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Luxembourg Centre for Contemporary and Digital History (C²DH)

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Belval Campus

Maison des Sciences Humaines

11, Porte des Sciences

L-4366 Esch-sur-Alzette

Editors

Asst. Prof. Dr. Marten Düring (Luxembourg Centre for Contemporary and Digital History | C²DH)

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Clemens Beck, M. A. (Friedrich-Schiller-Universität Jena)

Dr. Joëlle Weis (Universität Trier)

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Contact

Principal Contact

JHNR-editors@historicalnetworkresearch.org

Support Contact

Dr. Marten Düring (Université du Luxembourg)

JHNR-support@historicalnetworkresearch.org

Cover Design and Typesetting

text plus form, Dresden, Germany

Cover image

Martin Grandjean

Copyediting

Andy Redwood, Barcelona, Spain

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LEA WEISS/LAURA VON WELCZECK/
MALTE VOGL/MARTEN DÜRING/
ALEKSANDRA KAYE/JASCHA
SCHMITZ/RAPHAEL SCHLATTMANN/
BERNARDO S. BUARQUE

Past, Present, and Future of HNR: Reflections on the Practices and Methods in Historical Network Research Based on an Online Survey

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Abstract Historical network research (HNR) has always been characterized by the transfer of methods and the transgression of disciplinary epistemic boundaries. While various contributions reflect the historical development of HNR as well as the epistemological implications of applying network analysis methods to historical data, current discussions place less emphasis on the practical side of HNR. By conducting an exploratory survey, we aim to contribute to a better understanding of the ways scholars actually conduct HNR, focusing on the technical aspects of the network research practices of network construction, network visualization and analysis, and data organization as well as the problems scholars experience. We identify two trends: (1) While concepts, methods, and tools that originated in Social Network Analysis (SNA) still seem to be prevalent in current HNR, there is clear evidence of expansion beyond SNA, given the diversity of re-

search topics, interests, and methods. (2) Within this resulting broad methodical landscape, scholars need to attune the available indicators, software, and tools to their specific historical research. We conclude that difficulties in this process due to technological and methodological prerequisites could be mitigated through targeted resources.

Introduction

The past, present, and future of network analysis in the historical sciences – referred to as Historical Network Research (HNR) – has been discussed with various foci in recent years. Adding to the interpretative methods in history, it has been addressed as a “supplementary heuristic method”¹ or as an auxiliary apparatus for historical research.² By strengthening structuralist,³ processual,⁴ and relational⁵ perspectives on history, often focusing on the study of historical communities and their social relations,⁶ HNR has been understood as challenging well-established theoretical dichotomies, e.g., of the micro/macro-level or the local/global perspective.⁷ However, the essence of HNR – its common research practices and theoretical assumptions, but also the methodology and underlying epistemology – is part of an ongoing discussion.⁸ In this paper, we argue that a

Data accessibility: In our analysis of the network research practices in the field of HNR and among the HNR community, we relied on data gathered through the quantitative survey “Best-Practices and Tools in Historical Network Research” conducted online via the open-source tool *LimeSurvey* among the HNR community between 21. 09. 2022 and 30. 11. 2022. To ensure data privacy, we have not published the raw data set to prevent tracing a linked set of responses to a respondent. However, to fulfill the aims of reproducibility, reusability, and comprehensibility, we aim to present an extensive overview of the results and our data analysis process in the appendix. Additionally, the survey questionnaire is attached as a supplementary file in: Weiß, Lea, von Welczeck, Laura, Vogl, Malte, Düring, Marten, Kaye, Aleksandra, Schmitz, Jascha M., Schlattmann, Raphael, & Buarque, Bernardo (2025). Supplementary Materials to “Past, Present, and Future of HNR: Reflections on the Practices and Methods in Historical Network Research Based on an Online Survey”. Zenodo. <https://doi.org/10.5281/zenodo.15419244>

Ethics and consent: The authors do not have any ethical concerns to declare. The survey respondents participated in the survey on a voluntary basis. Before taking the survey, the participants were informed on an introductory page that the results would be made public.

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1 Broekaert et al. 2020, p. xi.

2 Düring & Eumann 2013.

3 Neurath 2008.

4 Düring & von Keyserlingk 2015.

5 Lemerrier 2015; Rollinger et al. 2017, Brughmans & Peeples 2023.

6 Wellman & Wetherell 1996; Erikson & Feltham 2020.

7 Bixler 2015; Düring & von Keyserlingk 2015; Lemerrier 2015; Kaye 2024.

8 e.g. Rollinger et al. 2017; Bixler 2015; Fickers 2020.

stronger focus on exploring the practical execution of conducting historical network analysis – the networks constructed, the methods used, and the challenges experienced – might help us to gain a better understanding of the current state of HNR. Drawing on perspectives of researchers within the field additionally allows us to highlight both the existing challenges and the potential opportunities within HNR.

Our argument for this practice-focused approach is twofold: first, following Lemercier (2015), HNR might be understood as a specific, relational approach towards the social world, inscribed into a “core of concepts that have been translated to indicators, implemented in software and presented in textbooks”.⁹ As these software packages, indicators, and measures are grounded in specific assumptions and are thus not neutral digital instruments,¹⁰ a deeper understanding of how scholars attune their historical research interests and HNR methods seems particularly interesting. Jacomy & Jokubauskaitė, for example, show for the network visualization software *Gephi*, how tools and methods not only shape the research process but are also subject to the epistemic cultures and specific practices that evolve around their use.¹¹ Second, and intertwined with the first, the methods applied in HNR are to a great extent inherited from Social Network Analysis (SNA), or the more mathematical and computer science-related field of network science, and are thus intertwined with the challenges that arose with the ‘digital turn’ in the humanities. HNR thus results from knowledge transfer between disciplines. As historians initiated the exchange of information and ideas with researchers from adjacent fields, an ongoing institutionalization process led to conferences and workshops, as well as the platform “The Historical Network Research Community”.¹² In this dynamic context, shared with closely related fields like Digital History and Digital Humanities that are marked by the transgression of epistemic cultures and the transfer of methods, we argue that attempting this rather practical understanding of the currently ongoing research in HNR can foster insights for both researchers and other interested parties.

To delineate what we mean when we refer to such a practical understanding of HNR, we draw on the notion of communities of practice (CoP) by Lave and Wenger.¹³ Practices, in this sense, can be understood as a “set of socially defined ways of doing things in a specific domain: a set of common approaches and shared standards that create a basis for action, communication, problem solving,

9 Lemercier 2015, p. 283.

10 Lemercier 2015; Zaagsma 2013.

11 Jacomy & Jokubauskaitė 2022.

12 <https://historicalnetworkresearch.org>.

