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Time and Temporality as Categories of Connectedness

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Time and temporality need to be considered essential concepts when studying networks of the past. Nonetheless, their implementation introduces varying forms of complexity, which provides challenges to navigate when operationalized as attributes of humanities data, as categories and methods of analyses, and even as factors in our research process in need of being optimized. Adjusting to temporal perspectives in networks highlights the inherent multiplicity, ambiguities, and uncertainty in our data, our concepts, and our models of analysis, as well as within the network dynamics studied. But when studying historical networks as *static networks,* these issues often remain hidden and neglected, potentially skewing our interpretation of past networks. Due to the fundamental differences between temporal and static networks, Holme & Salamäki (2023) have stressed the need for "new methods, new concepts, [and] new questions" (p. 1).

To address these challenges, in July 2023, the conference "GrapHNR 2023" gathered an interdisciplinary group of researchers to discuss "Graphs and Networks in the Fourth Dimension – Time and Temporality as Categories of Connectedness." The methodological and conceptual issues and implications for the historical and archeological disciplines, as discussed at the conference, are situated against a wider background of engagement with temporal networks in adjacent disciplines. Within social network research, graph sciences, and the study of complex systems (influenced by a plethora of fields including the social sciences, computer science, math, and physics, among others), longitudinal/temporal/dynamic/time-varying[1] networks have a long history of being studied with multifaceted formalized approaches to grasp and model the complexities of temporal changes in networks appropriately.[2] When introducing time intervals as edge attributes to a network, this re-interprets edges as 'events,' with, e.g., the potential for information exchange or opportunities of interaction. The connectivity of the network system is also fundamentally altered, when paths follow a timeframe of existence.

Network Snapshots. Some formalized approaches aim to simplify the complexities of temporal networks by projecting them onto static networks, i.e., by limiting the network to contain only nodes and edges within a certain time interval (often referred to as: time-sliced networks/network snapshots/stream graphs[3]). To do so, the complete network is split into multiple static (sub-)networks at each chosen time-point. These static subnetworks (or snapshots) can be

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1 Proposed by Casteigts et al (2012).

2 E.g., Newcomb 1961; Huisman and Snijders 2003; Snijders et al 2010; Batagelj et al 2015. For an overview, see the introduction to "Temporal Network Theory": Holme and Saramäki 2023.

3 Proposed by Latapy et al (2018).

formally described with established network methods.[4] Comparing the structural composition and attributes of these network snapshots based on different timeframes or time-points enables us to track their evolution (or change) over time, analyzing the properties of each network snapshot individually, the differences between two or more network snapshots, and the characteristics of their aggregations when two or more network snapshots are merged. Which phenomena continue throughout the time interval(s) being studied, and which are lost? What changes can be observed? Network metrics and properties can be compared here on the macro-level (network properties, e.g., density, connectivity), on meso-levels (sub-structures, e.g., components, communities), and on micro-levels (nodes and edges, and their attributes).

Actor-oriented models for dynamic networks. Other formalized conceptualizations of temporal networks have embraced simulations. Through the method of (stochastic) actor-oriented modeling of dynamic networks (such as SIENA[5]), "composition changes are modeled as exogenous events that occur at given time points".[6] This allows us to test the underlying and structurally determined preferences for ties (based on, e.g., homophily, or transitivity).[7] A different, simulation-based conceptualization was proposed by Butts (2008) on Relational Event Models (REMs), which focuses on preserving the sequential temporal order of interactions for analysis.[8]

Translating formalized approaches of temporal network analysis to historical and archaeological research

For applications within the fields of historical and archeological research, these formalized approaches of dynamic and longitudinal *social* network analysis need to be translated and adapted to the complexities of cultural and historical data and their specific historical contexts.[9] For studying the past, temporality constitutes a fickle, even fuzzy property of historical and cultural data. Such data might contain incomplete, uncertain, or vague temporal characteristics, exhibit discrepancies between self-referred and/or technically derived dates, or hold contested or even contradictory claims. Cultural and historical data may be based on complex and culturally specific perceptions of time, such as different calendars,

