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Towards Understanding the Dynamics of Digital Communication Networks

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Towards Understanding the Dynamics of Digital Communication Networks

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Abstract

Understanding structures and processes of virtual communication networks can help to improve knowledge sharing and collaboration in a corporate setting. One current research method for that objective is Social Network Analysis. Although this method can generate a static additive picture of the final structures resulting of virtual networks, it misses to uncover the underlying processes of structural evolvement. This article suggests and demonstrates a novel methodology which is based on longitudinal visualization of dynamic networks. It allows visualizing structural evolvement of communication networks over time and thus leads to improved understanding of networking processes. Using the corporate e-mail network of Enron, the approach is demonstrated by studying temporal activity bursts, organizational positions that integrate the virtual network, and longitudinal structural change.

1 Introduction

During the past years, electronic communication like e-mail, instant messaging, or videoconferencing have quickly climbed the ranking of preferred means to communicate and subsequently collaborate in an organization. This results in changes in organizational work towards more decentralization [LuBa94] where "electronic communications fuel the growth and effectiveness of an organization and its parts. Information, rather than being limited, controlled, and a source of power, appears to be instrumental for greater effectiveness when widely disseminated and freely available in so-called virtual electronic organizations." [DaLe93:iv].

The resulting complex communication network delivers fix points for the combination of order and chaos in the organization. Every person must be enabled to purposefully switch between the processing of expected and unexpected information. The necessary orientation for that is provided by a network, which is offering active connections (for coordination and communication), but even more importantly connections, which potentially can be activated on demand in special situations [Baec99:26].

With the above properties, novel means of communication can be conceived as a domain within traditional systems theory. It regards organizations as social systems, which are solely consisting of communication acts related to each other [Luhm84]. Following this approach, sociologically oriented systems scientists imply that a major issue for understanding organizations (or groups of people) is to understand their communication and their ability to communicate [Baec99:22]. These insights coincide with another recent approach: Communities of Practice (CoP). Here, ongoing informal communication is developing networks of employees, which eventually constitute CoPs, which are defined as a group of people bound by informal relationships who share common practices [LaWe91]. The role of extending or even replacing offline by online communication and the consequences for sociability in the enterprise is further discussed in the research domain of Computer-mediated Communication (CMC). Traditional work in CMC is focusing on the bandwidth of media (Media Richness Theory, Social Presence Theory) and determines its role for conveying the meanings or intentions of communication partners [DaLe86]. The studies found that due to low bandwidth, text-based online communication has been considered ineffective for developing interpersonal relationships, since there are greater chances of misunderstanding, and incorrect impressions are often generated [Pree00]. On the contrary, other researchers argue that such traditional theories may not apply to digital communication. For example, Parks and Floyd [PaFl96] report that an online communicator can develop an interpersonal relationship with someone met via an Internet newsgroup despite a lack of synchronous or spontaneous interactions. Walther [Walt92] also suggests that even though it may take longer than in face-to-face settings, online communicators can develop interpersonal relationships by devising their own relationship strategies in CMC to deliver social and emotional cues (also cf. [CTK05]). These relationship forming aspects are further substantiated by a recent study: Despite the virtuality and the large size of electronic groups, a survey of Berge and Collins [BeCo05] substantiates that there is a perception of community.

The increased interest of the above research domains implies the vital role of understanding the complex networks resulting from the abundance in lateral communication. It is fundamental to be able to create, foster, and manage a modern, competitive, and intelligent organization.

2 SNA – the current approach for understanding network structure

Substantially triggered by increased corporate focus on networking between employees is the desire to observe, analyze, and even 'measure' the actual state, an employee network is in. Next to approaches based on simple activity logging (e.g. [Coth00]), the rapid and regular advance in social network research provides a vast body of related measurements and methodologies [WaFa94]. The according field of Social Network Analysis (SNA) is defined as a framework for the analysis of structured social relationships [WaFa94], which in the organizational context can reflect role-based authority relationships of formal organizational structures, informal structures based on communication, information exchange, or affection [TTF79].

The main hypothesis of SNA is that human behavior is influenced by structural properties (e.g. restrictions). This shifts the focus towards observing relationships between actors and the actor's embeddedness in a complex relationship network. This relationship network and the individual relationships have influential structural conditions. According to Wellman [Well97], such social networks are virtually present whenever a group of people interacts electronically. This enables the systematic examination of such computer-networked communities.

