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Taking time seriously

How do we deal with change in historical networks?

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Sociologists are arguably the first, among humanists and social scientists, who have built a consistent canon of social network analysis. This includes often cited pioneering papers, the concepts and indicators that these had introduced, software allowing to calculate such indicators and to produce more and more standardized visualizations, and textbooks summing up and coagulating these elements (e.g. Scott/Carrington 2011).[2] In this canon, standard network data typically include a dozen to a few hundreds individuals or organizations, whose ties are described thanks to sociometric surveys, i.e. by asking individuals about one or a few specific types of relationships at a given moment. Non-standard data of course have always exi-

1 Previous versions of this text have been presented in various conferences and seminars and have very much benefited from collective discussions. I am especially grateful to Fabien Accominotti, Claire Bidart, Ainhoa de Federico, Michel Grossetti, Karim Hammou, Linda Reschke, Isabelle Rosé and Tom Snijders, who in various ways made me take time more seriously, and even more to Marten Düring, who made invaluable comments on a first draft. Figures are reproduced with permissions from the authors and the journal.

2 In fact, the sociologists who built this specific canon of quantitative and structural network analysis had borrowed their main ideas to a previous generation of anthropologists and social psychologists: see Freeman (2004).

sted, even more so before the mid-1990s, when social network analysis was still in the process of institutionalization; but the continuous improvement of specific methods for data gathering, analysis and visualization has fostered standardization. The analysis of longitudinal data, along with e.g. multiplex data and negative relationships and thus data, which reflect – or are considered to reflect – change, was more or less left fallow. Interestingly, all these features that are nowadays considered as complicated variants were present in the core examples discussed in a key paper by pioneers before standard software became available (White/Boorman/Breiger 1976). This is not to say that there have been no papers discussing the concept of change in networks since 1976, but they have not been produced in a cumulative fashion and they do not, for better or worse, provide historians with a „how to" guide.

We are now facing a new wave of network analysis. Physicists have come up with their own questions, tools – including simulation: one way among others to think about dynamics –, and preference for large datasets. Historians, archaeologists, geographers, political scientists, etc. increasingly use tools borrowed from sociologists and/or physicists, often naively, but also in ways that expose the limitations of these tools, due to the privileged status of standard datasets and questions. Hence a growing interest in questions of space and time in network analysis.[3]

In recent conferences and discussion lists centered on non-sociological disciplines, historian beginners in network analysis have regularly come up with embarrassing questions: How do I project my network on a map? Which software do I use if I want my ties to have two separate colors simultaneously? How do I input dates in the file that includes my tie data? And what happens if these dates are intervals or question marks, due to imperfect sources? These questions are basic and important for our discipline, but difficult to deal with in the context of current standard software. This does not imply, however, as is often stated, that our sources are not good enough (not perfect enough and/or not simple enough) to be used in

3 In 2013, three separate events on this topic were organized by „groupe FMR", mostly founded by French geographers, by NeDIMAH, the Network for digital methods in the arts and humanities, and as „ARS'13", organized by Italian economists.

network analysis; nor does it imply that network analysis is inherently static or blind to space. It merely reflects the fact that software has evolved, during a few decades, in the direction that fitted most of the sociological demand and was the simplest in computational terms. This can change, however, as a new demand arises and computers become more powerful. More importantly, questions and theories in network analysis can change thanks to the input of new disciplines.

As regards improving software in order to deal with time, two very difficult topics have already been addressed by statisticians and computer scientists in a cumulative way, generating new algorithms – although, of course, those have not solved all the practical problems. On the one hand, interpretable animated visualizations of changing networks can be produced; on the other hand, the so-called „actor-oriented" statistical modeling offers a specific way to test hypotheses about network dynamics. Historians should be aware of these tools, and I will briefly present their purposes in the second part of this chapter. Software, however, should be a mere tool for us, and these algorithms are only useful for some specific types of data and questions. I will also present, in the second part of the chapter, simpler representations of change in network, adapted from classical archaeological and historical tools. As there is yet no canon of historical network analysis, I take this opportunity to promote experimentation rather than a too hurried standardization of our tools.

In the same spirit, I will argue, in the first part of this chapter, that we need to take time more seriously at each stage of our investigations, not just at the advanced stages of drawing graphs or devising models. These preliminary stages in fact determine the very possibility of creating meaningful graphs and models. Yet two of these stages are rather under-discussed in the literature: the definition, gathering and coding of data, and the drawing up of research questions, or hypotheses. Which role does time play at these and other stages of research, and which precautions should we take in order not to end up with an a-historical network?

My discussion of these questions will be based on my own research experience and readings, which cannot claim to be exhaustive: While some parts of the relevant literature are visible as such and connected by citations, others are the product of individual experimentation, scattered in ol-

der or yet in-the-writing texts by historians, sociologists and others. I only hope to open a general discussion that is more practical than theoretical, but practical in the sense of rooted in the historians' practices, not centered on tools per se.

