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ORIGINAL ARTICLE

Social network analysis: developments, advances, and prospects

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Abstract This paper reviews the development of social network analysis and examines its major areas of application in sociology. Current developments, including those from outside the social sciences, are examined and their prospects for advances in substantive knowledge are considered. A concluding section looks at the implications of data mining techniques and highlights the need for interdisciplinary cooperation if significant work is to ensue.

1 The development of social network analysis

The origins of an approach to social structure explicitly using ideas of a 'social network' are difficult to discern. Structural thinking has deep roots in the sociological tradition, but it was really only in the 1930s that specifically network thinking emerged as a distinct approach to social structure.[1] German social theorists influenced by Georg Simmel took up his emphasis on the formal properties of social interaction to construct a 'formal sociology' in which sociologists were enjoined to investigate the configurations of social relations produced through the interweaving of social encounters. Alfred Vierkandt and Leopold von Wiese were the key proponents of this idea and explicitly adopted a terminology of points, lines, and connections to describe social relations. Their ideas influenced a number of workers in social psychology and psychotherapy who were interested in the ways in which small group structures influenced individual perceptions and action choices. Lewin (1936) and Moreno (1934) were the key contributors to investigations into the 'field' or 'space' of social relations and its network characteristics (and see Bott 1928). It was Moreno who gave his approach the name 'sociometry' and introduced the idea of depicting social structures as network diagrams—sociograms—of points and lines. Sociometry became a major field of investigation in education and social psychology (Jennings 1948), where it gave rise to the approach called 'group dynamics' (Cartwright and Zander 1953; Harary and Norman 1953) that was strongly developed at the University of Michigan and at the Tavistock Institute.

This work had some impact on the mainstream of American sociology, thanks to the work of Lundberg (1936; Lundberg and Steele 1938), but a stronger development of network thinking began when Lloyd Warner and Elton Mayo cooperated in a study of the Hawthorne electrical works in Chicago and went onto investigate community structure in American cities and towns. Drawing on the ideas that Radcliffe-Brown had taken from Durkheim's sociology, they focused their attention on the structure of group relations and began to devise network diagrams to represent this. They may have been influenced by the emerging sociometric ideas, but the particular stimulus to this way of thinking may have been the electrical wiring diagrams that they found in the factory studied and that served as a metaphor for group relations. Whatever its origins, the idea of seeing social groups as networks of relations was firmly established when their principal research report appeared a decade after the commencement of the research (Roethlisberger and Dickson 1939). In a study of Newburyport, carried out between 1930 and 1935, Warner developed techniques for depicting large-scale community relations in matrix form as a representation of

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[1] Overviews of the history of social network analysis can be found in Scott (2000: chapter 2) and Freeman (2004).

what he called the 'clique structure' of the city (Warner and Lunt 1941). George Homans developed these matrix methods in his reanalysis of the small clique of southern women studied by Warner in Natchez (Homans 1950).

These two traditions of research began to come together in anthropological work carried out in the 1950s by researchers from the University of Manchester. Attempting to break with the consensus assumptions of mainstream American sociology and to recognise conflict and divisions within community structure, they saw network analysis as providing the means to this end. It was Barnes (1954) who proposed taking the idea of a network of relations seriously, and his arguments were reinforced by Elizabeth Bott's London fieldwork on kinship networks (Bott 1955, 1956). Presenting their ideas to the Manchester researchers, they inspired a systematic statement by Nadel (1957) and a research programme on African communities (Mitchell 1969b). Mitchell's commentary on this work (Mitchell 1969a) counts as one of the earliest systematic summaries of a formal social network methodology.

By the time that Mitchell's work appeared, however, a number of American researchers had also begun to develop a formal methodology for social network analysis. Harrison White had begun to explore the uses of algebra to represent kinship structures (White 1963), while Edward Laumann (Laumann 1966) had begun to employ multidimensional scaling methods as an extension of Lewin's approach to the social field. White moved to Harvard University and brought together a large and dynamic group of associates to explore network methods (see the discussion in Mullins 1973). Levine (1972) explored multidimensional scaling methods for studies of corporate power, Lee (1969) and Granovetter (1973, 1974) used extended sociometric methods to investigate, respectively, abortion and employment, while White and colleagues developed methods of matrix analysis for studying social positions (White et al. 1976; Boorman and White 1976). It was from this group that a new generation of social network researchers took this style of research across the globe and influenced work undertaken in many countries.

