# Interactive Visualization of Dynamic Social Networks

Holger Hanstein and Georg Groh

{hanstein,grohg}@in.tum.de

Technische Universität München

**Abstract:** Understanding patterns and structural changes in an evolving network at first glance and performing hands-on exploration of actors' relationships and attributes are the primary goals of the dynamic social network visualizer "DySoN" (**Dy**namic **So**cial **N**etworks) presented in this work.

A lot of work has been done over the past few years to find visual metaphors for changes in network structures, partly showing how streaming event data of social interactions could be visualized by an interactive three-dimensional model of interpolated "tubes", representing dynamic social proximity within a given set of actors during a given time period by using three dimensions of temporal information mapping: spatial density, color and size.

Using the example of a collaboration network of musicians, "DySoN" takes event data and additional actor attributes from a relational database, calculates a virtual sociomatrix with proximity relations from it, builds a temporal graph object, applies a force-directed graph layout method and constructs a NURBS model which is then displayed as Java3D geometry, complemented by a two-dimensional section view and a filterable table view of actors and attributes.

## 1 Motivation & Objectives

Everybody has an idea of dynamic social structure, at least unconsciously, because some of the mechanisms that organize mankind into groups and hierarchies can be observed in real life when people form patterns with their bodies while interacting socially. In order to get an abstract view of relationships and their instantiations between actors in a social network, one can build upon these "physical patterns" which may be measured and modeled mathematically, especially when considering mobile interaction schemes with community- or social network platforms [Gro05]. Besides such physical expressions of social relations a wealth of other highly dynamical features or indicators of social relations exist that may be modeled (see section 2).

One of the most basic awareness class service which can be built upon such a dynamic social network model is a visualization which allows to intuitively recognize social distance and group structures. As the structure of social communities is subject to continuous changes, there is a clear demand for methods and software tools, that are able to analyze and visualize the evolution of networks [MMBd05, p. 1208ff]. Limited by visual and geometric constraints, a few basic metaphors for temporal or dynamic graphs and net-

works have been developed so far, including line graphs with summary statistics, series or animations of 2D- or 3D-snapshots, graph overlays, node position tracing and 2,5D or 3D-models with a temporal z axis. But the requirements regarding the aspects of visualization in general once formulated by Brandes [Bra99, p. 7ff] - substance, design and algorithm - are still not sufficiently met for the visualization of dynamic social networks by existing approaches.

The main objective of this paper is to develop an experimental database-driven application for explorative visualization of **Dy**namic **So**cial **N**etworks (DySoN) and verify the suitability of the technology used and of its visual metaphor by case studies.

The application should allow to inspect structures of social networks from the "connectedness perspective", as defined by Brandes [Bra99, p. 33]. It is intended to support awareness in communities and in social networks with dynamically changing relations and to give quick visual answers to questions like the following: Which are central, important or prominent actors and which are peripheral? How does the centrality of actors develop over time? Are there long-lasting partnerships between actors? Are there visible structures in the network? How do structures evolve? How do actor attributes correlate with visible network structures?

## 2 Related Work, Paradigms & Design Rationals

To create an application, that meets the goals defined in section 1, we will combine several well known techniques in a unique way and add some new ideas (we have compiled a more detailed review of the cited related work in [Han07]):

**Space-time path** We adopt Hägerstrand's "space-time path" principle [Häg70] and apply it to social networks. Geographic distances are replaced by abstract Euclidean distances derived from dimensionality reduction of multidimensional proximity data.

**Force-directed layout** Social structure will be visualized by a force-directed layout mechanism, as demonstrated for example by Krempel [Kre93] [Kre99] [Kre04], Dekker [Dek05] and others. We will use a modified version of the Fruchterman-Reingold algorithm [FR91], which will be adapted to support our notion of the "crowd" metaphor [Mil77].

**Stacked graphs** The inherent temporal graph structure is inspired by "combined", "stacked" or "stratified" graph layout methods as shown by Erten et al. [EHK+03] [EHK+04] and Dwyer and Eades [DE02] [Dwy05] and others.

**Mental map** We use strategies from dynamic graph drawing inspired by solutions described by Branke [Bra01], Diehl et al. [DGK01][DG02] and Brandes [Bra99] to minimize changes between subsequent layouts and to preserve the "mental map" [ELMS91] so that the evolution of structures can be followed through time.