4 Wasserman and Faust 1994, pp. 730–1; Hennig et al 2012, pp. 55–6; Batagelj et al 2014, pp. 23–5; Petz 2022, p. 78.
5 https://www.stats.ox.ac.uk/~snijders/siena/ (Last Accessed: 2025-03-28).
6 Huisman and Snijders 2003, p. 253; Snijders et al 2010.
7 See Lemercier 2015, p. 197.
8 For an overview: Bianchi et al 2024.
9 There, social networks are often based on survey data in order to understand how social structures develop over time (e.g., Batagelj et al 2015). These types of data, however, are rarely available in historical studies.

or dynamic or partially synchronized dating systems. Theories such as the paradox of "simultaneity of the non-simultaneous"[10] challenge us to closely examine our notions of temporality and the influences of our cultural predispositions on temporal standardization and scales. This requires us to expand our models to include a greater diversity of temporalities with regard to social and cultural developments, i.e., different 'flows' of time. This includes reconsiderations of when a person's influence on a network ceases, which might not necessarily coincide with their death; different methods may be needed to operationalize the duration and eventual 'decay' of nodes and edges – to give just one example of the many easily overlooked "general questions about memory and the impact of the past on the present".[11] On a meta-level, the reception and interpretation of historical subjects and historical objects throughout their 'lifespans', and often beyond, is also subject to change over time, reflecting developments and 'turns' in scholarly practices of knowledge production that need to be adequately expressed.

Beyond these conceptual considerations, thinking about time and temporality FAIRly poses additional challenges for ensuring the reusability and interoperability of the various conceptions of time and temporality in our data. Modeling temporal change(s) does not necessarily mean taking all of these considerations into account – however, our models[12] should support the epistemic process, and must thus focus on aspects deemed important depending on our research questions. While the terminology of models itself might sound foreign to historical studies, they are in fact already widely used, for example in the form of periodizations[13]. A periodization slices the continuous timeline of history into sections which share meaningful characteristics based on possible caesura points and according to the individual research object[14] – similar to the method of network snapshots detailed above. As humanities data is inherently volatile, and as there is not *one* right way to deal with ambivalence, the operationalization of our data and networks – our modeling decisions and assumptions – needs to be made explicit. In "Taking time seriously", Lemercier emphasized the need to precisely articulate research questions and experiment with different research designs, as well as to vary operationalizations and visualizations of volatile data, which may lead to different outcomes and insights.[15] While historical network research already bears a temporal connection in its name, most studies still focus on the 'final' aggregated network instead of its development in time-steps. A few take dynamic temporalities into account, comparing network snapshots using static visuali-

10 Coined by Ernst Bloch 1973, p. 104. Translated from German: "Gleichzeitigkeit des Ungleichzeitigen."
11 Lemercier 2015, p. 194.
12 Following the conception by Stachowiak 1973.
13 E.g., Flanders and Jannidis 2019, p. 3.
14 Pot 1999, p. 63; Osterhammel 2006, pp. 50–53.
15 Lemercier 2015, p. 196.

zations[16] or dynamic visualizations with tools such as *nodegoat*[17]. Some favor longitudinal analysis with visual comparisons using anchored node layouts[18] or grid layouts[19]. Others employ more sophisticated statistical measures to describe change in historical networks, for example when studying the cohesion and evolution of communities in networks[20], the effect of exogenous events on network structures[21], or utilizing agent-based modeling for hypothesis-testing[22]. How to model discrete and continuous time when dates are inherently fuzzy, however, remains a fruitful challenge.[23]

The conference

A powerful tool in this endeavor is the topology of the network, both as a means of communication of scope and relations, offering concrete quantification, but also as a heuristic method of knowledge production to spark discussion and creative exploration. The GrapHNR conference was framed by two keynote speeches, which examined the use of visualizations in network research and the humanities from two complementary perspectives: how can we visualize change and the passing of time, and how does this influence our heuristics?

