization environment—referred to as PolyCube framework. Its design offers a plurality of analytical perspectives, while also striving for an interconnected and coherent user experience, to more effectively navigate the respective visual complexities of multi-faceted, time-oriented datasets (ch. 3.2 and 4.2). Thirdly, the thesis reflected on mutual connections between its central subject matters, and on their contextualization in bigger socio-historical pictures (ch. 5). By doing so, a larger visualization framework for subject matters from the arts, humanities, and social sciences became visible, which awaits its future elaboration, evaluation, and utilization.

6.1 Achievements and Limitations

This work aimed to explore and document the visualization design space for two subject matters: For artwork collections, this documentation has been undertaken in a systematic fashion (A1), while the exploration for biography visualizations started with a wider focus on narrative data (B1) and zoomed in on biographies as a specific case (B1 and B2). This leaves space for a systematic state of the art-review with a specific focus on biography visualizations as a next step. However, for both artwork and biography collections, numerous relevant visualization perspectives have been documented and drawn together into the PolyCube framework (A2 and B2). This framework has been elaborated conceptually but also implemented as a prototypical, web-based visualization system for artwork collection data (for the most recent system description, see Windhager et al., 2020). While we were able to prove the PolyCube system's ability to visualize biographical data (see publication B1, Fig. 4, right-hand side), the systematic implementation remains a future development goal—together with the establishment of a connection to prosopographical databases and the sharing of the visualization platform with interested cultural heritage users and research groups. Finally, the visualization of artwork collections and biographies has been investigated with regard to their possible mutual contextualization—and with regard to larger meso- and macro-contextual pictures (ch. 5). By doing so, a variety of other societal fields and phenomena came into focus, which are located around the field of art, and to which the visualization framework technically could also be extended.

Generalization: This thesis elaborated on the PolyCube framework with specific regard to a functional nucleus of art-historical data, i.e. data which arise from the digitization of artwork collections and artist biographies. However, around the field of art, numerous further research fields and topic areas exist, where event-typed, object-oriented data and biographical data play a role. In this regard, the thesis also puts forward the outlines of an open visualization endeavor, which is waiting for its modular extension and wider application to data across the macro-historiographical knowledge- or hypergraph (McNeill & McNeill, 2003; Windhager, 2013).

Applications: As a main contribution, the PolyCube framework provides the means to support (art-)historical sensemaking processes in a visual fashion, which would be largely left to traditional analyses and language- or text-based reasoning methods otherwise. As such, the framework a) bundles visual analytical techniques for the orchestrated use of art history scholars and researchers, b) it defines the elements and syntax of a syndiachronic 'pattern language' for visual knowledge communication and pedagogy in the context of teaching arts and cultural history, but it also c) provides means for the public presentation and promotion of cultural heritage topics in the context of galleries, libraries, archives, and museums.

Especially for non-expert audiences (scenario b and c), future mediators can utilize visualizations productively in combination with traditional language-based or narrative accounts. Arguably, such a multimodal approach is of specific interest for audiences without elaborate mental models and prior knowledge structures, for whom hybrid (visual-verbal) communication strategies offer richer and more accessible learning materials. Thus, the PolyCube framework also strives to be a visual augmentation toolkit for pedagogy and knowledge communication in the arts and humanities, where reasoning activities with complex, time-oriented data structures, narratives, as well as object and knowledge collections count among the omnipresent tasks and challenges.

Evaluation: The first figure of this text (Figure 1, p. 11) set out the scope of the thesis and its methods against the background of a system and software development cycle. It also tried to localize five main components of this text (i.e. the publications A1, A2, B1, B2, as well as AB3 / chapter 5) in this scaffold. With closing this work, it becomes necessary to revisit this illustration and to reflect on certain limitations, together with subsequent work and central challenges for future work (see Figure 29).

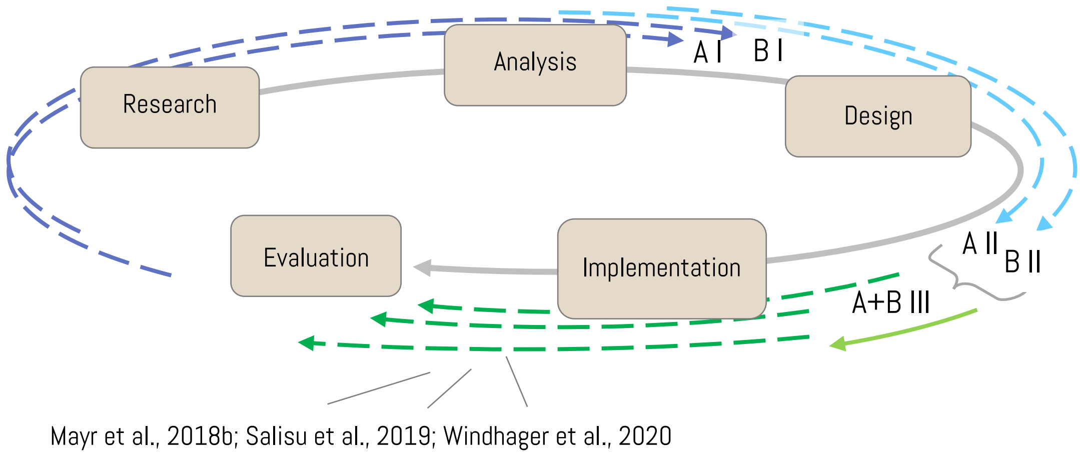


Figure 29: Amended Figure 1 (p.11), localizing the main components of this thesis (dark and light blue) together with subsequent implementation and evaluation studies (dark green) against the background of a system development cycle.

On the one side, a combined look at the blue arrows and the specific scope of the four publications reveals a limited accuracy of the arrow placement in the circular model: Both publications B1 and A2 already report on certain implementation efforts with regard to the PolyCube system, and publication A2 also reports on a very early effort to evaluate the intended effects by the means of an empirical user study. This point to the general requirement of visualization projects to go 'full circle' and to evaluate their intended effects with regard to real humans in the visual-analytical loop.

It is a common position in visualization research to declare that the *"purpose of visualization is insight"* (North, 2006, p.6). A responding tenet of equal importance emphasizes that the purpose of visualization "*evaluation is to determine to what degree visualizations achieve this purpose"* (ibid., p.6). From such a functional standpoint the value of visual interfaces can be only determined be assessing the actual support of human problem-solving and reasoning activities. For that matter a whole range of evaluation methods has been developed in the field of visualization research (Isenberg et al., 2013; Plaisant, 2004), and the following paragraphs will summarize corresponding efforts aimed at the PolyCube framework with regard to artwork collection visualization.