**Tube metaphor** We introduce the "tube" metaphor, an enhancement of the "worm" metaphor, which was introduced by Mathews and Roze [MR97], and enhanced by Dwyer and Eades [DE02] [Dwy05] and Ware et al. [War07] to implement the space-time path. Instead of aggregated cones or simple inter-temporal edges we use tubular shapes extruded from interpolated NURBS curves to achieve a better compliance with the continuity principle of Koffka's "Gestalt Theory" [Kof35] (cited after
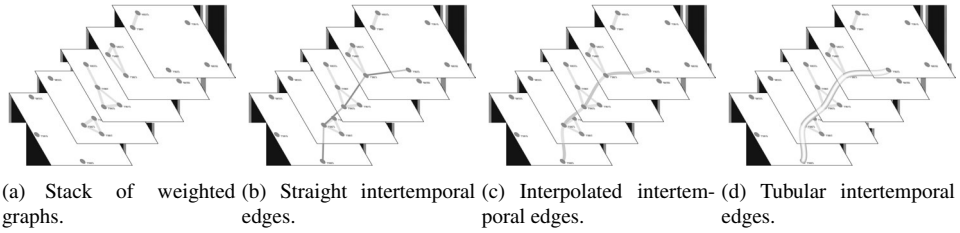
[Hin06]).



(a) Stack of weighted graphs.　(b) Straight intertemporal edges.　(c) Interpolated intertemporal edges.　(d) Tubular intertemporal edges.

*Figure 1: 2.5D Graph stack without and with intertemporal edges. (Time-Dim.:in z-Direction)*

**Abstraction from nodes and edges** The tube metaphor used will abstract completely from graph nodes and edges to prevent occlusion, to help focus on the structure and to reveal pure spatio-temporal movement (spatial proximity corresponds to social proximity)
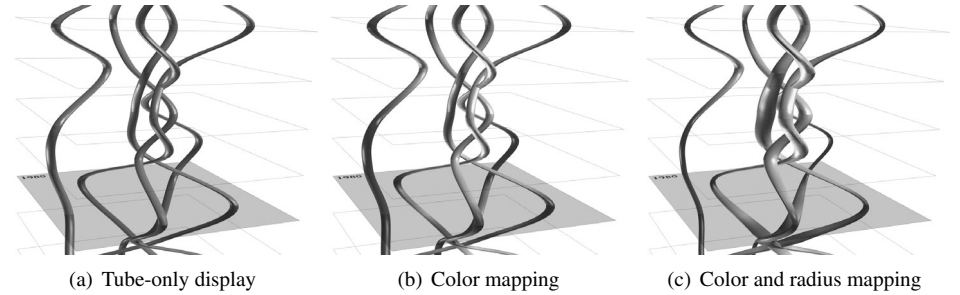


(a) Tube-only display　(b) Color mapping　(c) Color and radius mapping

*Figure 2: Tube-only model without and with mapping of degree centrality onto temporal axis.*

**Continuous-time model** Temporal attributes are represented by a simplified continuous-time model, where events are aggregated according to rules, similar to (but admittedly not as flexible as) the model suggested by Bender DeMoll and McFarland [BdM06] [MMBd05].

**Timeline and section view** A simplified timeline-based approach is used to show two-dimensional layouts of individual "frames" or "time-slices", similar to the "phase plot" mechanism by Bender DeMoll and McFarland [BdM04].

**Temporal attribute mapping** One network-related attribute can be mapped to the nodes' spatial coordinates (see above). Two additional syntactic or semantic actor attributes can be mapped to the temporal extension of the tubes, one by a continuous color gradient and the other by radius transition. Similar approaches have already been suggested [Dwy05, p. 101].

**Interactive GUI** An interactive, explorative three-dimensional user interface built of a Java3D universe is used, combined with a tabular database view and a two-dimensional graph layout. For a detailed discussion see [Han07].

**Database connection** The application will be database-driven, visual objects retain connection to the underlying data and its tabular representation.

# 3 Definitions, Assumptions & Realization

Our uni-modal dynamic social network model is a temporal multi-graph $G(t) = (V, E(t))$ with a set of actors $V$ and an undirected, weighted time dependent set of edges $E(t)$ which are known at discrete points in time $E(t_i)$ and are then interpolated. Each $G(t_i)$ is called a time slice. Each pair of nodes con be connected by an arbitrary number of edges. The weights of the edges are normalized to one via $w_{\mathrm{norm}}(e) = w(e)/w_{max}$ and will be interpreted as "'social proximity"' values. Furthermore we assume that every node has a profile which can be modeled as an attribute value pair list. We thus follow Brandes' view [Bra99, p. 32ff] that there are two main, which apply to analytic methods: the viewpoint of connectedness ($\rightarrow$ proximity) and the viewpoint of profile ($\rightarrow$ similarity). The profile viewpoint is realized in our approach by the concept that two real valued attributes (if existing) can be additionally visualized in our "'tube-only"' model via color and radius of the tubes. The connectedness perspective is attributed in our approach through the weight of the edges, which corresponds to social proximity [HR05, ch. 18, p. 27] and can be computed through the number of different pathways between two actors [HR05, ch. 7, p. 9], may result from the calculation of a geodesic path [HR05, ch. 7, p. 14], may be a combination of, e.g., weighted adjacency and geodesic distance [Dek05] or may be computed through any means that are reasonable for the targeted social environment.