Most notable of the developments in social network analysis outside North America was the work of Barry Wellman on community structure in Canada (Wellman 1979; and see Wellman and Berkowitz 1988), the work of Frans Stokman and colleagues on Dutch and international patterns of corporate control (Helmers et al. 1975; Stokman et al. 1985), and my own work on corporate ownership and control (Scott 1979; Scott and Griff 1984). Since the late 1970s the amount of work on the methodology of social network analysis has increased massively, and the range of applications precludes any easy summary. Key methodological landmarks in the development of social network analysis are major studies by Burt (1982), Freeman et al. (1989), and by Wasserman and Faust (1994), an edited volume by Wasserman and Galaskiewicz (1994), an introductory text by Scott (2000; originally published 1991), and a recent edited collection by Carrington et al. (2005). Recent developments and advances will be published in the forthcoming Handbook of Social Network Analysis (Scott and Carrington 2011).

2 Central ideas and applications of social network analysis

The predominant approach in social network analysis until fairly recently has been the mathematical approach called graph theory. This still, arguably, provides the core of formal social network analysis. Graph theory originated in the mathematical investigations undertaken by Euler and provides a method for studying networks ('graphs') of all kinds. In social network analysis, individuals and groups are represented by points and their social relations are represented by lines, as in the classic sociograms. Graph theory provides theorems for analysing the formal properties of the resulting sociograms. When network data are recorded in matrix form, graph theory can operate directly on the matrices without the need for the construction of an actual visual representation of the data: a great advantage when handling large scale data sets. The lines in a graph can be assigned a 'direction' to represent the flow of influence or resources in a social network and they can be assigned a 'value' to represent the strength of the relation. The theorems of graph theory use undirected, directed, and valued data to construct measures of the overall 'density' of a network and the relative 'centrality' of various points within the network. Centrality measures have typically been used as proxies for power and influence and have allowed the investigation of brokerage relations (Burt 2005). A major area of work within this approach has been the investigation of cliques and clusters, where a variety of alternative measures have been devised for representing the structural divisions within a social network.

Alongside this work has been a matrix-based approach originating in the ideas of Harrison White and Doug White that focuses not on the properties of individuals and groups but on the characteristics of social positions, roles, and categories. These positional approaches—sometimes termed 'block models'—are rigorous methods of matrix clustering that organise networks into hierarchical positions of the kind seen by Nadel (1957) as central to the role-theoretic concerns of sociology. A number of alternative measures of the 'structural equivalence' and 'substitutability' of individuals within social positions have been developed as ways of advancing this aspect of social network analysis.

These ideas have been developed in a number of general and specific pieces of software. The most widespread in common use has been UCINET, developed initially as an implementation of graph theoretical approaches by Lin Freeman, Martin Everett, and others at the University of California, Irvine. It has been extended into a general programme handling positional measures and graphical approaches and offers an intuitive and efficient way of undertaking network analyses. More recently, PAJEK has been developed by Vladimir Batagelj at the University of Ljubljana as a way of handling large-scale data sets and, in particular, using visual methods of representation (see De Nooy et al. 2005). It, too, is capable of general analyses of network structure, and is now included as a sub-program within UCINET.

Perhaps the major area, and also one of the earliest areas, in which social network techniques have been applied is the study of intercorporate power relations through the investigation of interlocking directorships.

One of the principal areas in which social network analysis has been applied is in the investigation of corporate power and interlocking directorships. A number of early studies by writers such as Sweezy (1939) had adopted ad hoc techniques for drawing network diagrams of board-level connections and had tentatively adopted the language of webs and networks, especially in relation to the formation of cliques. During the 1960s and 1970s these suggestions were furthered in a series of studies undertaken by network analysts in the United States and then in Europe, Australia, and Japan. Bearden et al. (1975) produced a path-breaking paper that elaborated on the idea of centrality in social networks as a way of exploring the power and influence of banks in the American corporate world, while Levine (1972) examined the mapping of the clusters associated with particular banks and their directors in social space, using techniques of multidimensional scaling. Key measures developed in the Netherlands (Helmers et al. 1975) became the basis for an investigation of transnational patterns (Fennema 1982) and an international comparative investigation (Stokman et al. 1985). This was extended into a comparative investigation of intercorporate shareholding networks (Scott 1986) and led to numerous studies in a variety of societies (see the review in Scott 1997).

