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Social networks as normal science *

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Social network analysis has emerged as an integrated scientific specialty concerned with the structural analysis of social interaction. Historical evidence suggests that members of this specialty are connected by an invisible college, a shared paradigm and a primary journal. The journal *Social Networks* is a primary outlet for researchers in this specialty, particularly those concerned with methodological issues. By examining the pattern of citations within this journal we are able to confirm this historical evidence and gain insight into how science is being conducted by members of this specialty.

Using main path analysis, we examined the pattern in the citation network in the first 12 volumes of the journal. We found six main path structures of connected articles that define and describe core developments in the specialty. The most important of these structures focuses on role analysis, and spans all 12 volumes of *Social Networks*. We find a high density of multiple citations, both to articles within the journal and to key articles outside the journal, and many authors who have published more than a single article in the journal. In addition, the main path tree structures extend through much of the total network, have a single identifiable coherent substantive concern, and are incremental in nature. The pattern of these main paths, and the overall citation pattern, is consistent with a pattern of scientific development labeled by Kuhn as 'normal science'.

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Introduction

The origins of social network analysis extend back approximately 60 years. Social network related concepts appear in the 1930s in the work of Moreno (1934) and Jennings (1937); in the 1940s in the work of Bavelas (1948) and Luce and Perry (1949); in the 1950s in the work of Barnes (1954) and Bott (1957). From the mid 1960s on there was a surge of activity in the area. [1] This growing interest was interdisciplinary and centered on developing a science of society by focusing on a general theory of social networks. Now, after nearly 60 years, we can address the question: "what is the nature of this specialty?".

That there is a specialty of *Social Networks* is in little doubt. Within sociology, anthropology, communications, and business there are social network communities and scholars who describe themselves as social network analysts. Faculty recruitment letters have focused on the area of social networks. Many major institutions teach courses in social networks. The American Sociological Association and the American Anthropological Association recognize social networks as a specialty group with sections at their annual meetings. Annual review volumes in both Sociology and Anthropology have published review articles.

Scholars interested in social networks have their own community with the following legitimating and gate keeping institutions: an international society requiring dues (INSNA), publications (*Social Networks* and *Connections*), and annual meetings (Sunbelt Social Network Conference). Freeman (1980, 1984), and Wolfe (1978) have described portions of the history of this specialty. Such historical and institutional evidence suggests that this movement is going strong and is affecting the parent disciplines both at a metaphorical and at a methodological level.

Whether this specialty is viable in the long run, whether it is well integrated into its parent disciplines, whether it is growing, are all

[1] This point has been documents in several ways. Freeman's 1976 *Bibliography on Social Networks* contained few pre-1965 articles. Wolfe's 1978 article "The Rise of Network Thinking in Anthropology" attested to the growing interest among anthropologists in the late 1960s and early 1970s in social networks.

important questions from a sociology of science perspective. However, they are not ours. Our focus is on the 'type of science' being done by members of this specialty. We are concerned with determining whether the research in social networks hangs together, whether there are major divisional splits, either institutional or paradigmatic, and whether the members of the specialty attend to each other's work. In order to address this concern we bring together data from three sources: (1) historical information on the field; (2) questionnaire data on the origin of the field and current membership; (3) citation data from the first 12 volumes of the journal *Social Networks*. We will focus primarily on the citation network derived from all articles published in *Social Networks* in Volumes 1 through 12. Using these data, we will conduct a main path analysis (Hummon and Doreian, 1989, 1990; Hummon et al. 1990; Carley et al. 1991) to determine the nature of scientific influence and development within the social network community.

As we engage in this analysis we will be looking to see whether there is evidence for what Kuhn calls 'normal science' (1970). That is, is there an active group of authors who view *Social Networks* as their primary professional outlet; an intellectual community that defines important problems, promotes common methods of analysis, and establishes criteria of accomplishment and advance; core substantive areas in which ideas develop incrementally. If the main paths through the citation network are few in number, densely connected, extensive in the number of articles linked together, substantively continuous and incremental we have strong evidence that the field has achieved 'normal science' status.

We focus on the journal *Social Networks* as it is the flagship journal of the specialty. Thus, if there is any place where work in this specialty hangs together, it should be in this journal. Nevertheless, the use of a single journal does introduce biases. Many of the articles published in *Social Networks* are quite formal, and the role of less formal work may be de-emphasized in our results. Moreover, many important social network articles are not published in *Social Networks*. To the extent that they are cited by articles appearing in *Social Networks*, they will be picked up. However, citations in them to articles in *Social Networks* will not be picked up. These two factors should actually decrease the likelihood of finding a main path.

Factors affecting the development of social networks

A full history of the specialty of social networks is beyond the scope of this paper. There are, however, a number of historical factors that affected the type of science being done in this specialty in the past 12 years. To orient the following discussion, we have listed in Table 1 some of the major events, including publications, in the development of this specialty. [2]

The first historical use of social networks pre-dates the computer. However, the proliferation of computers and computer networks and their acceptance and use by social scientists was a primary factor in the development of the social network specialty. There are two primary reasons for this being the case. First, many of the original researchers interested in social networks were quantitatively oriented, with at least some training in mathematics, matrix algebra, statistics, and graph theory. Computers facilitated the analysis and examination of moderate and large networks through matrix manipulation techniques. Many of the tools that facilitated network analysis were (and are still) developed as software programs by researchers in the area. Table 1 references many of the key software developments.

The second reason is that many of the active participants in this specialty during the 1960s and 1970s were also members of the EIES (Electronic Information Exchange System) project that began in 1978 (see Freeman 1980 and 1984 for additional details). For the social network community, the EIES project lasted almost a year and a half and social networkers were just one of many subgroups on the EIES network. Freeman (1980) found that the electronic communication could and did enhance more traditional means of communication. Electronic links also helped to maintain formerly established colleague, student, and teacher relationships in the absence of ongoing face-to-face communication. He found that, in addition, the computer link helped to establish new friendship and other purely social relationships (Freeman 1980).

A second major factor affecting the development of the social network specialty was the development of institutionally recognized

[2] The events listed include founding of journals and organizations, development of new software for network analysis, and events identified as important in the history of social networks by respondents to a questionnaire administerd by Carley and Huff in 1988.

Table 1
Timeline of major or events in the history of the social networks specialty

Year	Event
1956	Cartwright and Harary, 'Structural balance: a generalization of Heider' s theory', *Psychology Review*
1957	Bott, *Family and Social Networks*
1960	Coleman and MacRae, clustering program
1965	Harary, Norman, and Cartwright, *Structural Models: An Introduction to the Theory of Directed Graphs*
1971	Lorrain and White, BLOCKER program
1972	Barnes, *Social Networks*
1972	Levine, *Sphere of Influence*
1972	Alba and Gutman, SOCK program
1973	Granovetter, "The strength of weak ties" *AJS*
1973	Bernard and Killworth, CATIJ program
1974	Hawaii conference
1974	Granovetter, *Getting a Job: A Study of Contacts and Careers*
1975	Second Hawaii conference
1975	Mathematical Social Science Board Symposium on Social Networks, Dartmouth College
1975	Breiger, Boorman, and Arabie, JMP, CONCOR programs
1975	Richards, NEGOPY program
1976	INSNA founded by Wellman
1976	Third Hawaii conference
1976	Heil and White, BS, BLOCKER programs
1976	White, Boorman and Breiger, "Block modeling" *AJS*
1976	Burt, STRUCTURE program
1976	Freeman, *Bibliography on Social Networks*
1977	*Connections* founded
1977	Blau, *Inequality and Heterogeneity*
1977	Leinhardt, *Social Networks: A Developing Paradigm*
1977	Special issue devoted to social network research in *Journal of Mathematical Sociology*
1978	EIES started
1978	*Social Networks* founded
1978	Seidman and Foster, SONET program
1979	Fourth Hawaii conference
1979	Holland and Leinhardt, "Perspective on social networks research"
1979	Freeman, CENTER program
1979	Mullins, Social networks and scientific ideas
1980	Annual Sunbelt Social Networks Conference started
1981	Mokken and Stockman, GRADAP program
1981	Carrington and Heil, JMS, COBLOC program
1982	Knoke and Kuklinski, *Network Analysis* Sage Publications
1982	Berkowitz, "An introduction to structural analysis"
1983	Pappi and Kappelhoff, SONIS program
1984	Freeman, Borgatti, and Everett, UCINET program
1988	Wellman and Berkowitz, *Social Structures: A Network Approach*
1989	European Conference started