The current version of DySoN assumes that the edge weights ($w(e(t_i))$) are be computed by accumulating social events that take place in $[t_{i-1}, t_i]$ involving the adjacent actors $\{v_l, v_m\}$ of $e$. These events can e.g. be instantiations (e.g. "'physical meeting"') of social ties ("'friendship"').

One of the main goals for the relative layout of the planar graphs corresponding to each time slice is that is supposed to preserve the "'mental map"' [ELMS91] as much as possible which is a counter paradigm to mapping the social distances as exactly as possible. We solve these conflicting demands by using a modified Fruchterman-Rheingold [FR91] (FR) layout algorithm for each slice as a compromise, also because it is easy to adapt to our purposes (edge weights as measures of social proximity), and using the resulting layout of slice $t_i$ as initial layout for the Fruchterman-Reingold application for the next slice at $t_{i+1}$. Other algorithms like Kamada and Kawai [KK88], would be less suited for us because of their usage of the graph-theoretical path distance. In order to further preserve the mental map, we assume that a node should remain at it is current position as far as possible if its degree does not change substantially, so we introduce an additional attractive force from the nodes position during the FR-run to its position in the previous time slice with a strength proportional to its degree change. Using relative weight changes instead of degree changes (weights drop to / raise from zero) would be another possibility. For discussion of other alternatives see [Han07].

The original FR algorithm uses a "'spring-paradigm"' between nodes to compute a suitable layout, which uses a repulsive force $f_r = -k^2/\delta$ and an attractive force $f_a = \delta^2/k$ between two nodes, where $\delta$ is the euclidean distance between them and k (being roughly analogous to the spring constant or "'natural length of the spring"' is a simple function of the visualization canvas dimensions $w$ and $h$ and some experimental constant $c$). The forces are directed along the vector from node one to node two. We modify the origi-

nal approach by several means. First we introduce our edge weights by proportionally strengthening the attractive force $f'_a = f_a * w(e)$. The second modification introduces an additional attractive gravitational force (inspired by [FLM94]) to the center of the slice canvas. This accounts for the effect occurring with pure FR, that isolated nodes are pushed to the canvas borders by the lack of attractive force. In order to emphasize the impact of centrality our additional attractive gravitational force is $f_g = \delta^2 * (deg(v) + d)/k$ where $deg(v)$ is the degree of $v$, $\delta$ its distance to the center and $d$ an additional steering parameter. For a further in depth discussion on aspects of "'cooling'" and termination see [Han07].

While the complexity of the original FR algorithm has been stated as $\Theta(|V|^2 + |E|)$ [FR91, p. 1138] our complete layout algorithm can be shown [Han07] to have an overall complexity of $O(|V|^2 s)$ where s is the number of time slices.

Having computed the positions of each node in each time slice, these points have to be interpolated with a suitable smooth curve ($\in C^2$ (see [Wik07] for an easy motivation)) which is the center of the tube for that particular node (actor). We evaluated interpolation polynomials, Bezier curves and simple B-splines for the purpose and found severe drawbacks for each [Han07] and arrived at NURBS (Non Uniform Rational B-Splines) [Pie91] of degree 3 as the best choice for our problem. See [Han07] on how we compute knot points and control points or these curves. We then build our tube surfaces as cylindrical NURBS surfaces around the interpolation curves.

Concerning the "'profile'" dimensions "'color and radius we chose (for the current prototype) to visualize node degree with color and radius, because n our paradigm the edges are missing completely. The color paradigm is to chose "'hot colors for (nodes) tubes with a high node degree (these are perceived to be "'socially active'" in the given time slice) and also to give them larger radii the more connected they are. [Han07] describes the details of these calculations.

