

12 • Group Communication Networking in an Information Environment: Applying Metric Multidimensional Scaling

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TWO major components of social interaction have been receiving increasing attention by researchers. The first is new communication media and the second is social networks. The research reported here combines these interests by describing and modeling the changes in the communication network of ten groups using a computer conferencing system over a two-year period. This combined focus is natural in that communication technologies facilitate human interaction by helping to develop and maintain human communication networks, while the analysis of networks can begin to identify patterns of use and social structure in new situations, such as new communication systems.

Two aspects of *new media* are emphasized here: (a) the potential for changes in traditional communication patterns among groups due to attributes of these communication systems and (b) the availability of behavioral communication data collected by the medium's computer system. Two aspects of *network analysis* are emphasized here as well: (a) longitudinal analysis and modeling and (b) the application of metric multidimensional scaling as one appropriate network methodology.

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(whether due to affiliations, such as religion, or to individual characteristics, such as age), and Cappella (1980), Miller (1976), and Putnam and Pacanowsky (1983) are but a few of the communication researchers who consider interpersonal constraints (whether in dyads or in organizations). Mass media present their own constraints, such as scheduled distribution times and locations, one-way communication, rigid formats, inability to cross-associate content, and the like.

- (2) Information systems such as computer conferencing reduce the presence or effect of many of these constraints, although they do create others. In general, however, users are more able to participate in group discussion, are less swayed by group norms, and are less aware of typical social and communication differences; thus they are freer to search the system for exchanges of information that provide satisfactory resources or rewards than are individuals in face-to-face systems.
- (3) Individuals or groups in electronic environments must compete for resources, and they must achieve a minimum number of rewarding exchanges to maintain their roles in the system. This component of the argument is derived from the application of ecological theory to populations and organizations, and is discussed in greater detail by Hannan and Freeman (1977) and McKelvey and Aldrich (1983).
- (4) However, individuals have upper limits on how much information and how many interactions they can process and maintain (Miller, 1956; Simon, 1974).
- (5) Therefore, they are free to, and need to, maintain mutually rewarding reciprocal exchanges, but must do so early on in order to avoid draining their resources (processing and material) in excessive communication, especially if they must perform tasks on the system.
- (6) Hence, those who have early and successful access to information in the system and manage their interactions effectively are likely to continue occupying systemwide roles rich in access to information, and will survive better in the particular information-based environment.

DIFFUSION OF USERS IN THE SYSTEM AND STABILITY OF THEIR NETWORK

Another aspect of the present research considers computer conferencing as an innovation that diffuses through an aggregated system of users. The use of a computer conferencing system will tend to increase as it diffuses through a network of potential users, its members learn to use the system, and there are more users with whom one can communicate (Rogers, 1983). Indeed, implementation of such systems may fail if there is an insufficient number of users. Users' communication linkage would thus increase slowly at first and then increase more rapidly. Therefore, connectedness of users should increase as new members join. This rise, however, will not be linearly proportional to the increasing number of members (Friedkin, 1981), because, while the potential increase in interactions is geometric, users' processing limits would quickly be overcome by such a rise. Further, analysis of patterns of use in new media

COMMUNICATING VIA NEW MEDIA

New communication media such as personal computers, videotex systems, electronic mail, communication satellites, and computer conferencing are facilitating more and different kinds of human interaction. The ways in which people and organizations develop, implement, use, and are affected by these new media have received growing attention from communication and information scientists, and other social scientists (Kerr & Hiltz, 1982; Kling, 1980; Rice, 1980a, 1984; Rice et al., 1984). In particular, computer-mediated communication systems are being evaluated and analyzed to understand their design, application, use, and impacts. Such systems can process, augment, manage, and structure communications directly among sets of geographically dispersed users who do not need to be "on line" simultaneously in order to exchange messages. Reviews and descriptions of computer conferencing systems and their patterns of use are available in Hiltz (1983), Hiltz and Turoff (1978), Kerr and Hiltz (1982), Johansen, Vallee, and Spangler (1979), and Rice (1980b).

The EIES (Electronic Information Exchange System) service has been the most researched computer conferencing system. Specific questions addressed in prior research concern the determinants of initial acceptance and use of the system, changes in attitudes toward, and patterns of use of, the system over time, the effect of using such media on the quality and quantity of work, the development of affective ties through online communication, influences on cognitive and creative processes, quality and consensus in group decision making, and other communication variables, at the individual and group levels. Here, we are concerned with the system as a whole—a network of individuals who, as members of formally defined groups, conduct research and manage projects with others in a mediated information environment.