outlets for research in this area. Relevant events occurred almost simultaneously with the start of the EIES project. In 1976, Barry Wellman founded a professional association INSNA (International Network for Social Networks Analysis). Linton Freeman and Barry Wellman established two new journals devoted to the area of network analysis, *Connections* and *Social Networks*. Volume 1 of *Connections*, bulletin of INSNA, appeared in the summer of 1977. By the time the first issue of *Connections* came out, Barry Wellman had recruited over 170 members to INSNA. In addition, the journal, *Social Networks*, was first published in August 1978 with Linton Freeman as the first and only editor. *Social Networks*, the journal, defined its mandate as: "the study of the structure of human relations and associations that may be expressed in network form". The first Sunbelt Social Networks Conference was held in 1981, and became the annual conference of the INSNA. In Europe, social network analysts hold a biannual conference. The first was held in Holland in 1989, attended by 350 people. The second was held in France in 1991, and third is scheduled for 1993 in Germany. As of 1992, both journals conferences continue and are well supported.

A third major factor affecting the development of the social network specialty was the presence of institutional support and motivated senior academicians. Such institutional support came in part from the National Science Foundation that funded numerous grants in the area and supported a project to link together members of this community in a year long electronic conference (the EIES project). This project was carried out under the directorship of the sociologist Linton Freeman and among the initial organizers was the anthropologist Douglas White. In addition, the Mathematical Social Science Board sponsored a symposium on social networks at Dartmouth College in September 1975 (Leinhardt 1977). Another program important to many of the early developments was the interdisciplinary RIAS program at Harvard directed by Harrison White, a sociologist. Other programs and academicians also figured prominently in the development of the specialty. Table 2 lists the top ten academicians identified by researchers in the social network community in a 1988 survey as prominent in social networks during the pre-1970 period, and in 1988. The point we wish to draw from this historical review is that the initial involvement was interdisciplinary, institutionally supported, international, and involved senior researchers.

Table 2
Per cent of respondents citing social networks researcher as prominent ($N = 109$)

Time: Pre-1970 period Per cent	Social network researcher	Discipline
39.00	Harrison White	Sociology
38.00	Clyde Mitchell	Sociology
33.00	Elizabeth Bott	Anthropology
26.00	John Barnes	Anthropology
22.00	J.L. Moreno	Psychology
21.00	B Wellman [a]	Sociology
17.00	Linton Freeman	Sociology
17.00	Mark Granovetter [a]	Sociology
14.00	Frank Harary	Mathematics
14.00	James Coleman	Sociology

Time: 1988 Per cent	Social network researcher	Discipline
55.00	Ronald Burt	Sociology
43.00	Barry Wellman	Sociology
43.00	Linton Freeman	Sociology
28.00	Mark Granovetter	Sociology
23.00	Edward Laumann	Sociology
18.00	Harrison White	Sociology
17.00	Ronald Breiger	Sociology
15.00	Russ Bernard	Anthropology
11.00	Claude Fischer	Sociology
10.00	Stanley Wasserman	Statistics

[a] We realize that Granovetter's work was not published in the pre-1970 time period. However, 17 percent of the survey respondents believe this to be the case. Similarly, Barry Wellman had just started publishing in 1970.

A fourth major factor affecting the development of research in this area was a shift in substantive concerns in sociology and anthropology and the development of graph theory. Wolfe (1978) has documented this shift of concerns in anthropology. Researchers within social networks listed the texts in Table 3 as particularly influential to the development of the specialty. These texts illustrate the type of developments and concerns instrumental in the progress of the field.

In summary, the historical evidence and the perceptions of researchers in this area suggest that after 60 years, social network analysis has reached the status, at least from an institutional perspective, of an established scientific specialty. Factors of importance in this development were the proliferation of personal computers and computer networks,institutional recognition, and research outlets. In addition we note that the members of the social network community meet the requirements for being an invisible college (Crane 1972; Price and Beaver 1966) – shared paradigm (society as network), a core group of scientists who are 'in the know' (INSNA members), and regular face-to-face interaction (through the conference). As such, the benefits of being an invisible college should accrue to the members of this specialty – social association with others with similar backgrounds and interests, potential for working relationships not based on proximity, and development of shared knowledge. From a Kuhnian perspective, such benefits should facilitate the doing of 'normal science' and the development of knowledge in a building block or incremental fashion. The remainder of this paper addresses these issues.

Citation analysis

Citation data

The *Social Networks* citation network covers Volumes 1 through 12, spanning the years 1978 through 1990. The 227 articles in these 12 volumes cite 5573 articles. However, there are many citations to the same articles; the number of unique articles cited is 3580. To do this analysis, we constructed a database of citing and cited articles following the three step process outlined below.

Step 1. Text base creation
We entered every article and its references into a text file. For citing articles, we created tokens such as $$78.01.03.4, to represent the year, volume, issue, and article within issue. The $$ flagged the start of a *Social Networks* article in the text file. For each citing article, we entered this token, the full list of authors, and the full title. Following each citing *Social Networks* article in the text file, we entered the list of cited articles. We created a second token containing the year of publication, and the number of the reference within the list of references. A complete cited article entry contained this token, a list of authors, the full title, and a code for the journal or type of

Table 3
Influential articles, journals, and books in the development of social networks

Author	Article or book	Journal or publisher	Year
Moreno, I.L.	*Who Shall Survive?*	Washington: Nervous and Mental Disease Publishing Co.	1934
Bavelas, A.	Communication pattern in task-oriented groups	*Journal of the Accoustical Society of America*	1950
Leavitt, H.	Some effects of certain communication patterns on group performance	*Journal of Abnormal and Social Psychology*	1951
Barnes, J.A.	Class and committees in a Norwegian island parish	*Human Relations*	1954
Bott, E.	*Family and Social Network; Roles, Norms, and External Relationships in Ordinary Urban Families*	London: Tavistock Publications	1957
Nadel, S.F.	*The Theory of Social Structure*	Cohen and West Ltd.	1957
Milgram, S.	The small-world problem	*Psychology Today*	1967
Mitchell, J.C.	*Social Networks in Urban Situations*	Manchester University Press	1969
Barnes, J.A.	*Social Networks*	Addison-Wesley	1972
Levine, J.	The sphere of influence: A methodological inquiry into U.S. banking and industrial networks	*American Sociological Review*	1972
Granovetter, M.S.	The strength of weak ties	*American Journal of Sociology*	1973
Laumann, Edward O. and Franz Pappi	*Networks of Collective Action: A Perspective on Community Influence Systems*	New York: Academic Press	1976
Leinhardt, S.	*Social Networks: A Developing Paradigm*	New York, NY: Academic Press	1977
Rapoport, A.	Contribution to the theory of random and biased nets	*Social Networks, A Developing Paradigm*, S. Leinhardt (ed.), Academic Press	1977
de Sola Pool, I. and M. Kochen	Contacts and influence	*Social Networks*	1978/79
Wellman, B.	The community question: the Intimate Networks of East Yorkers	*American Journal Sociology*	1979
Mullins, N.C.	Social networks and scientific ideas: The case of the idea of networks	Holland and Leinhardt (eds.), *Perspectives on Social Network Research*	1979
Warren, D.I.	*Helping Networks: How People Cope with Problems in the Urban Community*	Notre Dame Press	1981
Berkowitz, S.D.	*An Introduction to Structural Analysis: The Network Approach to Social Research*	Toronto: Butterworth and Co.	1982
Wellman, B. and S. Berkowitz	*Social Structures: A Network Approach*	New York: Cambridge University Press	1988

publication of the reference. We coded all books, chapters, and similar productions, as BOOK. [3]

Step 2. Parsing and database creation
The second step involved writing software that would parse the text file, checking for correct format, and outputting three files suitable for direct loading into a relational database. These files contain the data on the citing articles, the cited articles, and the complete set of ties that define the citations.

