Harald Katzmair

Social Network Analysis

The Science of Measuring, Visualizing and Simulating Social Relationships

"You can't find a new land with an old map!"
English Proverb

Everybody's talking about networks: physicists are scrutinizing the network structures of the World Wide Web;[1] biologists are researching the highly brachiated mappings of genetic networks;[2] the US military is organizing its forces according to the *Robust Self-forming Tactical Networks* model;[3] marketing experts are looking into the patterns of how opinions, trends and the latest products proliferate in networks of consumers;[4] epidemiologists are researching contagion and transmission networks of dangerous viruses; ecologists are investigating the stability of food chains in ecosystems; lobbyists identify key players in networks of social relations (influential people are those who have influential friends who are themselves influential people); genealogists and anthropologists analyze the network structures of familial and marital relationships. Researchers in the area of policymaking designed to promote innovation, technology and science seek operative laws and basic patterns in networks that display the capacity to innovate and to adapt.[5] This list of examples of "networks" that are the focus of scientific, artistic, commercial and military interest could go on indefinitely.

Currently the most comprehensive and multifaceted model for the analysis of networks is provided by a scholarly discipline known as social network analysis (SNA), which has rapidly developed the methods and software applications of structural analysis in recent years.[6] Even if not all proponents of SNA would concur with the following assessment, SNA is less of a unified, discrete science than a comprehensive, integrative, interdisciplinary approach that enables specialists in a wide variety of scholarly disciplines such as sociology, economics, computer science, psychology, business administration, biology, mathematics and urban planning as well as consultants, artists and art theorists to formulate and work on problems in their respective fields in a common language—the language of mathematics and algorithms. And this is the reason for SNA's innovativeness: the diversity of the disciplines involved and, simultaneously, the adoptability and stringency of a model-building process based on the language of mathematics and computer science.

The roots of modern network analysis go back to the structuralist (relational) revolution in the natural sciences and especially mathematics in the last third of the 19th century, which was comprehensively described by Ernst Cassirer.[7] Modern number theory, relational logic, Boolean algebra and set theory that were emerging at the time were the points of departure for the formulation of graph theory, which today constitutes the central point of reference of social network analysis. Graph theory is a sub-discipline of discrete mathematics—i.e. the mathematics of finite structures—that also encompasses code theory, cryptography and combinatory optimization.

Graph theory is universally applicable in modeling social relationships. Data on social relationships are transformed into graphs and evaluated on different analytical levels (level of the individual agent, dyadic or triadic level, cluster level, level of the entire network). Typical social relationships for network analytical consideration are:

Communication Relationships:

- Who influences whom in reaching purchasing decisions and in opinion formation processes?
- Within companies, who talks to whom about possibilities for improvement?
- Who gets tips and advice from whom?

Cooperative Relationships:

- Which departments collaborate and which impede one another?
- Who works jointly with whom on a project?
- Who is a fellow member in a consortium?

Formal Relationships:

- Who reports to who?
- Who is on the board of directors of which corporations?
- Who is a shareholder of which corporations?

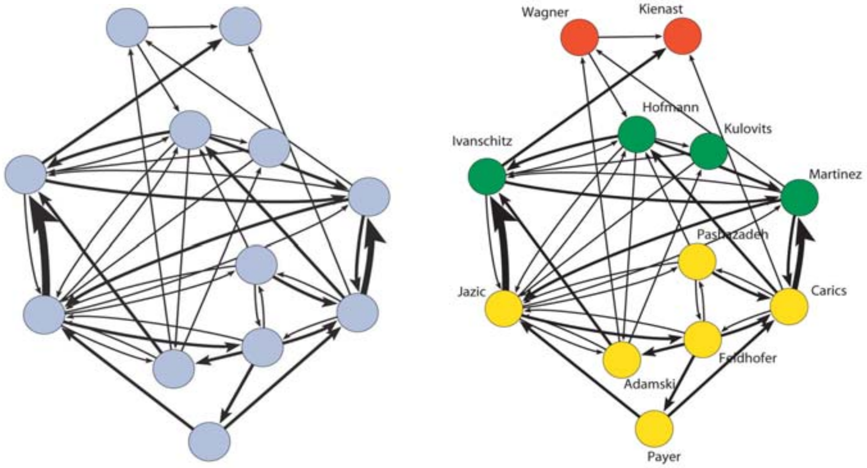
Economic Relationships:

- Who is a trading partner / customer of whom?
- Who sponsors which events?
- Who is a supplier of whom?