Evaluating visualizations is generally considered to be "*complex since, for a thorough understanding of a tool, it not only involves assessing the visualizations themselves, but also the complex processes that a tool is meant to support*" (Lam et al., 2012, p. 1520). Evaluation challenges then also rise with the complexity of visualization tools, and the PolyCube system arguably brings together both: a certain amount of inherent complexity, and a complex user group with a diverse background of expertise and intended activities. Given this setup—together with the only partial implementation of the outlined framework—the larger part of the intended evaluation for the system ranks among 'limitations and future challenges. Regarding various 'coherence techniques' and cognitive coherence claims, which guided the framework design, it also might also be necessary to further develop appropriate evaluation methods in parallel (Mayr et al., 2018b; Windhager et al., 2019c).

However, four different user studies have been conducted to shed light on various aspects of the PolyCube system at various development stages with regard to cultural object collections (see Figure 30).

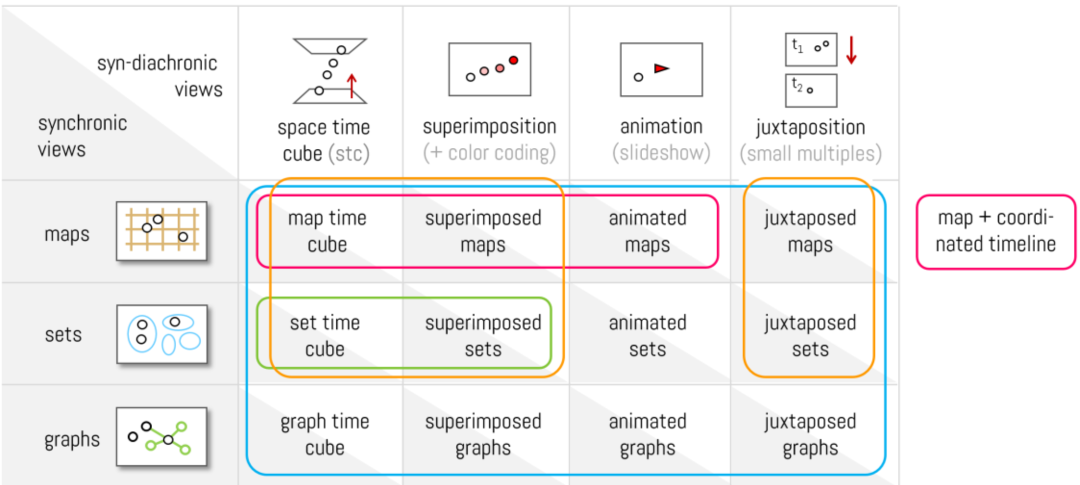


Figure 30: Visualization matrix of the PolyCube system and evaluation perspectives of publication A2 (ch. 4.1, orange), Mayr et al. (2018b, magenta), Salisu et al. (2019, green) and Windhager et al. (2020, blue).

As a recurring objective, these studies aimed to compare the performance of syndiachronic views against each other (i.e. the columns in Figure 30) to shed light on their visual-analytical strengths and limitations.

i. Publication A2 (see ch. 4.1) documents a qualitative user study with three non-experts on selected geo- and set-temporal views (space-time cube, juxtaposition and superimposition) of an early version of the PolyCube visualization. Insights from the think aloud-protocols—recorded during free exploration, simple task completion exercises and from final interviews—included numerous suggestions for improvement, as well as positive feedback for the space-time cube perspective with regard to its ability to integrate spatiotemporal information and its aesthetic qualities.

ii. A second, more systematic user study (Mayr et al., 2018b) investigated the performance of four syndiachronic visualization techniques for cultural object data in a comparative fashion. Three different syndiachronic visualizations of geo-temporal data (space-time cube, animation, and superimposition) were tested against a coordinated multiple view (i.e. a map with a coordinated histogram). As a main result, the study established nuanced profiles of strengths and limitations for each syndiachronic view, gained from task-completion exercises, think aloud protocols, NASA-TLX questionnaires, and interviews conducted with 18 participants.

iii. A third study (Salisu et al., 2019) collected user feedback for two syndiachronic views of the completed set visualization module of the PolyCube system, comparing a space-time-cube representation of time-oriented, set-typed data with a color-coded superimposition view. Feedback from four non-expert users during task completion exercises and an interview pointed towards balanced performance and preference profiles of the two selected syndiachronic views.

iv. Finally, a fourth study (Windhager et al., 2020) took a comprehensive look at the PolyCube system for collection visualization and complemented its description with insights from a user study conducted with 10 casual users. This study shed light on the effectiveness of various coherence techniques, which were implemented to interconnect and visually synthesize the multiple visual-analytical perspectives of the PolyCube system (e.g. animated canvas transitions), and it had a look at individual preferences for different syndiachronic views. Regarding the latter, a strong preference of casual users for space-time cube representations of collection data could be documented. Given the widespread skepticism within the visualization research community regarding the use of three-dimensional designs (cf. Munzner, 2014, pp. 117-130; Sedlmair et al., 2013), this result provides an interesting argument for a renewed discussion of this technique in the context of art history topics and public or non-expert audiences, where the attraction power and the aesthetics of representations have been shown to play an important role for the onboarding to—and adaptation of—visualization tools (Lamqaddam et al., 2018).

Given the complexity of the PolyCube design—together with the complexity of its potential topics and application scenarios—the outlined user studies appear as a combination of first steps, which require continuation, extension and future consolidation. Especially the practical and ecological validation of implemented polycubistic designs, and their evaluation in the context of (art) historical research and teaching, counts among prioritized development goals, together with the refinement of corresponding evaluation methods for information integration across multiple views (Mayr et al., 2018b; Windhager et al., 2019c).

Limitations: Around the margins of achievements, limitations preside. While this thesis elaborated and discussed a nuclear framework with a wide range of potential applications, a whole spectrum of theoretical and practical questions has emerged which translates into challenges for future work.

6.2 Future Challenges

Around the outlined framework, a variety of development challenges wait for their resolution. The following paragraphs address a selection thereof, which arises from practical questions of system development, but also from challenges known to exist with specific regard to visualization in the arts and humanities context.

- **Data import, curation, and exchange:** The PolyCube framework has found a prototypical implementation with regard to cultural collection data, which also offers a simple spreadsheet editor for the import of object collections (Windhager et al., 2020). This spreadsheet editor also allows to engage in crucial analysis-and-curation-cycles, connecting visualization activities with options for manual data annotation, correction, and further enrichment. For the potential use of the PolyCube system with regard to large cultural collections and data on the web, the development of an API or an interoperable data format will have to facilitate the import of structured data from a variety of tools and platforms. This challenge is even bigger for biography data, where no unified data format exists up to now, and where approaches to automated data creation (bridging the gap between written biographies and structured data) remain largely tied to local efforts (Fokkens & Braake, 2018). For both domains, the development of a whole working and workflow environment seems desirable, which supports data creation, data curation, data analysis, data exchange, and knowledge communication by visual means.