SOCIAL STRUCTURE IN AN INFORMATION-BASED ENVIRONMENT

One aspect of the present research is based upon a preliminary model of how groups of individuals develop and maintain their networks in computer conferencing systems and similar information-based environments (Rice, 1982). The main arguments include the following:

- (1) In face-to-face interaction, there are a considerable number of constraints on participation, control and leadership. These constraints include interactants' status, presence of nonverbal cues, speech patterns, physical proximity, physical characteristics and disabilities, ethnic or gender biases, and the like. Blau (1977) and other sociologists consider social constraints

systems typically shows an early rise in usage, a decline (as the novelty wears off, system problems discourage continued use, the benefits of heavy usage do not match the costs in time and money, and so on) and then a general leveling into stable utilization (Rice & Case, 1983; Rice & Paisley, 1982).

Further, it is expected that the relational patterns among the nodes, the structure of the network, would stabilize over time. That is, the network would reach an equilibrium as users establish rewarding relations, occupy their roles, and perform their necessary tasks. This assumes that membership in the network and the content of information are constant, that the environment is placid, that deviant members are decoupled or persuaded to accept group norms, and that the communication system is relatively reliable.

Barnett and Kincaid (1983) and Kincaid, Yum, Woelfel, and Barnett (1983) specify the general equations that describe the process of convergence at the equilibrium. The theoretical assumptions underlying this model have been discussed in detail by Kaplowitz and Fink (1982), Kaplowitz, Fink, and Bauer (1983), and Woelfel and Fink (1980). In those cases where no perturbations affect the system, convergence may be modeled by equation 1.

$$m\ddot{x} + C\dot{x} + Kx = 0 \quad [1]$$

where

- m = the node's mass or resistance to change;
- x = the displacement from the equilibrium;
- \dot{x} , \ddot{x} = the first and second derivatives with respect to time;
- C = a velocity-dependent linear dampening force; and
- K = a linear restoring force.

In those cases where new nodes, discrepant information, or other disturbances enter the system, equation 2 describes convergence to the equilibrium.

$$m\ddot{x} + C\dot{x} + Kx = F_t = 0 \quad [2]$$

where F_t = the impact from outside the system. This is the generalized second-order equation for the process of regaining equilibrium, such as an object hanging from a spring when pulled and released.

Following our model of the development of communication networks in an electronic information-based environment, the process by which a network approaches equilibrium should resemble an underdamped

oscillation. An underdamped oscillation occurs when the deviation from equilibrium decreases over time. It has a sinusoidal waveform with decreasing amplitude. This may be modeled by equation 3. The derivation of equation 3 for a system's departure from equilibrium (equation 2) has been presented elsewhere (Kaplowitz & Fink, 1982; Kaplowitz et al., 1983; Kincaid et al., 1983; Woelfel & Fink, 1980, p. 159).

$$y = e^{-mt} [C_1 \cos \theta(t) + C_2 \sin \theta(t)] \quad [3]$$

For the oscillations to decrease in size and converge to an equilibrium, $-1 < m < 0$. C_1 and C_2 are the amplitudes of the oscillations and θ is the phase angle of the amplitude expressed in radians.

HYPOTHESES

- (1) Task-oriented groups in an electronic conferencing system will be less central to the system network than non-task-oriented groups.
- (2) Over time, the network of users in a conferencing system will become more connected.
- (3) The structure of this network will stabilize over time, if there are no external "shocks" such as new members. The structure of the network will change if its membership changes, but will return to equilibrium, in the manner predicted by equation 3.

DATA

Conferencing Groups

The data analyzed herein comprised the "private messages" of users of the EIES computer conferencing system. These data constituted 70 percent of all items sent on the system during the two-year period. Other kinds of data are comments from separate conferences, entries in private notebooks, and the like.