In his opening speech "From Data to Stories with Visualization"[24], **Benjamin Bach** tackled one of the ever-present problems in network research: how to "see through the hairball" of a myriad of nodes and edges? Bach argued that visualizations possess a dual nature: as both artifacts of the research process and a methodology for exploring the data researched. Visualizations highlight but also obstruct our view of the data, and do not fully represent the information they are based on. Bach proposed using novel design and interactive components to strengthen "storytelling" with network data: time arcs, matrix cubes for dynamic networks[25], interactive time-series of measures, time curves, and even techniques of sequential storytelling such as graph comics to communicate more effectively with network visualizations.

16 E.g., Düring 2015.
17 E.g., Vugt 2017.
18 As, e.g., Rosé 2005.
19 Conroy et al 2022.
20 E.g., Petz et al 2022.
21 E.g., Bissieres 2023.
22 E.g., Lemercier & Rosental 2010.
23 Kudella 2019, p. 50.
24 https://docs.google.com/presentation/d/1UDlLYk_ORcUZK0PRCHmSeMBOQSn0mqA6avw8I4HpzaA/edit?slide=id.g1e4ec2a843a_0_147#slide=id.g1e4ec2a843a_0_147 (Last accessed: 2024-03-01).
25 Bach et al. 2014.

Adding to Bach's more technical considerations, **Johanna Drucker** focused on visualizations as graphical representations of concepts and constructs in the quest for knowledge production. In her closing keynote on "Modeling Temporality: Visualizing Chronologies & Graphical Modeling as Knowledge Production", she examined visual epistemologies in digital research and their graphical engagement with temporalities, as expressed in her current work on the "Chrono-Vis"-project. This experimental platform for humanistic modeling of relative and non-standard timelines aims to incorporate these into visual representations. For this purpose, she presented examples of what she and her team have termed "heterochronologies": "culturally specific understandings and epistemologies of chronology which demonstrate unique approaches to accounting for chronological events".[26] She subsequently built up the distinction between "time" as an *a priori* category of empirical research and "temporality" as a component of a hermeneutic, humanistic approach to understanding these chronologies as situated, culturally contingent, and historical conceptions.

Papers in this Special Issue

The contributions within this special volume aim to continue and expand the discussions of the GrapHNR conference on dealing with graphs and networks in the fourth dimension, and how to incorporate time, temporalities, and dynamics into graph technologies and network research.

In "Temporalities in the Spread of Knowledge", **Malte Vogl and Roberto Lalli** presented a workflow to study the development of socio-epistemic networks using time-dependent clustering of co-citations in order to track the development of scientific fields, focusing on the example of astrophysics in the 20th century. Instead of using 'post facto', often ahistorical metadata characteristics that are influenced by present views, they suggest utilizing an approach to cluster large corpora of co-citations and to explore the evolution of these both on a macro- and microscopic scale. This helps to disentangle different scientific fields with a structural analysis that goes beyond the infamous "fuzzy hairballs" of big data networks.

Matteo Valleriani, Hassan El-Hajj and Maryam Zamani investigated "Time as a Causal Factor" in the "Circulation of Astronomy Knowledge" based on the Sphaera-Sacrobosco dataset of Early Modern Astronomy books. They combine the analysis of multiplex (multi-layered) networks, which trace the interconnections of editions and textbooks on astronomy, with agent-based modeling. This allows them to take multiple temporalities of entities, institutions, environments, historical (historized) and social time, and even "future expecta-

26 Drucker et al. 2022, par. 2.

tion of time" into account, thus simulating a dynamic Early-modern book marketplace across time and space, and highlighting accelerations and innovation in the knowledge circulation dynamics of book production.