- **Coping with heterogeneous data quality:** Whether for cultural collections or historical accounts of artists and other actors—heterogeneous data quality is everywhere. Challenges thus arise from all types of data uncertainty, heterogeneous metadata standards, heterogeneous concepts and granularities, contested information, and lots of data which is outright missing (Windhager et al., 2019a; 2019b). Such uncertainties—whether acknowledged or not—are known to propagate through visual-analytical systems (Sacha et al., 2016) and to affect all further procedures of data modeling, processing, representation, and sensemaking. Against this background, visualization and system design have to find a balance between techniques to a) productively simplify arts and humanities data, b) to make all types of data uncertainty transparent, or c) to offer on board-means of disambiguation, data curation, and discursive visualization. While the explicit representation of uncertainty will commonly add to the deeper understanding and the creation of trust for experts, the added layers of visual complexity (required for encoding of quality indicators) can also unfold detrimental effects for overall usability and non-expert users (Windhager et al., 2019b).

- **Visualization of collective entities:** Object collections and biographies have been explored as individual units of visual analysis until now. However, in both scenarios, the combined and comparative analysis of larger data assemblies can be of utmost interest. As such, comparative collection visualizations could show how different exhibitions and object collections inhabit different regions of space-times. Also, in the area of biographical studies, the comparative or contextual analysis of collective phenomena appears as an indispensable development goal. This will not only allow to bring a prosopographical perspective into play (i.e. going from individual histories to histories of groups and collectives), but also to represent a variety of collective phenomena—from art schools and genres to art-related institutions and organizations, together with their conflicts, intergenerational developments, and movements of innovation—into the visual-analytical focus, and will add another (intermediary) layer of context to the study of single objects and lives (cf. ch. 5).

- **Specific design challenges for collection visualizations:** Publication A1 (sec. 3.1) complemented the analysis of existing collection visualizations with the discussion of future challenges (Windhager et al., 2018a). These aspects translate into open research and development gaps worth recollecting at this point. Visual interfaces to artwork collections require design solutions which allow for *serendipitous encounters* (Thudt et al., 2012), they should honor a collections' complexity by *generous design* (Whitelaw, 2015), they should support *critical analyses and modes of critical-theoretical reasoning* (Windhager et al., 2018b), be compatible with *narrative approaches to sensemaking* (Mayr & Windhager, 2018; Segel & Heer, 2010), reconcile tensions between *remote access and in-situ experiences* (Rogers et al., 2014), take *heterogeneous data quality* and uncertainty into account (Windhager et al., 2019a; 2019b), and transcend a siloed data experience by providing *rich context* (ch. 5). While pioneering work in visualization design has started to address these complex issues, the work on these specifically sensitive design dimensions has literally just begun, and substantial further research is needed to enable and create more conscious and autonomous humanities approaches to graphical display design (Drucker, 2011a).

- **Specific design challenges for biography visualizations:** Publication B2 (sec. 4.2) marks a variety of research gaps for biography visualizations (Windhager et al., 2018c). As for a short recapitulation, these include prosopographical visualization of collective entities (see above), the visualization of multi-granular activity patterns (McKenzie et al., 2015), sentiment visualization (Kucher, Paradis, & Kerren, 2018), uncertainty visualization (see above), visual storytelling (see publication B1, sec. 4.1), the integration of close and distant reading (Jänicke, Franzini, Cheema, & Scheuermann, 2015), and the integration of automated and qualitative data creation and visualization (Windhager, 2019; Windhager et al, 2019b).

- **Humanities challenges for visualization design**: Recent years brought about a whole discourse of critical reflections on visualization in and for the humanities (Bradley et al., 2018; Correll, 2019; D'Ignazio & Klein, 2016; Dörk et al., 2013; Drucker, 2011; Glinka, Meier, & Dörk, 2015; Kienle, 2017; Lamqaddam et al., 2018; Lupi, 2017). Among the many noteworthy strategies to appropriate and adapt visualization design for the arts and humanities, we find recommendations to abdicate the velocity and efficiency dogma of visual analysis for the sake of *slow art history* (Bradley et al., 2019; Lamqaddam et al., 2018), to fully account for the *provenance, subjectivity and constructedness* of visualization and representation standpoints (Drucker, 2011a), to aim for *empowerment* (Dörk et al., 2013), to legitimize *body and affect* (D'Ignazio & Klein, 2016), to *embrace imperfect data* (Lupi, 2017), to deliberately design for the *aesthetic experience* of arts experts (Lamqaddam et al., 2018), to decidedly embrace complexity and to *pluralize and diversify interpretive perspectives* (D'Ignazio & Klein, 2016; Dörk et al., 2013; Drucker, 2011a; Lupi, 2017; Whitelaw, 2015), and—last but not least—to *embrace context* (D'Ignazio & Klein, 2016). As stated at the outset, the central work of this thesis focused on the last two design strategies—*plurality* and *contextualization*—and it developed solutions for a major follow-up challenge (i.e. lack of information integration), which can arise from an all too carefree implementation of the plurality principle. Given this prioritization, future development options also include the consideration of how to utilize other humanist strategies for visualization design within the PolyCube approach—and how to engage its users in argumentative and discursive appropriation procedures.

- **Discursive data curation, contextualization, and visualization**: In the arts and humanities context, many subject matters and phenomena are at the center of controversial discussions, of collective self-reflections, of political discourses, or of larger interpretive debates. Humanists interpret symbolic and cultural materials, including the works and lives of the past, and they do so commonly in a text- or language-based fashion, which frequently prefers a polylogic, open-ended discourse. Guiding notions of efficiency, precision and problem-solving thus are often set aside for the sake of interpretative openness, novelty, provocation, critique, theoretical diversity, and a dynamic unfolding of plural perspectives (Drucker, 2011a). Whatever the specific area of application—we should not expect such a contested pluriverse of interpretations ever to translate into uncontested data and visualizations. On the contrary—these foundational debates deserve their own representation techniques so that visualizations can become an integral part of discursive and critical sensemaking procedures. On the one hand, this requires open visualization systems, which allow for distributed and competing settings of multilateral data curation and interpretation (van Ruymbeke et al., 2017). On the other hand, it seems necessary to make critical and adversarial standpoints and interpretations visible in the representations themselves (Solli et al., 2018). This would allow to utilize the outlined framework not only for the communication of agreed-upon results but also for the collective critical editing, revising and annotating of cultural collections and biographical knowledge graphs. As such, historiographical controversies can migrate from the realms of academic prose into the hybrid worlds of graphical displays, to be studied, taught, and engaged with on a polycontextual, multimodal basis (Marres, 2015).

