Structural reasoning of networks

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Abstract. In recent years, there has been considerable growth of different kind of networks. From physics and computer science to biology and the social sciences, researches have found that a great variety of systems can be represented as networks. Network evolution has led to the extensive investigations in order to understand and explain network effects. The main advantage is that graph theoretic concepts can be used as principal mathematical language for describing properties of networks. One of the continuously and rapidly evolving fields in the study of networks and complex systems is structural reasoning based on Social Network Analysis (SNA). The purpose of the paper is to discuss about the importance and possibilities of structural reasoning based on SNA and to show the application of SNA for non-typical social network. In this article particular interest is devoted to the relational analysis of network.

Keywords: structural reasoning, network analysis, relational analysis, systemic analysis, actors, relationships, nodes, links, centrality.

1 Introduction

In recent years, there has been considerable growth of different kind of networks in economics, mathematics, sociology, computer science and a number of other fields (there are computer networks, social networks, citation networks, hyperlink networks and countless more). From physics and computer science to biology and the social sciences, researches have found that a great variety of systems can be represented as networks, and that there is much to be learned by studying those networks [1]. Network evolution has led to the extensive investigations in order to understand and explain network effects [2]. Internet has amplified the power of many existing networks and sustains a large collection of new networks. Increasingly, there is recognition that network analysis can tell us a great deal about the relationships between people and between entities. The study and analysis of networks can be spread to many tasks from interdisciplinary investigations. First of all, networks have to be built, which means that empirical studies of networks are necessary. The key aspect here is knowledge acquisition and representation. The goal of this stage is representation of a network as a model appropriate for formal analysis. Afterwards, models have to be read and processed using mathematical or statistical analysis. Finally, it is very important to capture the insights obtained from observational data and quantitative analysis so that one can create models, such as mathematical models or computer models of processes taking place in networked systems. Modeling work of this type allows to make predictions about the behavior of network as a function of the parameters affecting the system. Every stage of this study requires appropriate tools and knowledge from a certain branch of science. Network theory is compatible with systems theory and complexity theory [3]. Therefore ability to take a look on the structure from the qualitative (relational) as well as from the quantitative (systemic) point of view is very useful and important. Qualitative/relational analysis gives an insight on the individual actors and their properties, while the quantitative/systemic analysis let us compare different kind of structures. The aim of such comparative analysis is to make a set of properties to measure the complexity of networks. This article discusses structural reasoning based on social network analysis (SNA). The particular interest is devoted to the process of relational analysis of network.

2 Structural reasoning based on SNA

The task of structural reasoning is to understand properties of structural environment, and how these structural properties influence observed characteristics and associations among characteristics. The main advantage of structural reasoning is mathematical description based on graph theoretic concepts of network. Graph theory provides both an appropriate representation and a set of concepts that can be used to study formal properties of networks. It gives us mathematical operations and ideas with which different kind of properties can be quantified and measured. There are many sources of literature where to read the main graph theoretic concepts and effectiveness of using graphs in network analysis [1, 2, 4, 5, 6, 7, etc.]. There are several key concepts at the heart of network analysis that are fundamental to the discussion of social networks. These concepts are: actor, relational tie, dyad, triad, subgroup, relation, and network [5]. In SNA graph is used as a model of network, where nodes serve as actors and links are relationships between them. In the network analytic framework, links may be any relationship existing between units (material transactions, flow of resources or support, kinship, behavioral interaction, information exchange, citation etc.). The patterns of connections between nodes form a network and it is intuitively clear that the structure of such networks must affect the pattern of different transactions where the certain network exists. There are three primary components in the study of networks [2]:

- empirical studies of networks, when network structure is probed using a variety of techniques such as interviews, questionnaires, direct observation of individuals, use of archival records etc. The goal of such studies is to create a picture of the connections between objects.
- applying mathematical or statistical analyses for a network, namely the quantitative analysis of network data. This is the domain of classical social network analysis, which focuses on issues such as: who are the most central members of a network and who are the most peripheral? Which people have most influence over others? Does the community break into smaller groups

and if so what are they? Which connections are most crucial to the functioning of a group?

- mathematical modeling of networked systems – building on the insights obtained from observational data and its quantitative analysis, one can create models, such as mathematical models or computer models, of processes taking place in networked systems. Modeling work of this type allows us to make predictions about behavior of a community as a function of the parameters affecting the system.