13 Lave & Wenger 1991. The CoP-approach was translated to the context of scientific communities by Kienle & Wessner 2005 and used by Fickers & van der Heijden 2020 to discuss knowledge transfer in the setting of an interdisciplinary postgraduate school in Digital History.

performance and accountability”.¹⁴ The historical network research practices can thus be understood as specific, socially defined and approved ways of carrying out HNR. According to Lave and Wenger, practices form within CoP composed of “groups of people who share a concern, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise in this area by interacting on an ongoing basis”.¹⁵ Within a scientific context, the composition of CoPs can be quite heterogeneous, as the members may stem from distinct disciplinary backgrounds, participate in multiple different communities, and work on different aspects of the shared research object.¹⁶ We think of the HNR community as such a CoP, united by the aim of analyzing historical networks.

In HNR, historical interpretation, questions of digital hermeneutics, and network analysis methods go hand in hand. With a focus on currently relevant methods and tools, our perspective leans more to the technical side of those practices, which are usually a common denominator in data-driven historical network research: practices of network construction, analysis, and visualization, and in parallel the organization of a dataset. We wish to contribute to an empirically enriched understanding of these by collecting insights from researchers in the field, both in terms of these practices and their embeddedness within the wider CoP of HNR. Therefore, we draw on the results of an online survey that was conducted between September 21st and November 30th 2022 among researchers who self-identified as applying network analysis methods to historical research subjects. We aim to approach the survey results as a snapshot in time in an exploratory manner, and thus to inform further debates within the community that can benefit from an understanding of present historical network research to discuss pathways for the future.

The triad of past, present, and future structures the text as we view the historical development of HNR based on a review of existing literature. We then interpret the survey results with an interest in the possible current characteristics of HNR, and finally conclude with future outlooks, both in terms of dynamics and possible further research on HNR practices.

Literature Review on HNR

The beginning of the use of data-driven network analysis in history, as opposed to merely metaphorical references to the relationality of historical processes, is often attributed to late 1970s research on the interconnectedness of elite

14 Wenger et al. 2002, p. 38.

15 Wenger et al. 2002, p. 4.

16 Kienle & Wessner 2005.

groups.¹⁷ However, there were even earlier adaptations of computational¹⁸ and even network theoretical approaches in historical research.¹⁹ Additionally, since the 1990s, important contributions to network studies with a historical research focus have come from the field of historical sociology.²⁰ Today, prominent fields of application of network analysis methods in history include historical elite research, the history of economics, science, gender and politics, and transnational history.²¹ While it remains a niche field within the more qualitatively oriented historical sciences, historians have thought about and applied network analysis methods to historical data for almost fifty years now. As a consequence, under the name of HNR or historical network analysis (often used interchangeably), there are a diverse collection of approaches and methods, theoretical discussions, and anticipated potentials for historical research, all united by the shared goal to systematically analyze relations between historical entities. This multitude can be traced back to several streams of converging research and trends, namely historical sociology and social and economic history, but also quantitative history, digital history, the increasing digitization of archives, and the prevalence of digital humanities in general.²² HNR, often described as a growing field in its formative stage,²³ owes its unifying label to institutionalization processes including the formation of “The Historical Network Research Community”²⁴ as a platform for historical network research in c. 2011, as well as the publication of the first issue of the *Journal of Historical Network Research* in 2017.

As historical network analysis is applied to the study of different historical contexts and time periods, specific research designs vary.²⁵ Nonetheless, in order to understand its epistemological influences, it is important to trace its connections to two relevant streams of research: the sociological SNA that gained relevance in the 1970s, and the more mathematically and physically informed formal network science that gained prominence in the 1990s.²⁶ SNA has traditionally

17 Düring & Eumann 2013; Düring & von Keyserlingk 2015; Bixler 2015. For an early example of sociological network analysis in the anglophone context, see Wetherell 1989, 1998.

18 e.g. Shorter 1975.

19 e.g. Pitts 1965; Gardin 1965.

20 Bixler 2015; Rollinger et al. 2017.

21 Düring & von Keyserlingk 2015.

22 Reynolds 1998, Erikson & Feltham 2020; Kaye 2024; Rehbein 2020.

23 Bixler 2015; Rollinger et al. 2017.

24 <https://historicalnetworkresearch.org/>.

25 For literature reflecting on network analysis in specific fields of historical research, see e.g. Rollinger 2020 and Preiser-Kapeller 2020 for ancient history, Jullien 2013 and Gramsch et al. 2017 for the medieval period, Ahnert et al. 2023 and Davison 2019 for early modern and modern history, as well as Brughmans & Peeples 2023 and Holland-Lulewicz & Roberts Thompson 2022 for archaeology. See also the bibliographies of historical network research (<https://historicalnetworkresearch.org/bibliography/>) and medieval SNA (<https://medievalсна.com/bibliography/>).

26 Düring & Eumann 2013; Jacomy 2020.

been used to understand structures and functions of social relations, be it Mark Granovetter's (1973) concept of strong and weak ties from his research on job searches, or Ronald S. Burt's (1995) organizational sociological studies on social capital and the strategic use of knowledge gaps in structural holes.²⁷ Network science, meanwhile, is an umbrella term for network research from various disciplines that can be understood as "the study of the collection, management, analysis, interpretation, and presentation of relational data".²⁸ This research field includes approaches that draw on graph theory for the quantitative analysis and modeling of complex networks, e.g. with statistical models like Exponential Random Graph Models (ERGM), multi-layer networks, or networks with a temporal dimension, and is increasingly integrated with other computational methods such as simulation and agent-based modeling (ABM) that allow the study of network development and diffusion processes.²⁹ Methodological approaches developed in this field of research are gaining attention from historians working with historical data that is increasingly available, but also layered and complex.³⁰ In a similar conceptualization, Grandjean (2021) understands network science as a research field of its own that focuses on complex systems, and SNA as focusing more on the empirical phenomena themselves, while network analysis subsumes the concrete techniques of data analysis.³¹ In the following, we will try to briefly localize HNR in relation to these fields.