A second major plank of social network analysis has been the investigation of community structure. This area has a long history in the investigations undertaken by Lloyd Warner into small town cliques and business networks (Warner and Lunt 1941) and in anthropological studies of tribal communities. In the 1960s, a group of anthropologists associated with the developments in network analysis at Manchester University began a series of formal studies (Mitchell 1969b), but it was Fisher (1977) and Wellman (1979) who generated the work that moved this field on in a systematic direction. Wellman undertook a series of investigations into the changing structure of communal relations in a Canadian city and examined the role of friendship in social integration. He was particularly concerned with changing means of maintaining contact and has recently elaborated on electronic means of communication as bases for interpersonal networks (Wellman and Hogan 2006). This work has most recently converged with ideas on social capital that developed out of Putnam's (2000) work. The most important contributions to this work have been the reflections of Lin (2001) and Burt (2005; see also Lin et al. 2001).

Numerous other application—too numerous to cite here—have extended social network analysis into political and policy networks, social movements, criminality and terrorism, religious networks, and elsewhere. Many of these areas are reviewed in the forthcoming Sage Handbook of Social Network Analysis (Carrington and Scott 2011).

3 Enter the physicists

Perhaps the most striking development within network analysis has been the growth of interest apparent among physicists in applying network ideas to social phenomena. In 1998, Duncan Watts and Steven Strogatz published a paper (Watts and Strogatz 1998) that revisited some of the ideas on random networks that had grown out of Stanley Milgram's work on 'small worlds' (Milgram 1967; Travers and Milgram 1969). Taking up these suggestions and prior work on random networks, theorists such as Barabási (2002) and Watts (1999, 2003) proposed what they regard as new areas of application to the social world. Unfortunately, these physicists have ignored or have been unaware of the vast amount of prior work on social networks and have proposed investigations into, for example, networks of directorships on the grounds that none has so far been undertaken! Public awareness of the implications of network analysis for investigating the social world has been strongly influenced by the proselytising activities of the physicists, and their work is frequently lauded as both novel and innovative by those who are equally unaware of the work of sociologists (see, for example, Buchanan 2002).

A review of published studies undertaken by Freeman (2004) has shown that work by physicists has rarely cited work by social network analysts—and social network analysts have been reluctant to engage with the work of the physicists. Indeed, a network analysis of citation patterns sows an almost complete separation of the two groups. There are signs that this division is breaking down, at least so far as sociologists are concerned. Watts has converted

into sociology, but Barabási and others influenced by him still persist in ignoring prior work. Nevertheless, work by physicists has outlined areas of investigation that were underemphasised in prior social network analysis and a rapprochement will be fruitful to both sides.

A key area highlighted in the work of the physicists has been network dynamics and change over time and this has, undoubtedly, been an area that has been developed only weakly, if at all, by sociologists working in social network analysis. Much sociological work has been static or concerned simply with a sequence of static cross-sections of networks, but the methods of the physicists promise ways of moving forward to properly dynamic studies of network transformation and the explanation of network processes.

4 Areas of advance

In current work, four major areas of advance can be identified. These are the use of statistical significance tests, the development of models of longitudinal change, the exploration of new methods of visualisation, and explorations into the cultural context of social network models.