1. Multiple dimensions of change in networks

Before addressing the visualization or modeling of change itself, it is important to discuss the many different ways in which timing and change could, or should, be taken into account when we think about historical networks. Each visualization or modeling tool can only deal with some of these dimensions. As we are now accustomed to thinking of networks as graphs, we often tend to think of change in networks in terms of a series of snapshots. I will begin with this simple idea, but insist on the fact that „change in a network" in fact covers many dimensions of change that have to be carefully distinguished. Provided that the researcher is aware of such distinctions, comparing snapshots can provide important historical insights, especially into processes of (de-)institutionalization. However, in the next sub-part of this chapter, I will emphasize the fact that historical information is not naturally shaped as snapshots. Hence, important choices have to be made if we want to represent it as such. Snapshots implicitly imply that individuals, organizations, and their ties have a date of birth and a date of death, which is never obvious and never obviously found in historical sources; but taking this issue into account has the potential to help us think more seriously both about networks and about time.

1.1 Change in panel data: Comparing snapshots

When tools exist to deal with time in social network analysis, they have typically been designed to accommodate so-called panel studies. Sociologists have long recognized the limitations of data on relationships among a group of people (or data on ego-networks) that only refer to one point in time. They have attempted to solve this problem by revisiting their respective case studies after a few months or years and collecting network

data for a second time – which is costly and difficult[4], but often produces interesting results.

In such typical „panel data", we find the same actors at two or more moments with different ties among them; in ego-networks, we have the same egos but not necessarily the same alters. It is likely that some attributes of the actors will have changed, in addition to the obvious cases of age and seniority; this already complicates visualization and modeling. In addition, changes in location or other attributes related to the ability or will to answer sociometric surveys often produce a change in the list of actors for whom information is available. Furthermore, if the boundaries of the observed network are institutional or if it is based on snowball sampling, it is likely that the list of nodes that should be observed will be quite different at separate moments, meaning that the members of an institution X or the contacts of person A and their contacts will not be the same individuals as in the original study. Researchers therefore have to balance two requirements: the *continuity of observation*[5] vs. the substantive *relevance of the boundaries*[6] of the observed network . Depending on the choice made on this boundary issue, the type and amount of change in networks that will be observed is likely to be quite different. Decisions therefore have to be made in order to ensure comparability, and should be made for substantive, historical reasons, not dismissed as technical quibbles.

This can be exemplified in the case of „interlocking directorates"

4 See for example the study of migrants in Spain discussed in Molina/Lerner/Gómez Mestres 2008 and Lubbers/Molina/Lerner/Brandes/Ávila/McCarty 2010. The research design is particularly interesting, especially in that interviewees were asked to comment on changes in their networks, thus helping to build hypotheses; but only a few dozens ego-networks could be reconstructed.

5 The relationships of the people, who were members of X *at time 0* are followed with the prospect that – at some point – some of them will not be members anymore. Members who joined afterwards, and their ties to others, are excluded from observation.

6 All the ties between the members of X will be exclusively observed for each time period, accepting that – at some point – the network will not include the exact same individuals as at time 0.

studies, based on yearly directories or reports on firms listing the members of their boards: These sources generated some of the first descriptions of change in historical networks (e.g. Roy 1983; see also Krenn 2010). Even with such seemingly simple sources, boundary problems are made even more acute in the case of longitudinal data. Should we compare, for example, interlocks between all the firms listed in the Paris stock exchange in 1911 and in 2011 (an institutional boundary)? These networks would differ so much in the number of nodes that it would become very difficult to compare their structures. Conversely, if we try to track ties in 2011 between the firms that were listed in 1911, we are at risk of not even being able to identify these firms and, more importantly, of considering a network between firms that had important things in common in 1911, but not in 2011. If we only take into account the firms that were listed both in 1911 and 2011, we come up with a very small and extremely specific (although interesting) sample. Finally, if we focus on, for example, the 100 firms with the largest share capital at each date (a different institutional boundary), we overcome the issue of comparing networks of an extremely different size. We still have to deal with the fact that the individual nodes in the network differ, which may or may not be a problem, depending on our research questions. More importantly, we have to remember that the very (legal, managerial, social) definition of a board in fact changed between the two periods. For example, in 1911 some of the board members specialized in verifying accounts, while others also acted as top managers of the firms; in 2011 these two roles have become more specialized and their holders are not considered as part of the board anymore. „Interlocks“, i.e. common members in boards – the type of tie between firms that we want to concentrate on – have a very different substantive content and likelihood to appear in 1911 and in 2011; all these aspects have to be taken into account when interpreting numbers or graphs.

More generally, even if we dismiss the changes in the list of nodes and only concentrate on changes in ties between those nodes that are observed in several waves, panel studies are likely to re-open interesting questions on the coding of relationships. The aim is often to know whether, how or why some relationships switch from non-existence (0) to existence (1), or vice versa. In some cases, it might be possible and even more interesting to

think about change in the strength or contents of ties. Furthermore, interaction in survey research, as well as historical sources such as diaries or personal letters, might allow researchers to distinguish broken but remembered ties from forgotten ones.

Panel studies therefore are an incentive for researchers to think about choices that have too often become implicit in static network analysis: first, the drawing of boundaries (a theme that is surprisingly under-represented in the literature; see however Laumann/Marsden/Prensky 1983 and Eloire/Penalva-Icher/Lazega 2011); secondly, the coding of ties, that necessarily aggregates relationships with a slightly different strength or meaning (for an excellent discussion, see Düring 2012: 75-102); thirdly, the non-differentiated analysis of unstable and enduring attributes. While static observation only allows us to discuss correlations between ties and attributes, e.g. the prevalence of ties among people sharing an attribute (*homophily*), longitudinal observation, at least in some cases, offers possibilities to disentangle processes. Sociologists have recently pointed out its potential for the discussion of social influence and social selection. Social influence describes a process in which actors tend to become more similar, for example to adopt the same behavior, because they are strongly related. Social selection on the other hand describes a process in which ties to alters, who are too different from ego, tend to be severed while ties to similar alters are sought-after.[7] This distinction also makes sense for many historical processes, i.e. the closure of a social elite or that of a mobilized group, and could be integrated in historical conceptualization.