Event Participation and Memberships:

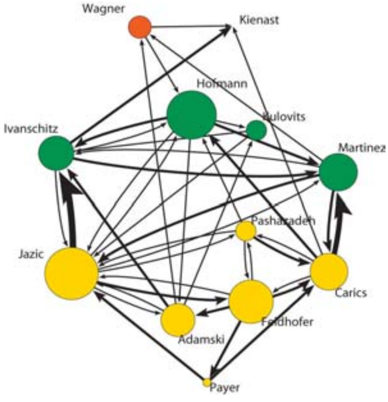
- Who is on the guest list of a particular affair?
- Who is a member of which club, party, and organization?
- Who participated in which event?

Let's look at an example on the soccer field.
The Rapid Vienna network consists of 12 persons (11 players on the field and one substitute), and we observed who passed the ball to whom during the course of a match. The resulting graph consists of a quantity of players (nodes) and a quantity of passes (arcs). To the left is the graph that depicts Rapid's passing game during the last 15 minutes of a soccer match between Rapid Vienna and Sturm Graz on December 7, 2003. As soon as we add additional information such as the players' names and their positions (red = attack, green = midfield, yellow = defense), we have produced a network. Networks are graphs with additional information about nodes and / or arcs.



Rapid's passing game during the last 15 minutes of a soccer match between Rapid Vienna and Sturm Graz on December 7, 2003 (data by Harald Katzmair and Helmut Neundlinger). Left: graph, Right: network

Once the empirically calculated data have been transformed into a relational graph, various questions can be answered. Which player initiated the most passes (Jazic)? Who was on the receiving end of the most passes (Jazic)? Who controlled Rapid's play (Jazic, Hoffman)? Which players were involved in the most combination pass plays (Jazic, Hofmann, Feldhofer, Martinez, Carics)? Who played together with whom and who didn't (not a single pass from Ivanschitz to Wagner!)? Which combinations of players made up the backbone of the team (e.g. the Feldhofer-Carics-Pashazadeh triad)? Which players had a similar role (Ivanschitz / Martinez)? Where are the weak points of Rapid's play (Kulovits)? Which players do I have to "shut down" to achieve maximum disruption of the flow of Rapid's play (Jazic, Hofmann, Feldhofer)?



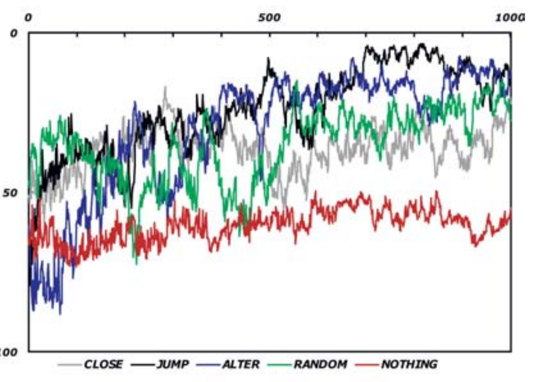
The centrality of the Rapid players based on betweeness-centrality

To answer questions like these, social network analysis has developed a comprehensive set of measurement, visualization and simulation techniques.[8] There exist commercially available software solutions (UCINET, NETMINER, yFILES) as well as outstanding freeware products (PAJEK, VISONE, MULTINET, KEYPLAYER, WILMASCOPE, TULIP, MAGE etc.).[9] These software applications are to a considerable extent responsible for the systematic ongoing development of the field's structural methods. Despite SNA's dynamic development and the diversity of its content, the attraction of freely available software like PAJEK and VISONE is what maintains a shared vocabulary and generally accepted methodological standards. The reason for SNA's dynamism lies precisely in this collaboration of social scientists, mathematicians and computer scientists. It is a scholarly field with strongly integrative power, one most comparable with modern biology and ecology or sub-disciplines of nanotechnology. Social network analysis erects bridges between the social, natural and technological sciences and continually generates new models out of this joint effort. Radical innovations (breakthroughs) come about when extremely diverse elements are combined with the capacity to translate these different forms of knowledge and scientific cultures into one another and to integrate them into a unified system of symbols. SNA is itself a radical innovation and its unified system of symbols is assured by software (among other tools). The mathematization of the models gives assurance of this because only mathematics provides a purely symbolic language—a lingua universalis—that makes possible link-ups and translations in all directions.