Tracking the changing temporalities of historical subjects, their relations and interactions, **Giulia Clarizia** analyzed the evolution of transatlantic relations between Italian Antifascists and US Intelligence Agents during 1943–1953. There, she focuses on the development of ego-networks of the agents Allen Dulles and Alfredo Pizzoni, their personal, financial, and institutional connections, and the influence of these connections in terms of the political impact they could exert. Though its emphasis is on interactions at the individual level, the study balances the ever-present disparities between quantitatively measurable connections and qualitative interpretations.

Tackling the problem of "sifting through the haystack" of large quantities of text, such as collections of diaries, **Ashley Dennis-Henderson, Matthew Roughan, and Jonathan Tuke** propose identifying entries and dates of interest in "Temporal Network Analysis as a Method to Explore Australian World War I Diaries." They map diary entries in vector representations as networks based on cosine similarity in order to identify both outliers and representative texts and diaries within a collection, offering a novel way of distant reading of the historical sources.

Integrating time into network analysis also means that the flow of information not only has a semantic direction (for example, who writes to whom) but also a complex chronological one. **Ramona Roller** adds this consideration to her analyses of correspondence networks by studying time-respecting paths from a micro-historical perspective in "Time-Respecting Paths in Letter Networks Reveal Opportunities for Influencing Information Transmission during the European Reformation". She models information transmission in letter correspondence networks of 16th century Protestant reformers in three different dimensions: access to information, resilience of information diffusion, and control of information flows.

In "Dating dated sites", **Florian Thiery and Allard Mees** address another fundamental issue of historical research: the uncertainty of dates and how we run the danger of constructing a *circulus vitiosus* when we infer the date of an object – or even an entire site – based on other assumed dates. Using the example of sections of the *limes* in the Roman provinces Britannia and Germania, they showcase how to combine statistical methods and semantic web technologies, such as temporal reasoning, to establish a chronological order of these dated sites that takes these uncertainties into account.

Networks in the Fourth Dimension

A decade has now passed since Claire Lemercier (2015) famously encouraged historical network researchers to "take time seriously." Integrating 'time' as a category of connectedness into our analyses fundamentally requires cross-disciplinary collaboration: between network researchers and complexity scientists working on historical data and topics, and archeologists and historians working with network methodologies and concepts. While new operationalizations are needed for these endeavors, we do not always have to 'reinvent the wheel': approaches from disciplines such as network science, graph theory, complexity studies, and the social sciences can all contribute to an improved handling of temporal data when studying the past. This, too, introduces another level of temporality into our research: the conflicting temporalities inherent to the rapid evolution of technologies that require us to constantly re-assess how we deal with data.[27] This special issue aims to provide a 'stepping stone' on the way to a considerate, nuanced approach to studying temporal dynamics and change in networks through all fields of history, highlighting the profound importance of well-considered conceptualizations, explicit models, and their thorough documentation as an essential part of computational approaches to the study of the past, and historical network research.

Bibliography

Bach, Benjamin, Emmanuel Pietriga, and Jean-Daniel Fekete. 'Visualizing Dynamic Networks with Matrix Cubes'. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* 877–86. New York: Association for Computing Machinery, 2014. doi: https://doi.org/10.1145/2556288.2557010.

Vladimir Batagelj, Patrick Doreian, Anuska Ferligoj, and Natasa Kejzar. *Understanding Large Temporal Networks and Spatial Networks: Exploration, Pattern Searching, Visualization and Network Evolution.* New York: John Wiley & Sons, Ltd, 2014. doi: https://doi.org/10.1002/9781118915370.

Batagelj, Vladimir, Doreian, Patrick, Ferligoj, Anuska, and Kejzar, Natasa. 2014. Understanding Large Temporal Networks and Spatial Networks: Exploration, Pattern Searching, Visualization and Network Evolution. First. Wiley Series in Computational and Quantitative Social Science. John Wiley & Sons, Ltd.