Step 3. Pattern matching
This step is technically the most complex and required that all common articles be identified and the network adjusted to reflect that articles can both cite and be cited. Given the size of the network, this is not a manual task. We used the database to sort and manipulate article data. We also wrote special software to accomplish this task. Appendix 1 presents the pattern matching algorithm used to determine whether two 'articles' are the same.

This three step process produced a database with which we can study the structure and recent development of the social networks specialty. Researchers interested in following this line of inquiry and producing such databases should recognize that this three step process is non-trivial. First, there are the errors associated with data entry in Step 1, and the time such data entry takes is substantial. Clearly electronic journals would minimize such errors and time. In addition there are errors beyond the researcher's control, to wit; despite the best intentions of editors and authors, published citations are often incomplete and inaccurate. Portions of the data that may be incomplete include the list of authors, the title, the page number, and so on. In addition, these data may simply be incorrect. For example, citing authors may leave out subtitles and words such as 'an' or 'for' in the titles of the articles they cite.

[3] Most of the raw citation data were entered by 'volunteers' and we did not worry about high standards of accuracy in data entry. We entered about 1000 articles, out of 5800, with a hand held OCR scanner. In the future, all raw data entry should be done with a scanner.

We can provide an example of errors introduced by citing authors. We found the following two citations in one *Social Networks* article:

Faust, K. and A.K. Romney
(1979) "Centrality in social networks: I, conceptual clarification." *Social Networks* 1, 215–239.
Freeman, L.
(1985) "'Does STRUCTURE find structure? A critique of Bart's use of distance as a measure of structural equivalence." *Social Networks* 1, 215–239.

These two citations contain several errors. First, Freeman wrote "Centrality", and Faust and Romney wrote "Does STRUCTURE". Next, the second citation should read Burt's rather than Bart's. Finally, the volume and page numbers for the second citation duplicate the first rather than give the correct values. The 'Bart's' instead of 'Burt's' error is particularly troublesome because the single character difference precludes direct matching based on title. The pattern matching algorithm described in Appendix 1 deals with this type of problem.

Methodology

We used two types of methods to analyze the structure of the *Social Networks* citation network – relational database computation and the search algorithms and techniques associated with main path analysis.

Database methods
We computed frequency distributions within the relational database. Some frequency computations are simple counts of unique keys within a single table, while others are counts based on relations defined across several tables. One of the most important database tasks is the identification of multiple citings of the same article, and the development of new keys that reflect these common ties. The citation network used in the main path analysis is the transpose of the network created from the raw data. The directed ties are from the cited article to the citing article. Thus the citation network is a network of scholarly influences through time.

Main path analysis, network search algorithms and exhaustive trees

Main path analysis has two steps. In the first step we compute the exhaustive search tree for each node in the network. Each tree contains the set of all possible paths emanating from a node. We do this by using the exhaustive search algorithm described in Sedgewick (1983). This algorithm found 47 998 distinct paths through the network emanating from all the nodes. We then accumulate the number of times network ties are found in every path generated by the exhaustive search algorithm. This produces a valued network, where the tie values are the total frequencies for a tie cumulated over all exhaustive search trees.

In the second step, we search the valued network, following the most 'likely' ties. Specifically, from any starting node, we choose the outgoing tie with probability proportional to the value of that tie. We do this by using a uniformly distributed random number and applying this number to the relative cumulative distribution of tie values emanating from a node. In previous applications of main path analysis, we have used the simple rule of choosing the maximum valued tie. This works well when there is always one dominant tie emanating from each node. However, with the *Social Networks* citation network, we found several instances where a single dominant tie did not exist; instead we found cases with pairs of equivalent, and very large, tie values. Thus the maximum value rule breaks down. To solve this problem, it would be possible to restart the algorithm, with two (or more) new starting nodes. However there is still the problem of dealing with cases where one tie has a slightly larger tie value than others. Moreover, such an approach leads to unwanted complexity in programming. [4]

In contrast, in this paper we use simple random selection to choose a single outgoing tie. An advantage of this is that we do not have to modify the overall structure of the software. Because we generate a main path for each of the 3580 unique articles, we have many 'replications' in applying this random selection. Thus, the actual pattern of selections will mirror the relative values across a set of tie

[4] To implement a restart procedure would require explicit rules about how close tie values must be before the maximum value rule breaks down and then recursively restart the search for each new start node.

choices. Finally, random selection yields the main paths that have a 'maximum likelihood' interpretation. Stated more formally, given tie weights generated by exhaustive tree search, the main paths are the most likely ways to traverse the citation network. Random selection seems to address a range of methodological issues in a clean fashion. We would suggest it for future work employing the main path methodology.

Using random selection, we continue to the 'next' node until we reach a terminal node, one with no ties leaving it. This sequence of choices traces a path through the network for a given starting node. This path, this sequence of 'visited' articles, is a main path. If we apply this form of priority search to every node, we generate the list of all main paths through the network. The details of implementing these techniques are discussed in Hummon and Doreian (1990). [5] On the basis of these data, there are two additional statistics of particular importance to the following analysis. These are main path tie frequency and main path endpoint frequency. We create a valued network by counting the number of times a tie (i.e. cited-article-citing-article pair) occurs across the set of all main paths. The value of each tie is the main path tie frequency of the citation network. Endpoint frequency is the number of main paths that terminate in an article. We use these statistics to identify the most important main paths. Keeping in mind the analogy of a watershed, the endpoint frequency measures the total flow of the watershed at its mouth, and the tie frequency measures the size of tributaries within the watershed. Source articles in the headwaters of the watershed are also important, but they are difficult to identify on the basis of simple counting. Their importance is, in part, a function of what happens down stream. Our approach is to identify the major water systems and tributaries, and then trace back to the source articles that contribute to these important flows.

[5] The computational methods are updated from the 1990 article in that a more efficient form of sparse matrix data structure is employed. The new data structures store the 3600 by 3600 network in about 35 000 bytes of memory. The search tree algorithms are the same as described in the 1990 article.

Scientific influence within social networks

Origins of citations

Of the 5573 citations, 646 are made to articles in previous issues of *Social Networks*. Another 254 are made to the *American Journal of Sociology*, 149 to *American Sociological Review*, and 134 are to the *Journal of Mathematical Sociology*. Table 4 presents the distribution of the most frequently cited journals by articles in *Social Networks*. This list of journals suggests that the members of the social network community have strong intellectual ties both internally and to the external scientific community. Of all the citations, 11.6% are to previous articles in *Social Networks*. The typical *Social Networks* article cites an average of 3.0 articles from the journal. As a point of comparison, Carley et al. (1991) found that articles in the *Journal of Conflict Resolution* cited an average of only 0.5 *JCR* articles.This suggests that members of the social network community have strong intellectual ties to each other and scientifically influence each other, at least as compared to the researchers in the peace research movement.