# 4   Study: The Jazz-Network

As a first step to verify the suitability of the approach we collected an extensive dataset on musical collaborations in Jazz and checked from our own pre-existing knowledge of the Jazz-scene whether the tool was able to fulfill the goals. We crawled on of the numerous publicly available, Wiki-style (socially crafted) discography data-base Discogs (www.discogs.com) with a snowball approach [HR05] and substituted missing biographical data of the musicians by a supplemental crawling process of Wikipedia. This resulted in 96798 musicians who played on 224173 tracks on 37773 albums. Each musical cocontribution of two musicians for a track is viewed as an event and accumulated to the temporal weight of the respective edge in the respective time slice. We made substantial efforts to avoid counting re-releases. The color corresponds to the node degree as explained before and the tube radius is also set to reflect the node degree to support the color coding.

Figure 3, for example, depicts the breakup of a band which played together for some years. The involved musicians all started solo careers and their own band projects after one suc-
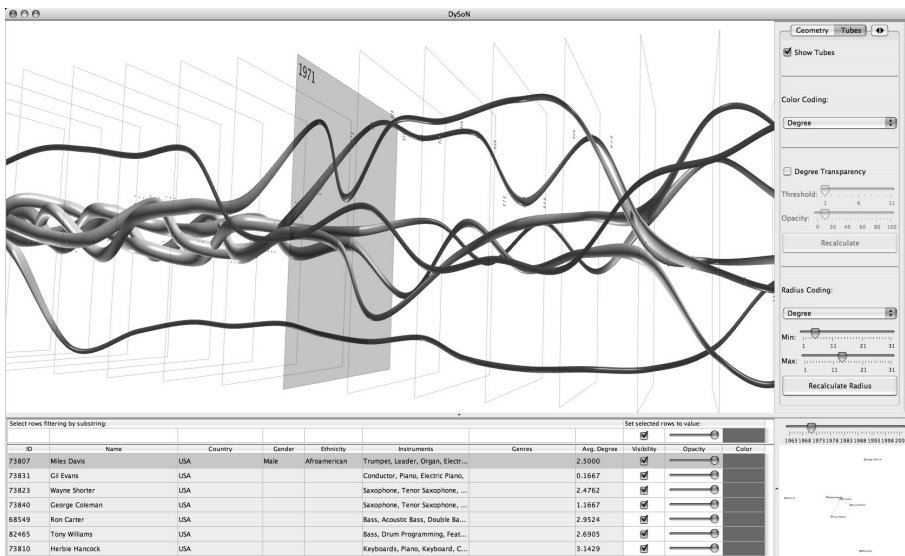
*Figure 3: Decay of the Miles Davis Band in the early seventies.*

cessful key recording with the band leader. You see the effect that tubes are crossing here, though the clique has not changed, which has to be addressed by improving the incremental layout algorithm. Our findings with several other examples were, that the system was able to meaningfully visualize phenomena in the Jazz scene over the last decades. A further evaluation would have to empirically manifest this claim by doing an extensive study with a set of Jazz experts

## 5   Summary, Discussion and Future Work

We discussed a novel method to visualize dynamic social networks. A case study of collaborating Jazz musicians revealed that the approach indeed matches the goals that were formulated in section 1. In [Han07] numerous detail improvements and technical issues of the prototype are addressed and discussed which are subject to further improvements. On a more general level an empirical user study would have to be conducted. Since it is very hard to measure the "'quality'" of a visualization the design of such a study would have to involve standardized data and a comparison with other approaches which is difficult since every existing other approach aims at slightly different aspects. Since the dynamics of social networks is coming more more to the focus of attention (especially due to mobile interaction paradigms), the problem of useful dynamic social network visualization still remains an interesting topic for the future.

# References

[BdM04]     Skye Bender-deMoll and Daniel A. McFarland. Interaction, Time, and Motion: Animating Social Networks with SoNIA, 2004.

[BdM06]     Skye Bender-deMoll and Daniel A. McFarland. The Art and Science of Dynamic Network Visualization. *Journal of Social Structure*, 7(2), 2006.

[Bra99]     Ulrik Brandes. *Layout of Graph Visualizations*. PhD thesis, Universität Konstanz, 1999.

[Bra01]     Jürgen Branke. Dynamic graph drawing. *Lecture Notes In Computer Science*, pages 228–246, 2001.

[DE02]      Tim Dwyer and Peter Eades. Visualising a Fund Manager Flow Graph with Columns and Worms. In *Proceedings of the 6th International Conference on Information Visualisation, IV02*, pages 147–158. IEEE Computer Society, 2002.

[Dek05]     Anthony Dekker. Conceptual Distance in Social Network Analysis. *Journal of Social Structure*, 6(3), 2005.

[DG02]      Stephan Diehl and Carsten Görg. Graphs, They Are Changing – Dynamic Graph Drawing for a Sequence of Graphs. In *Graph Drawing: 10th International Symposium, GD 2002, Irvine, CA, USA, August 26-28, 2002. Revised Papers*, volume 2528/2002 of *Lecture Notes in Computer Science*, pages 23–30. SpringerLink, 2002.