Using well-established concepts and methods from quantitative SNA, including centrality measurements, calculations of density, blockmodeling and clustering algorithms, HNR draws heavily on the concepts and methods developed in SNA and is therefore often defined as an application of SNA methods to historical data.³² This statement becomes especially plausible from a perspective that views HNR purely as the research of historical communities, characterized by a common research object: social relations between people.³³ However, looking at examples of HNR on relations involving artifacts, e.g. in archaeological network research³⁴ or knowledge, e.g. in network research in the history of science,³⁵ such a conception seems too narrow for the broad research landscape of HNR. Following this strand, HNR is also characterized by the adoption of SNA methods while

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- 27 Burt 1995, Granovetter 1973. See Freeman (2004) for a more detailed overview of the historical development of SNA and Freeman (2014) for a reflection of the encounter of SNA and network science since the 1990s.
 - 28 Brandes et al. 2013, p. 2.
 - 29 e.g. Namatame & Chen 2016.
 - 30 Siebold & Valleriani 2022, Zamani et al. 2023.
 - 31 Grandjean 2021.
 - 32 Wellman & Wetherell 1996; Düring & Eumann 2013; Bixler 2015; Lemerrier 2015; Rollinger et al. 2017; Kaye 2024.
 - 33 Wellman & Wetherell 1996; Erikson & Feltham 2020.
 - 34 e.g. Brughmans et al. 2015; Moreno-Navarro et al. 2023.
 - 35 e.g. Renn et al. 2016; Herfeld & Doehne 2019.

leaving the purely social research focus behind,³⁶ and applying the concept of networks in various senses.³⁷ An openness of research interests to various kinds of ties and entities – of which the social is just one –, their relationship manifesting as network structure, and the shared relational perspective on historical phenomena, can be regarded as the common foundation of HNR.³⁸ The interest in complex data and interaction between various entities enables HNR to fit under the umbrella term of network science and shows its openness to methodology from various disciplines.

After shining a spotlight on the influences of SNA and network science, we want to take a step back and look at the specific challenges that HNR faces as part of the wider ‘digital turn’ in the humanities. Similar to digital humanities and digital history, HNR builds on the digitization of bibliographic data, archival funds, and collections by memory institutions like libraries, museums and archives.³⁹ In this context, questions of the availability of historical data and its pre-shaped form – for instance through selection processes⁴⁰ – become particularly relevant for the network construction process. Even though the incompleteness of networks can be seen as an integral part of network research,⁴¹ questions of archival bias, forgetting, and data heterogeneity due to a variety of sources are central. Corresponding discussions on how the historical-critical method might be translated for such new digitized or digital-born data types and, intertwined with this, on the implications of applying quantitative network methods to such limited, pre-shaped historical datasets are taking place under the labels of algorithm criticism, digital source criticism, tool criticism and the unifying label of digital hermeneutics.⁴² Additionally, contributions that address the caution needed when applying network approaches foreign to the discipline to historical questions, as well as the importance of carefully interpreting HNR in the light of previous historical research, should also be mentioned here.⁴³

While situating network-related approaches within the distinct context of the historical sciences, questions regarding data cleaning, storage, and potential sharing mix with existing debates in digital humanities and digital history on open science and data interoperability, for which concepts like the Semantic Web or Linked Open Data (LOD) can serve as infrastructural examples.⁴⁴ Inter-

36 Lemercier 2015.

37 Grandjean 2021.

38 Düring & Eumann 2013.

39 Siebold & Valleriani 2022, Fiscarelli 2022.

40 Hauswedell et al. 2020.

41 Ryan & Ahnert 2021.

42 van Es et al. 2018; Fickers et al. 2022, Romele et al. 2020.

43 Lemercier 2015; Düring & von Keyserlingk 2015; Siebold & Valleriani 2022; Kaye 2024; Erikson & Feltham 2020.

44 Romein et al. 2020.

operability, in the sense of the FAIR principles of open science, focuses on the formalization of data and vocabularies to allow the reuse of data between different research projects.⁴⁵ To make research data inter-operable for historical research, Beretta (2021) suggests the use of ontologies and shared vocabularies such as taxonomies or authority files, while highlighting the challenge of reusing data collected within a specific historical context.⁴⁶ According to Siebold & Valleriani (2022), these suggestions can be viewed in light of “a vision that has always been inherent to the DH, namely being able to share and link data as well as to enable interoperability across projects and institutions”.⁴⁷ Nonetheless, the preservation – and especially the re-use and documentation – of datasets created in methodologically specialized and time-limited projects remains problematic, as heterogeneous data modeling practices make the desired linking, sharing and re-use of those datasets difficult.⁴⁸ In the context of HNR, these future hopes for the availability of linked and openly accessible data are connected to questions concerning the reproducibility of results and the further development of methods that are usable for different historical datasets.⁴⁹

Research Design

We base the following reflections on an online survey that was conducted between September 21st 2022 and November 30th 2022, and which targeted researchers using network-related methods on historical data. We utilize the survey results as findings in the sense of an explorative research perspective,⁵⁰ in that they provide an empirical basis for our reflections on network research practices in the HNR community. As there is, to the best of our knowledge, little existing research on the community of HNR scholars and their network research practices,⁵¹ we have decided to take an exploratory approach. To achieve our goal of a first snapshot of research practices based on a larger sample, we chose a standardized survey format. Qualitative expert interviews remain a promising avenue for future work.

The survey arose out of a workshop that was held in April 2022 at the Max-Planck-Institute for the History of Science in Berlin, Germany which gathered researchers from diverse backgrounds who worked with network-related methods

45 Wilkinson et al. 2016, p. 4.

46 Beretta 2021.

47 Siebold & Valleriani 2022, p. 175.

48 Siebold & Valleriani 2022.

49 This has also been stated in the collaborative white paper that stems from the same workshop series as the online survey that motivated this article: Buarque et al. 2022.

50 Stebbins 2001; see also Ma & Xiao 2020 for the application of an exploratory design in researching data practices in the context of digital history.