The next most cited journals are the *American Journal of Sociology* and the *American Sociological Review* with *Social Forces* listed in seventh place. The presence of these journals reflects the strong participation of sociologists in the specialty, and the scientific influence of a parent discipline, sociology, on the work in the social network specialty. As will be more obvious when we examine the list of high frequency articles, the influence of sociologists through *AJS*, *ASR* and *Social Forces* is primarily a methodological influence. That is, the articles cited have a strong quantitative and formal emphasis, an emphasis shared by contemporary social network analysts. This second observation is reinforced by the fourth most cited journal, the *Journal of Mathematical Sociology*. Many of the remaining journals in the Table 4 have a strong formal or quantitative emphasis including: *Psychometrika, Sociological Methodology, Journal of Mathematical Psychology, Sociological Methods and Research, Journal of the American Statistical Association,* and *Social Science Research.*

The list of journals in Table 4 also reflects the interdisciplinary origins and the continued interdisciplinary flavor of social network analysis. We identify no fewer than six disciplines among the journals

Table 4
Frequency distribution of journals cited by *Social Networks* articles ($N = 5573$)

Journal	Frequency	Per cent
Social Networks	646	11.59
American Journal of Sociology	254	4.56
American Sociological Review	149	2.67
Journal of Mathematical Sociology	134	2.40
Psychometrika	132	2.37
Sociometry	119	2.14
Social Forces	88	1.58
Sociological Methodology	85	1.53
Journal of Mathematical Psychology	71	1.27
Sociological Methods and Research	62	1.11
Journal of the American Statistical Association	60	1.08
Administrative Science Quarterly	55	0.99
Human Relations	51	0.92
Behavioral Science	48	0.86
Social Science Research	48	0.86
Management Science	46	0.83
Human Organization	45	0.81
PR	35	0.63
Human Communications Research	29	0.52
SNUS	28	0.50
Journal of Applied Social Psychology	26	0.47
Annual Review of Sociology	25	0.45
Total	2236	40.12

in Table 4: anthropology, communications, organization and management, psychology, sociology, and statistics. The complete list of journals derived from the database reflects even broader disciplinary participation. On the basis of the location of cited work, it appears that the social network community has strong intellectual ties to multiple scientific disciplines. Second, these disciplines exert scientific influence on the social network community. This influence, however, is primarily through shared methodological concerns and substantive issues for which theoretical advances require methodological advances.

Frequency of publication

One hundred and ninety-four (194) authors published 227 articles in the first 12 volumes of *Social Networks*. Of these, 142 authors

Table 5
Frequency of authors in *Social Networks*

Author	Frequency	Author	Frequency
Burt, R.S.	14	Arabie, P.	2
Everett, M.G.	12	Bolland, J.	2
Doreian, P.	10	Boster, J.	2
Bernard, H.R.	8	Capobianco, M.F.	2
Killworth, P.D.	8	Carrington, P.J.	2
Borgatti, S.	7	Conrath, D.W.	2
Johnson, J.	6	Corman, S.	2
Boyd, J.	5	Dow, M.	2
Freeman, L.C.	5	Erickson, B.H.	2
Friedkin, N.	5	Frank, O.	2
Marsden, P.V.	5	Gould, P.	2
Bonacich, P.	4	Greenbaum, S.	2
Fararo, T.J.	4	Groffman, B.	2
Faust, K.	4	Higgins, C.A.	2
Hammer, M.	4	Hummon, N.P.	2
Reitz, K.R.	4	Hurlbert, J.S.	2
Romney, A.K.	4	Klovdahl, A.S.	2
Seidman, S.	4	McClean, R.J.	2
Skvoretz, J.	4	Miller, M.L.	2
Berkowitz, S.	3	Nosanchuk, T.A.	2
Foster, B.	3	Pattison, P.	2
Harary, F.	3	Rogers, E.	2
Johnsen, E.	3	Sade, D.	2
Kochen, M.	3	Sudman, S.	2
Krackhardt, D.	3	Waverman, L.	2
Rice, R.	3	Weinmann, G.	2
Sailer, L.D.	3	Weller, S.C.	2
Snijders, T.	3	White, D.R.	2
Stokman, F.	3	Wilson, T.	2
Wasserman, S.	3		

published one article in *Social Networks*, and the remaining 52 published more than one *Social Networks* article (see Table 5). While some of the authors in Table 5 are established senior academics, it is noteworthy that several of the authors with the highest publication frequencies are relatively near the beginnings of their careers. These 'junior' authors have focused their efforts on network analysis, and view *Social Networks* as an important, if not primary, professional outlet. This is a key indicator. These younger academics seem to believe that social network analysis is well enough established that

Table 6
Characteristics of *Social Networks*, 1978 to 1990

Year	Articles	Citations	Citations/ article	Unique citations	Unique citations /article
78	9	277	30.8	147	16.3
81	15	319	21.3	170	11.3
82	25	599	24.0	297	11.9
83	21	389	18.5	196	9.3
84	15	354	23.6	134	8.9
85	15	545	36.3	259	17.3
86	18	382	21.2	174	9.7
87	21	461	22.0	214	10.2
88	19	491	25.8	180	9.5
89	15	420	28.0	205	13.7
90	20	472	23.6	255	12.8

they can invest their careers in its pursuit. Whether in fact they are justified in this belief is a question these data do not answer.

Citations per article

In Table 6 we present the data on the number of articles, citations, and unique citations through time. Although the number of citations per article fluctuates, there appears to be no trend in the number of citations per article. The overall mean is 24.5 citations, and the mode is between 10 and 19 citations. The distribution of citations per article is quite skewed (Fig. 1), with about 11% of the articles having 50 or more citations and a single article with 112 citations. [6] Many of these citations are unique. That is, they are the only citation in all of the articles in *Social Networks* to article or book 'X'. Unique citations appear to account for about one half of the total. Turning this indicator around means that about half the citations made by articles in *Social Networks* are to a shared literature. The existence of such a literature is an indicator that one of the benefits of being an invisible college, the sharing of knowledge, has indeed occurred.

[6] On entering or editing some of the very long lists of references we have to wonder about the relevance of some of the cited material. For example, why would the same article cite both Talcott Parsons and an introductory statistics book?

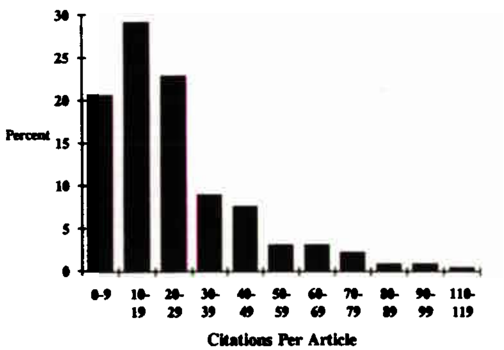

Fig. 1. Frequency distribution of citations per article.

Citations outside of and within Social Networks

In Table 7 we have listed those texts, which were not published within *Social Networks*, that are nonetheless frequently cited by articles published in *Social Networks*. Similarly, in Table 8 we list those texts, which were published within *Social Networks*, and frequently cited by articles published in *Social Networks*.

Several patterns are evident in these two tables. First, across the frequently cited texts, there is the strong emphasis on formal, mathematical and quantitative analysis. Five of the ten most cited external articles (Table 7) have this characteristic including the two most frequently cited, Lorrain and White's "Structural Equivalence of Individuals In Social Networks", and White, Boorman, and Breiger' s "Social Structure From Multiple Networks". We would also include in this category those articles concerned with methodological issues of collecting and analyzing social network data like the Bernard, Killworth, and Sailer series of articles.

A second group of frequently cited texts represents significant theoretical contributions to social network analysis. This second category includes Granovetter's "Strength of Weak Ties" and Burt's structural theory writings.

A third pattern evident in Table 7 is that there are several prominent collaborative groups within the specialty who are also recognized (and publish) outside of social networks. These include the 'Harvard'

Table 7
Most frequent citations outside of *Social Networks*

Freq	Authors	Article/Book	Jrnl
44	Lorrain F. and H.C. White	Structural equivalence of individuals in social networks	JMS
41	White, H.C., S.A. Boorman, and R.L. Breiger	Social structure from multiple networks, I. Blockmodeling approach	SM
38	Granovetter, M.S.	The strength of weak ties	AJS
35	Breiger, R.L., S.A. Boorman and P. Arabie	An algorithm for clustering relational data with application to social network analysis and comparison with multi-dimensional scaling	JMP
20	Burt, R.S.	Models of network structure	ARS
20	Burt, R.S.	*Toward A Structural Theory Of Action*	BOOK
20	Killworth, P.D. and H.R. Bernard	Informant accuracy in social network data	HO
19	Bernard, H.R. and P.D. Killworth	Informant accuracy in social network data II	HCR
19	Whitten, N.E. and A. Wolfe	Network analysis	HSCA
18	Laumann, E.O.	*Bonds Of Pluralism*	BOOK
17	Boorman, S.A. and H.C. White	Social structure from multiple networks. II	AJS
17	Burt, R.S.	Positions in networks	SF
17	Homans, G.C.	*The Human Group*	BOOK
17	Mitchell, J.C.	Social networks	ARA
16	Holland, P.W. and S. Leinhardt	An exponential family of probability densities for directed graphs	UNP MA
14	Burt, R.S.	Cohesion and structural equivalence as a basis for network subgroups	SMR
14	Fischer, C.S.	*To Dwell Among Friends*	BOOK
14	Harary, F.R. Norman and D. Cartwright	*Structural Models: An Introduction To The Theory Of Directed Graphs*	BOOK
14	Holland, P.W. and S. Leinhardt	Local structure in networks	SM
13	Arabie P., S. Boorman P.R. Levitt	Constructing blockmodels: How and why	JMP
12	Alba, R.	A graph theoretic definition of a sociometric clique.	JMS
12	Bott, E.	*Family And Social Network*	BOOK
12	Granovetter, M.S.	The strength of weak ties: A network theory revisited	MS
12	Heil, G.H. and H.C. White	An algorithm for finding simultaneous homomorphic correspondence between graphs and their image graphs	BS
12	Luce, R.D. and A. Perry	A method of matrix analysis of group structure	P
12	Nadel, S.F.	*The Theory Of Social Structure*	BOOK
11	Cartwright, D. and F. Harary	Structural balance: A generalisation of Heider's theory	PR