The mathematics of the structures and orderings (graph theory) is not only the basis for a functional interdisciplinary approach and linguistic coherence within the SNA community; it also makes possible the application of advanced visualization algorithms (graph drawing algorithms) within the social sciences. These were developed for totally different purposes (e.g. computer-aided geometric design, computational geometry). Here as well, yet another boundary between scholarly disciplines has been removed. The software developments of the graph drawing community[10] as well as the application of modes of visualization in accordance with the laws of color metrics and color psychology[11] make possible the application of highly sophisticated graphic algorithms regardless of the user's profession or background. Biologists and chemists work with the same software and graphic "language" as researchers in the social sciences, which opens up totally new possibilities of information exchange and collaboration beyond historically conditioned prejudices and skepticism (such as reservations on the part of social scientists about biology and the theory of evolution).

SNA's nexus with modern biology and physics is by no means limited to the use of shared software applications. In recent years, research into dynamic aspects of networks has increased dramatically. A mutual interest in the simulation of complex, non-linear processes in networks has resulted in models from the field of complexity research (Santa Fe Institute) and chaos theory flowing into SNA models (and vice versa). Today, dynamic processes in networks are modeled with the help of so-called agent-based simulation software (e.g. SWARM, STARLOGO, NETLOGO, BLANCHE). With them, various different strategies for setting up efficient and robust networks can be advance tested in silicio. The aim of simulations, however, is not so much to derive unerring predictions about the future; rather, it is to obtain superior insights into the behavior of complex systems.

The latest research proceeds under the assumption that the individual elements of the system follow simple rules that are equally valid for all elements, and investigates the resulting (usually nonlinear) behavior of the system.[12] Today the behavior of complex systems, such as stock market crashes and mass panics, and even the behavior of a flock of birds, can be simulated very well proceeding from the individual agent level. Nonlinear (usually abrupt) progressions are well-known, particularly in connection with processes of diffusion like the propagation of fashions, opinions or new high-tech products. Once certain critical values are exceeded, the network undergoes a sudden shift. It starts with a few individuals who, for example, vote for a different political party, but once a certain number of swing voters has been exceeded, then suddenly all the rest of the individuals in a core network switch their allegiance to that party too. A similar phenomenon is apparent in the case of highly network-dependent processes like the selection of a cell phone service provider or a person's public reputation. Once a certain threshold value has been surpassed, a snowball effect kicks in—opinions are formed or revised collectively and no longer individually. SNA researchers have had increasing success in discovering the laws that govern such discontinuities in a system's behavior.[13] Generally speaking, the stability of networks and their vulnerability will be an important topic in years to come. Terror attacks, breakdowns of electric power grids or collapses of Internet networks due to virus attacks shift the question of how networks react to exogenous shocks into the focal point of ongoing consideration—both in the computational organizational sciences[14] as well as in physics.[15]



Who will survive? Results of a simulation of five different networking strategies using NETSTRAT™ software from FAS.research

The branches of SNA research that deal with the social structure of innovation (understood in the broadest sense) are providing what is probably the strongest impetus for new approaches to social, cultural and economic policymaking. Which structural conditions are conducive to the emergence of new developments in the arts, cultural life, politics or business? Innovation is the result of the transformation and recombination of previously existing elements (technologies, knowledge, artifacts, cultural codes and languages, modes of behavior). Agents (persons, institutions) that bring previously separate elements into contact with one another (technology brokerage)[16] and build bridges in the process are the driving structural forces behind innovation. Since such agents often operate on the periphery of established networks, the role peripheral agents play in knowledge and innovation networks has to undergo a process of complete reevaluation. With the models it provides, SNA is making a key contribution to a general theory and practice of cultural creativity and innovation. After all, the structural conditions and the conditions of conformity to generally applicable laws under which the new technologies (such as the Nanotechnology Revolution) are emerging are the very same ones that are bringing forth new culinary, artistic, cultural and scientific ideas and techniques. Here, SNA can offer very detailed instructions as to how creative processes can be nurtured and how innovation networks have to be designed in order to stimulate and ensure the thriving of a culture of innovativeness—whether in a social, economic or artistic context.