51 An exception is the literature review on the application of SNA in historical research by Sarno 2017.

on historical questions. The workshop resulted in a white paper in which shared desiderata for the further development of the HNR community were formulated. Within this endeavor, the survey was developed⁵² with two objectives in mind: first, on a more descriptive, exploratory level, to enable a deeper understanding of network research practices and the methods and tools currently used; second, and more future-oriented, to inform the development of further tools and educational resources for historical network analysis.⁵³ With the survey, we thus aimed to gain insights into the respondents' use of network-related approaches, their methods of conducting network research, and their perceptions of the HNR community. The resulting questionnaire consisted of eight questions each on the scholars' academic profile and research projects (up to three projects could be added), 21 questions on research practices and the application of standards and tools, and nine questions on the HNR community. The questionnaire consisted of both quantitative and qualitative questions,⁵⁴ and was directed towards scholars who self-reported that they have previously or are currently working on a research project that entails historical network analysis. It was conducted online via LimeSurvey⁵⁵ and distributed through the website of "The Historical Network Research Community", via email, Twitter, and word-of-mouth at shared conferences and talks. Overall, 129 scholars took part in the survey; of these, 65 fully completed the questionnaire. The survey was analyzed by applying descriptive statistics, using Jupyter Notebooks. The responses from the qualitative parts were manually coded and categorized.⁵⁶

Our research design choices led to some distinct difficulties and limitations. Perhaps the most crucial of these is the limited number of respondents, which may limit the survey's validity. This is due to both the size of the sample and the breakoff rate of 50%. To put our sample size in perspective, we draw on some reference values. While there is, as far as we know, no solid proxy for the overall number of scholars who conduct historical network research, there are some indicators which can help contextualize it: there are 152 people involved in a shared Zotero database of the community, 249 participants in a joint Slack channel, 815 subscriptions to the HNR community's newsletter, 1766 followers of the

52 The survey was a result of the joint discussions of the workshop participants. The design and carrying out of the survey was part of the ModelSEN project at the Max-Planck-Institute for the History of Science in collaboration with "The Historical Network Research Community". The paper authors were, largely, a part of both the workshop series and carrying out the survey.

53 Buarque et al. 2022.

54 For most of the closed questions, a five-point Likert Scale was used (see e.g. Blasius 2022).

55 LimeSurvey is a free and open-source software and is used under the *GNU General Public License*, <http://www.limesurvey.org>.

56 A more detailed description of the coding process is provided in the footnotes of the results section; an overview of the codes can be found in the appendix.

HNR Community's Twitter/X channel, and 1860 subscribers to its YouTube channel.⁵⁷ Compared to proxies such as Zotero and Slack, which require a higher degree of involvement, our sample size seems reasonable. Nonetheless, the fact that only half of the respondents affirmed that they were involved in the platform indicates the limited power of those proxies and demonstrates the need for different evaluation methods of the community in future (App. Tab. A7).

Results

In the following, we structure the presentation of the survey results according to two focal points: the social structure of the sample we were able to reach with the survey, and a description of the network research practices applied in the projects mentioned. Therefore, in the first two sections, we give an initial overview of the academic backgrounds of the respondents, look at (interdisciplinary) collaboration, and summarize the most common rationales for using HNR in the individual historical research projects. The last three sections then describe the practices of data analysis – including the construction, analysis, and visualization of historical networks – and the practices of data organization that the respondents we reached reported to be a part of their work.

Who is conducting HNR?

The survey reached a globally dispersed research community working with historical networks. However, the sample does exhibit a geographical concentration, as most of the respondents were located in Europe (77%), followed by North America (14%), and small groups of people in Asia (6%) and South America (5%) (App. Tab. A1). While overall researchers from 25 countries participated in the survey, most responses came from Germany, the UK, the USA, France and the Netherlands (arranged in descending order).

Representing around one third of the sample, the biggest share of scholars held a postdoctoral position, followed by around a quarter of professors, and a quarter of doctoral students. The smallest group consisted of Master's and undergraduate students, with the former outnumbering the latter (App. Fig A1, Tab. A2). Thus, the largest part of the sample consists of mid-level academic staff. This aligns with the distribution of the years of engagement with network-related methods, where most respondents indicated having used network-related methods for up to five years (App. Fig. A2).

57 All numbers as of January 2024. For comparison, see also Martin Grandjean's (2024) visualization of the HNR community in numbers, presented at the HNR 2024 conference.

Regarding the disciplinary composition of the field,⁵⁸ the vast majority of respondents were affiliated with history and/or archaeology. Only a minority came from other humanities, social sciences, or STEM disciplines (Fig. 1, App. Tab. A3). A deeper look into the historical sciences revealed that most scholars worked on contemporary history, and in almost equal shares the late modern period, ancient history, and the early modern period. Medieval history and prehistory were mentioned more rarely (App. Fig. A3).

While these insights indicate that scholars from a plurality of disciplines engage in HNR, the level of interaction between these disciplines is still unclear. Is

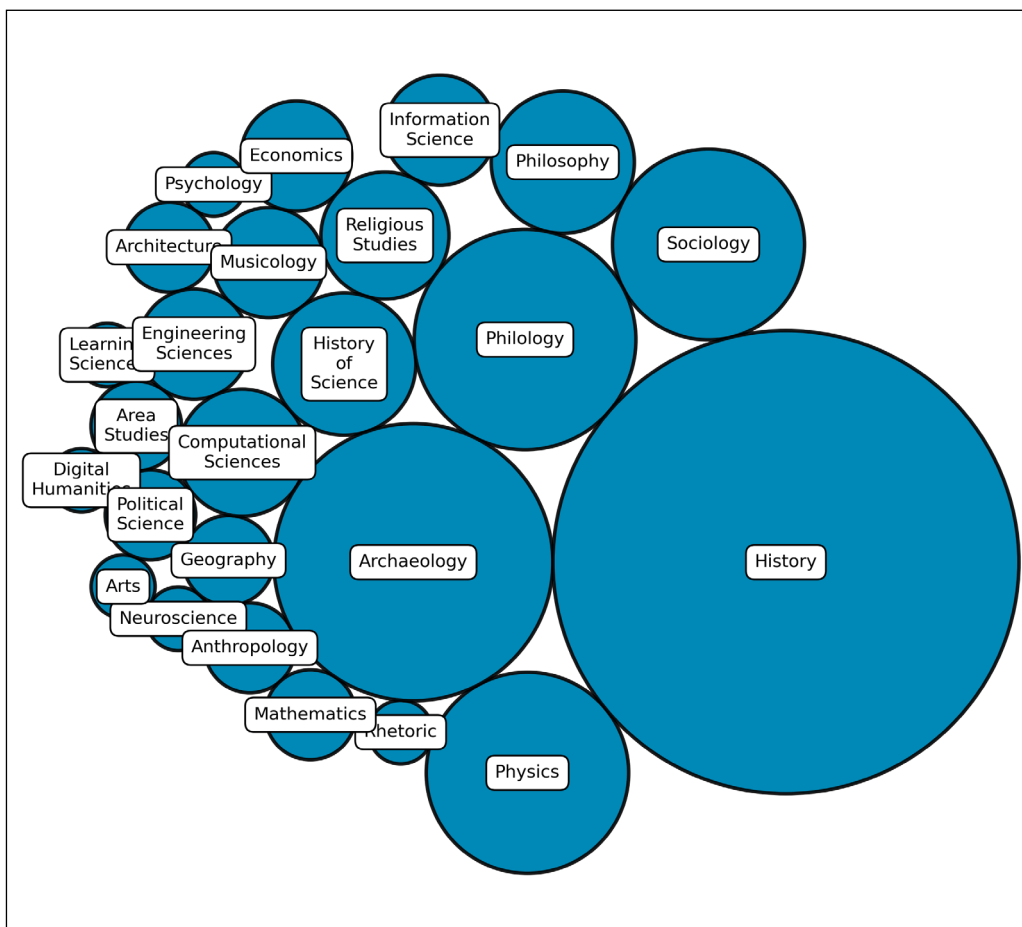


Fig. 1 A proportional display of the disciplinary backgrounds of HNR scholars (n = 120)

58 The respondents were asked for their disciplinary background in an open text question which was manually coded afterwards. Responses were subsumed into more general categories. Respondents who mentioned more than one discipline were counted multiple times.