Table 7 (continued)

Freq	Authors	Article/Book	Jrnl
11	Holland, P. and S. Leinhardt	The structural implication of measurement error in sociometry	JMS
11	Milgram, S.	The small world problem	PT
11	Roethlisberger, F.J. and W.J. Dickson	*Management And The Worker*	BOOK
10	Barnes, J.	Networks and political process	L-LP
10	Bernard, H.R., P.D. Killworth and L.D. Sailer	Informant accuracy in social-network data V: An experimental attempt to predict actual communication from recall data	SSR
10	Breiger, R.L.	Career attributes and network structure: A blockmodel study of a biomedical research specialty	
10	Davis, J.A. and S. Leinhardt	The structure of positive interpersonal relations in groups	STP
10	Fienberg, S.E.	*The Analysis Of Cross-Classified Categorical Data*	BOOK
10	Freeman, L.C.	A set of measure of centrality based on betweenness	S
10	Harary, F.	*Graph Theory*	BOOK
10	Johnson, S.C.	Hierarchical clustering schemes	P
10	Kapferer, B.	Norms and manipulation of relationships in a work context	SNUS
10	Mitchell, C.	The concept and use of social networks	SNUS
10	Newcomb, T.	*The Acquaintance Process*	BOOK
10	Rapoport, A. and W. Horvath	A study of a large sociogram	BS
10	Winship, C. and M. Mandel	Roles and positions: A critique and extension of the blockmodeling approach	SM

group (Harrison White, Lorrain, Boorman, Breiger, Arabie, Heil, Winship, Bonacich, Carley, Wellman, Fischer, B. Ericson, M. Weinstein, and Mandel), the BKS group (Bernard, Killworth, and Sailer), the sociometric group (Davis, Leinhardt, Holland), Burt and his students, and the 'Irvine' group (L. Freeman, Douglas White, Reitz, Faust, Romney, Borgatti, Johnson, Boyd, Weller, Dow, Krackhardt, B. Groffman, and Sailer). These collaborative research groups are critical to the formation and initial maintenance of a scientific specialty. The Harvard group is predominately external to the journal and Irvine group predominantly internal. The sociometric group published most of their work before the founding of *Social Networks*.

Significantly, several of these groups are geographically dispersed yet engaged in cooperative and coordinated research. Carley with Wendt (1991) note that electronic mail has facilitated the development of the 'extended research group' – a very large, unified, cohesive

Table 8
Most frequent citations within *Social Networks*

Freq	Yr	Authors	Article
23	78	Sailer, L.D.	Structural equivalence: Meaning and definition, computation and application
23	79	Freeman, L.C.	Centrality in social networks: conceptual clarification
18	80	Bernard, H.R., P.D. Killworth, and L.D. Sailer	Informant accuracy in social network data IV: A comparison of clique level structure in behavioral ad cognitive network data
18	83	White, D.R. and K.P. Reitz	Graph and semigroup homomorphisms on networks of relations
14	78	Pool, I.D.S. and M. Kochen	Contacts and influence
14	79	Killworth, P.D. and H.R. Bernard	Informant accuracy in social network data III: A comparison of triadic structure in behavioral and cognitive data
14	81	Burt, R.S. and W. Bittner	A note on inferences regarding network subgroups
12	84	Burt, R.S.	Network items and the general social survey
11	85	Faust, K. and A. K. Romney	Does Structure find structures?: A critique of Burt's Use of distance as a measure of structural equivalence
10	82	Romney, A.K. and K. Faust	Predicting the structure of a communications network from recalled data
7	78	Killworth, P.D. and, H.R. Bernard	The reverse small-world experiment
7	81	Fararo, T.J.	Biazed networks and social structures theorems
7	85	Everett, M.G.	Role similarity and complexity in social networks
7	86	Breiger, R.L. and P.E. Pattison	Cumulated social roles: The duality of persons and their algebras
5	78	Seidman, S.B. and B.L. Foster	A note on the potential for genuine cross-fertilization between anthroplogy and mathematics
5	79	Fennema, M. and H. Schijf	Analyzing interlocking directorates: Theory and methods
5	87	Doreian, P.	Measuring regular equivalence in symmetric structures

and cooperative group of researchers that, though geographically dispersed, work together in a coordinated fashion as though at a single location and under the direction of a single director. The groups we observe, despite access to electronic mail, are not of this type. In contrast to the extended research group, they are much smaller (typically less than ten members), less coordinated, and often brought together by a single research issue rather than a collection of related and coordinated issues. Thus, what is being observed in the

Table 9
Frequency of citation of articles by *Social Networks* articles

Number of *Social Networks* articles citing an article	Number of cited articles	Per cent	Cumulative Per cent
1	2758	79.92	79.92
2	338	9.79	89.71
3	145	4.20	93.91
4	72	2.09	96.00
5	29	0.84	96.84
6	16	0.46	97.31
7	21	0.61	97.91
8	9	0.26	98.17
9	9	0.26	98.44
10	14	0.41	98.84
11	5	0.14	98.99
12	7	0.20	99.19
13	1	0.03	99.22
14	7	0.20	99.42
15	1	0.03	99.45
16	1	0.03	99.48
17	4	0.12	99.59
18	3	0.09	99.68
19	2	0.06	99.74
20	3	0.09	99.83
23	2	0.06	99.88
35	1	0.03	99.91
38	1	0.03	99.94
41	1	0.03	99.97
44	1	0.03	100.00
Total	3451	100.00	

social networks community is not the product of a unified project group, but a product of multiple research groups.

Table 9 presents the frequency of citation of articles by articles in *Social Networks*. The listings in Tables 7 and 8 represent the high frequency tails of Table 9. Note that at the extreme tail of the distribution in Table 9, 44 *Social Networks* articles cite one article, the Lorrain and Harrison White, *AJS* article. At the other end of this distribution, 2758 articles are cited by only one *Social Networks* article. Thus 2758 of 5573 citations (49%) are unique, and 2758 of 3451 articles (80%) are cited only once and the literature of articles cited more than once by a *Social Networks* article contains 693 articles, 20% of the total cited literature.

Main path analysis

Using main path tie and endpoint frequency statistics, we identified and extracted six main path structures in the *Social Networks* citation network. These main path structures were extracted in decreasing order of the tie frequency statistics. Specifically, we identified all ties with main path tie frequencies of 25 or greater in the valued network of main path tie frequencies. The tie with the highest frequency of 80 is from Borgatti, Everett 1989 to Everett, Borgatti 1990. This latter article also happens to have the highest endpoint frequency. The second highest tie frequency is 75 for Breiger, Pattison 1986 to Faust 1988. The set of ties exceeding the minimum tie frequency share common nodes and can be linked into subnetworks, e.g. the cited article of one tie is the citing article of another tie. We linked these ties into six sub-networks using the common nodes, but distinguishing the different terminal nodes. These six sub-networks are the six main path structures presented in the tables and figures below.