According measurements within the domain of SNA can either include composition variables, i.e. the number and properties of actors, or structural variables, i.e. the properties of relationships. Among the most important factors for evaluating actor networks are currently network size, relationship strength, network roles (broker, gatekeeper, pulsetaker, hub, isolate, transmitter, receiver, carrier), degree (activity, prominence, symmetry or reciprocity), betweenness and centrality, density, and diameter.

For example, relationships in a network can differ in their strength, although there is no specific definition of what is weak and what is strong. It has been found, that pairs who maintain strong ties are more likely to share the resources they have [WeWo90]. Further, a network's diameter, i.e. the longest distance between two nodes in a network, is a proxy for the likelihood that information passes through the net. Network density is the ratio between existing ties and the maximum possible ties. It indicates if a network is tightly or very sparsely connected. The density can be applied together with relationship strength to discover clusters or groups in a network. They usually are highly interconnected sets of actors (thus having a high density). The evaluation of subgroups or epicenters of communication can help to identify structural patterns of the overall network. The nodal degree is a measure of the activity and connectedness, assuming that connections need activities to maintain strength. A network can be characterized by its average nodal degree, which shows the average number of connections of each actor. If an actor has a degree of zero, i.e. no direct relationships, he is called an isolate. Related to the nodal degree is the measure of author centrality. Larger social networks tend to have more heterogeneity in their social characteristics and more complexity in their structure [WePo97], which can be measured by degree distribution.

3 Research Objectives - Towards Dynamic Network Visualization and Analysis

The existing indicators, mainly provided by the field of Social Network Analysis, help to evaluate a variety of properties of a network which emerges from ongoing virtual communication. Although relevant properties like dense areas, general (high versus low) activity levels of the network, balance of relationships, likelihood of transporting information from one end to another, and essential actors are identified, the method provides an additive picture of the final state of the network to derive its insights. For example, it can not be observed, if the actor reacted to external events, or if he had a long steady or a short but quick growth in his degree. Alternatively, an actor with a low degree might have experienced restrictions for his connectedness induced by his specialized field of expertise. Finally, the strength of a relationship does not inform the analyst, if this relationship is stable or eventually already decaying again.

Such shortcomings of static visualizations and measurements motivated the research project Commetrix, which started in 2004 (cf. [Trie04; Trie05]). Next to providing the maximum possible visual transparency of otherwise invisible communication networks, the research seeks to extend the insights from Social Network Analysis by enabling observation of dynamic network processes. Periods and areas of decay, stagnation, growth, acceleration, or deceleration can lead to improved analysis of network stability (or change). The emergence of central nodes and clusters can be visually traced and quantitatively measured, which helps with the issue that "understanding of the betweenness of these centre nodes changes once the temporal nature of the network is revealed" [MMB05:1218]. This can include observation, visualization, and measurement of changes in density, the integration of dispersed substructures, the stability of components, the growth of relationships or their maintenance, equilibrating (balancing) processes, or the sensitivity and reactions to events. By working on such novel means of observing and analyzing real networking processes, the actual underlying lifecycle of a community can become the focus of analysis. The research is based on the fact, that the development of Social Network Analysis has always been strongly related to visualizations in the form of Sociograms [More34]. We hence suggest that extensions towards dynamic SNA should consequently also be founded on sophisticated means of longitudinal visualization to cope with the resulting complexity. This is also substantiated by McGrath and Blythe [McBl04] who find, that visual motion has a positive effect on the accuracy of viewers' perceptions of change in status in a social network.

In summary, our research objective is hence to develop a methodology based on longitudinal visualization of evolving network structures, which is able to extend the insights of Social Network Analysis by detecting and showing the dynamic behavior behind the static measures utilized by SNA. The visualization method builds on dynamic network graphs and needs to be able to transparently capture time periods and structural areas of decay, stagnation, growth, acceleration, or deceleration. It needs to visually trace and quantitatively measure the emergence of central nodes. Another focus is the observation of overall network stability (density, integration of substructures, stable components, growing relationships, relationship maintenance, balancing processes), change, sensitivity, and reactions to events.

Following the Design Research methodology [e.g. cf. VaKu04], this research objective will now comprise the framework for the design of a novel visualization approach for analyzing dynamic network evolution. Afterwards, its novel insights are demonstrated and evaluated by analyzing the dynamic evolvement of Enron's e-mail corpus.

4 Designing a Method for Dynamic Visualization and Measurement

Advancing from current pictures of social network graphs (Sociograms) to animations of graph evolution over time raises methodological and technical questions. How can the graph be defined to cover for longitudinal data streams and how can such a graph best be visualized to create an organic view on network evolution.