The added complexity of panel data, or series of snapshots, as compared to static networks, thus complicates the analysis, but allows researchers to ask more subtle questions. In an attempt at listing what could be analyzed from repeated observations of ego-networks, sociologists (Feld/Suitor/Gartner Hoegh 2007) mentioned the persistence of ties over time (type 1), change in the contents of persistent ties (type 2), change in the size of ego-networks (type 3), and changes in the overall composition of ego-

7 This distinction is clearly introduced at a conceptual level by de Federico de la Rúa 2007. For a list of many papers statistically testing selection and influence in a variety of field studies (often centered on adolescent behaviors) see http://www.stats.ox.ac.uk/~snijders/siena/siena_applications.htm (25.10.2013).

networks in terms of attributes of the alters, e.g. gender, profession, age, etc. (type 4). This is a useful list for historians interested, for example, in correspondences; but it actually deals with the evolution of *lists* of contacts, not of ego-*networks* in the strong sense, those that include information on ties between alters and that specifically require network analysis. To analyze them, we need to focus on a fifth type of change: that in the overall structure of the (ego-)networks, i.e. the persistence and formation of ties among alters (Lubbers/Molina/Lerner/Brandes/Ávila/McCarty 2010). This „type 5 analysis" focuses on the evolution of various indicators of structure, sometimes discussing their correlation with attributes of the alters.

Very interesting substantive conclusions have been reached in social science research by studying such indicators over time based on panel data extracted from historical sources (in the sense of written, pre-existing material as opposed to interviews). Among those from which historians could borrow not only methods, but also ideas applicable to similar questions for a more distant past, are for example:

- a path-breaking, but too often forgotten history of the development of a scientific specialty – molecular biology – in the 1930s-1960s (based on a collective book written by the actors; Mullins 1972),
- research on the birth of a new „art world", that of rap artists recognizing each other as such, during the 1990s and 2000s in France (based on tracklists on records and audio tapes: Hammou 2009),
- a study of English suffragettes acting alone or in more or less overlapping small groups, making good sociological use of simple historical information extracted from court records (Crossley/Edwards/Harries/Stevenson 2012),
- research on the emergence, or non-emergence, of local high-tech „clusters" in various US cities in the last decades of the 20th century (based on contracts between firms; Powell/Packalen/Whittington 2012), and
- work in progress on the co-operation between various organizations in the peace-keeping process in South Ossetia in 1990-2005, as recorded in official databases (Pellon 2013).

These seemingly very heterogeneous case studies have two important things in common. First, the number of actors and ties described during each time slice is low enough so that a series of graphs can already give readers an idea of changes in the overall structure, although these graphs are generally accompanied by network indicators in order to strengthen the demonstration. Secondly, despite the variety of themes, all authors are interested in a process of institutionalization – or delayed or failed institutionalization, or de-institutionalization. They are looking for a dense and ordered set of connections, which emerge (or do not) from sparse and seemingly random ties. This question on the birth (or non-birth or death) of institutions, i.e. meso-/macro-scale enduring structures, is certainly of interest for many historians. Its typification by Mullins (1972: 53) in terms of a scientific specialty born of a paradigm group, then a network, then a cluster, each stage being characterized as a specific configuration of multiplex relationships, is especially inspiring, beyond science studies.[8]

If institutionalization is the substantive question at stake, it does not always matter whether actors in the successive snapshots are the same or not: Actually, the fact that a structure endures while actors change might in itself be considered as a key criterion of institutionalization. It is probably the question for which the calculation of indicators from panel data (such as density, centralization, etc.) and the visual inspection of successive small graphs or „blockmodels“ provides the most useful answers. Successive snapshots may allow us to discover an enduring structure, or general shape of the network, in spite of many changes in the nodes or in specific relationships – the very definition of an institution. It is for example the main result in François/Lemercier (2014). Such snapshots may also demonstrate the emergence, absence or collapse of such a structure.

In other cases of the „type 5 analysis“ we are interested in the precise and possibly changing shape of a series of ego-networks rather than the order or anomie in an overall structure: Are the ego-networks centralized (star-like), disconnected, clustered, etc.? When we already have an idea of the ideal typical shapes that we are looking for, it is possible to match these

8 In addition, for a thought-provoking list of possible abstract network mechanisms related to the birth or death of institutions and organizations, see Padgett/Powell 2012.

ideal types with snapshots and to discuss trajectories of (ego-)networks. Two elaborate examples of this kind of research could inspire historians. As for personal networks, a detailed interview-based investigation of change in those of French young people in their twenties used a typology of ego-network shapes in order to discuss which life events (e.g. moving to a new place, leaving a partner) could lead to a specific change in shape (Bidart/Cacciuttolo 2013). As for organizations, a study of the transition to capitalism in Hungary based on written documents used the same typological approach to discuss the changing „local network topographies" of individual firms in the context of a national network of ownership ties (Stark/Vedres 2006). This allowed the identification of typical and rare patterns in the trajectories of firms between successive positions in the network.