Barats, Christine, Valérie Schafer, and Andreas Fickers. 'Fading Away … The Challenge of Sustainability in Digital Studies'. *Digital Humanities Quarterly* 014, no. 3 (2020). http://www.digitalhumanities.org/dhq/vol/14/3/000484/000484.html (Last accessed: 2025-09-12).

27 As addressed by, among others, Barats et al. 2020.

Bloch, Ernst. *Erbschaft dieser Zeit.* Frankfurt a.M.: Suhrkamp, 1973.
Bianchi, Federica, Edoardo Filippi-Mazzola, Alessandro Lomi, and Ernst C. Wit. 'Relational Event Modeling'. *Annual Review of Statistics and Its Application* 11 (2024): 297–319. doi: https://doi.org/10.1146/annurev-statistics-040722-060248.
Bissieres, Louis. '"Taking Time Seriously": An Empirical Approach to an American Merchant Network at the End of the 18th Century'. *Journal of Historical Network Research* 8 (2023): 56–90. doi: https://doi.org/10.25517/jhnr.v8i1.142.
Butts, Carter T. 'A Relational Event Framework for Social Action'. *Sociological Methodology* 38 (2008): 155–200.
Casteigts, Arnaud, Paola Flocchini, Walter Quattrociocchi, and Nicola Santoro. 'Time-Varying Graphs and Dynamic Networks'. *International Journal of Parallel, Emergent and Distributed Systems* 27, no. 5 (2012): 387–408. doi: https://doi.org/10.1080/17445760.2012.668546.
Conroy, Melanie, Kimmo Elo, Malte Rehbein, and Linda von Keyserlingk-Rehbein. 'Visualizing the Evolution of Historical Networks Using Small Multiples in Grid Charts'. *Journal of Historical Network Research* 7, no. 1 (2022): 86–113. doi: https://doi.org/10.5072/jhnr.v7i1.87.
Drucker, Johanna, Peter Polack, and Pietro Santachiara. 'Heterochronologies: A Platform for Correlation and Research in Temporal Graphics'. *Digital Humanities Quarterly* 16, no. 3 (2022). https://www.digitalhumanities.org/dhq/vol/16/3/000624/000624.html (Last accessed: 2025-09-12).
Düring, Marten. Verdeckte soziale Netzwerke im Nationalsozialismus: Die Entstehung und Arbeitsweise von Berliner Hilfsnetzwerken für verfolgte Juden. Verdeckte soziale Netzwerke im Nationalsozialismus. Berlin/Boston: De Gruyter, 2015. doi: https://doi.org/10.1515/9783110368949.
Flanders, Julia, and Fotis Jannidis. 'Data Modeling in a Digital Humanities Context. An Introduction'. In *The Shape of Data in Digital Humanities. Modeling Texts and Text-Based Resources,* edited by Julia Flanders and Fotis Jannidis, 3–25. Digital Research in the Arts and Humanities. London: Routledge, 2019. doi: https://doi.org/10.4324/9781315552941.
Hennig, Marina, Ulrik Brandes, Jürgen Pfeffer, and Ines Mergel. *Studying Social Networks. A Guide to Empirical Research.* Frankfurt/New York: Campus, 2012.
Holme, Petter, and Jari Saramäki. 'A Map of Approaches to Temporal Networks'. In *Computational Social Sciences,* edited by Petter Holme and Jari Saramäki, 2nd edn, 1–24. Cham: Springer International Publishing, 2023. doi: https://doi.org/10.1007/978-3-031-30399-9_1.
Huisman, Mark, and Tom A. B. Snijders. 'Statistical Analysis of Longitudinal Network Data With Changing Composition'. *Sociological Methods & Research* 32, no. 2 (2003): 253–287. doi: https://doi.org/10.1177/0049124103256096.