Structural reasoning points out two perspectives from which one can make analysis of network, namely qualitative/relational and quantitative/systemic point of view. Of course, quantitative and qualitative approaches are not mutually exclusive - contrary, they must be considered as two supplementary approaches. Many complex systems in the real world can be modeled as social networks. Social network analysis is a continuously and rapidly evolving field, and is one branch of the broader study of networks and complex systems. The concepts and techniques of social network analysis are informed by, and inform the evolution of these broader fields [8]. Social network is characterized by a distinctive methodology encompassing techniques for collecting data, statistical analysis, visual representation, etc. [3]. SNA techniques discover patterns of interaction between social actors in social networks. However, one of the SNA's advantages is that it can in fact uncover subtle, unrecognized relationships between actors, and thus can aid in the development of more accurate classification schemes in the future. Common SNA procedures include [8]:

- information flow analysis (to determine the direction and strength of information flows through the network);
- calculation of centrality measures (to determine individual roles within a network);
- hierarchical clustering (to uncover cliques whose members are fully or almost fully connected);
- the block modeling (to discover key links between different subgroups in a network);
- calculation of structural equivalence measures (to identify network members with similar characteristics);

Freeman defined the basis for a whole family of node centrality measures: local centrality (degree), betweenness, and global centrality (closeness) [4]. Centrality measures address the question "Who is the most important or central person (actor) in this network?" Centrality measures are some of the most fundamental and frequently used measures of network structure. They show the role of individuals and also the whole population in a network [8].

Due to the scope and goal of this paper the relational analysis of basic centrality measures proposed by Freeman is made. The application of SNA and the results of analysis are in the following chapter 3. It should be admitted that the process of analysis can be widened to very deep level according to the interests and the aim of the person who makes analysis.

3 The relational analysis of network

The application of SNA was taken to analyze the network which depicts some streams of systemic thoughts. This network represents a family tree of systemic thinking and it was elaborated by International Institute for General Systems Studies (IIGSS) during the period 2000 – 2001 (IIGSS 2001). Nodes and links of the digraph are colored according to its major scientific realm. There are twelve groups of nodes in this diagram: general systems, cybernetics, physical sciences, mathematics, computers & informatics, biology & medicine, symbolic systems, social systems, ecology, philosophy, systems analysis, engineering. Figure 1 shows the network elaborated by IIGSS. There is a visualization of network as a digraph in Figure 2.

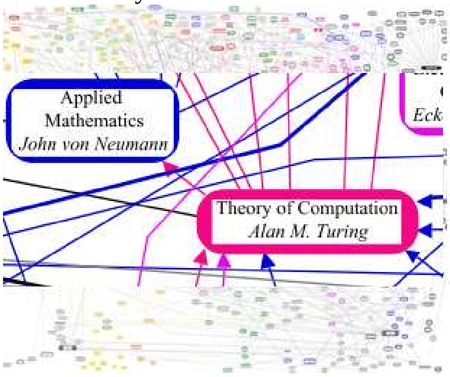

Figure 1. Some streams of systemic thoughts [10].

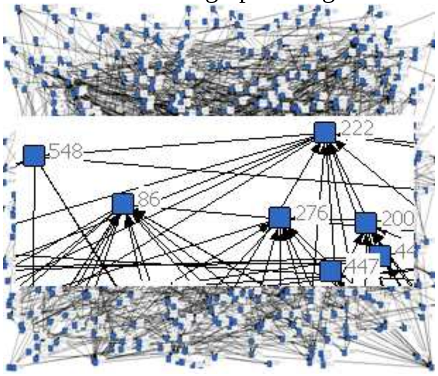

Figure 2. Visualization of network using NetDraw [11].

Digraph describes the interdependence of different directions of science and research. The relationships between nodes depict the mutual exchange of information, where the node can serve as a sender and/or as receiver of information, where a node is influenced by or has an influence on another node in graph. The core disciplines play the most important role (like mathematics, system theory etc.), but it is interesting to know also the origin and the following growth of different kind of directions, namely which branch of science was influenced by another one or which one has a mediate impact on the development of another one. Also it is interesting to think about the common evolution of scientific trends and directions, while in comparison to the previous version of this network (draft update in 2000) many subjects from social and symbolic systems are added. This network can not be treated as a typical social network where nodes are human beings and links show relationships between them. But still using SNA one can think and discuss about the causes and consequences of processes surrounding us. Social network analysis was made using SNA analysis tool UCINET 6.0 [12]. Detailed explanation of mathematical background for each measure one can find also in [5, 6]. The core information about the network is given in table 1.

Table 1. The core information about the networks under investigation.

Measure	Value
Number of nodes	615
Number of links	1288
Number of isolated nodes	37
Number of internal nodes	409
Number of input nodes	50
Number of output nodes	119
Number of strongly related subcomponents (with 2 or more members)	24

Actually, the goal of this analysis is twofold: first, to ensure that SNA can be applied to such kind of structure, and secondly, to get interesting and useful results to better understand systemic thoughts depicted in this structure.