The methodological aspect should be based on graph theoretic foundations, but needs to consider time-related data. The according sociomatrix [WaFa94] is formally described with a set of actors and their relations. Both constitute a Graph G = (N, E), which consists of a finite set of nodes N and a finite set of edges E that are constituted by pairs (u,v) of nodes [Batt99:3]. To accommodate for the usually sparse networks found in the computer-mediated communication domain, we store such sociomatrices in list form to be able to manage large datasets efficiently. Capturing time related data into such a model now requires a list of events, i.e. communication acts. In other words, the individual message (and its reply) constitutes an event on a time scale, which impacts the relationship strength. This can either be switching from null (the relationship is absent) to one (the relationship exists) or it is growing stronger by a certain value (weighted relationships). This approach can be extended to represent more information, as other changes in data can in principle also constitute events. For example, change in author properties, decay of a relationship, the appearance of an author without acting, etc.

The above model is extended to represent additional information. This allows capturing as much information from individual electronic discourses as possible in a systematic and standardized way. It is allowing for subsequent analysis in one model, which we termed 'communigraph'. Such a communigraph consists of two elements. First, a data model has to be defined to capture the individually specified properties of a digital communication network. Primary elements are authors, their messages, and the relational information, i.e. how the authors and their messages relate to other authors' comments. Additional data stores information about the authors, including their names, e-mails, or indexes for anonymous analysis. Further, messages are saved together with their subjects, body texts and time stamp. Finally, dynamic properties can be defined to store individual data about each discourse (i.e. peer evaluations or organizational departments (cf. application in [CTK05]). We further include keywords in the data model, as we regard the technological challenge of integrating keyword analysis and Social Network Analysis as a major potential in understanding large decentralized network structures.

Next to the data model of the communigraph, there need to be visual model specifications, which utilize the underlying data structure to enable insights into the complex structures, activities, and contents of electronic collaboration. The two main elements of the visual model are author and relation. The relation is the sum of interpersonal contacts between authors in the form of replying messages. Authors are represented by a node (sphere). Means like labels, node colors, node size, or a number of rings around the node are available to represent author core attributes like name, e-mail, and index number and their properties (defined as conveying a qualitative or quantitative meaning) like for example the author's location, his number of contacts, the most important keywords, or his organizational hierarchy. Relations are graphically represented by an edge with properties like the number of messages it represents, the average evaluation of its contents, the time stamps of its messages, or its main keywords.

The technical aspect of visualizing and animating this data structure over time is very challenging. The essential element of a longitudinal visualization of the above event-based graph is the handling of transitions between different network states. This aspect can be termed 'transition problem'.

In general, our experiences are consistent with related work of Moody et al. [MMB05] and Gloor et al. [GLZD04], two research groups which are working in the field of longitudinal network visualization. Both suggest technical approaches to visualize temporal social networks by creating movies of animated graph structures. Generally, both existing approaches handle the transition problem between two successive network layouts via a linear transition between different states of a network, represented by a sliding window. For example, Gloor et al. suggest a time frame of [d, d+n], where d represents the current day and n is the size of the time frame (e.g. 30 days). All communication within this frame will be used to calculate a network's state at the time point d. Subsequently, "the animation of the changing layout is interpolated between […] keyframes" [GLZD04].

By looking at the resulting visualization, it can be found, that such rendering of transition frames disturbs the impression of organic movement. Nodes move in changing speeds and moreover in changing directions across the screen, eventually also crossing other nodes on their way. The main problem arises from inconsistent repositioning methods. For example, force-directed layouting could first move a node away from the center. Subsequent interpolation to bring a node to the next force-directed layout position of the subsequent time frame often results in a translation where nodes move sideward but equidistant to the center. The user has to mentally switch between the organic impression of attraction and repulsion of particles and the linear translation between two subsequent network positions. In visual outputs using interpolation frames, centers often move without being attracted by other nodes (in the transition phase), intuitively resulting in an unstable impression of an actually stable network transition. Being trained to evaluate stable parts by their inertia, the user is distracted from observing how new nodes find their position, because established centers also shift positions and all adjacent nodes in their clusters with them. We conclude that though being a technical option, interpolative transition between sequential network states (also known as 'tweening') results in suboptimal impression of node movement and network evolvement and thus seems to be a suboptimal approach to the transition problem. The approach suggested in this paper is omitting the idea of 'morphing' between two layout frames. Rather, we suggest an adapted version of the layout algorithm, which uses iterative layout steps to animate the changes. New nodes are added to the layouting algorithm at the time, when the resulting events occur. To keep a conceivable behavior of existing components through time, new layout calculations are initialized with the node positions from the previous time frame. We propose a relative temperature approach which is able to produce an ergonomic and conceivable animation (for visual results see next section). It builds on personal node temperatures to control the graph's overall temperature function (i.e. the energy function where low remaining tension in the graph corresponds with a high fit to optimal position). Personal node temperatures correspond with the nodes' degrees. It indicates how inert they are in their position (i.e. how far they can move). Nodes with high degrees automatically would get a lower temperature and accordingly are less movable. These layout modifications reduce the movement of large structures while new nodes, entering the network, efficiently move towards their equilibrium position.