I only know one example of the same analytical strategy applied by a historian to historical data: the comparison between six snapshots of two ego-networks of help provided to Jews in hiding in Germany during World War II (Düring/Bixler/Kronenwett/Stark 2011). Although each ego-network includes less than a dozen of nodes, the density of information makes them extremely interesting – and difficult to represent. Visual comparison, in this case, helps to assess the comparatively high density and diversity of some networks at some points in time. In addition, the visualization allows the reader to know whether the same nodes were present at successive moments in the same ego-network: focusing on structure (the „type 5" analysis" presented above) does not necessarily comes at the expense of dealing with the persistence of individual ties (type 1). However, careful choices of boudaries, coding and visual representations have to be made if we do not want to inadvertantly concentrate on only one dimension of change.

1.2 Assigning dates to ties: difficult decisions

The choice of tools for analysis and visualization therefore has to be rooted in the specification of research questions, in the case of panel data even more so than in that of more standard network data. There is no one best way for the analysis or even description of such multidimensional data.

Change is multidimensional, and we need more than one view to assess it. I have presented examples of some of these views, assuming that historical data are akin to sociological panel data. But is this really the case? In fact, we always have to construct data from our sources, in ways that are driven by the sort of analysis that we have in mind. Network snapshots are of course not an exception: If we are not aware of the choices made when creating datasets, and especially when assigning dates to nodes and ties, we are at risk of producing graphs and numbers that are neither true to our sources nor suitable for our research questions. As soon as panel data have been constructed from the historical sources, calculations and visualizations are no more complicated than in sociological research and can be inspired by it; but constructing panel data requires all our historical skills.

Thinking of panel data as snapshots is in fact already a simplification, and even more so when simultaneity is assumed at a fairly wide time scale, such as one or several years. The stock exchange directories that I already mentioned, for example, present lists of board members for a given year; but the archives of each company describe changes happening at specific moments, so that co-membership as presented by directories is only an approximation. At the scale of one year, it is arguably a reasonable approximation for most research purposes, but it is not necessarily so in other cases. For example, Camilo Argibay (2011) has studied overlaps between various groups of leaders in left-wing organizations or editors of left-wing political journals in France in the 1970s and 1980s, from lists found in the archives or publications of each organization.. In some cases, leaders changed very often, in others, they kept their seats for years. According to his research questions, Argibay chose to draw graphs covering periods of several years: He therefore needed to decide on how to represent change happening *during* each „snapshot“, the term used rathermetaphorical here, as the time periods are actually quite long. If he represented each organization as one node, he would indicate co-membership for some leaders, who in fact had succeeded one another.The alternative possibility was to represent some of the organizations as several different nodes (e.g. Socialist Party 1972 vs. Socialist Party 1973), accounting for the fact that they were led by different groups. There is no one best strategy in such a case that occurs quite often in co-membership

studies; but choices should be made explicit and based on substantive reasons, as they are likely to influence interpretation.

Choosing a time span for a visual representation or for the calculation of indicators is generally a decision that historians have to make explicit – as opposed to researchers gathering interviews, who can only talk about „interview wave 1“, „interview wave 2“, etc. and hope that interviews in each wave have been simultaneous enough for snapshots to make sense. As sociologists interested in more continuous network data put it, „we must identify chunks of time that substantively capture the nature of relational events and the character of temporary networks that arise in the focal context“ (Moody/McFarland/Bender-deMoll 2005: 1211). Figure 1 in Bender-deMoll/McFarland 2006 gives an impressive example of how the choice of specific time spans can give birth to entirely different network structures.

This choice of a time span should urge us to take another question very seriously: that of the more or less implicit dates of birth and death that we assign to the entities that we study as well as to their ties. Is the national council of the French Socialist Party in 1972 the same entity as that of 1973? Could we represent it as two different nodes, although it bears the same name? Dates of birth and death are not necessarily simpler to deal with in the case of human beings. Do people, who die, immediately disappear from their own networks, creating gaps where there were bridges?[9] Or should we maybe consider them as shadows for some time, in order to check whether their contacts found ways to replace them by more direct relationships, or to account for the fact that an indirect relationship mediated by a now dead person does not immediately vanish from memories and might still shape practices? An interesting representation of family relationships in the *domus Augusta* shows that at some point, if the dead are excluded from the network, there is no structure anymore (Düring/Bixler/Kronenwett/Stark 2011). In order to point that out, we have to allow for the two options: hiding or showing their position as nodes.

This question about the dead in networks is actually part of the wider problem of the duration that we assign more or less explicitly to ties. Even

9 This question has been discussed in a qualitative but precise way by Dolan 1998.

if we decide that dead actors should disappear from graphs and calculations, the question of severed ties remains important.[10] Should we consider former spouses to have the same (non-)relationship as random single people? Should we create a separate relationship („formerly married“)? And until when should we maintain it? Should we apply a „decay function“ to ties that we consider, for some reason, to be past, not present, but that might still have an effect, even a decreasing effect, for a given duration?