While there have been some attempts to use basic statistical measures of probability and significance to test hypotheses about network structure, it is only recently that significant advances have been made in this area. Standard statistical procedures such as significance tests, regression, and the analysis of variance all assume the independence of observations, and this assumption does not accord with typical network data. For this reason, novel statistical techniques have been required, the most important work having been the work of Stanley Wasserman and his colleagues (Wasserman and Pattison 1996; Pattison and Wasserman 1999; Robins et al. 1999) to generalise Markov graphs to a larger family of models. Their exponential random graph models—sometimes referred to as p^* models—define a probability distribution on the set of all networks that can be constructed on a given set of points using specific parameter vectors. Randomly generated graphs vary along the full range from completely unconnected to completely connected, and log odds ratios of the probabilities are used to produce Monte Carlo estimations that make possible a comparison of an actual network with the set of logically possible graphs in order to assess the likelihood of its occurrence by chance alone.

As well as its descriptive focus, much social network analysis has also concentrated on the static features of social networks. This has also begun to change in recent years as more attention has been given to the dynamic processes involved in changes over time. A key advance in this direction has come from the use of models that depict the ways in which the behaviour of individual agents results in global transformations of network structure. In so-called agent-based computational models, agents (whether individuals or groups) are seen as rule-following entities whose decisions to act in one way or another are consequential for the overall network by virtue of their concatenation with the action consequences of others. Therefore, knowledge of the rules under which agents act can be used to predict broad patterns of change in network structure.

The pursuit of explanations of change over time has been furthered by the development of a number of longitudinal methods that have drawn on agent-based computational models (see Monge and Contractor 2003). Tom Snijders (Snijders and van Duijn 1997; Snijders 2001, 2005) has developed an approach that sees the incremental adjustment of individual action to the changing network structure, resulting in a continuous—but often non-linear—process of network development. Agents act 'myopically', with only partial conception of the wider consequences of their choices and the changes that have resulted from their actions. Networks evolve through the continual iteration of actions, and small, incremental changes can accumulate to a tipping point at which non-linear transformation in network structure can occur. Current work in this area is making important connections with the early work of Wasserman (Wasserman 1980) and his exponential random graph models. The overall approach has been implemented in Snijders' SIENA program for easy use.

The visualisation of social networks has long been a goal of social network analysis, originating in the early sociograms. Once networks reach a size greater than a handful of points, however, it became difficult to draw accurate and legible sociograms. The desire to recapture the simple visual impact of the sociogram has motivated the attempt to investigate ways of drawing network diagrams that retain the spatial patterns inherent in relational data. Multidimensional scaling emerged as one of the earliest attempts to overcome the jumble of criss-crossing lines and to display points according to their relative distance in social space. Implementations of this approach are now available in the major software packages, and such techniques as multiple correspondence analysis are also now beginning to become available. Freeman and others, however, have been exploring alternative bases for visualisation, including those that are able to prevent moving images of network change.

Theoretical work has long been underdeveloped in social network analysis. While the methods themselves do not require or imply any particular sociological theory, they do require theoretical contextualisation in wider debates. The most important recent theoretical arguments have been those that have taken up the work of White (1992) on issues of culture, identity, and agency. Ann

Mische (Mische 2003; see also Mische 2007) has developed some interesting arguments that build on work undertaken with Mustafa Emirbayer (Emirbayer and Mische 1998). Emirbayer himself has contributed important work on the framework of 'relational sociology' that he sees as underpinning social network analysis (Emirbayer and Goodwin 1994; Emirbayer 1997).

5 Conclusion

The potential of data mining techniques for the analysis of available data sources is beginning to be recognised across the social sciences (see Savage and Burrows 2007), and the formation of this journal and of Advances in Social Network Analysis and Mining (ASONAM) is a mark of its potential for the field of social network analysis. The new techniques of network analysis are most appropriate for large-scale data sets of the kind that have not generally been possible to investigate using conventional social network analytic techniques. Data mining techniques allow such data sets to be examined in ways that promise further advances in methodology and substantive knowledge.

It is important, however, that the use of these techniques does not lead to a reversion to purely descriptive work. In the early days of computerised techniques of social network analysis, the tendency among researchers was to generate data and 'findings' with little or no consideration of its significance for substantive theoretical questions. This led many observers of the statistics and sociograms produced to respond 'so what?' Social network analysis struggled to mature to the point at which analytical questions became the focus of investigations and data was used to test and further explanatory aims.