The adapted force-directed layout approach further includes longitudinal temperature control: Keeping the temperature changes between the layout iterations low and decreasing temperature slowly over time will force the nodes to slowly move around each other. Since the proceeding state is well layouted and the changes between states of a network are usually small, new animation frames will most likely be well layouted themselves. Mainly the parts of the network will move which are changing since the rest will - in terms of temperature (which relates to inertia) - be close to its equilibrium state. The advantage is now, that the force directed layout is the only layouting principle (instead of interchanging between force-directed and transitional linear layout. This results in a much better and intuitive understanding of the network's evolvement as it keeps established parts as stable as they should appear, while drawing the user's full attention to the areas where the actual change happens. Movement is thus not a general behavior of the network graph but is directly related to structural changes.

This eventually gives the impression of a real living system of interactive elements in a network, which we found to be of fundamental importance for optimal dynamic network visualization.

The resulting iterative layout approach introduced above is able to produce interim layouts for every event in a network's evolvement. It is not influenced by the final structure but only shows the network as it would have been if the sample ended on the current time t. Optionally, old nodes can be excluded to show only the recent activity in the network's evolution.

To summarize this section, we are suggesting a novel method for longitudinal network visualization, which is based on an animation of a series of events (i.e. communication acts) which finally constitute the communication network. On the methodological level, we utilize data of sociomatrices stored in list form and extend them to create the communigraph. This consists of a data model and visual model elements, which together model information about author and relationship properties, like author affiliation, relationship strength, important keywords (topics), etc. Technically we propose an improved approach to longitudinal layout, based on a concept for node-dependent and dynamic temperature control.

In the next section, we will now apply and evaluate this method for visualizing streaming data of communication networks using data about the e-mail communication network of Enron. It allows for visual observation of some novel longitudinal effects.

5 Experiments –Dynamically exploring an e-mail communication network

For demonstration and evaluation of the above method we will take a sample of Enron's e-mail network. It consists of a set of 19808 messages exchanged between 151 authors during a 959 day period ranging from 11/05/1999 to 06/21/2002. Using the analytical methods of SNA, we arrive at a preliminary static picture of the network: It contains 1525 relationships with the average relationship strength (replies on messages) of 26.55. The network's density is 13.47 percent. The diameter only amounts to 4. The core group of active people, which together accumulate 80 percent of overall message volume, has a share of 27 percent. The maximum degree is 74 contacts.

To compare the insights generated by dynamic network visualization with conventional network statistics, we discuss the following four research questions, which all relate to dynamic evolvement of virtual communication networks:

1) How can the network behavior be described in terms of separation of clusters?
2) How can longitudinal analysis show artifacts of additive pictures provided by static SNA, using the most central node and the establishment of its position as an example?
3) Which organizational roles are responsible for spanning large distances and for integrating separate parts of the corporate network? What role does organizational hierarchy play in such processes of network integration?
4) How can dynamic visualization help to observe and evaluate the current activity and thus also the current level of change. Is there a relation to external events noticeable?