HNR fairly multidisciplinary, approaching a research object from different angles and thus engaging different forms of knowledge that remain separate, or is it instead interdisciplinary, linking and integrating perspectives from different disciplines in a shared research approach?⁵⁹ Within our sample, more than half of the scholars indicated a regular collaboration with partners from other academic disciplines on network-related topics (App. Tab. A5), thus suggesting interdisciplinary interaction rather than independent work. However, this interdisciplinary collaboration seems to be dominated by the humanities: half of the respondents indicated regular collaboration with other historians and other (digital) humanists, while one fifth regularly collaborate with the social sciences. Collaborations with mathematics (5%) or physics (9%) were rare (Fig. 2, App. Tab. A6). Interestingly, the more applied discipline of computer science seems to deviate from this trend, and appears as a collaborative partner just as frequently

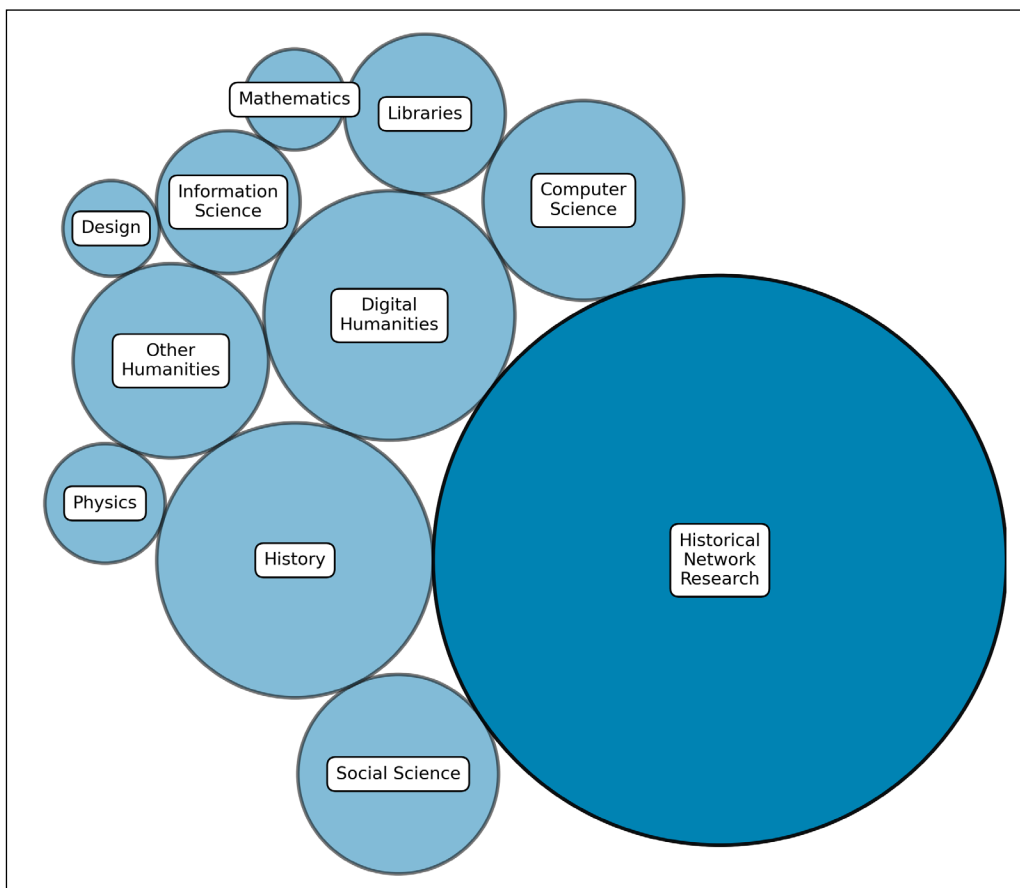


Fig. 2 A proportional display of the disciplinary backgrounds of the collaboration partners of HNR scholars (n = 101)

59 e.g. van den Besselaar & Heimeriks 2001; Alvargonzález 2011.

as the social sciences. Such an interdisciplinary tendency was also found in the researcher's biographies themselves, as around one quarter of the respondents indicated a background of two or more disciplines (App. Tab. A4).

Why HNR?

To understand the scholars' motivation for applying network analysis methods to their research, we introduced a set of questions aimed at investigating the role that these methods played in their individual projects. Here, two main forms of use were rated as crucial by the respondents (App. Tab. A8): first, almost all of the respondents deemed network analysis methods important for generating new hypotheses in their research projects (92%). The possibility of visualizing data through network analysis was also given high importance in free-text answers. This indicates a rather exploratory use of the network approach, valuing its suitability for organizing and exploring data in a way that may allow for shifts in perspective. We may thus ask what role technical affordances of network approaches, and especially network visualization software, play in enabling such an exploratory use. Second, almost as many participants as the hypothesis-generating approach indicated that they applied network analysis to test historical hypotheses (89%). This suggests a more formal and deductive use of network-related methods, in the sense that the properties of networks as representations of (at least partially) reconstructable social processes are analyzed to test an argument concerning historical phenomena. This corresponds to the finding that the respondents were especially interested in analyzing clusters or the relevance of nodes, as well as changes in the structure of their network (App. Tab. A9). These two approaches – the generation of new hypotheses and the testing of existing hypotheses – thus appear to be different forms of network use coming into play at different moments of the research process. Both highlight the relevance of network analysis as a heuristic instrument for the evaluation of historical situations and processes. In this way, historical network analysis appears more as a formal and quantitative set of tools to complement the methods of the empirical historical sciences, rather than a standalone method in itself.