It would be a disaster if the use of the new data mining techniques were to return us to that earlier situation, where researchers were more interested in patterns than they were in the substantive interpretation of those patterns. This should not be a time for methodological specialists alone to explore given data sets. The opportunity should be taken for interdisciplinary cooperation in which those with a substantive knowledge of a particular field are able to cooperate productively with technical specialists to produce those powerful analytical and explanatory studies that can further the agenda of social network analysis in the many substantive fields of social science.

References

Bearden J et al (1975) The nature and extent of bank centrality in corporate networks. In: Scott J (ed) Social networks, vol 3. Sage, London

Barabási A-L (2002) Linked: the new science of networks. Perseus, Cambridge

Barnes JA (1954) Class and Committee in a Norwegian Island Parish. Hum Relat 7:39–58

Boorman SA, White HC (1976) Social structure from multiple networks: II Am J Sociol 81:1384–1446

Bott H (1928) Observation of play activities in a nursery school. Genet Psychol Monogr 4:44–48

Bott E (1955) Urban families: conjugal roles and social networks. Hum Relat 8:345–384

Bott E (1956) Urban families: the norms of conjugal roles. Hum Relat 9:325–341

Buchanan M (2002) Small world: uncovering nature's hidden networks. Weidenfeld and Nicolson, London

Burt RS (1982) Towards a structural theory of action. Academic Press, New York

Burt RS (2005) Brokerage and closure: an introduction to social capital. Oxford University Press, New York

Carrington PJ, Scott J (eds) (2011) Sage handbook of social network analysis. Sage, London

Carrington PJ, Scott J, Wasserman S et al (eds) (2005) Models and methods in social network analysis. Cambridge University Press, Cambridge

Cartwright D, Zander A (eds) (1953) Group dynamics. Tavistock, London

Clyde MJ (1969a) The concept and use of social networks. In: Mitchell JC (ed) Social networks in urban situations. Manchester University Press, Manchester

Clyde MJ (ed) (1969b) Social networks in urban situations. Manchester University Press, Manchester

De Nooy W, Mrvar A, Batagelj V (eds) (2005) Exploratory social network analysis with Pajek. Cambridge University Press, New York

Emirbayer M (1997) Manifesto for a relational sociology 103(2):281–317

Emirbayer M, Goodwin J (1994) Network analysis, culture, and the problem of agency 99:1411–1454

Emirbayer M, Mische A (1998) What is agency? Am J Sociol 103(4):962–1023

Fennema M (1982) International networks of banks and industry. Martinus Nijhof, Hague

Fischer CS (1977) Networks and places: social relations in the urban setting. Free Press, New York

Freeman LC (2004) The development of social network analysis: a study in the sociology of science. Empirical Press, Vancouver

Freeman LC, White DR, Romney AK (eds) (1989) Research methods in social network analysis. Transaction Books, New Brunswick

Granovetter M (1973) The strength of weak ties. Am J Sociol 78(6):1360–1380

Granovetter M (1974) Getting a job. Harvard University Press, Cambridge

Harary F, Norman RZ (1953) Graph theory as a mathematical model in social science. Institute for Social Research, Ann Arbor

Helmers HM et al (1975) Graven Naar Macht. Van Gennep, Amsterdam

Homans G (1950) The human group. Routledge and Kegan Paul, London

Jennings HH (1948) Sociometry in group relations. American Council on Education, Washington, DC

Laumann EO (1966) Prestige and association in an urban community. Bobbs-Merrill, Indianapolis