3.1 Degree (local centrality)

A degree of node is the number of nodes adjacent to it [6]. As our graph is directed it is necessary to distinguish between the 'in-centrality' and the 'out-centrality'. In typical social network one quantifies it as the tendency of actors to make 'choices' and the other quantifies the tendency to receive 'choices'. It depends on a specific network under investigation. Table 2 lists the most important nodes according to their direct connectivity, namely in-degree and out-degree of node is taken into account. The more links an actor (node) has, the more power they may have. If an actor/node receives many ties, they are often said to be prominent, or to have a high prestige. Actors who display high out-degree are often said to be influential actors [5].

Table 2. Nodes with the highest in-degree and out-degree.

In-Degree	Out-Degree
InD = 13: Classical mathematics (n_9); Informatics (Computer Science&Engineering) (n_{208}); InD = 12: Management cybernetics (n_{147}) ; InD = 11: Structuralist mathematics (n_7); InD = 10: Natural evolution(n_{156}); Human science(n_{187}); Rational philosophy (n_{219}); Geometrodynamics (n_{290}); Classical physics (n_{581}); etc.	OutD = 31: General systems (n_{47}); OutD = 23: Operations research (n_{613}); OutD = 21: Rational philosophy (n_{219}); Modern theoretical physics (n_{598}); OutD = 16: Informatics(Computer Science & Engineering) (n_{208}); etc.

The results show that *Classical mathematics* and *Informatics (Computer Science&Engineering)* are nodes with the highest in-degree. These nodes serve as point of reference for another one to be valuable and observable. One can see that node *General systems* has the greatest out-degree and therefore it might be regarded as the most influential node in the network. This science has initiated many other investigations in different scientific realms. That other branches share information with these three would seem to indicate an interest on the part of others to exert influence.

3.2 Closeness (global centrality)

Importance of a node can be exerted by direct influence and information (or some other value) exchange, but it can also be seen as a “reference point” by which actors judge themselves, and by being a center of attention who’s views are heard by large number of actors. Freeman’s measure of global centrality is expressed in terms of the distances among the various nodes. A node is globally central if it lies at short distances (geodesics) from many other points [6]. This is the most common approach, alternatively one may focus on reciprocal ties, or on all paths or all trails in a network. The measure focuses on how close an actor is to all the other actors in the set of actors. The idea is that an actor is central if it can quickly interact with all others. Actors who are able to reach other actors at shorter path lengths, or who are more reachable by other actors at shorter path lengths have favored positions [8]. Table 3 shows results of closeness centrality analysis.

Table 3. Nodes with the highest in-closeness and out-closeness.

In-Closeness	Out-Closeness
Systemic Perspectivism (n_{258}); Topology of Meaning (n_{176}); Cyber-semiotics (n_{360}); Socio-Cybernetics (n_{202}); General Systemology (n_{121}); Social Cybernetics (n_{173}); Teleonics (n_{100}); Cybernetic Epistemology (n_{451}); etc.	Astronomy (n_{489}); Philosophy of Regularity (n_{488}); Philosophy (Anaxagoras) (n_{482}); Naturalism (n_{240}); Heroic Legends (n_{484}); Law (n_{341}); Reciprocities (n_{239}); Unity & Stasis (n_{216}); Apocalyptic Dualism (n_{481}); etc.

Actually here some kind of ranking also must be applied, while it is important to distinguish the quantity of nodes from which node can be reached (as well as node can reach) and the sum of geodesics. While there is a difference if a node can reach a lot of other nodes with larger geodesics in total or if it has less reachable nodes with smaller sum of geodesics. What one suggests as more important: the number of nodes or the sum of geodesics? The process of analysis has shown that node ‘*Systemic Perspectivism (n_{258})*’ is reachable from the 381 other nodes on the total geodesic paths of 1621, while analysis of out-closeness points out the node ‘*Astronomy (n_{489})*’ from which 476 nodes are reachable on the geodesics of 3016. Interestingly, both these nodes (n_{258} and n_{489}) have additional characteristic – they are output and input nodes, respectively. Also distance matrix shows that there are 3 different paths connecting them. The analysis of results here can be widened to a very deep level.

3.3 Betweenness centrality

Betweenness is the third basic concept of centrality defined by Freeman [4]. This concept measures the extent to which a particular node lies ‘between’ the various other nodes in the graph: a node of relatively low degree may play an important ‘intermediary’ role and so be very central to the network [6]. That is, the more other nodes depend on certain node to make connections with other nodes, the more important the certain node is. If there are several connections through this node, then the importance decreases. In typical social networks these nodes are called ‘brokers’ or ‘gatekeepers’ with a potential for control over others. Betweenness centrality also is calculated based on geodesic distances which go through the certain node. Table 4 shows the results of analysis of betweenness centrality.