To approach the first research question (1), Figure 1d shows the final static picture as it would have been produced by conventional Social Network Analysis. A network of only one component can be seen. The most central node (in terms of degree centrality) is at the center. The layout shows a very dense area at the center (named section 1). Further, there is a strongly interconnected section at the top right area (section 2) and some more peripheral nodes at the bottom (section 3). The other parts of Figure 1 (a-c) are snapshots taken from an animation generated with the novel method. They show three intermediate communigraphs[1]. This now allows to visually trace the various activities which finally constitute figure 1d. In the first period, no separation can be observed, a central network exists. However, in period 2 (Figure 1b), section 1 is increasing its density and section 3 starts to exist. It is connected to the main section 1 by only a few nodes. First traces of section 2 are also visible. A further small component (section 4) is visible on the right hand side but it does not survive period 3 (Figure 2c). Section 2 is much more separate now, whereas section 3 has established a very broad connection (many connecting nodes) to section 1. Many authors of section 1 are growing in their degree (denoted by node size), thus improving the density of that area. In the final period 4, the bridge between section 3 and 1 gets narrower again, section 3 thus achieves more separation, section 2 is also remaining separate. However, all areas are connected with each other. The animation further highlights, that there are very important events, which largely influence the resulting structures. Two examples for very important network changes are an

[1] As this print medium does not allow for movies showing the change in networks, all animations of network evolution have been made available for viewing online at http://www.commetrix.de/enron/.

action caused by the CEO (K. Lay) on 08/24/2001 or the most central employee's action on 02/07/2002. Their relevance is mainly due to spreading a message to a larger group of people and receiving replies to it. However, it remains to be explored, if they are also that important from a contents perspective or only in terms of structural network activity.

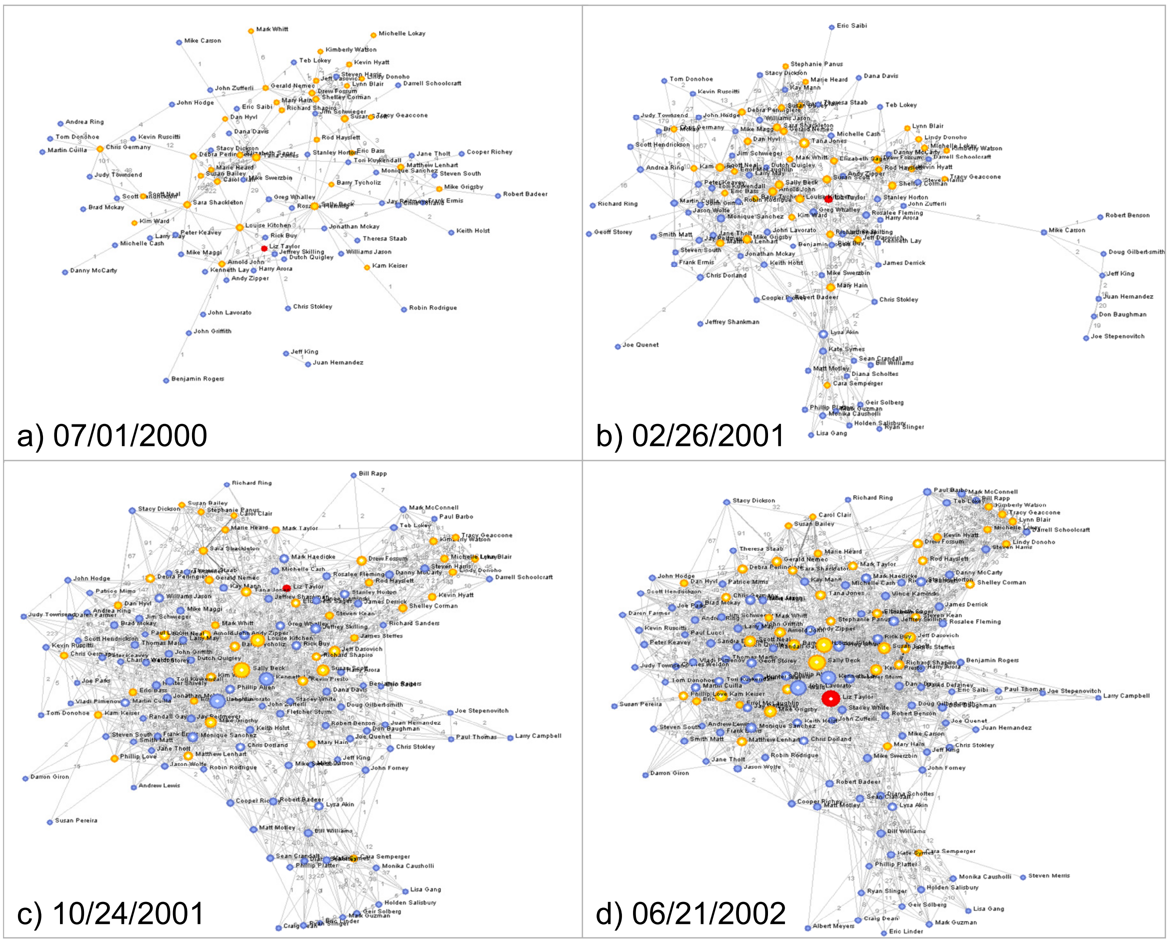

Fig. 1: The evolution of the most central author's position in the network. The observed (most central) author is marked red, the size is representing the nodes' degree. Orange nodes represent members of the 'core group' of active people. The final static picture of the ENRON e-mail corpus as would be produced by an SNA Sociomatrix is shown on the bottom right. The according animation is available at http://www.commetrix.de/enron/.