Table 10 contains the list of articles in the first main path structure, and Fig. 2 presents a diagram of the actual ties among these articles. We have labeled this sub-network the Role Analysis structure of social network analysis. When we elaborate the complete structure over the citation network, we link in 668 unique articles to the Role Analysis main path structure. [7] This constitutes about 19% of all articles in the network.

While all articles in Fig. 2 exceed minimum tie or endpoint frequency counts, the density pattern of the ties suggests that some articles are more densely linked than others in the development of Role Analysis. Sailer's 1978 article "Structural Equivalence: Meaning And Definition, Computation And Application" is the key article at the beginning of the main path diagram. This article discusses the substitutability of nodes in a network, and proposes a generalization of the concept of structural equivalence. Next is the Douglas White and Reitz article in 1983, "Graph And Semigroup Homomorphisms On Networks Of Relations". This paper defines the concept of regular equivalence. This article has broad influence over the main

[7] Elaboration refers to tracing all ties and articles connected to a main path structure back to all initial articles. This is equivalent to using a tie frequency criterion of one for extracting the main path structure.

Table 10
Articles in first main path structure: role analysis

ID	Year	Author(s)	Title
6	78	Burt, R.S.	Stratification and prestige among elite experts in methodological and mathematical sociology circa 1975
4	78	Sailer, L.D.	Structural equivalence: Meaning and definition, computation and application
3	78	Seidman, S.B. and B.L. Foster	A note on the potential for genuine cross-fertilization between anthropology and mathematics
25	80	Boyd, J.P.	The universal semigroup of relations
48	81	Burt, R.S. and W. Bittner	A note on inferences regarding network subgroups
91	83	Boyd, J.P.	Structural similarity, semigroups and idempotents
90	83	Freeman, L.C.	Spheres, cubes and boxes: graph dimensionality and network structure
93	83	White, D.R. and K.P. Reitz	Graph and semigroup homomorphism on networks and relations
119	84	Arabie, P	Validation of sociometric structure by data on individuals' attributes
111	84	Fararo, T.J. and P. Doreian	Tripartite structural analysis: Generalizing the Breiger-Wilson formalism
134	85	Everett, M.G.	Role similarity and complexity in social networks
122	85	Faust, K. and A. K. Romney	Does Structure find structures?: A critique of Burt's use of distance as a measure of structural equivalence
146	86	Breiger, R.L. and P.E. Pattison	Cumulated social roles: The duality of persons and their algebras
144	86	Burt, R.S.	A cautionary note
158	87	Doreian, P.	Measuring regular equivalence in symmetric structures
186	88	Borgatti, S.P.	A comment on Doreian's regular equivalence in symmetric structures
180	88	Boyd, J.P. and M.G. Everett	Block structures of automorphism groups of social relations
188	88	Doreian, P.	Using multiple network analytic tools for a single social network
177	88	Everett, M.G. and S.P. Borgatti	Calculating role similarities: An algorithm that helps determine the orbits of a graph
189	88	Faust, K.	Comparison of methods for positional analysis: Structural and general equivalence
183	88	Winship, C.	Thoughts about roles and relations: An old document revisited
195	89	Borgatti, S.P. and M.G. Everett	The class of all regular equivalences: Algebraic structure and computation
211	90	Burt, R.S.	Detecting role equivalence
219	90	Everett, M.G. and S.P. Borgatti	A testing example for positional analysis techniques

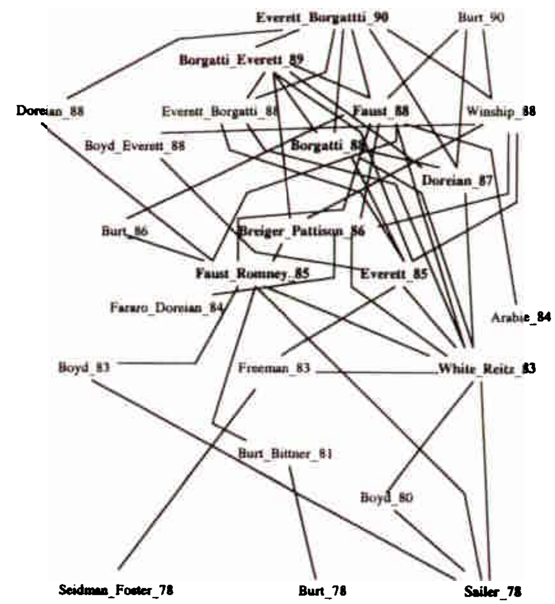

Fig. 2. First main path structure: role analysis.

path structure. In computing the main path, the distribution of outgoing tie counts for this article spread over several subsequent articles. Thus, the random selection procedure picks up several articles that are influenced by the Douglas White and Reitz article. Among these are Faust and Romney's "Does Structure Find Structures?: A Critique Of Burt's Use Of Distance As A Measure Of Structural Equivalence" in 1985, Everett's "Role Similarity And Complexity In Social Networks" in 1985, followed by Breiger and Pattison "Cumulated Social Roles: The Duality Of Persons And Their Algebras" in 1986. Doreian's "Measuring Regular Equivalence in Symmetric Structures" in 1987, and Borgatti's "A Comment on Doreian's Regular Equivalence in Symmetric Structures" are the next pieces in the chain. Continuing, in 1988, with Faust's "Comparison of Methods for Positional Analysis: Structural and General Equivalence", followed by Borgatti and Everett in 1989, "The Class of All Regular Equivalencies: Algebraic Structure and Computation", and finishing this branch of the main path structure with Everett and Borgatti 1990, "A Testing Example for Positional Analysis Techniques". As indicated by many of their titles, this chain of articles develops the concepts pertaining to generalized equivalence in a network.

This subset of ten articles shares an important attribute. Michaelson (1989, 1990 1991) studied the role analysis literature by applying an innovation and diffusion model. First, using the *Social Science Citation Index*, she identified all articles that cite Lorrain and White's 1971 article, "Structural Equivalence Of Individuals In Social Networks" published in the *Journal of Mathematical Sociology*. In the 1989 paper, she identified the innovative articles that contributed to the development of role analysis in one of four ways: (1) positions based on ties to the same others, e.g. structural equivalence; (2) positions based on ties to similar others, e.g. regular equivalence; (3) relational structures; (4) goodness of fit indices. This second list contained 66 articles. All ten of the articles in the Sailer to Everett–Borgatti chain are part of Michaelson's list of innovators. Michaelson identified two additional articles as key innovators, but as these articles were not published in *Social Networks*, they could not have been part of this analysis. Furthermore, Michaelson coded all but one of the articles in the chain as contributors to the theory of general or regular equivalence. The exception is the Breiger–Pattison article, which Michaelson coded as a contributor to the theory of structural equivalence. Yet this article does not break the chain because it proposed a more abstract approach to structural equivalence based on the idea that two actors are in the same position if their relation structures look the same from their two perspectives. Thus, almost all the articles in this chain of ten articles in the first main path are included in Michaelson's list of innovators in the theory of regular or general equivalence. [8]

In summary, these ten articles exhibit substantive coherence, and map many of the key developments in Role Analysis. Most of the other articles in Fig. 2 are closely related to this progression of articles. For example Burt's contributions to role analysis, from 1978 to 1990, closely parallel the Sailer to Everett–Borgatti path. The first main path is not only substantively connected, it is incremental. A new

[8] The details of this correspondence were supplied in a personal communication from Alaina Michaelson.

article appears in the main path structure almost every year. Few years are unproductive. Further the new work tends to build on the immediately previous work, and few years are skipped. In addition, most of the researchers represented in this main path are sociologists, with anthropologists contributing several main path articles.