Such problems are generally overlooked in the case of single observations, but become important in longitudinal studies and especially when continuous timing is transformed into snapshots. They are actually general questions about memory and the impact of the past on the present, which are too easily overlooked in traditional historical research as well as in network research. They surface when data construction is taken seriously. There are many practical – certainly not perfect – ways to deal with them, but these solutions are preferable to acting as if ties had an infinite duration or as if past ties never mattered. Snapshots can be chosen in order to overlap (e.g. 1971-72, then 1972-73), so as not to artifically separate ties that exist at the end of a period and at the beginning of the next. Decay functions can assign a lower strength to past ties.[11] These

10 On the difficult construction of matrices of simultaneous ties, even in the seemingly simple case of demographic data (birth, baptism, death, marriage, divorce), see Fertig 2009 and Munno 2010.

11 In the wider research related to the aforementioned paper, Karim Hammou experimented with this strategy to discuss the significance of past artistic cooperation. When does the fact of having recorded a song together cease to be meaningful for actors? An ethnographic study allowed him to choose a threshhold in a not too arbitrary way. As far as I know, decay functions are rarely discussed in the network analysis literature. Moody/McFarland/Bender-deMoll emphasized the fact that „[o]ne implication of the time window [a feature of their algorithm] is that relational events have a residue that extends beyond their occurrence“ (2005: 1212), and de Nooy mentioned that „little is known about the salience of previous ties and the decay rate at which previous ties tend to be forgotten or ignored“ (2011: 38). This last question is addressed in some qualitative micro-studies, but until now with little effect on formal network analysis.

strategies can only be used, however, if we have first decided that we are able to date ties, and especially their end.

Our sources often do not tell us when a given tie began; even more often, they do not tell when it ended.[12] Yet assigning an infinite duration to ties because we lack precise information is just an arbitrary choice among others, and generally not the best: Do the oldest always have the highest social capital? It is unlikely. Micro, qualitative historical studies generally do not have to make this assumption; even if they do not put a date in a spreadsheet, they roughly assess the longevity of ties and the weight of past ties. More systematic, formal studies, even if they lack precise data on each tie, should not for this reason turn to infinite durations. Ties that appear at one point in time as precise interactions or exchanges of resources do not necessarily become enduring relationships and therefore potential for new exchange: This transformation requires relational work. „Sets of interaction sequences" do not always „transform into stable relations" (Moody/McFarland/Bender-deMoll 2005: 1210), and the way they sometimes do is an important thing to investigate. Flows do not always create riverbeds, and riverbeds without any flow tend to disappear.[13] Therefore, in her pioneering research on the ego-networks of an abbott and a queen of the 10th century, Isabelle Rosé (2011 and forthcoming) decided to consider kinship and allegiance ties (including spiritual kinship, marriage, etc.) as lasting until the death of the first person to die, while more routine ties (for the elite, such as the joint signing of a charter) were

12 See the specific discussion on this point in Düring 2012 – and the way in which he was nevertheless able to use dates in order to discuss the rapid growth and demise of some relational structures (esp. S. 146-151).

13 This metaphor emphasizes the key but under-discussed distinction between relation and interaction, that are too often aggregated under the label „ties" or „links". I have used it during a few years before discovering that it had equivalents in the literature in terms of pipes and flows (in Luhmann 1995: chapter 10) and, more importantly, backcloth and traffic in the work of mathematician Ron Atkin (cited by, among others, Maisonobe 2013). Specialists of longitudinal visualization also mentioned „cognitive networks", or abstracted relations, as opposed to „behavioral networks" (Bender-deMoll/McFarland 2006).

assigned the arbitrary duration of one year, i.e. the time span used for snapshots. What is important in such choices is that they are rooted in historical reflection on the significance of each type of tie for the actors and that they can be reversed and experimented with, so as to measure how they influence interpretation. If we do not make such explicit choices, our historical networks are at risk to become „largely artificial constructions built by aggregating dead past events“ (Moody/McFarland/Bender-deMo 2005: 1208).

2. VISUALIZING AND MODELING CHANGE

Longitudinal data call for caution in the definition of boundaries (those of time spans as well as those of the network), of nodes, ties, attributes and their dates of birth and death. It is demanding, but also rewarding, especially as it helps specifying research questions. Once we have defined exactly why we are interested in change in networks, and which change we want to focus on, it is time to look for tools helping us to visualize or model this change – or to create our own. In the papers that I already cited, this stage of research was generally dealt with in a quite simple way: The authors computed classical network indicators and/or drew classical network graphs for each time span. The value of these papers lies in their research questions, data construction and interpretation. Thinking about change in networks in a sophisticated way does not always require specific tools. Yet, some historical questions can benefit from recent developments by statisticians and computer scientists – while others rather require ingenuity in adapting classical visualizations of historical change to change in networks.

2.1 „Actor-oriented“ statistical modeling

One of the most cumulative efforts to develop hypotheses and tools to deal with change in networks has taken place around the algorithm Siena (now implemented in the open source statistical software R) and the underlying

statistical models.[14] As a tool it is only useful for specific situations. It allows to model change in panel data within several time spans – but it is restricted to only a handful of changes in the list of nodes or in ties, and not too many nodes at that. Changes in attributes are taken into account, but change in ties is only dealt with as change from 0 to 1, or vice versa. It is particularly suited to oriented ties.