Digitization surely has changed—and keeps changing—practices in the humanities. In his reflections on digitization and academic change, Liu (2009) invokes a Kafka-esque lens: We went to sleep one day as cultural critics and woke the next metamorphosed into data processors. With Nabokov (1980), though, he reclaims hope for the humanist bugs, befallen by computational technologies and quantitative epistemologies: They might wake again a second day to discover that "the bug had hidden wings able to bear us aloft to a new vision of a broader humanities" (Liu, 2009, p.17).

Among the elevating and vision-expanding of digital times, Liu counts new research and teaching practices ("practices 2.0"), and the interdisciplinary organization of work, which they necessitate. The formerly solitary practice of *scholarly writing*, for instance, often evolves into *collaborative (web) authoring*, which newly combines the practices of writing, designing, image editing, and programming. Good DH authorship thus requires new forms of collaboration and becomes teamwork. The basic practice of *reading*, on the other side, evolves into *social computing*, as digital texts reach us via social media streams whose margins contain comments, links, friends, adversaries, tags, and trackbacks which draw us into complex reading and annotation practices, re-entangling potential ivory tower dwellers into the horizontal realpolitik of socio-epistemological squares (Liu, 2009, p.18 ff.).

However, digitization obviously also transforms the scholarly core practices leading up to writing and reading, such as *capturing* and *creating* cultural artifacts, *enriching* and *storing* them, as well as *analyzing* and *interpreting* them (see Figure 31).

Figure 31: Types of digital research practices in the humanities, according to the Taxonomy of Digital Research Activities in the Humanities (TaDiRAH) (cf. Borek et al., 2016).

According to the TaDIRAH taxonomy (Borek et al., 2016), digitization has generated a whole panoply of new research practices in the humanities, as summarized by eight categories.[14] Digital scholarship thus would be the art and craft of selecting and interweaving practices from several of these categories to assemble whole studies and larger investigations. With its focus on *visualization*, this thesis aimed to further develop and interconnect a variety of techniques and practices, which this taxonomy subsumes under its fourth category of *analysis*, but which arguably also play a major role for the activities of *interpretation*, *storage* and *dissemination*, and even more so for meta-activities like *teaching*, *learning*, or *giving overviews*. It was among the motivating forces of this thesis to document and connect visualization techniques for these areas of application, and thus strengthen the substantial role that visualization as a *functional art* (Cairo, 2012) can play in a knowledge realm, that largely relies on language-based thinking and communication otherwise. However, given this thesis' focus on multiperspectivity and contextualization, it might be well-advised to have a closing look at the possible role of DH visualization practices in the larger context of "traditional" humanities (TH) research, discourse, and scholarship.[15]

Unfortunately though, no established TH taxonomy exists, which would allow to juxtapose the TaDIRAH categories of DH activities with a line-up of non-digital practices, also because the tent of traditional humanities is just too big, too heterogeneous, and too fond of arguing to even try (Bianco, 2012). Yet, a makeshift extension of Figure 31 with provisional categorical adaptations can help to point to the rich body of non-digital practices, which TH scholars have defined and documented for centuries as ways and means to study the products of human culture (Figure 32).[16]

Regarding the much-debated relations between DH and TH practices, Figure 32 (center) enlists some wide-spread positions, which declare DH methods either to be a) supportive means to established TH ends, b) detrimental, trojan, or distractive, c) a

[14] For an interactive version see http://tadirah.dariah.eu.

[15] Obviously, the choice of a contrasting adjective (i.e. *traditional* as opposed to digital) should try to avoid any value-laden connotations, which makes the alternating use of adjectives with complementary connotation biases (such as "actual", "established", or "time-proven") an interesting discursive option.

[16] Given the heterogeneity of TH domains—and their diversified methodologies—this figure can only be of heuristic nature, and act as an invitation for local TH/DH communities—whether in the realm of art-history, media studies, image studies, biography studies, or cultural studies—to collect and map their practices in a more detailed fashion.

quasi-autonomous area of methods development, d) mutually beneficial or complicating investigative options, or e) already ubiquitous technologies, allowing for pacified cohabitation in non-binary, post-digital times (Berry, 2014; Rodriguez-Ortega, 2019).

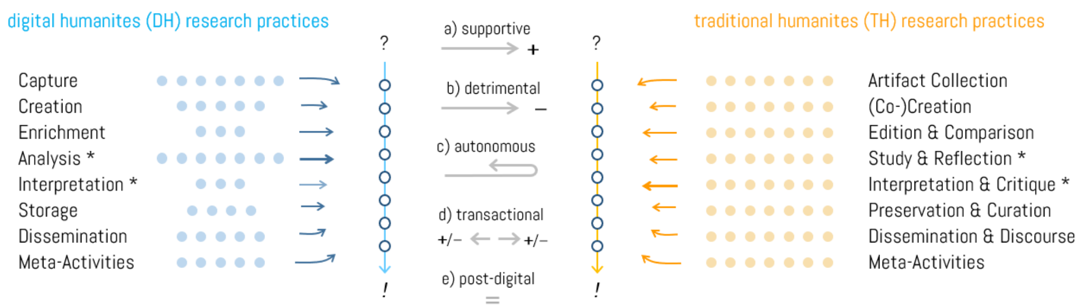


Figure 32: Schematic juxtaposition of traditional humanities (TH) and digital humanities (DH) research practices, mirroring and extending the TaDiRAH taxonomy (cf. Fig. 31).

While each of these positions might have its situational merits, a nuanced look arguably soon arrives at a position such as (d): To not make uniformed nails out of their subject matters, scholars should know about the specific strengths and weaknesses of tools and practices on both sides of the aisle—and eclectically choose the most effective, interesting, prolific or innovative combinations. Notwithstanding all the technological advances, it might remain among the most notable and non-trivial challenges to actually create such combinations and "intellectual fusions" (Vaughan, 2005, p.1), and to assemble elegant and relevant hybrids of TH/DH scholarship.

Regarding these choices between TH or DH practices, it seems worth noting, that most debates are focusing on a few categories only: Making use of digital file formats (storage), using email and word processors (dissemination), or taking and scanning pictures (capture) has become ubiquitous even among fervent TH scholars. However, intense debates still revolve around the digitization of scholarly "core processes", which notably include the practices of "analysis" and "interpretation".[17]

It is also for these core practices, that distinctive profiles of strengths and weaknesses have been discussed in a comparative fashion—and where a basic transactional constellation has been suggested to provide a quasi-ecumenical standard solution to reconcile positions across the technological borderline (Table 2).