Practices of data analysis: Network construction

The research projects pursued by the scholars within the survey sample addressed a broad thematic scope at different points in history. Based on the answers from an open text field where the respondents could describe up to three of their research projects, we derived thirteen rather high-level thematic clusters from these networks.⁶⁰ In terms of numbers, *scientific networks* – comprising networks that

60 The respondents were asked for a brief outline of their research interest with the specific project, as well as for a description of the networks they built, including their edges and nodes.

focus on the social, semiotic, or semantic layers of scientific knowledge production – were the most common network type. Here, the respondents worked in projects that, for example, visualized the relationship between different collaborating scientists and their institutional affiliation, or constructed multi-layer networks that connected authors, their publications and the text within their publications. This seems particularly interesting considering the low disciplinary affiliation to the history of science of 4% (App. Tab. A3). This anomaly could be the subject of further investigation, provoking questions into the varying data availability in different historical research contexts. Related to the scientific networks was the group of *epistolary networks*, comprising letter correspondences from diplomats or intellectuals, for example. *Archaeological material networks* formed another large subgroup in our findings, connecting geographical places through the material objects found therein, as well as their proximity. Additionally, another cluster consisted of networks built on *affiliations* between people, including networks of political movements, policymaking, professions, or religious communities. Further to this, the respondents constructed and investigated *economic, royal court, language, or urban networks* (App. Tab. A25). These different forms of studied networks indicate a conception of networks that centralizes social processes, yet also goes beyond the more traditional research objects of SNA as it includes not only social entities and their relations in the historical analysis, but also material or semiotic objects.

On the more detailed level of constructing the nodes and edges of a network, this relation between social and other types of networks can be investigated further. In terms of nodes, most respondents worked with uni- (57%) or bipartite (41%) networks, namely networks of one or two different types of entities as nodes (App. Tab. A12). Additionally, around one third of the scholars created multipartite networks using several node types. The nodes mostly represented persons (71%), followed by places (55%), objects (35%), and concepts (25%) (App. Tab. A13). Other node entities mentioned were text documents (e.g. scientific papers or ancient texts), collective actors (e.g. firms, organizations, or institutions), events, names, and attributes (App. Tab. A14). Looking at the edges connecting those nodes, most researchers worked with multiple types of edges (59%) compared to a single type (41%) (App. Tab. A15). Relationships between social actors were by far the most common (64%), followed by acts of communication (52%), co-occurrences (44%), and references (31%) (App. Tab. A16). Different proxies for linking by similarity were mentioned in the free text field (App. Tab. A17).

While the main area of problems researchers faced during their projects was connected to data-related issues, difficulties with network construction were also mentioned several times. The main issues here were the operationalization of concepts, and matching theory with methods. This included the choice of an appropriate method for a specific research question, as well as problems with non-specific theories, but also more detailed aspects of network construction. These

included issues of fixing the boundaries of a network, and defining the specific meaning of interactions represented by links (App. Tab. A26), difficulties that might indicate gaps in conceptual and methodological clarity in the network construction literature.

Practices of data analysis: Algorithmic network analysis and visualization

Another group of questions concerned the specific methods and tools used to analyze and visualize network data and evaluate results. In the network analysis process, programming languages played an important role. Half of the respondents used Python for their analysis, followed by one third who use R, and one tenth Javascript (App. Fig A4). The importance of Python and R also showed in the relevance of network analysis packages available in these languages, like NetworkX, graph-tool, or igraph. Meanwhile, almost one quarter of the respondents indicated using no programming language. For network visualization, around 70% of the scholars used the network visualization tool Gephi, while 15% used Visone.⁶¹ We found it interesting that the majority of respondents used programming in their projects, despite the frequent use of visualization tools that had network analysis algorithms implemented. This may show that scholars make use of multiple analysis tools in their work, rather than relying on a single software.

For data analysis, the calculation of centrality measurements and the application of community detection algorithms were very common among the respondents (Fig. 3, App. Tab. A19). More than 95% used centrality measurements like betweenness centrality in their research, closely followed by community detection algorithms like density-based clustering or random-walk approaches (70%). By contrast, positional analysis (e.g. blockmodeling or structural equivalence), stochastic approaches for dynamic networks (e.g. RSiena), and Exponential Random Graph Models (ERGM) were less frequently applied; nonetheless, these approaches were at least known by almost half of the respondents. The popularity of the former may relate to the importance of classical SNA influence on HNR, where centrality measures in particular are widespread: 88% of the respondents indicated using concepts or methods from this field, while 21% indicated getting inspiration from the field of Complex Systems, and 15% from the field of Scientometrics (App. Tab. A18). Another possible explanation may be their easy accessibility due to their implementation in visualization tools, as well as pro-

61 In addition to these, various other visualization tools were mentioned, which might be useful to share: R-libraries (e.g. ggraph), igraph, nodegoat, UCINET, Cytoscape, QGIS, NetDraw, Pajek, Vistorian, NodeXL, Kumu, Tableau, Social Network Visualizer, ORALITE, Palladio, Epistemic Network Analysis, Organizational Network Analysis, Neo4j Bloom, graph-tool, matplotlib, and Citespace.