A total of 10 groups made up the EIES system of users for the first 25 months of its life. Group 0 (N = 17) included consultants and staff, whose role was to maintain the system and help other users. These users would naturally communicate more with other groups than would any other specific group. Groups 1 (N = 45), 5 (N = 56), 6 (N = 25), 7 (N = 30), and 8 (N = 76) were formally constituted as task-oriented groups, while groups 2 (N = 32), 3 (N = 46), and 4 (N = 67) were not formally mandated to accomplish a task. Group members were typically researchers, university faculty, or personnel from government-sponsored agencies. Group 9 included all those users not otherwise members of a specific group. Thus they are a group only in the data analysis; they did not perceive themselves

Such data better represent the interactive nature of communication data and allow network analysis for which entire populations are typically required. Third, extensive longitudinal data are accessible, so that the limitations of cross-sectional research on communication process may be overcome (Krippendorff, 1970; Monge, 1982). The data reported here combine these three advantages. They represent longitudinal, accurate, communication behavior of a full network of system users.

METHOD: NETWORK ANALYSIS AND METRIC MULTIDIMENSIONAL SCALING

A social network may be represented by an $N \times N$ similarities matrix S , where N equals the number of nodes in the network. The value in each cell (S_{ij}) is a measured attribute of the relationship or link between nodes i and j . In communication research, the value is generally the frequency of communication. While there exist a variety of techniques for analyzing this matrix, none of these methods is clearly superior for the analysis of sociometric data and most have drawbacks when used to describe changes in networks over time. (See the reviews by Burt, 1980; Knoke & Kuklinski, 1982; Moreno, 1960; Rice, 1981; Rice & Richards, 1985; Rogers & Kincaid, 1981.)

Multidimensional Scaling— One Network Analysis Method

Multidimensional scaling (MDS) has frequently been applied in analyzing social networks (Barnett, 1979, 1984; Breiger, Boorman, & Arabie, 1975; Freeman & Freeman, 1979; Gillham & Woelfel, 1977; Goldstein, Blackman, & Collins, 1966; Jones & Young, 1972; Lankford, 1974; Romney & Faust, 1982). MDS is a spatial modeling procedure that transforms a distance matrix into Cartesian coordinates. The process reveals the dimensionality of the space and provides projections of stimulus points on the space's axes. For example, a matrix of distances among cities can be converted to a coordinate system in which latitude, longitude, and altitude are the three reference axes and the cities' locations on each axis are given. From the coordinates a graphic representation such as a map may be drawn. In that case, an $N \times N$ matrix of intercity distances may be described with no loss of information in a three-dimensional Euclidean space.

When applied as a method of network analysis, the process arrays the nodes into a space such that the greater the frequency of interaction or the stronger the link between two nodes, the closer they are in the space. While geographic data do not suffer a substantial loss of information in

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as members of any group, and were free to roam electronically throughout the conferencing system.

Because some of the users were part of the staff of EIES, some were researchers invited to join the system as part of the NSF evaluation, and others were members of ongoing research or project groups, not all groups were on the system for all 25 months. Groups 0, 2, 3, 4, 5, and 9 were on the system throughout the two-year period. However, groups 6, 7, and 8 entered during month 12. Group 1 left the system at this time, but a new set of users identified as group 1 entered again in months 21 through 24. A note or two on characteristics of usage by other groups: The second Group 1 became particularly active in its last few months on the system. Group 2 reported having difficulty sustaining discussions within the group. Group 3 showed a tendency to communicate with other groups, as did Group 4. Group 6 never had many members and entered late, so communication within the group may have been hard to develop; the members and leader considered the group a failure. Both Groups 7 and 8 began with high internal communication, sustained active use of the system, and only later began to explore the wider system of users. Group 9 consisted primarily of users unaffiliated with any specific group.

Over the 25 months, more than 700 users participated. The first month was a start-up time, so the analysis begins with month 2. Although data were collected by the computer continuously, they were aggregated into monthly intervals to facilitate handling and analysis. The monthly aggregation resulted in nearly 87,000 data points, each a link identified by individual and group, sender and receiver, and month.

Computer-Monitored Data

One important attribute of the data is that they have been collected by the computer. Computer-monitored data for communication and information science research are becoming more accessible as new computer-facilitated media proliferate. Full reviews of the issues, advantages, disadvantages, and prior use of computer-monitored data appear elsewhere (Danowski, 1982; Rice & Borgman, 1983). Three advantages are relevant here.