[17] Among these core processes (marked with an asterisk in Figure 32)—and despite extended poststructuralist and anti-hermeneutical debates—numerous observers tend to locate *interpretation* at the heart and center of humanities practice—even within DH communities: "*The proper business of the humanities remains the interpretation of meaning*" (Liu, 2009, p. 19). Thus, only the digital modification of this core would justify to speak of a truly "digital" (instead of "digitized") art history (Drucker, 2013b).

Table 2: Suggested strengths, limitations and transactions of DH and TH practices.

DH practices	TH practices
strengths: large scale capture and analysis of cultural object data and features (practices of "distant reading & viewing")	**limitations:** focus on relatively few objects only, due to constraints of scholarly time and attention
limitations: possible only for low-level features of cultural objects	**strengths:** historical-critical interpretation, evaluation and contextualization of cultural materials (practices of "close reading & viewing")

This cursory juxtaposition of (dis)advantages can be specified with regard to the study of cultural artifacts: DH research in the field of artworks frequently relies on two types of data, including a) object metadata (both from existing archival sources or from enrichment procedures), and b) automatically extracted object features (Windhager et al., 2018a; 2019b). Visual artworks are unique compositions within a complex design and feature space—which can be ordered from low-level features (such as hue, brightness, edges, shapes, or simple objects) to mid- and top-level features, which technically include such complex concepts and discursive ascriptions like *meaning*, *quality*, *value*, or *context* of a cultural object.

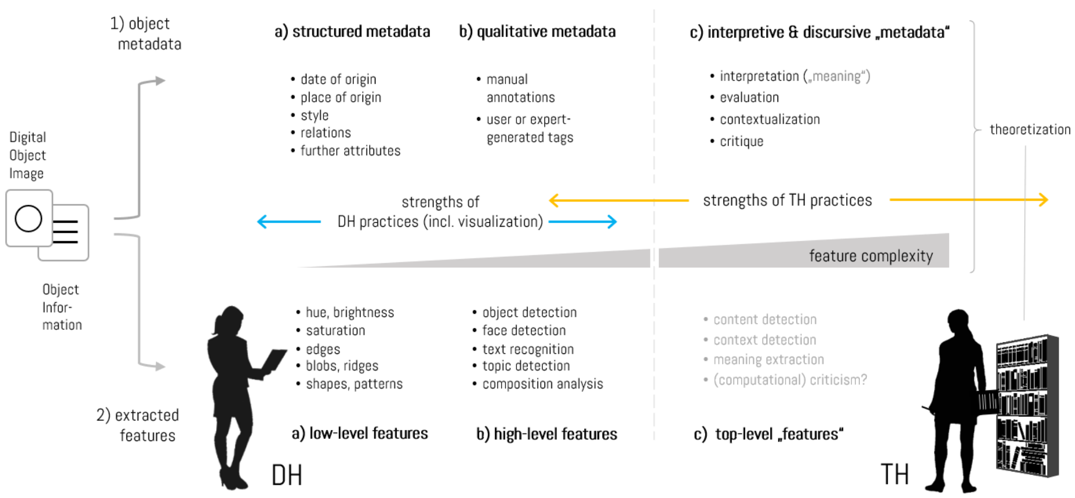


Figure 33: An illustration of the graduated feature space of visual cultural objects (such as paintings or photographs) with an increasing gradient of semantic complexity towards the right hand side, which resists direct algorithmic operationalization and analysis by DH means, but where hermeneutic and critical methods of TH inquiry thrive.

Figure 33 (adapted from Windhager et al., 2019b) depicts this graduated design and feature space for visual objects, such as paintings or photographs. For both types of image data (metadata at the top and extracted features at the bottom) a gradient of semantic complexity has to be taken into account: Relatively simple types of metadata or features (represented on the left hand side) are followed by increasingly complex and conceptual (and also observer-dependent) types of features or metadata towards the right-hand side. On the DH side, distant viewing techniques are known for their strengths in extracting and analyzing relatively simple phenomena or features instantaneously and computationally on a large scale (Arnold & Tilton, 2019; Bender, 2015). The recognition, interpretation and assessment of cultural top-level features, by contrast, remains largely beyond the ambit of digital and computational methods so far, which is documented by structurally equivalent discussions across the spectrum of cultural object types (e.g., Arnold & Tilton (2018) and Drucker (2013b) for images, Zaharieva et al. (2011) for films, as well as Liu (2009) and Ramsay (2011) for literary texts).[18]

Thus it is the main instrument of TH practice, the "*ultimate hermeneutic machine—the human mind*" (Meister, 1995, p. 269), guided by training and theory, which has to take over to process these top-level features (like the overall *quality* of an artifact, its *meaning*, *relevance*, or *role in a larger historical or socio-political context*) by activities of close reading, interpretation and contextualization—and there is a widespread skepticism, if there even is a mid- to long-term perspective for DH methods to also conquer these prime sensemaking operations on the right hand side (Drucker, 2013b).[19]

Three concluding recommendations, which can be derived from such restrictive assessments for humanities computing and visualization, include a) the advancement of *hermeneutical-circular designs*, b) the cultivation of *connections to art-historical theory*, and last but not least c) the defense of DH achievements, which arguably already provide a prospect of a new kind of *"dheory"*.

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[18] For textual artifacts, it has been stated that the "*digital revolution, for all its wonders, has not penetrated the core activity of literary studies, which, despite numerous revolutions of a more epistemological nature, remains mostly concerned with the interpretive analysis of written cultural artifacts*." (Ramsay, 2011, P. 2). "*Tools that can adjudicate the hermeneutical parameters of human reading experiences—tools that can tell you whether an interpretation is permissible—stretch considerably beyond the most ambitious fantasies of artificial intelligence*" (ibidem, p. 10).

[19] While Drucker (2013b) does not see a successful digitization of art historical core processes yet, she sketches out possible movements in this direction, including the continuation, advancement and resituation of extraction and computation activities in networked information environments, where the digitized art-historical discourse—which stores and represents the complex core practice of art-historical interpretation and critique—will become available for extraction and computation itself.