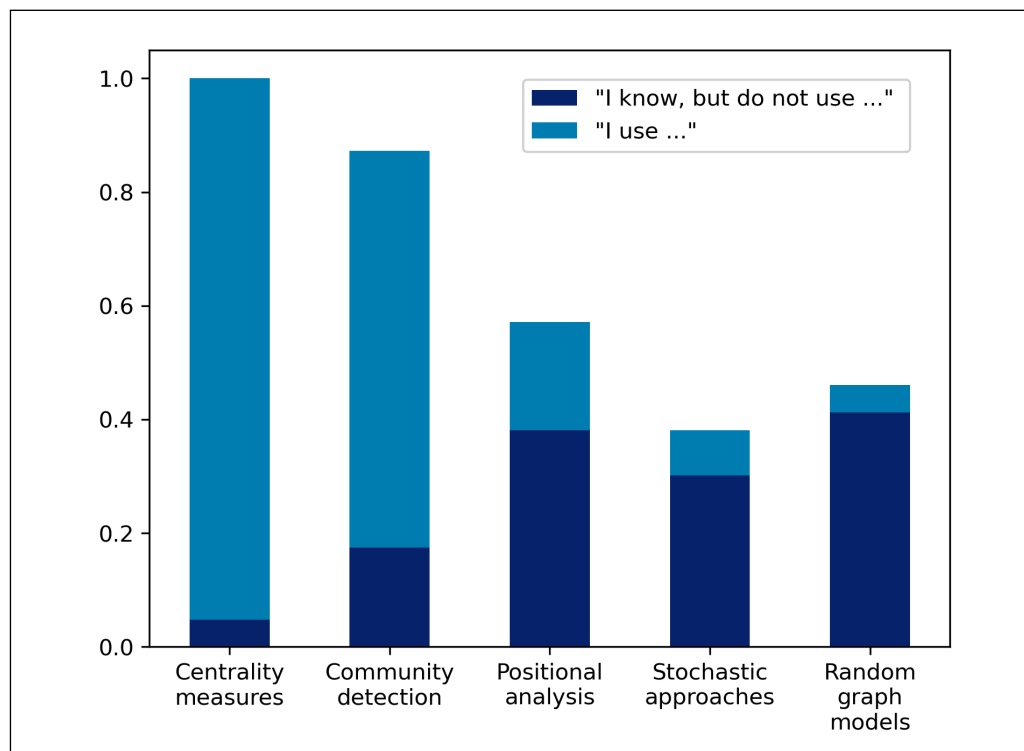


Fig. 3 The relative numbers of use and knowledge of different network analysis methods (n = 63)

gramming libraries. Nonetheless, it is noteworthy that these methods seem to act as a shared knowledge base for almost all of the scholars surveyed.

In addition to the aforementioned methods, the researchers mentioned various other methods that played a role in their projects. Regarding network simulation and modeling, the approaches mentioned included agent-based modeling, spatial interaction models, and configuration models. In terms of analysis methods for single networks, approaches for evaluating diffusion processes, link/node prediction, meso-scale analysis (e.g. k-core decomposition), and epistemic network analysis were also mentioned.⁶² Additional statistical methods like rank correlation, bivariate correlation and regression models were also integrated into the network analysis process. Furthermore, the analysis of complex relationships of networks was indicated by some respondents, with researchers indicating that they used methods for analyzing multiplex networks, the relationships between multi-layered networks (e.g. Quadratic Assignment Procedure (QAP), covari-

62 See e.g. DiMeo & Ruis 2019.

ance matrix), or differences in groups of networks (e.g. T-Test, Mann-Whitney-U-Test).⁶³

Regarding the difficulties of the respondents in the process of network analysis and visualization, the diversity of methods reflected in their responses may have, in some cases, contributed to uncertainties. One aspect here was the question of the suitability of methods for different network types (e.g. the applicability of structural network analysis metrics to lexical networks). Also, respondents struggled with specific questions that required a deep understanding of network analysis, e.g. the application of network analysis methods to dynamic or complex datasets, or using advanced mathematical analysis. Here, some researchers were missing help from colleagues with additional knowledge of network analysis and thus needed a joint assessment of the network analysis metrics. Additionally, some respondents indicated a lack of comparative studies and the possibility of replicating approaches or comparing results. Also, common proven approaches or methods were deemed to be missing. The last category of difficulties consisted of the proper interpretation of results, as well as an assessment of the implications of missing data for network analysis results (App. Tab A26).

Practices of data organization

Modeling and analyzing historical networks involves data processing, storage and potentially also sharing. The survey asked the respondents if and how they organize data in their research projects in terms of data formatting, modeling, and standardization. Additionally – and building upon the discourse of interoperability in the digital humanities mentioned before – we questioned respondents on the publication of datasets, code, and the subsequent results.

For data storage, by far the most common data formats among the respondents were CSV (84%) and Excel (58%), while JSON and GraphML were used by around 20% (App. Fig. A6).⁶⁴ To model the data, a little less than one third of the respondents affirmed that they use data models and/or ontologies in their research process (App. Tab. A22). In the experience of these scholars, this was seen as beneficial in terms of both the technical and collaborative aspects: data modeling was valued for comparing and integrating datasets, publishing data for easier reuse, sharing data, and analyzing data from multiple sources. The most commonly used standards were the CIDOC Conceptual Reference Model and the Resource Description Framework (RDF), but scholars also used a variety of other formats, including the Web Ontology Language (OWL) (App. Fig. A8). Further-

63 Other methods that were not directly associated with network analysis, but were also important in the research projects, include automated classification, Natural Language Processing (NLP), and image analysis.

64 Also mentioned were data formats like OWL, Pajek, Ncol and GML.

more, around a quarter of the respondents use authority files for data harmonization, metadata organization and storage (App. Fig. A7, Tab. A20). Here, Wikidata in particular was deemed useful for different entities, namely people, institutions, places, and objects. Besides Wikidata, researchers indicated that they most often use VIAF for people, GND for institutions, and Geonames for places (App. Tab. A21).

Finally, regarding the practices of digitally publishing datasets, code, and results, one third of the respondents already had experience with publishing online using open standards or tools for software publication (e.g. via Git or Jupyter Notebooks) (App. Tab. A23, A24). The researchers spent on average around one fifth of their project time on these forms of publication (App. Fig. A9). The scholars noted that this publication was beneficial in different ways, including the possibility of more detailed and extended publication of data and results, data disclosure and transparency for publications that do not require an official peer-review process, as well as a new ability to publish interactive network visualizations – a particular challenge in the field of HNR, where research outcomes may be networks as visual objects instead of traditional written text.⁶⁵ Only a minority of scholars were able to follow guidelines or find orientation concerning the best practices for publishing data, code and results online.

Data-related problems were by far the most commonly mentioned (37 times) and thus seem to be the most substantial problem area. By grouping the answers, it became clear that scholars face these in different steps of their research process: during data collection, data cleaning, and dealing with missing data. For data collection, problems included the organization of data, data scraping (e.g. from PDFs), as well as missing examples of best practices or guidelines. The process of data cleaning was deemed especially problematic for being too time-consuming. Many issues were related to disordered data: messy (e.g. uncured) or inconsistent data led to difficulties, and respondents also struggled with recognizing and disambiguating specific people, the incompatibility of different data-formats, and the linkage to and availability of pre-existing cleaned datasets. They also mentioned the uncertainty of comparing data over time, especially the question of whether one variable could represent the same entity at different points in time. Finally, dealing with missing data affected the scholars the most: here, the respondents struggled with detecting and evaluating missing data, the incompleteness of datasets, how to visualize potentially missing data and gaps in the dataset, and how to interpret missing data (App. Tab. 26).

65 Venturini et al. 2021.

Discussion

What can we thus ascertain from the survey results in terms of the practical side of HNR? Even if it is just a snapshot in time, we captured two trends in our survey results: first, HNR may currently be in a paradoxical stage of being both ‘historical SNA’ and ‘something beyond SNA’. Second, the variety of methods and tools mentioned speaks of a broad methodical landscape in which scholars attune the available indicators, software, and tools to their historical research, and thus partially experience difficulties due to technological and methodological prerequisites.