Table 11
Articles in second main path structure: methods

ID	Year	Author(s)	Article
6	78	Burt, R.S.	Stratification and prestige among elite experts in methodological and mathematical sociology circa 1975
1	78	Pool, I.D.S. and M. Kochen	Contacts and influence
14	79	Fennema, M. and H. Schijf	Analyzing interlocking directorates: Theory and method
20	79	Killworth, P.D. and H.R. Bernard	Informant accuracy in social network data III: A comparison of triadic structure in behavioral and cognitive data
31	80	Bernard, H.R., P.D. Killworth and L.D. Sailer	Informant accuracy in social network data IV
33	80	Doreian, P.	On the evolution of group and network structure
26	80	Freeman, L.C. D. Roeder and R.R. Mulholland	Centrality in social networks: II. Experimental results
72	82	Allen, M.P.	The identification of interlock groups in large corporate networks
70	82	Mariolis, P.	Region and subgroup: Organizing concepts in social network analysis
78	82	Mcpherson, J.M.	Hypernetwork sampling: Duality and differentiation among voluntary orgnizations
94	83	Barnes, J.A. and F. Harary	Graph theory in network analysis
48	83	Burt, R.S. and W. Bittner	A note on inferences concerning network subgroups
69	83	Romney, A.K. and K. Faust	Predicting the structure of a communications network from recalled data
113	84	Mizruchi, M.S.	Interlock groups, cliques, or interest groups? Comment on Allen
131	85	Barnett, G.A. and R.E. Rice	Longitudinal non-euclidean networks: Applying Galileo
130	85	Tutzauer, F.	Toward a theory of disintegration in communication networks
193	89	Stephenson, K. and M. Zelen	Rethinking centrality: Methods and examples
224	90	Borgatti, S.P., M.G. Everett, and P.R. Shirey	Ls sets, lambda sets and other cohesive subsets

Table 12
Articles in third main path structure: network data

ID	Year	Author(s)	Article
1	78	Pool, I.D.S. and M. Kochen	Contacts and influence
7	78	Killworth, P.D. and H.R. Bernard	The reverse small-world experiment
117	84	Burt, R.S.	Network items and the General Social Survey
139	86	Campbell, K.E., P.V. Marsden and J.S. Hurlbert	Social resources and socioeconomic status
155	87	Bernard, H.R., G.A. Shelley and P.D. Killworth	How much of a network does the GSS and RSW dredge up?
216	90	Bernard, H.R. et al.	Comparing four different methods for measuring personal social networks
222	90	Killworth, P.D. et al.	Estimating the size of personal networks

Main path analysis: other structures

In addition to the first path, we have identified five other main path structures in the *Social Networks* citation network. We have labeled these: Methods, Network Data (also known as BKS), Biased Networks, Structure, and Personal/Cognitive Networks. We present these in Tables 11 through 15, and Fig. 4 through 7.

Across all these secondary paths, there are several points worth noting. Other than Personal/Cognitive Networks (Fig. 7), these secondary paths essentially span the twelve volumes of *Social Networks*. Arguably, Personal/Cognitive Networks represents the least focused, and has the weakest ties of those paths examined. [9] Of the secondary paths, the most incremental path is that on Structure (Fig. 6). The path that 'leaps' over the most years is the Network Data (Also known as BKS) path (Fig. 4). In all but two of the paths, researchers from multiple research groups take part. The exceptions are the Network Data path (Fig. 4) and the Biased Networks path (Fig. 5) each of which 'belongs' to a single research group. In these secondary paths, sociologists dominate the Biased Networks path (Fig. 5) and the other four are interdisciplinary. Further, of these secondary paths the Biased Networks path (Fig. 5) and the Network Data path (Fig. 4) are

Table 13
Articles in fourth main path structure: biased networks

ID	Year	Author(s)	Article
19	79	Rapoport, A.	A probabilistic approach to networks
44	81	Marsden, P.V.	Models and methods for characterizing the structural parameters of groups
54	81	Fararo, T.J.	Biased networks and social structures theorems
84	83	Fararo, T.J.	Biased networks and the strength of weak ties
115	84	Fararo, T.J. and J. Skvoretz	Biased networks and social structure theorems: Part II
129	85	Skvoretz, J.	Random and biased networks: Simulations and approximations
217	90	Skvoretz, J.	Biased net theory: Approximations, simulations and observations

Table 14
Articles in fifth main path structure: structure

ID	Year	Author(s)	Article
25	80	Boyd, J.P.	The universal semigroup of relations
26	80	Freeman, L.C., D. Roeder and R.R. Mulholland	Centrality in social networks: II. Experimental results
90	83	Freeman, L.C.	Spheres, cubes and boxes: graph dimensionality and network structure
94	83	Barnes, J.A. and F. Harary	Graph theory in network analysis
93	83	White, D.R. and K.P. Reitz	Graph and semigroup homomorphism on networks and relations
48	83	Burt, R.S. and W. Bittner	A note on inferences concerning network subgroups
119	84	Arabie, P.	Validation of sociometric structure by data on individuals' attributes
122	85	Faust, K. and A.K. Romney	Does Structure find structures?: A critique of Burt's use of distance as a measure of structural equivalence
136	86	Doreian, P.	On the evolution of group and network structure II: Structures within structure
153	87	Wasserman, S. and C. Anderson	Stochastic a posteriori blockmodels: Construction and assessment
205	89	Iacobucci, D.	Modeling multivariate sequential dyadic interactions
212	90	Arabie, P., L.J. Hubert and S. Schleutermann	Blockmodels from the bond energy approach

[9] Recall that the six main path structures were extracted in decreasing order of their tie and endpoint frequencies.

Table 15
Articles in sixth main path structure: personal networks

ID	Year	Author(s)	Article
93	83	White, D.R. and K.P. Reitz	Graph and semigroup homomorphisms on networks and relations
122	85	Faust, K. and A.K. Romney	Does Structure find structures?: A critique of Burt's use of distance as a measure of structural equivalence
137	86	Johnson, J.C. and M.L. Miller	Behavioral and cognitive data: A note on the multiplexity of network subgroups
146	86	Breiger, R.L. and P.E. Pattison	Cumulated social roles: The duality of persons and their algebras
150	86	Johnson, J.C.	Social networks and innovation adoption: A look at Burt's use of structural equivalence
159	87	Krackhardt, D.	Cognitive social structures
172	87	Boster, J.S., J.C. Johnson and S.C. Weller	Social positions and shared knowledge: Actors' perceptions of status, role, and social structure
192	88	Pattison, P.E.	Network models: Some comments on papers in this special issue

not linked to any other of the paths, including each other, through one or more shared articles. We can piece together all other main path structures into a single network. Collectively, this evidence suggests

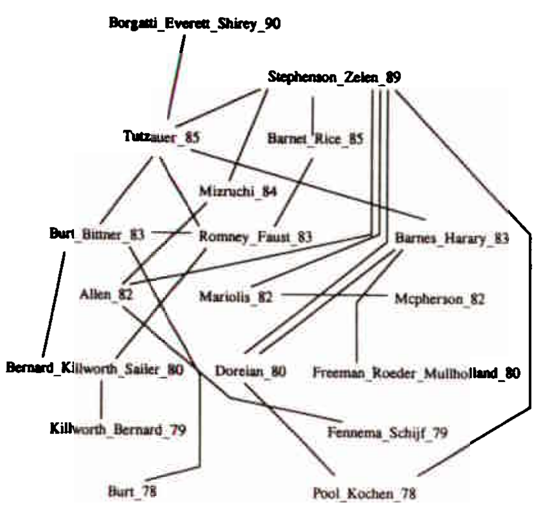

Fig. 3. Second main path structure: methods.

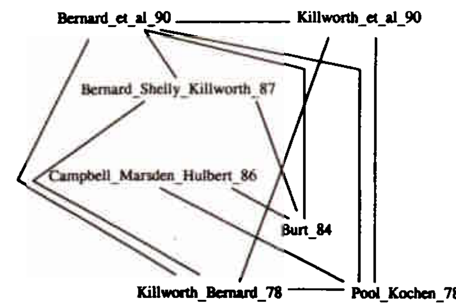

Fig. 4. Third main path structure: network data.

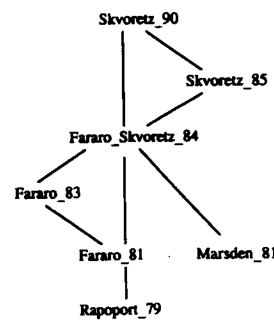

Fig. 5. Fourth main path structure: biased networks.