Figure 1 also yields a first insight into research question 2 concerning artifacts of additive pictures of networks. An example showing this wrong impression of a network structure can be demonstrated, when the most central actor gets observed to see how she established her position: Although the author was active in the network during the complete period, almost all of her centrality has been achieved in the last quarter (note the difference in node size between Figure 1c and 1d). This comparison of different states of the network can now be analyzed in more detail by looking at the dynamic evolvement in the last quarter of the sample period[1]. To produce a transparent picture, only the direct ego-network around the observed node is shown.

Further, only relationships with a weight of more than one are involved. Figure 2 highlights the animation's main result: after a long period without significant change, between February 5th and 7th of 2002, the centrality of our observed node increases by 50 percent in just three days. Afterwards it remains stable again until the end. This implies that the most central node established its position in a very fast burst of activity instead via continuous growth. Color has been employed to code function. It can be seen, that many new vice presidents and common employees entered the central node's egonet during this process. The observed non-linear behavior in node activity is a first insight, which can not be derived from the final additive network picture. Rather, it shows that the eventually most connected node seems to have a short period of untypical behavior, which brought it into its position.

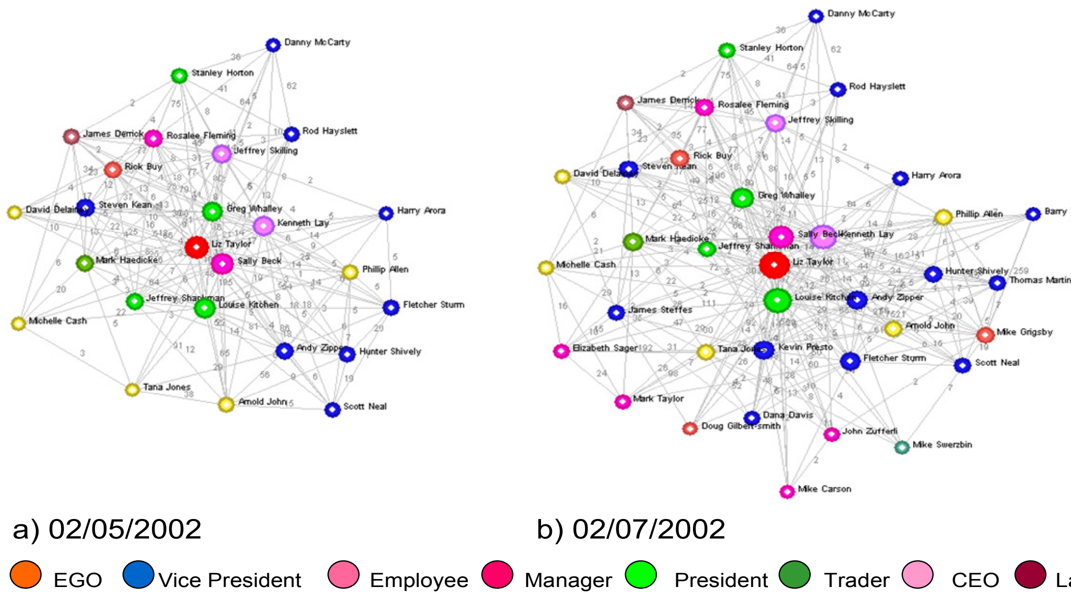

Fig. 2: The evolution of the most central author's position in his ego-network between 02/05/2002 and 02/07/2002 (constant scale). The observed author is central and marked red. Yellow nodes have no known job position. Only relationships with a weighting of 2 and more are shown. Their increase in degree is from 24 to 36 contacts. The according animation is available at http://www.commetrix.de/enron/.