These technical possibilities and limitations, however, are not the important thing about Siena. What is specific and interesting is that it is not merely an algorithm, but a way to think about network dynamics, in the strong sense of the word: about forces that might lead networks to change. Some historians should look into „actor-oriented" stochastic models not because of the shape of their datasets (or because the name looks nicely complicated), but because they have come to think of their networks in the same way as Tom Snijders, who created the algorithm. His basic idea is that everything happens as if nodes in networks (especially human beings) chose to maintain, sever or create ties on the basis of a set of preferences. These preferences might be based on various attributes, of themselves and of potential partners (which allows e.g. to test homophily), and/or on the shape of local network structures around them (which allows e.g. to test a preference for reciprocated ties, or the fact that I like friends of my friends to become my friends, i.e. a preference for „transitivity"). In addition, when change in attributes as well as in ties can be observed, Siena allows to jointly model them, hence to disentangle social „influence" from social „selection".

Many historical questions, especially on ego-networks, could be rephrased in this seemingly technical vocabulary. For example, if the reading of their letters lets us think that scientists, or merchants, chose to establish their correspondence or cooperation ties preferably with a specific sort of partners, or tended to privilege reciprocity or transitivity, we can simulate networks that are likely to emerge following such social rules, describe their shape, and compare them with what we know of actual ties in order to judge the value of our hypotheses. At a different scale, I personally

14 For an excellent introductory presentation, see de Federico de la Rúa 2004; for excellent documentation and references, see http://www.stats.ox.ac.uk/~snijders/siena/ (25.10.2013).

used such modeling to test hypotheses on the choice of preferred destinations by short-distance migrants; it allowed me and my co-author to specify how exactly the often mentioned „chain migrations“ could work (Lemercier/Rosental 2010).

It is therefore interesting to acquire a layperson's view of this type of modeling in order to decide whether specific historical questions would benefit from being translated in this vocabulary and possibly, if the appropriate sources are available, from being statistically tested. Some questions about change, however, will not benefit very much from this translation. This is the case for the more descriptive questions about (de-) institutionalization that I mentioned above. In a nutshell, thinking of dynamics in the language of Siena is probably useful when hypotheses on change involve the idea of underlying forces in terms of more or less conscious preferences and when these preferences are related both to attributes (e.g. in the case of homophily) and to what network specialists call structural variables, which is just a different name for anthropological concepts such as reciprocity, *potlatch* (generalized exchange), or transitivity (that is e.g. a feature of some alliance systems).

2.2 Visualization of snapshots and animation

Visually comparing snapshots of successive time spans, however well chosen, is extremely demanding, even when there is a limited number of nodes and ties. For her aforementioned studies of „network itineraries“ in the 10th century, Isabelle Rosé had to face this difficulty.[15] Her visualizations arguably would not be readable for non-specialists without the accompanying text. It is her previously acquired deep knowledge of the sources and historical context that allowed her to make sense of the snapshots and guide her readers. They also led her to choose a unique way to position nodes in the graphs, whatever the year. This strategy implies that positions in each graph are not based on the structure of the network for

15 Her animated PowerPoint presentations are online at http://medievistes.wikispaces.com/Isabelle+Ros%C3%A9 (25.10.2013). Of course, the fact that films are currently not easy to display in scientific publications or to store in a perennial way is also a problem for animated visualizations.

this year, hence that this specific structure is not as readable as it would be if presented in a static network graph. In addition, the position of nodes has been chosen according to one of their attributes, emphasizing the relationship between this attribute (a mix of descent and geographical location) and the network, at the expense of other possible interpretations. As with all choices, what is important here is that they are made explicit and that alternatives can be tested. Once again, there is no unique view of change in a network.

This is not to say that the visualization of successive snapshots, with or without animation, should be abandoned. Even when it is not readable for non specialists, it is an important heuristic tool for the researcher: It shows features, especially local ones, which aggregate indicators (and Siena modeling) hide. Therefore, it can lead to choose better indicators, or to change the boundaries of the network or of time spans. It is particularly important to visualize in order to check whether medium scores in an indicator could be caused by heterogeneity in the network – e.g., the fact that a clear, hierarchical structure in part of the data coexists with seemingly random noise in other parts, which should lead to focus on each part separately in subsequent analysis.

Visualizing successive snapshots is particularly demanding and requires many experiments as it is impossible to grasp all the dimensions of change simultaneously (think of the five types of change that I listed above). Something must be deliberately fixed in the visualization, so that „a mental map of the structure“ is preserved from view to view and change in other dimensions can be seen. Displaying the results to non-specialists is even more challenging, as reading one static network graph is already a still unusual task. If several graphs are displayed, it is important that „the time a viewer spends on familiarizing with the drawing is not wasted“ (Brandes/Indlekofer/Mader 2012). Hence the importance to keep node positions as fixed as possible („anchored“, in technical jargon). This leads to what some specialists call a „flip-book approach“: „The flip books are a combination of fixed node layout and dynamic social relations, where nodes remain in a constant position and arcs fill in the holes among these nodes“ (Moody/McFarland/Bender-deMoll 2005: 1234).