In this sense, social network analysis is not only a scholarly discipline, since thinking in terms of networks opens up completely new ways of looking at social processes. It remains to be seen how well social analysis on the basis of SNA will be able to deliver new ideas and approaches to cultural, social and economic policymaking issues. Nevertheless, SNA most certainly is in a position to provide the cartographic fundamentals for a new policy oriented on the concept of overall social innovativeness and creativity, one that lays claim to the regulative idea of the expansion of that which is "adjacently possible"[17] within a modern, 21st-century society characterized by autocatalytic diversity.

Translated from the German by Mel Greenwald

1 Barabasi, A.L.(2002): *Linked. The New Science of Networks.* Cambridge, Perseus Publishing; Kleinberg, J.; Lawrence, S. (2001) *The Structure of the Web.* Science 294, 1849
2 Kauffman, S. (1992): *The Origins of Order,* Oxford University Press, Oxford
3 Cf. DARPA—Defense Advanced Research Projects Agency (Overview), March 2004, *http://www.darpa.mil/*
4 Baker, W. (2000): *Achieving Success Through Social Capital;* San Francisco, A Wiley Company; Rosen, E. (2000): *The Anatomy of Buzz. How to Create Word-of-Mouth Marketing,* Doubleday, London / New York
5 Neurath, W.; Katzmair, H. (2004): "Networks of Innovation—Evaluation and Monitoring Technology Programs Based on Social Network Analysis," Newsletter, Plattform für Forschungs- und Technologieevaluierung (20); Neurath, W.; Katzmair, H. (2003): "Innovationsnetzwerke in Österreich. Potenziale und Anwendungen der sozialen Netzwerkanalyse im Kontext der österreichischen F&E Politik," in *Wirtschaftspolitische Blätter* 50(3), pp. 353 – 365
6 The SNA community is organized under the aegis of the International Network for Social Network Analysis (INSNA). The group publishes its own journal (Connections) and holds an annual convention (Sunbelt Conference). For further information about the INSNA as well as about social network analysis, log on to *http://www.sfu.ca/~insna/*
7 Cassirer, E. (1910): Substanzbegriff und Funktionsbegriff; Berlin
8 A good overview is to be found in Monge, R. M.; Contractor, N. S. (2003): *Theories of Communication Networks,* Oxford University Press, Oxford
9 PAJEK *http://vlado.fmf.uni-lj.si/pub/networks/pajek/*
VISONE *http://www.visone.de/*
MULTINET *http://www.sfu.ca/~richards/Multinet/Pages/multinet.htm*
KEYPLAYER *http://www.analytictech.com/keyplayer.htm*
WILMASCOPE *http://wilma.sourceforge.net/*
TULIP *http://www.tulip-software.org*
MAGE *http://kinemage.biochem.duke.edu/kinemage/kinemage.php*
10 Jünger, M.; Mutzel, P. (2004): *Graph Drawing Software,* Springer, Vienna / New York
11 Krempel, L. (2004): *Visualisierung komplexer Strukturen. Grundlagen der Darstellung mehrdimensionaler Netzwerke.* Cologne: Max Planck Institute for the Study of Societies
12 Strogatz, S. H. (1994): *Nonlinear Dynamics and Chaos,* Westview Press, Boulder, CO
13 Rogers, M. E. T. (2003): *Diffusion of Innovations* (5th edition), Free Press, New York; Valente, W. T. (1995): *Network Models of the Diffusion of Innovations;* Cresskill
14 See the research activities at the Carnegie Mellon University's Center for Computational Analysis of Social and Organizational Systems *(http://www.casos.cs.cmu.edu/index.html)*
14 Watts, D. (2004): *Six Degrees;* W. W. Norton & Company, New York
16 Hargadon, A. (2003): *How Breakthroughs Happen,* Harvard Business School Publishing, Harvard
17 Kauffman, S. (2000): *Investigations,* Oxford University Press, Oxford