We build the first argument on a pattern of similar insights that occurred throughout the survey: while HNR scholars appear to have widespread knowledge of network analysis methods reaching beyond SNA, we still found that the vast majority of scholars applied classic SNA methods like centrality measurements and community detection algorithms which were often intended to represent social historical processes with social types of nodes and edges.⁶⁶ One explanation may be the easy accessibility of these methods, as network visualization tools like Gephi allow researchers to both make the necessary calculations and visualize their results.⁶⁷ Additionally, these methods have been applied to historical case studies many times before⁶⁸ and are explained in standard introductory literature to HNR.⁶⁹ However, while research on social relations seems dominant, various other types of nodes and edges were used as well. These can be understood as a research object-wise transgression beyond the scope of SNA – a dynamic that has been mentioned in HNR literature before.⁷⁰ This shift towards non-social objects seemed to be accompanied by an interest in the dimensions of time and space in networks, e.g. in the construction of archeological networks of objects, or networks spanning over a long time period. This interest in the dynamics of networks may be a factor in the methodical diversification within HNR, which may have been influenced by network science. We see evidence of this from the small group of scholars who affirmed that they use concepts from the interdisciplinary field of complex systems; indeed, around half of the scholars surveyed indicated that they had knowledge of the methods used for network modeling and simulation. The extent to which the interdisciplinary, yet more mathematically oriented field of network science has been adopted by HNR, and vice versa, could present an interesting desideratum for further research.

66 A similar observation was made by Brughmans 2013 for the use of formal networks in archaeology.

67 Jacomy & Jokubauskaitė 2022.

68 e.g. Preiser-Kapeller 2015; Deicke 2017.

69 e.g. Düring et al. 2016.

70 Lemerrier 2015.

Our second argument is based simply on the variety of different methods and tools mentioned by the researchers. Here, we recur to Lemerrier's important concern that in times of "methodological sophistication" historians may be at risk of becoming "pure data-providers for model-makers"⁷¹ – something that, in her view, can be prevented by methodological literacy. The fact that more than three out of four respondents used programming languages may be taken as a first indicator of such computer science literacy. In this sense, the observed variability of methodical approaches and tools could also hint at an ongoing exploration and tailoring of existing methods to HNR questions. However, it seems that the heterogeneity of methods also brought challenges to the researchers surveyed. Several mentioned a lack of comparative studies and proven common approaches, struggled with the question of which methods would be suitable for analyzing specific network types, and felt challenged by specific questions in their research projects that would involve a profound insight into network analysis, e.g. how to assess the incompleteness of a network, or which methods to apply to dynamic or complex data. Addressing these needs with additional resources may therefore be a fruitful endeavor for future projects in HNR. The same applies to the problems with incomplete or messy data within the processes of data collection and cleaning. We have seen that only a subgroup of the respondents used authority files, ontologies or data models, or published digitally with open standards. These techniques, which were designed with the aim of interoperability in mind, could potentially help foster collaboration and methodical exchange within the community.

Finally, we wish to conclude with some critical remarks that may be helpful for future research in a similar direction. Our survey appears to have reached a broad group of researchers in terms of disciplinary background, career, and level of experience and research interest. However, the narrow geographical concentration and the relatively small sample size remain a limiting factor. Thus, while we are confident that our results still yield valuable insights into network research practices in HNR, we would like to underline that our results primarily account for the survey respondents, and that questions of sample segmentation, and especially strategies for a higher survey completion rate, should be taken into account for further research. The high breakoff rate of almost 50% has further aggravated the small sample size. As this seems higher than usual breakoff rates,⁷² it raises the question of why people abandoned the survey early. Apparently, a peak of forty dropouts happened on the first page, which is dedicated to a description of the research project. The page started with an open text field for respondents to outline the research interest behind their project, and may have been abandoned in order to avoid the expected burden.⁷³ Additionally, as shorter surveys

71 Lemerrier 2015, p. 282.

72 Liu & Wronski 2018.

73 Galesic 2006; Liu & Wronski 2018.

with simple questions seem to prevent dropout,⁷⁴ the length of the survey and the number of open-ended questions may have been an additional reason. Since the open text fields were in general valuable to obtain extensive information and personal opinions, these might be placed differently in future survey designs.

Conclusion

It was the aim of this article to capture insights from historical network researchers in terms of their network research practices and their embeddedness within the wider HNR community, especially with a technical focus on methods and tools. While viewing what approaches appear to currently shape the field, we also wanted to open up discussions on the implications and possible further developments in HNR, as well as to pose an invitation to explore the diverse landscape of HNR methods and tools used by the respondents. From the literature review, we identified two main characteristics of HNR research: methodological and thematic diversity, and the challenges of working with historical data that is naturally complex and unsystematic. As reviews on the specific practices that shape HNR have yet to be produced, we conducted a survey on the methods and tools in use in present HNR research projects. Our results showed that SNA is still widely applied at the level of individual scholars and projects, as well as being the dominant means of analysis. Nonetheless, a transgression beyond SNA became apparent in the selected research focus, as well as an expanding interest in network science approaches that consider temporality and dynamics. This heterogeneity of research topics, concepts, and tools constantly confronts individual HNR researchers with challenges regarding the translation and attunement of network analysis methods to history, as many questions remain open. Therefore, we wish to emphasize the need for further resources that address issues of matching research interests and data to methods and network types, the handling of dynamic and complex data sets, and the lack of comparative studies. As many respondents faced data-related issues, strategies for dealing with missing, incomplete, or inconsistent data additionally seem to be much needed.

As this article can only provide an initial insight into the historical network research practices at this point in time, future research is necessary to shed more light on the questions and debates highlighted here. First, it seems valuable to enrich our research with qualitative data, namely further qualitative interviews or ethnographic research to better understand the work undertaken by HNR scholars, e.g. how they approach the apparatus of formal methods and make it work for their research questions and data, how the resulting networks are interpreted and analyzed, and how processes of knowledge transfer and negotiation between HNR scholars from different disciplinary backgrounds take place. Sec-

74 Mavletova & Couper 2015; Liu & Wronski 2018.

ond, we posit further quantitative research, as an enlarged sample would potentially allow inferential statistics. Here, group segmentation could yield insights into subcommunities of different kinds concerning disciplines, seniority, or research interests. Future quantitative inquiries could thus add a longitudinal perspective on the dynamic development of HNR.

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