Which positions should be chosen then? They can be based on an

attribute (e.g. spatial coordinates, but also sex, age, etc.), if it is of substantive importance for the change that is described. This choice can be made more radical, and sometimes more effective, if we choose to simply aggregate nodes by attribute (which most visualization tools allow), focusing the graph on the relationships between groups. For example, all young women could be represented as one big node, with more or less ties to other sex/age group and inside the group. If discussing the changing relationship between ties and attributes is one of the main substantive purposes of the analysis, which is often the case in history, a series of such simple graphs provides one of the best possible visualizations of change in the network, while being much more readable than complete graphs. For example, William Roy (1983) represented common board members between firms as common board members between economic sectors (and inside each sector). José Luis Molina and his co-authors (2008) aggregated alters in the ego-networks of immigrants according to their citizenship and migrant status, which allowed easier comparisons both across individuals and across waves of study for each individual.

Another popular solution for the placement of nodes in „flip books" involves a different sort of „aggregation". In this case, time is first ignored, and a single network graph aggregating all periods is produced. Nodes are then assigned their position in this aggregate graph. They keep this position for all time spans. This can be understood as a way to present the emergence of the aggregate structure with the risk of teleology, as positions are assigned from the beginning on the basis of ties that were only created afterwards (as if potential ties just waited for an opportunity to be created). If this risk is properly understood and taken into account, snapshots using aggregation to decide on positions can help to answer the question „through which stages did we get to this point?" I have used them to discuss private ties between members of economic institutions in 19th-century Paris, over a period of several decades (Lemercier 2006). Because of the interpretive risks associated with aggregation, I took special care to discuss to which degree the actors could or could not be aware of their position in the overall structure.

Finally, a third strategy is „chaining anchor", i.e. beginning with a layout of nodes in the first period based on the network structure at that

time, and allowing only for small successive moves of nodes from period to period according to changes in their ties. This method keeps the visualization closer to the network structure in each period, while allowing readability by not changing too much the positions of nodes (see e.g. Moody/McFarland/Bender-deMoll 2005: 1221-2; on anchoring strategies generally, Brandes/Freeman/Wagner 2013). Contrary to the two other strategies, it requires specific software tailored for longitudinal data.

Still other, exciting new possibilities seem to be emerging in the landscape of animated networks, for example allowing non-linear navigation in time (choosing to compare more or less distant snapshots, not just looking at a film in video mode). Despite cumulative efforts from computer scientists, the available software however is still far from perfect; but the fact that these colleagues are pleading for more tests with actual users and various sorts of data should foster interdisciplinary cooperation, hopefully leading to improvement.[16]

3. Time as a dimension in visualization

Sociologists or computer scientists who discuss visualization of change in networks almost always start and end up with animation, i.e. a more or less smoothed succession of snapshots. There is however a different way to include time in network visualizations. While certainly not the only or always the best solution, it is technically simple and often rewarding in terms of heuristics and/or communication of research results. It simply involves assigning one of the dimensions in a two-dimensional graph to the representation of time (which most visualization tools easily allow).

This choice implies that there is only one dimension left to represent some structural features of the network, which is not much. However, it makes graphs more familiar for readers, as they acquire some of the features of time-lines, genealogies or, in archaeology, stratigraphy, with

16 For a review of software made by historian Ulrich Eumann for historians, see three shorts documents online at http://conference.historicalnetworkresearch.org/index.php/resources (25.10.2013). For a review of recent advances based on an observation of users, see Bach/Pietriga/Fekete 2014.

time flying from left to right or from the top to the bottom of the page. It seems promising to experiment with these more familiar visualizations in order to accommodate exotic network data. Exciting independent re-inventions in the past decades could now serve as models to more systematically explore the strengths and weaknesses of this strategy.

Quite early on, it had been used by social anthropologist Douglas White as part of an attempt to demonstrate the potential of network analysis as a complement to more classical family trees. While White innovated in representing marriages as nodes and people as ties, thus making important alliance patterns more visible, he also kept an axis for time in his visualizations. This allowed, for example, a very effective back-and-forth reading from the micro to the macro scale in the case of an Austrian village studied over several centuries (Brudner White/White 1997: Figure 7). Stark/Vedres (2010) used the same representation to describe „recombinant lineages" among firms.

Such time scales in longitudinal networks are especially well-suited when the relationship that we are interested in intrinsically involves nodes situated at different moments in time. It is the case of descent (children being younger than parents), as well as the metaphorical descent involved in the PhD adviser-doctoral student relationship (Sigrist/Widmer 2011) or the flow of activists from a movement to a newly founded organization (Rosenthal/Fingrutd/Ethier/Karant/McDonald 1985). It is also the case of citation (a more recent paper citing an older one, which can also be regarded as metaphorical kin). In these cases, the dates assigned to the nodes themselves (dates of birth, PhD, creation of an organization, publication, etc.) are often as important for the analysis as the date when the relationship began. Hence the value of visualization that places nodes on a time axis according to a date, rather than, like „flip books", slicing time into separate observations.

It is even more rewarding in studies of diffusion, when the time of adoption of an innovation is the key issue to explain. Despite the prevalence of this theme in the network analysis literature, however, few researchers seem to have thought of experimenting with time axes in network graphs – an early and exciting exception being, once again, Mullins (1972: 62) showing when, and invited by whom, biologists joined

his research group. Later exceptions are – not surprisingly – found in papers by historians. Langthaler (2012) studied the diffusion of the application for the „debt relief and construction“ action of the Nazi state among neighbors: He projected neighborhood ties in a space where the horizontal dimension described the timing of applications. The vertical dimension then showed how neighborhood was at play. Even if comparing imprisonment to innovation might look shocking, the process of denunciation in the context of the „pyramid scheme“ of the Gestapo in its fight against the German resistance movement can be abstracted, hence visualized in a similar way (Eumann/März 2012).