Kudella, Christoph. 'How Do We Model the Republic of Letters?' In *Reassembling the Republic of Letters in the Digital Age. Standards, Systems, Scholarship,* edited by Howard Hotson and Thomas Wallnig, 41–53. Göttingen: Universitätsverlag Göttingen, 2019. doi: https://doi.org/10.17875/gup2019-1146.

Latapy, Matthieu, Tiphaine Viard, and Clemence Magnien. 'Stream Graphs and Link Streams for Modeling of Interactions over Time'. *Social Networks Analysis and Mining* 8, no. 1 (2018): 61:1–61:29. doi: https://doi.org/10.1007/s13278-018-0537-7.

Lemercier, Claire. 'Taking Time Seriously: How Do We Deal With Change in Historical Networks?' In *Knoten und Kanten III: Soziale Netzwerkanalyse in Geschichts- und Politikforschung,* edited by Markus Gamper, Linda Reschke, and Marten Düring, 183–211. Bielefeld: Transcript Verlag, 2015.

Lemercier, Claire, and Paul-Andre Rosental. *The Structure and Dynamics of Migration Patterns in 19th-century Northern France.* Portail HAL Sciences Po, 2010. https://sciencespo.hal.science/hal-01063603v1 (Last accessed: 2025-09-12).

Newcomb, Theodore M. 'The acquaintance process as a prototype of human interaction'. In *The acquaintance process,* edited by Theodore M. Newcomb, 259–261. New York: Holt, Rinehart & Winston, 1961. doi: https://doi.org/10.1037/13156-015

Osterhammel, Jürgen. 'Über die Periodisierung der neueren Geschichte (Vortrag in der Geisteswissenschaftlichen Klasse am 29. November 2002)'. *Berlin-Brandenburgische Akademie der Wissenschaften, Berichte und Abhandlungen* 10 (2006): 45–64. https://nbn-resolving.org/urn:nbn:de:kobv:b4-opus-10739 (Last accessed: 2025-09-12).

Petz, Cindarella. 'On Combining Network Research and Computational Methods on Historical Research Questions and Its Implications for the Digital Humanities'. Dissertation, Technische Universität München, 2022. https://nbn-resolving.org/urn:nbn:de:bvb:91-diss-20220202-1624881-1-5 (Last accessed: 2025-09-12).

Petz, Cindarella, Raji Ghawi, and Jürgen Pfeffer. 'Tracking the Evolution of Communities in a Social Network of Intellectual Influences'. *Journal of Historical Network Research* 7, no. 1 (2022): 114–54. doi: https://doi.org/10.5072/jhnr.v7i1.146.

Pot, Johan Hendrik Jacob van der. Sinndeutung und Periodisierung der Geschichte. Eine systematische Übersicht der Theorien und Auffassungen. Leiden/Boston/Cologne: Brill, 1999.

Rosé, Isabelle. 2011. "Reconstitution, représentation graphite et analyst des rébeaux de pouvoir au haut Moyen Âge. Approach des pratique socials de l'aristocratic à parter de l'exempla d'Odin de Cluny († 942)." REDES–Revista Hispano para el anàlists de redes sociales 21 (5). https://revistes.uab.cat/redes/article/view/v21-n2-rose/420-pdf-en.

Snijders, Tom A. B., Gerhard G. Bunt, and Christian Steglich. 'Introduction to Actor-Based Models for Network Dynamics'. *Social Networks* 32 (2010): 44–60. doi: https://doi.org/10. 1016/j.socnet.2009.02.004.

Stachowiak, Herbert. *Allgemeine Modelltheorie.* Wien, New York: Springer Verlag, 1973.

Vugt, Ingeborg van. 'Using Multi-Layered Networks to Disclose Books in the Republic of Letters'. *Journal of Historical Network Research* 1, no. 1 (2017): 25–51. doi: https://doi.org/10.5072/jhnr.v1i1.7.

Wasserman, Stanley, and Katherine Faust. *Social Network Analysis: Methods and Applications.* Structural Analysis in the Social Sciences 8. New York: Cambridge University Press, 1994.