A) Design for Advanced Hermeneutic Circles

Being aware of the contemporary limitations of datafication—and thus of art-historical computation and visualization—does not preclude further DH engagement. In fact, essential insights can be derived from all sorts of critical debates about actual strengths and weaknesses of DH practices, and these insights can help to advance future visualization designs. Knowing about computational limitations allows to design for hybrid ensembles with more prolific and synergistic circles of cognitive-computational interactions (Hayles, 2012). If the art-historical core practices of *interpretation* and *critique* remain beyond the ambit of computational processing activities, the most obvious consequence for interface designers becomes the systematic support of qualitative close viewing-options. "(T)he main source of information in art history research remains the artwork itself. For that reason, developed visualizations should have a way to go back to the artwork representation" (Lamqaddam et al., 2018). The provision of 'immersive' movements into photographic detail views thus has started to become a de facto standard of visualization design, together with mental map-preserving transitions (Dörk et al., 2011, Glinka et al., 2017; Gortana et al., 2018).

These immersive dives into details equal one half of the venerable 'hermeneutical' movement, which aims "*to find the spirit of the whole through the individual, and through the whole to grasp the individual*" (Ast, 1808, p. 178, cited in Mantzavinos, 2016). By offering unconditional close-up access to cultural objects, visualizations in the field of art history can support the 'ultimate hermeneutic machine' of the human mind to engage in its core activity of interpreting symbolic and semiotic materials on a detail level. The second half of the circular movement (i.e. the contextualizing zoom-out) brings scholars back to a corpus or collection level, where *distant* overview visualizations reside and thrive, and where macroscopic *context* is added to the reflection.[20] It is the ongoing concatenation of these semicircular movements to *algorithmic-hermeneutic circles*, which resides at the center of the most widely shared con-ception of a fruitful DH-TH transaction (see Table 2).

[20] While hermeneutics started with a focus on texts, it has been generalized, to operate as any (circular) "process of questioning the meaning of the thing to be interpreted (e.g., a tree, forest, historic site, rare species or artefact) in relation to its broader contexts (e.g., history, world or environment)" (Ablett & Dyer, 2009, p.216f.). Related methodological revitalization efforts thus also reflect on implications of this time-honored method for the development of interpretational machines (Romele et al., 2018) and for human-visualization-interaction (Rodrighiero & Romele, 2020).

Absent a widely shared DH terminology, though, this decisive movement has been given multiple names, including the interplay of "immersion and abstraction" (Dörk et al., 2011), "rapid shuttling" (Kirschenbaum 2009, according to Hayles, 2012, p. 31), "screwmeneutic" or "hermenumerical" switching (van Zundert, 2016), "synergistically recursive interaction" (Hayles, 2012., p. 30), or the basic operation of "algorithmic criticism" (Ramsay, 2011)—mostly in the context of literary studies. It stands to reason, that this circular movement can also enrich art-historical scholarship with its focus on visual materials as a quasi-ecumenical practice, reconnecting both sides of the "great divide" (Pfisterer, 2018).

However, most of the visualization-based interfaces with distant viewing-functionality for visual materials remain quite restricted regarding the cardinality or richness of context, which they provide. It was the main aim of chapter 5 (p. 106 ff.) to show how some of these restrictions can be transcended—and as a consequence, the rather simplistic standard concept of the algorithmic-hermeneutic circle (Table 2) has to be revisited for a structural overhaul (see Figure 34, p. 154).

The current standard design of distant views utilizes mostly the artworks of a given collection to draw up a 'bigger picture', and to localize an artifact within. Traditional hermeneutical contextualization, though, is free in its choice of (scale, type, composition and complexity of) context—and it might be one of the main challenges for future DH work in the image-oriented field, to also develop visual representations for such contextual riches. To do so, related efforts will have to interconnect existing data collections (e.g. digital artwork and biography collections), and to deliberately connect and mine further relevant aggregations of data and knowledge collections thereafter (cf. Drucker, 2013b). Arguably, this will inevitably also include the foundational texts that revolve around cultural objects in the fields of art-historical discourse, criticism, and theory.

B) Cultivating Connections to Art-Historical Theory

From chronological to geographic, relational, or multidimensional arrangements: Contemporary distant views on artworks frequently focus on given object collections and rearrange them as diagrammatic tableaus, so that objects can contextualize themselves according to inter-object similarities and differences. This collection-focused, local contextualization concept might prove to be a first-generation approach to visualizing cultural collections, which could be followed by richer contextual designs, as soon as linked data principles will have worked their way into the confines of 'siloed' archival collection databases and upgraded them to semantic portals to cultural heritage (cf. Hyvönen, 2020). For that matter, it could be instructive to approach the next generation designs of "bigger DH pictures" with due regard to the designs of the "bigger TH pictures", which have been developed by art-historical theories**.**

Theories in the humanities are complex beasts: Whether in the fields of art history or art criticism—they provide interpretive lenses, (onto)logical perspectives, and discursive frames for studying and reflecting on artworks. On the one hand, they instruct and guide close reading-practices and interpretations on the micro-level of scholarly activity, which cluster around relevant works, artists, schools, or periods of production. On the other hand, they create also bigger pictures with socio-historical, political, technological, and methodological dimensions, which emerge and draw from local observations, while also guiding and informing them. As larger interpretive and normative frameworks, they also define and co-create the *objects* of study to begin with (e.g. "images", "texts", "authors", "artists") and help to prioritize, canonize, select and reject objects—and which of their related entities might deserve closer analytical or critical attention. Arguably, designers of future distant views could benefit substantially from following, formalizing, and utilizing these theoretical and contextual conventions. What makes this task complex, though, is the obvious parallelism of several theoretical endeavors within the art-historical discourse, and their constant, combative development over time.

Nevertheless—researchers and designers as builders of DH visualization tools should "*learn to view each field in its complexity, appreciate its culture, vocabulary and agenda, in order to better address the needs of its researchers*" (Lamqaddam et al., 2018). This thesis took steps into this direction by following the theoretical suggestions of one of its founding figures: If Giorgio Vasari (1550/2008) established the scholarly strategy to study the *lives* of painters, sculptors and architects, in order to better understand their works, then also contemporary interfaces should be able to complement their close-up and collection views with biography visualizations, to bring this theoretical option to our screens (ch. 4, p. 76 ff., and ch. 5.1 and 5.2, p. 107 ff.).

However, if scholars—due to their theoretical preferences—prefer to study and situate objects, forms and motifs in the *larger stylistic formations* of an ‘art history without names’ (Wölfflin, 1915/2015), linked data architectures should allow for a shift to the bigger pictures of art-historical “meso-level contextualization”, where categorial and taxonomic formations within the field of art become visible (ch. 5.3.1, p. 124 ff.).