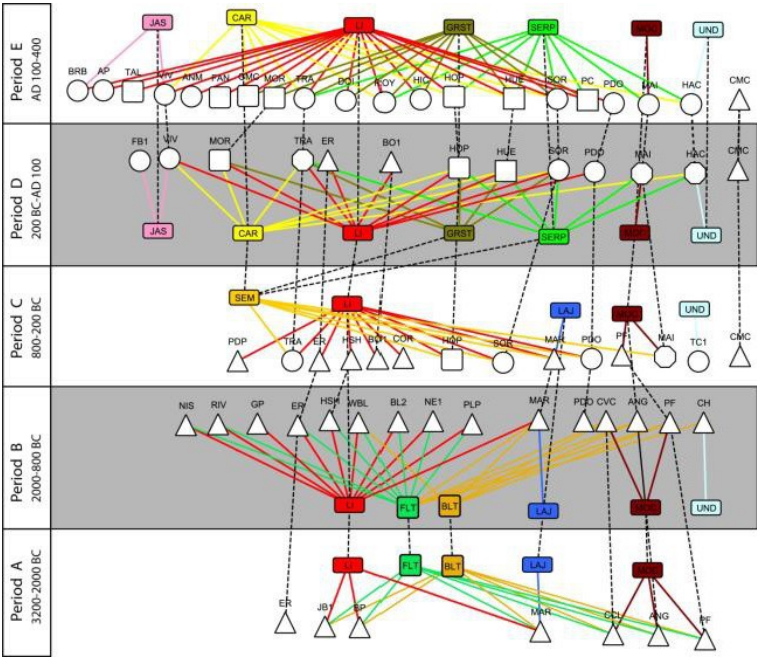
In the previous cases, each entity (individual or organization) was placed on a time scale according to a date (often a date of birth) that characterized it; the other dimension was used to display ties between entities, hence the network structure unfolding other ties. My two last examples are variants of this strategy that take into account an important fact, discussed in the first part of this chapter: entities themselves can change so much, while keeping the same name, that it sometimes makes sense to represent them as a set of nodes, not a singular node. These intuitions give birth to a specific type of representation, which seems to have great potential for historical research. Mol (2014, here Figure 1) came to it by modifying stratigraphy, a classical representation in archaeology. As opposed to classical stratigraphy, however, his graph both emphasizes continuities between periods (vertical lines) and allows us to visualize complex two-mode patterns inside each period (with colored shapes representing materials or types of objects and white shapes representing places). Some materials and places are present in the analysis in most or all periods, hence represented as several nodes, while others are not: Vertical ties show this sort of descent, while horizontal ties show distributions during each (in this case very long) observation span. François and Chartrain (2009, here Figure 2) used the same visualization strategy, only with time as the horizontal axis and simultaneous ties represented as vertical lines. Here, the nodes are journals publishing art criticism, and ties represent the number of shared authors. Using several nodes for each journal allows to jointly represent and discuss three different phenomena: the persistence of the same authors in the same journal (horizontal lines),

the (quasi)-simultaneous activity of the same authors in different journals (vertical lines), and moves from journal to journal, from year to year (diagonal lines).

4. CONCLUSION

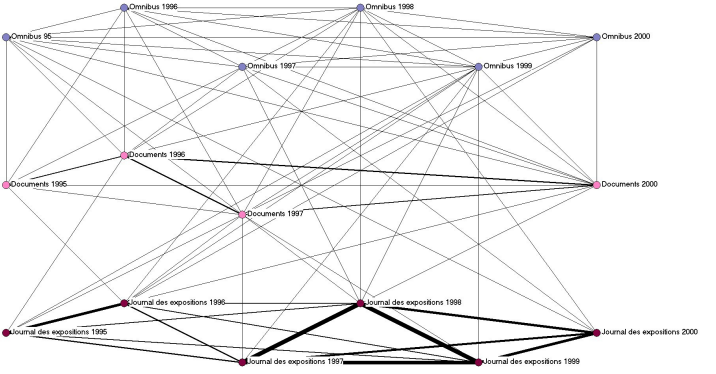
Beyond their technical simplicity (and lack of aesthetics), the two visualizations that I last commented on exemplify what longitudinal network analysis at its best has to offer to historians: novel ways to think about the multiple dimensions of change, not only in ties, but also in historical entities. When confronted with changing networks in our sources, we should not run looking for software „offering dynamic features“: It will not solve historical problems. What we first need to do instead is to make our research questions more explicit, so that they can be translated into „tasks“, in the vocabulary of visualization. Which dimensions of change are we interested in? Did our choices of boundaries and coding produce data that allow us to explore these dimensions? How did we assign dates to nodes and ties? These are the important questions, and only historians can answer them. It is only afterwards that work on visualizations, indicators or modeling can be dealt with – and it can become an exciting experimentation, be it by playing with simple software or cooperating with statisticians or computer scientists to tailor better tools.

Figure 1: Change in relationships between places and artefacts in the Caribbean



Source: Mol (2014)

Figure 2: Change in the sharing of authors between contemporary art journals



Source: François/Chartrain 2009

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17 All the hyperlinks were valid on October 25th, 2013.

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