[DGK01]     Stephan Diehl, Carsten Görg, and Andreas Kerren. Preserving the Mental Map using Foresighted Layout. In *Proceedings of the Joint Eurographics-IEEE TVCG Symposium on Visualization, VisSym*, pages 175–184. Springer Verlag, Wien, New York, 2001.

[Dwy05]     Tim Dwyer. *Two and a Half Dimensional Visualisation of Relational Networks*. PhD thesis, University of Sydney, 2005.

[EHK+03]    Cesim Erten, Philip J. Harding, Stephen G. Kobourov, Kevin Wampler, and Gary Yee. Exploring the computing literature using temporal graph visualization, 2003.

[EHK+04]    Cesim Erten, Philip J. Harding, Stephen G. Kobourov, Kevin Wampler, and Gary V. Yee. GraphAEL: Graph Animations with Evolving Layouts. In *Graph Drawing*, volume 2912 of *Lecture Notes in Computer Science*, pages 98–110. Springer Verlag, 2004.

[ELMS91]    Peter Eades, Wei Lai, Kazuo Misue, and Kozo Sugiyama. Preserving the Mental Map of a Diagram. In *Proceedings of Compugraphics*, pages 34–43, 1991.

[FLM94]     Arne Frick, Andreas Ludwig, and Heiko Mehldau. A Fast Adaptive Layout Algorithm for Undirected Graphs. In Roberto Tamassia and Ioannis G. Tollis, editors, *GD '94: Proceedings of the DIMACS International Workshop on Graph Drawing*, volume 894, pages 388–403, London, UK, 10–12 1994. Springer-Verlag.

[FR91]      Thomas M. J. Fruchterman and Edward M. Reingold. Graph drawing by force-directed placement. *Software - Practice and Experience*, 21(11):1129–1164, 1991.

[Gro05]     Georg Groh. *Ad-Hoc-Groups in Mobile Communities - Detection, Modeling and Applications*. PhD thesis, 2005.

[Häg70]     Torsten Hägerstrand. What about people in regional science? *Papers of the Regional Science Association*, 24:7–21, 1970.

[Han07]    Holger Hanstein. Interactive Visualization of Dynamic Social Networks. Master's thesis, Fakultät für Informatik, Prof Schlichter, Technische Universität München, Munich, Germany, 2007.

[Hin06]    Klaus Hinum. *Gravi++ - An Interactive Information Visualization for High Dimensional, Temporal Data*. PhD thesis, Vienna University of Technology, Institute of Software Technology and Interactive Systems, Favoritenstrasse 9-11/186, A-1040 Vienna, Austria, December 2006.

[HR05]     Robert A. Hanneman and Mark Riddle. Introduction to social network methods, 2005.

[KK88]     Tomihisa Kamada and Satoru Kawai. Automatic display of network structures for human understanding. Technical Report 88-007, Department of Information Science, University of Tokyo, 1988.

[Kof35]    Kurt Koffka. *Principles of Gestalt Psychology*. Harcourt, Brace, & World, 1935.

[Kre93]    Lothar Krempel. Simple representations of complex networks: strategies for visualizing network structure. Presented at the 3rd European Conference for Network Analysis, Munich, 1993.

[Kre99]    Lothar Krempel. Visualizing Networks with Spring Embedders: Two-mode and Valued Graphs. Presented at the Joint Statistical Meetings of the American Statistical Association, August 1999.

[Kre04]    Lothar Krempel. The Language of Networks. Presented at the Ars Electronica 2004, Linz, September 2004.

[Mil77]    Stanley Milgram. *The individual in a social world - Essays and Experiments*. Series in social psychology. Addison-Wesley, Reading, Massachusetts, 1977.

[MMBd05]   James Moody, Daniel McFarland, and Skye Bender-deMoll. Dynamic Network Visualization. *American Journal of Sociology*, 110(4):1206–1241, January 2005.

[MR97]     Geoffrey Matthews and Mike Roze. Worm Plots. *IEEE Computer Graphics and Applications*, 17(6):17–20, November-December 1997.

[Pie91]    Les A. Piegl. On NURBS: A Survey. *IEEE Computer Graphics and Applications*, 11(1):55 – 71, January 1991.

[War07]    Colin Ware. GeoZui4D – GEOreferenced Zooming User Interface 4D, 2007.

[Wik07]    Wikipedia. Nonuniform rational B-spline, July 2007.