If, by contrast, the reflection on *larger external (i.e. socio-economic, political, technological, colonialist, racial, historical) realities* is seen as a theoretical key to guide and complement an object’s close-up study (e.g. Harris, 2001), distant views should be able to represent materialist, critical, postcolonial, or gender-theoretical perspectives and structures, and bring corresponding historical formations into the time-oriented perspectives of “macro-level contextualizations” (ch. 5.3.2, p. 130 ff.).[21]

Figure 34 draws these layers of contextual magnitude together for both digital (blue) and traditional (orange) perspectives and approaches, and outlines with vertical and horizontal movements, what the resulting *advanced design space* of multi-circular, computational-hermeneutic studying and reasoning could look like.

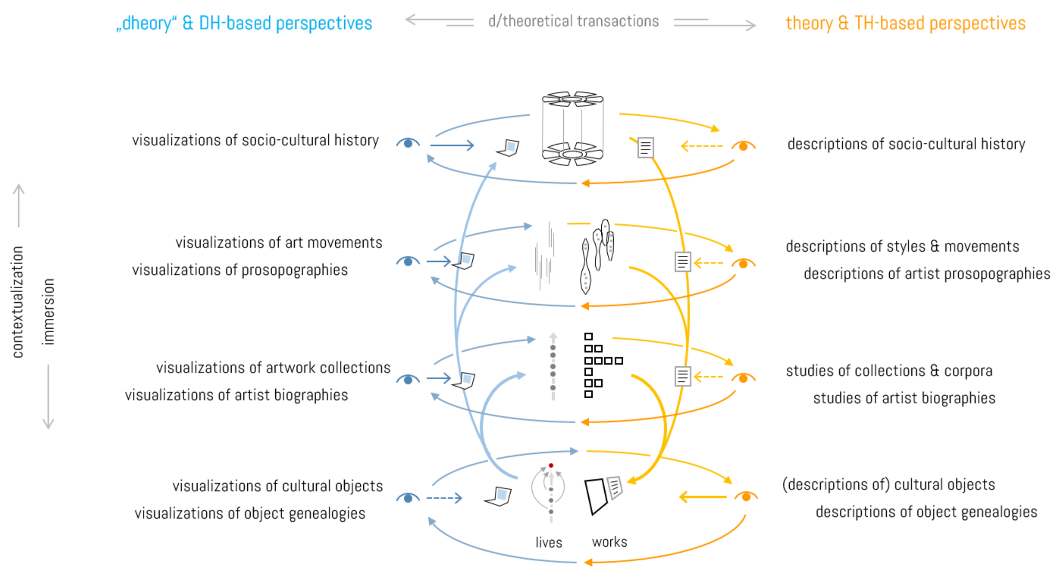

Figure 34: Conceptualization of the multi-layered and multi-circular operation space of digital-traditional theorizing and sensemaking in the art-historical data and topics domain.

[21] Correspondingly, it seems necessary to explore representational options for theoretical lenses of formalism, iconography, (post)structuralist or semiotic contextualization conventions with future visualization endeavors, even if substantial challenges regarding operationalization, mining and representation are to be expected.

While chapter 5 (p. 106 ff.) developed concepts and blueprints how to visually represent such meso- and macro-contextual perspectives on art history, the related mining, extraction, and data-driven (re)construction of such "higher" contextual layers will be a challenge of its own. The most essential development in this regard might be the secondary and tertiary waves of digitization, currently sweeping over the disciplines dedicated to the study of cultural materials.

Art-historical theory and criticism are consistently language-based practices, and they document their tenets and developments in the form of a complex scholarly para- and hypertext, woven around and between the primary visual materials. Due to the ongoing digitization of scholarly texts, it is the ongoing advancement of natural language processing, which will expectedly also advance the endeavors of (indirect) artificial image processing on the complex right-hand side of the image-analytical feature space (cf. Fig. 33, p. 149). Arguably, the complexity gradient of this object-oriented feature space will also be found at each level of the advanced feature space (Fig. 34, p. 154), i.e., for artwork collections, art movements, and socio-historical formations. For the study of each of these levels, a gradient between rather simple machine-readable features, and more complex, "human-readable" aspects will materialize. However, "as primary and secondary textual sources for art historical research become available in full-text format, our engagement with discourse analysis will escalate dramatically. Simply tracing terminology for style, technique, attribution, and other basic concepts will expose aspects of the field that could only be partially glimpsed through traditional reading and study" (Drucker, 2013b, p. 10).

Thus, it would be a closer look at the historical and traditional 'core practices' of theoretical descriptions and interpretations—not at the digitized objects themselves—from which new types of higher-level contextualizations and visualizations could draw their data points. Next generation approaches to cultural analytics and distant viewing interfaces thus might transcend their restrictions and dependencies on the rather low hanging fruits of easy extractability, and could construct new distant views, by making *distant reading-detours* into the archives of art-historical theory and discourse. This could also contribute to a new phase of complementary theory reception—which would further revive the long-forgotten but fantastic faculties of human vision as new means for scholarly ends.

C) Daring to Think "Dheory"

The research questions of this thesis have been situated in the digital periphery of art history, where it developed concepts and methods to represent specific types of art-historical information differently. Its main motivation was the advancement of "interactive, visual representations of abstract data" (Card et al., 1999) to support art historians' cognition and communication processes, and to facilitate the creation of new "insights with regard to massive, dynamic, ambiguous, and often conflicting data" (Cook & Thomas, 2005, p.4). In the greater scheme of things, such a digital and visual approach to the study of culture is still quite contested, and skeptical questions about its value and merit are still dealt out freely and frequently (Allington et al., 2016; Bishop, 2018; Rodriguez-Ortega, 2015; Schelbert, 2017; Zorich, 2013). Despite the sobering effects of such common skepticism, this thesis pleads for a sanguine reaction, and for making the best of the ambivalent historical situation. Quite some critique of the DH field seems well deserved, yet there is ample reason to stay with the trouble, and to appreciate these objections as a "*rich opportunity to think about the field's methodological potential*" (Spahr et al., 2016), and as a chance for transformative growth **(**Epstein, 2012; Rodriguez-Ortega, 2015).

Data-based visualization systems organize and represent data and topics *differently* than the language-based research and teaching practices of traditional art history. They could be argued to operate in an "orthogonal" fashion to established means of qualitative information processing, and their analytical views can augment and contrast established interpretive perspectives. For that end, "complementarity is key" (Bonfiglioli & Nanni, 2015)—and aside from mediating well-established information (most notably for pedagogic purposes), the relevance of visualizations lies in their potential to offer unprecedented *macroscopic* perspectives, which grant perceptual access to "what is at once too great, to slow, and too complex for our eyes" to see (de Rosnay, 1979, p. 4).[22] Advanced datafication and visualization approaches to cultural materials thus enable new investigation, contemplation, and communication practices, without simply replacing non-digital practices that have developed before. They bring

[22] Terminological and metaphorical suggestions to refer to such technologies, resulting from the interplay of digitization, data science and visualization include "telescopes of the mind" (Masterman, 1962; McCarty, 2012), as well as "macroscopes" (de Rosnay, 1979; Börner, 2011; Stefaner, 2014), which both draw analogies to established scientific observation technologies, whose optical apparatus brought formerly hidden data dimensions into a perceptually and cognitively accessible format.

about new ways for scholars to observe and perceive cultural riches—and they tap into different cognitive faculties, than the propositional meaning structures of academic prose (Tversky, 2011).