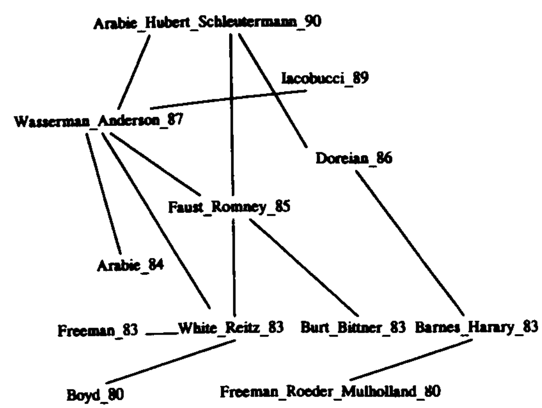

Fig. 6. Fifth main path structure: structure.

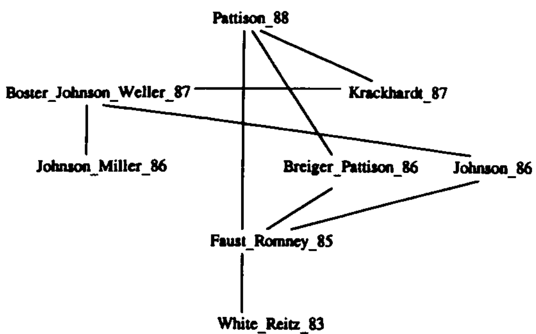

Fig. 7. Sixth main path structure: personal networks.

that the Network Data and Biased Networks research is different in kind from the rest of the work in *Social Networks*. Each is carried out by a single research group, is not linked with the rest of the work in *Social Networks*, and exerts scientific influence in a unified fashion primarily upon researchers in that particular research group. However, when we consider the frequency of citations, this research, particularly the Network Data research, does have a broad dispersed influence across the specialty.

Discussion

None of the texts in Table 3 cited as influential by the survey of researchers in the specialty are picked up as part of the main path. This is due, in part, to the way we coded books. More importantly, these 'influential' works occurred substantially prior to the birth of the *Social Networks* journal and outside the journal. Hence, they can not be part of a main path based only on articles in the journal. Of the ten individuals listed by researchers as most prominent in the 'early, pre-1970 days' of social networks only one, L. Freeman, appears in the first main path. However seven of the ten are among those individuals who wrote articles that appeared outside of Social Network that were among the most frequently cited by *Social Networks* articles. These seven are H. White, Mitchell, Bott, Barnes, Granovetter, L. Freeman, and Harary, whereas, only one of the ten, again L. Freeman, wrote

one of the most frequently cited *Social Networks* articles. In contrast, of the ten individuals listed by researchers as most prominent in 1988 three – Breiger, Freeman, and Burt – appear in the first main path. Eight of the ten (Bernard, Breiger, Laumann, Granovetter, White, Fischer, Freeman, and Burt) wrote frequently cited external references and four (Bernard, Breiger, Freeman, and Burt) wrote frequently cited *Social Networks* articles. These results suggest that scientific influence and prominence are different factors. Moreover, the increase in prominent, frequently cited authors appearing on the main path suggests the development of an integrated specialty moving into a period of normal science.

We note another feature of the main path structures; all contain articles that employ formal or statistical models. While the *Social Networks* citation network has a great many qualitative and non-formal theory articles, they are not cited with enough consistency by other network researchers to be part of a main path structure. We have observed this pattern in other main path analyses. Hummon et al. (1990) in an analysis of the complete literature on centrality in social networks, the main path contains either formal experiment designs or mathematical models with a heavy emphasis on graph theory. Carley et al. (1991) in an analysis of the *Journal of Conflict Resolution*, the most consistent main paths focused on game theory. Other main paths in the *JCR* network describe various political and psychological models of conflict resolution. Again, the theoretical and qualitative articles are generally not evident in the main paths. Models, whether formal, statistical, or even diagrammatical, apparently increase the likelihood that other researchers will further develop the ideas presented in an article. This mode of research and presentation promotes and clarifies the paradigm under consideration. As such, it may also be an important component of 'normal science'.

Conclusion – normal science and specialty development

In 1977, Leinhardt edited a book titled, *Social Networks A Developing Paradigm*. Today, we argue that our evidence shows that social networks is in a 'developed' or 'emerged' stage. We find that the specialty hangs together. There are no major divisional splits, either institutional or paradigmatic, and the members of the specialty attend to each others' work. We do find numerous minor splits, all of which interact synergistically to encourage additional research. Collectively, the pattern of citations, the pattern of influence as evinced in the main paths, the style of articles, and the institutional legitimation of the specialty suggest that the type of science engaged in within social networks is what Kuhn has labeled 'normal science'. In addition, the presence of an invisible college, the presence of young scientists willing to base their careers on work in this field, the existence of a common literature, the incremental nature of influence within the specialty, the interdisciplinary flavor of most main paths, the increased appearance of prominent, frequently cited authors on the main path all suggest that social networks as a specialty is in a 'normal science' phase rather than an early developmental phase. Whether this phase will continue, and for how long, are questions this analysis can not address.

Appendix 1.

Pattern matching method

To identify citation ties within the *Social Networks* database, we developed a method of matching titles of articles. The procedure has eight steps.

1. Treating titles as string tokens, eliminate trivial differences by transforming all characters to upper case, and processing all titles through a spell checker.
2. Sort the transformed strings into alphabetical order.
3. Parse each string into a list-of-words, eliminating non-alphanumeric characters, e.g. punctuation, slashes, dashes.
4. For list-of-words $i = 2 \ldots N$, count the number of common words shared with list-of-words $i-1$.
5. For list-of-words $i = 2 \ldots N$, count the number of words that are in the same *order* as list-of-words $i-1$.
6. Compute a similarity score.
   Define Maxwords = max(number of words in list i, number of words in list $i-1$).
   Nwords[i] = number of words in list i
   Nsame = number of words common to lists i and $i-1$.
   Norder = number of words in same order in lists i and $i-1$.

   if string i identical to string $i-1$ then score = 1

   if Nwords[i] - Nwords[$i-1$] < = 1 and
   Nsame-Maxwords < = 1 and
   Norder-Maxwords < = 1 then score = 2

   if Nwords[i]-Nwords[$i-1$] < = 2 and
   Nsame-Maxwords < = 2 and
   Norder-Maxwords < = 2 then score = 3

   if Nwords[i]-Nwords[$i-1$] < = 3 and
   Nsame-Maxwords < = 3 and
   Norder-Maxwords < = 3 then score = 4
7. Manually examine all strings with scores of 2,3, and 4.
   If string/title i same as string/title $i-1$, set similarity score to 1.
8. Reassign keys of article records using similarity scores. If score = 1, set key of record $i-1$ to record i.

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Call for papers

The 1993 annual meeting of the Classification Society of North America (CSNA) will be held on the campus of the University of Pittsburgh, starting Thursday evening, June 24 and continue until Saturday afternoon, June 26. The purpose of the annual meeting is to provide a forum for presentation and cross-disciplinary discussion of data-oriented approaches related to classification and understanding of complex data structures.

This meeting marks the 25th anniversary of the CSNA. Invited sessions will feature the application areas of Numerical Taxonomy, Numerical Ecology, Molecular Biology and Information Retrieval. This CSNA meeting will directly precede the annual meeting of the ACM Special Interest Group on Information Retrieval (ACM SIGIR) and the Numerical Taxonomy meeting, both being held in Pittsburgh.

The program will include plenary talks by invited speakers and symposia on Neural Network, Genetic Algorithm, Multivariate Density Estimation and Visual Clustering approaches to classification. As in the past, there will be invited and contributed papers by CSNA members, non-members and students in the areas of cluster analysis, multidimensional scaling and related methods of exploratory data analysis and their use in applications. The programs for previous meetings can be found in the *Journal of Classification*. Because of the informal nature of the meeting, speakers often present research that is currently in progress.

The meeting will be preceded by optional short courses on Classification and Clustering, Multivariate Density Estimation and Visual Clustering, on Thursday June 24.

We are interested in soliciting presentations in all areas of the scientific study of classification and clustering. Persons wishing to