By defining a sliding window, we can now eliminate messages which are falling outside the time window, i.e. to delete message activity from the visualization which is too old and has decayed. The result of such an animation is that the observer can follow the current activities of the network's evolution without being distracted by past structures. All visible activities directly represent change in the network. Nodes get active and can initialize or join clusters. These clusters are either dissolving or growing over time depending on the ongoing activity level. We found, that this visualization mode helps to understand, who contacts whom to actually establish (or change) a communication network. Periods of high activity can be implied, when many nodes and relations remain active in the time frame. Brokering actions are becoming visible, even if the nodes do not establish broker positions in the long run.

This mode of analysis is now being applied to investigate the third research question: We want to analyze the brokering actions in the evolving network overtime to find out whether brokers which are higher up in the organizational hierarchy have a different role than employees. For that, we code the job positions of the e-mail network's authors by node color and label. This allows observing, which nodes where active and which connected sections to establish the final network structure.

Figure 3 depicts four frames of a part of the overall network evolution, which includes an important brokering situation. A node with job position President connects three otherwise disconnected segments of the network. Interestingly, the other segment's contacts are also above management level: one director and two vice presidents. This visualization raises questions regarding the properties of important acts of brokering between dispersed parts of the network have and regarding the role different job positions have in this process. It could be assumed, that positions higher up in the organizational network show more such brokering activity (connecting otherwise distant parts) than normal employees, as managers should be better connected across the enterprise.

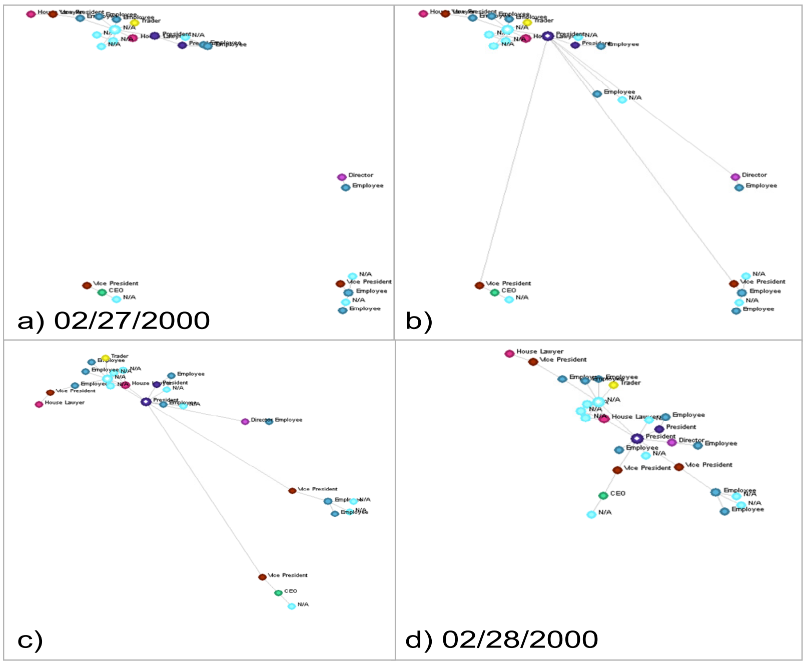

Fig. 3. A node with job position President connects three otherwise separate clusters (via two vice presidents and one director) on 02/28/2000. Four separate frames of the according animation. Time filter is set to show only one past month of mail activity.

To further investigate this question, for the year 2000 all brokering activities have been detected by monitoring the according animation[1]. They include the creation of relevant shortcuts (shortcuts which are not only a result of triadic closure, i.e. bypassing the intermediary node) and the integration of clusters. Together, 74 individual actions have been classified as brokering actions in the one year sampled. 25 of those connected previously separated network segments and further 49 actions created fundamental shortcuts within one large component. For 36 of these actions, the organizational function of both adjacent participants is known (as 52 of the 151 job positions of the sample's actors have not been disclosed). With that information, the role of cross-hierarchical relationships for establishing the final interconnected network can be analyzed. Out of 36 brokering actions in the year 2000, 9 actions (25 percent) have involved only top management positions, further 9 actions (25 percent) only employees. The majority of 18 connecting actions (50 percent) have been cross-hierarchical. This quantitative pattern is supported by the visual impression, which implies that managers connect with distant employees in a brokering action to join separate parts of the communication network. Overtime this behavior results in the establishment of a single integrated component.