Visualizations arguably re-elevate the role of the scholarly *senses of sight* and promote them from line-oriented symbol scanning tasks to the more natural callings of wide-band vision, exploration, pattern recognition, and sensemaking. To augment the (in)sights, which are known to emerge from reading and logocentric reasoning, visualizations bring the highly evolved faculties of visual perception and sensemaking (back) into play, so that a complementary system of image-oriented perception-cognition can join the language-oriented sensemaking system of propositional processing (Schnotz, 2014). The resulting mental structures—whether as cognitive collages or mental models—are known to interweave aspects of both visual-spatial information and propositional information of language-based, theoretical thought in a multimodal fashion (see Fig. 3 of publication B1, p. 81). [23]

Ironically, the concept of "theory"—whose alleged absence is often admonished in DH contexts (Warwick, 2015)—has a deep cultural history, which goes back to the act of "seeing" (Nightingale, 2004). Before *theory* was defined to be the post- or non-empirical contemplation of ideas by the "blind" eye of philosophical reason,[24] the term signified the practice of viewing and interpreting sacred rites, objects and images (*theôria* as seeing, beholding, gazing, and viewing) in the Greek *theatron,* literally a "place of seeing" (Sennet, 2008, p. 124). Before Plato cast doubt on the shadowy images of sensory perception—and called for their transcendence by the light of discur-

[23] Addressing the essential dual role of visualizations as *models* on our screens and in our minds, Tversky (2018, p. 63 f.) summarizes: "Models are necessary for thinking; by omitting, adding, and distorting the information they represent they can recraft the information into a multitude of forms that the mind can work with to understand extant ideas and create new ones. Models take elements and relations among them in the represented world and map them onto elements and relations in the representing world. In the case of tangible, diagrammatic, and gestural models, the elements and relations are spatial. The fundamental elements are dots and lines, nodes and links. A dot can represent any concept from a place in a route to an idea in a web of concepts. Lines represent relations, any relation, between dots. As such, spatial models rely on more direct and accessible mappings than language, which bears only arbitrary relations to meaning. These mappings can be put into the world and made visible or visceral in graphics and gesture. Putting thought into the world promotes thought in self and other."

[24] "The philosopher must accept the condition of blindness as the precondition for philosophic insight. He goes blind in order that he may see" (Nightingale, 2004, p. 104).

sive-dialectical reasoning—the senses of sight had a major say in the theophanic perception and interpretation of the world (Sloterdijk, 2016, p. 6 ff.). Against this background, one feels tempted to argue that the academic arc of logocentric and iconoclastic history is long but eventually bends back to multimodal justice (cf. Tversky, 2005; 2011). The late-modern rise of "Visualizationism" (Staley, 2002) as a wellspring for new kinds of epistemological images (Drucker, 2020) thus could be read as the late renaissance of a pre-traditional, pro-visual practice and interpretation of *theory*. We might even consider calling it "*dheory*", to emphasize its significant scholarly potential with a straining but salient term.

"Dheory" in the realm of the arts and humanities then might serve as an aspirational term and a regulative idea, whose evocation might occasionally fall by the post-digital wayside, like a second installment of Wittgenstein's ladder. Nevertheless, dheory—as a novel practice, and as indicated by its initial letters—would build on the recent achievements of digitization in the humanities, but it would emerge only from multiple further procedures of subsequent information processing. This thesis has made the case for several of them.

The growing repository of visualization techniques already provides the basic procedures to establish local views into complex data collections. Like stringent theoretical descriptions, they allow scholars to *see* specific aspects and selected "cuts" of a subject matter in a variety of ways (*plurality of interpretive perspectives*). This practice introduces a difference that already makes a difference: Instead of transiently talking about the massive corpora of cultural materials (such as texts, images, sculptures, songs, films), visualizations make them visible, so that both professional and casual audiences can newly access, experience, analyze, explore, share, and communicate these riches. This is a genuinely new way to represent and deal with cultural complexity, and even just its pedagogical potential deserves a spirited defense at any time.

The main thrust of this thesis, however, aimed to argue for the development of further, *post-productional* procedures, which would rise the expressive magnitude of local perspectives and visualizations by a new kind of "visual syntax" (Windhager et al., 2019c), maybe even to aspire to the level of traditional theoretical expressiveness. For that matter, the mere construction and provision of multiple views is not enough. To arrive at bigger historiographic pictures, several visual-synthetical procedures are needed. Especially in the historical context, the dynamization of visualizations is key (*emphasis on the diachronic data dimension*). To draw multiple synchronic and diachronic perspectives together, coherent macroscopic designs are needed (*utilization of coherence techniques*). To further situate and interpret these multi-perspective visualizations against various backgrounds, rich contextualization options are needed (*design for rich contextualization*)—on multiple levels of contextual magnitude (see Fig. 34, p. 154). Furthermore, these representational ensembles have to establish various types of inter-perspective transitions. Along the vertical axis, immersive avenues have to enable dives into close-up contemplation, while macroanalytical elevators offer the inverse movement of contextualizing abstractions (*design for advanced hermeneutic circles*). Finally, a new kind of horizontal connectivity will be needed, to transition as a scholar from digital to traditional accounts—and vice versa—and to allow for d/theoretical reframings, recodings and inter-representational translations (*cultivation of d/theoretical connections*). Some of these design strategies have been elaborated and discussed with regard to the PolyCube framework. Others have been adumbrated only, to preregister for future concretization.

Scholarly practices—*they are a-changin'*, and this thesis set out to contribute to related developments in the art-historical context. Not to naively replace existing perspectives and practices, but rather to amend and complement their explicatory and expressive profiles. Thus, the striving for an advanced "dheoretical" practice does not aim to supersede traditional theory, but to prepare post-digital alliances, which could give rise to synoptic instruments for extended, inquiring minds. Tellingly, the talk about such an intellectual fusion remains evocative in tone and is still happening "*perhaps a little ahead of time*" (Vaughan, 2005, p.1). But after all, the transformation has just begun, and not yet fixed animals are said to benefit from visualizing their guiding ideas.

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