Lee NH (1969) The search for an abortionist. Chicago University Press, Chicago

Levine JH (1972) The sphere of influence. Am Sociol Rev 37:14–27

Lewin K (1936) Principles of topological psychology. Harper and Row, New York

Lin N (2001) Social capital: a theory of social structure and action. Cambridge University Press, New York
Lin N, Cook KS, Burt RS (eds) (2001) Social capital: theory and research. Transaction Press, New Brunswicvk, NJ
Lundberg G (1936) The sociography of some community relations. Am Sociol Rev 5(1):47–63
Lundberg GA, Steele M (1938) Social attraction-patterns in a village. Sociometry 1:375–419
Milgram S (1967) The small world problem. Psychol Today 2:60–67
Mische A (2003) Cross-talk in movements: rethinking the culture-network link. In: Diani M, McAdam D (eds) Social movements and networks: relational approaches to collective action. Oxford University Press, Oxford
Mische A (2007) Partisan publics: communication and contention across Brazilian youth activist networks. Princeton University Press, Princeton, NJ
Monge PR, Contractor NS (2003) Theories of communication networks. Oxford University Press, Oxford
Moreno JL (1934) Who shall survive?. Beacon Press, New York
Mullins NC (1973) Theories and |theory groups in american sociology. Harper and Row, New York
Nadel SF (1957) The theory of social structure. Free Press, Glencoe
Pattison P, Wasserman S (1999) Logit models and logistic regressions for social networks: II. Multivariate relations. Br J Math Stat Psychol 52:169–193
Putnam RD (2000) Bowling alone: the collapse and revival of American community. Simon and Schuster, New York
Robins GL, Pattison P, Wasserman S (1999) Logit models and logistic regressions for social networks. III. Valued relations. Psychometrika 64:371–394
Roethlisberger FJ, Dickson WJ (1939) Management and the worker. Harvard University Press, Cambridge
Savage M, Burrows R (2007) The coming crisis of empirical sociology. Sociology 41(5):885–899
Scott J (1979) Corporations, classes and capitalism, 1st edn. Hutchinson, London
Scott J (1986) Capitalist property and financial power. Wheatsheaf Books, Brighton
Scott J (1997) Corporate business and capitalist classes. Oxford University Press, Oxford
Scott J (2000) Social network analysis, 2nd edn. Sage, London (Originally 1991)
Scott J, Carrington PC (eds) (2011) Handbook of social network analysis. Sage, London
Scott J, Griff C (1984) Directors of industry. Polity Press, Cambridge
Snijders TAB (2001) The statistical evaluation of social network dynamics. In: Sobel ME, Becker MP (eds) Sociological methodology. Basil Blackwell, Oxford
Snijders TAB (2005) Models for longitudinal network data. In: Carrington PJ, Scott J, Wasserman S (eds) Models and methods in social network analysis. Cambridge University Press, Cambridge
Snijders TAB, van Duijn MAJ (1997) Simulation for statistical inference in dynamic network models. In: Conte R, Hegelmann R, Terna P (eds) Simulating social phenomena. Springer, Berlin
Stokman F, Ziegler R, Scott J et al (eds) (1985) Networks of corporate power. Polity Press, Cambridge
Sweezy PM (1939) Interest groups in the american economy. In: Sweezy PM (ed) The present as history. Monthly Review Press, New York
Travers J, Milgram S (1969) An experimental study of the small world problem. Sociometry 32(4):425–443
Warner WL, Lunt PS (1941) The social life of a modern community. Yale University Press, New Haven
Wasserman S (1980) Analyzing social networks as stochastic processes. J Am Stat Assoc 75:280–294
Wasserman S, Faust K (1994) Social network analysis: methods and applications. Cambridge University Press, New York
Wasserman S, Galaskiewicz J (eds) (1994) Advances in social network analysis. Sage, Beverley Hills
Wasserman S, Pattison P (1996) Logit models and logistic regressions for social networks: I. An introduction to Markov random graphs and p*. Psychometrika 60:401–426
Watts D (1999) Small worlds: the dynamics of networks between order and randomness. Princeton University Press, Princeton
Watts D (2003) Six degrees. The science of a connected age. W. W. Norton, New York
Watts DJ, Strogatz SH (1998) Collective dynamics of "small-world" networks. Nature 393:440–442
Wellman B (1979) The community question: the intimate networks of east yorkers. Am J Sociol 84:1201–1231
Wellman B, Berkowitz S (eds) (1988) Social structures. Cambridge University Press, New York
Wellman B, Hogan B (2006) Connected lives: the project. In: Purcell J (ed) Networked neighbourhoods. Springer, London
White HC (1963) An anatomy of kinship. Prentice-Hall, Englewood Cliffs
White H (1992) Identity and control. Princeton University Press, Princeton
White HC, Boorman SA, Breiger RL (1976) Social structure from multiple networks. I. Am J Sociol 81:730–780