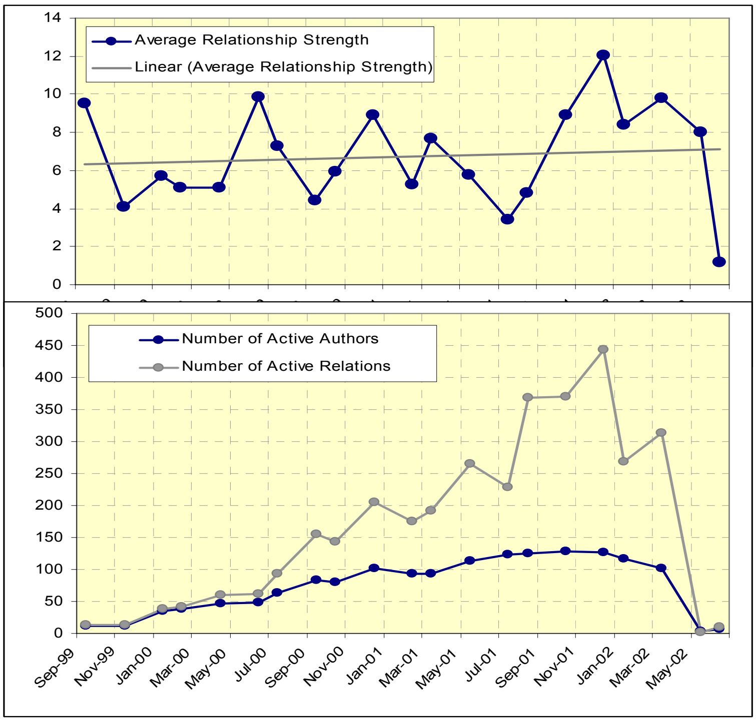

Fig. 4. Level of network change. Time window, showing only the last month of network activity to indicate the change in active authors, active relationships and current average relationship strength across the time period. A clear peak in change and in relationship strength is visible around the time when the Enron scandal was published.

The final research question (4) requires an analysis of the network's level of change. This can again be indicated by observing a time window animation (e.g. of one month). While moving forward in time measurements of active nodes, active relationships between them, and the current average relationship strength were measured. The active nodes and relationships can be interpreted as the added amount of network activity and thus the change in the network's overall structure. Figure 4 shows the quantitative results. The measurements show that a clear peak of change is visible around the time when the Security and Exchange Commission started their investigations into the Enron fraud scandal on 10/31/01 and Enron filed for bankruptcy in December 2001. The Enron e-mail corpus hence seems to react to a fundamental external event by adjusting its level of change.

In summary, these four analyses showed that the developed research method based on longitudinal visualization and measurement is able to provide new insights: It helps to visually observe and understand the dynamic behavior of virtual communication networks.

6 Conclusion and Outlook

Although the field of Social Network Analysis provides a series of useful measures for the analysis of communication networks [WaFa94], there are various shortcomings due to the static nature of the underlying model. This can lead to wrong impressions about nodes' status or even a lack of understanding, especially as far as evaluation of a network's dynamic properties is concerned.

By conducting an analysis of the dynamic behavior of a corporate e-mail network, a novel research method that is being introduced in this paper, proved its ability to help with the detection and description of periods, areas, or components of high activity. It further supports the analysis of structural integration (brokering) actions or the establishment of special network positions over time. It has been found, that the most central node is actually likely to be only a statistical artifact, as it acquired a large part of its high degree in only three days, by some obviously untypical behavior. Animating the network evolution further showed, that clusters form and decay overtime, which is largely affecting the final picture of the network. By eliciting the network's current zone of activity, change could be visually captured. This technique has been applied to visually study brokering actions, which finally resulted in a network with only one component. We found that the majority of such brokering actions included cross-hierarchical relationships. Managers were very actively involved in connecting otherwise distant parts of the overall network. Here, findings are consistent with a recent publication by Kossinets and Watts [KoWa06:89]. They observe different network measures and their varying levels of stability. One of the main findings regarding network evolution is that bridges in their sample show an unstable nature [KoWa06:90] and seem to provide only temporary advantage for their owner. The method of only showing change also allowed to identify a peak in the speed of network evolution (activity) in fall of 2001. This coincided with an important external event.

It can thus be concluded, that the introduced research approach allows for novel insights, which are able to improve the understanding of network dynamics, both in a visual and in a quantitative way. This can help to better observe and understand corporate virtual networks and their hierarchical, organizational, or locational integration behavior or artifacts in the future.

Based on these initial experiments with longitudinal network behavior and first approaches to actually visually observe, what happens in a network's evolution, future research will now need to systematize, augment, and extend the exploratory experiments discussed in this paper to arrive at a methodology together with according measures, which is providing novel visual but also robust scientific insights into network dynamics.

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