Table 4. Betweenness centrality of nodes.

Betweenness (SNA)
Classical mathematics (n_9); Mathematical logic(n_8); Operations Research (n_{613}); General systems (n_{47}); Mechanistic Physics (n_{277}) ; Mathematical Nominalism (n_{86}); Informatics (Computer Science & Engineering) (n_{208}); Rational Philosophy (n_{219}); Logical Positivism (n_{33}); Sructuralist Mathematics (n_7); etc.

The results of analysis show that the highest betweenness characterizes nodes *Classical mathematics (n_9), Mathematical logic(n_8); Operations Research (n_{613}) etc*. These nodes/actors play the most important role as intermediaries. Author explains it so, that many directions, researches cannot be made without mathematical background. It would be interesting also to make deeper analysis to find subsets of nodes which go through these ‘gatekeepers’. Betweenness is one of the most complex of the measures of node centrality to calculate [6].

4 Conclusions

In this paper we have described the main ideas of structural reasoning based SNA approach. The application of structural reasoning based on SNA was made to the network depicting streams of systemic thoughts. Due to the scope and aim of this paper and also due to the specific network under investigation the most well-known measures of relational process of analysis were discussed here, while the depth and the process of analysis can be spread according to the aim of analysis and knowledge the researcher or the person who makes analysis has. The main conclusion is that SNA can be applied to analysis of specific, non-typical social structures. The results of analysis can be treated as ‘short-term’ and ‘long-term’ perspective. If we speak about the meaning of scientific researches and directions from the present point of view, when a huge amount of new investigations are made, which are mostly based on fundamental theories, then such nodes as *Classical mathematics, Computer Science&Engineering, General systems, Operations Research* etc. are the most important. But, from the ‘long-term’ perspective point of view, when we think how the things have originated, such nodes as *Rational Philosophy, Fluxation&Unified Opposites, Idealistic philosophy* are the most significant, while these nodes have the highest connectivity to other nodes in the structure. Does it mean that today we have to take a look on events around us from the philosophical point of view? Maybe deeper analysis of this structure could give us an answer to this question. Although, the relational point of view was stressed here, it would be useful to make systemic or macro level analysis, to form a set of properties to measure the complexity of networks. It is obvious that both views – relational and systemic – can be used as mutually complementary approaches. Future research will be focused on deeper analysis of this structure to find new measures or any interesting consequences and also on analysis of other 'non-typical" social network structures. Special interest will be devoted to the use of social networks analysis in software engineering, where it is relatively unexplored and holds much promise for future applications.

References

1. Newman, M., Barabasi, A.L., Watts, D.J. (Eds.): The Structure And Dynamics Of Networks. Princeton, USA: Princeton University Press (2006)
2. Newman, M. E. J.: Mathematics of networks. In Steven N. Durlauf and Lawrence E. Blume (Eds.), The New Palgrave Dictionary of Economics (2nd edition), Basingstoke, UK: Palgrave Macmillan (2008)
3. Borgatti, S.: Social Network Analysis Instructional Website. Retrieved from web address http://www.analytictech.com/networks/topics.htm. Last visited on 28.04.2009.
4. Freeman, L.C.: Centrality in Social Networks: Conceptual Clarification. Social Networks, 1(3), 215-239. (1979)
5. Wasserman, S., Faust, K.: Social Network Analysis. New York: Cambridge University Press (1994)
6. Scott, J. P.: Social Network Analysis. London: SAGE Publications Ltd. (2000)
7. Casti, J.: Connectivity, complexity and catastrophe in large-scale systems. New York: John Wiley & Sons (1979)
8. Hanneman, R., Riddle, M.: Introduction to social network methods. Retrieved from web address http://faculty.ucr.edu/~hanneman/nettext/C10_Centrality.html. Last visited on 21.04.2009.
9. Polites, G. L., Watson, R. T.: The Centrality and prestige of CACM. Communications of the ACM, 51(1), 95-100. (2008)
10. IIGSS.: Genealogy: A family tree of systemic thinking. Retrieved from web address http://www.iigss.net/. Last visited on 8.04.2009.
11. Borgatti, S.P.: NetDraw: Graph Visualization Software. Harvard: Analytic Technologies (2002)
12. Borgatti, S.P., Everett, M.G. and Freeman, L.C.: Ucinet 6.0 for Windows: Software for Social Network Analysis. Harvard: Analytic Technologies (2002)