First, the data measure actual communication behavior, thus avoiding measurement error due to the discrepancies between communicants' reports of their behavior and their actual behavior, or due to instrumentation bias. Such discrepancies in network analysis indicate that we have reason to lack confidence in self-reported data as measures of communication behavior, although the issue has not yet been resolved (Bernard & Killworth, 1977; Bernard, Killworth, & Sailer, 1980, 1982; Berger & Roloff, 1980; Nisbett & Wilson, 1977; Romney & Faust, 1982; Shweder, 1980). Second, a full census of the system users can be obtained.

two dimensions, the spatial manifold for network analysis may be considerably more complex, containing up to $N - 1$ dimensions.

The present research uses the Galileo program to scale the network data. It is a metric MDS algorithm that allows for the analysis of change on all the dimensions in a multidimensional manifold (Woelfel et al., 1977; Woelfel & Fink, 1980). The use of a nonmetric algorithm would be inappropriate in this case because data representing the frequency of communication are ratio-level rather than ordinal-level.

Applying MDS to Longitudinal Network Analysis: Rotation to Congruence

Change in network structure may be examined by repeating the measurement phase and projecting the data for each time period into a multidimensional space. To compare several time periods (or several different groups at the same time), the spaces at each period must be translated to a common origin and rotated to a least-squares (OLS) best fit that minimizes the departure from congruence among the spaces (Woelfel, Holmes, & Kincaid, 1979). Change in the position of the nodes (network structure) is calculated by subtracting the coordinate values between adjacent time periods. With these measured velocities (the rate of change over time) and accelerations (the change in the rate), predictions of future network structure may be attempted and communication processes may be described (Barnett, 1984; Barnett & Kincaid, 1983).

There has been a considerable number of longitudinal analyses of networks (see Rice, 1981). Galileo, in particular, previously has been applied to describe social networks over time. Gillham and Woelfel (1977) examined changes in the perceptions of a university faculty over three periods by students, staff, and the faculty members themselves. The authors found that perceptions of the faculty were relatively stable but changed as a function of the information the subjects received about the faculty. For example, there was greater change for subjects who had less information about the faculty members. The attributes of perceived political positions of the faculty and the degree of quantification in their research were regressed on the spaces' coordinates. The multiple correlations for these regressions were .92 and .78, respectively, indicating that the arrangement of the nodes in the space exhibited face validity. Barnett (1984) used Galileo to describe the air traffic network among 31 major American cities over the 14-year period from 1968 to 1981. Results provided insights into activities within the network; exogenous factors such as physical distances among the nodes, changes within the airline industry, and economic conditions all affected the network structure. For example, network connectedness increased rapidly between 1968 and 1974, then remained stable until 1980, when a reversal in connectedness began. This change in connectedness was described by an exponential

function that accounted for 86 percent of the variance over the period and a polynomial that accounted for 75 percent of the change. The opening of the Dallas-Fort Worth airport and the air traffic controllers' strike were the primary causes of changes in the network structure.

Network Indices from MDS

The application of Galileo, a metric MDS, results in a number of indicators of the state of a network. They include *centrality* and *system connectedness*. These indicators may be used to describe how a network changes over time.

Centrality is, in general, a node's average distance to other nodes in a network, although it has a variety of interpretations and formulae (Freeman, 1979). Because the MDS algorithm used in the present research places the centroid of the nodes at the origin, centrality of a node here is its distance from the origin. This may be obtained directly from the diagonal of the adjusted scalar products matrix. The value of the diagonal, b_{ii} , is the squared distance of node i from the center of the network. The greater the value of b_{ii} , the less central the node is in the network. Thus centrality here is the square root of b_{ii} .

System connectedness has been defined by Rogers and Kincaid (1981, p. 346) as "the degree to which members of a system are connected to others in the system." The trace, or sum of the squares, of the coordinates provides an indicator of connectedness. The smaller the trace of the distance matrix, or the greater the trace of the frequency matrix of the system's nodes, the greater the system connectedness.

Prior Network Analysis of the Data

At the system level of analysis, the data indicate (among other measures) how many messages were sent within each group and to each of the other nine groups in each month. Prior analysis of these data used both intragroup and intergroup data to describe and test models of network development over time (Rice, 1982). Specifically, the system as a whole was very well described by a log-linear model that posited reciprocal flows of information between groups but similar levels of flows within groups. The model fit the data exceptionally well. Groups were categorized into four network roles based upon the estimated parameters of these flows of information. For example, a group that sent and received more messages than the average group (in that month) was classified as a "carrier." "Receiver" groups received more messages but sent fewer messages than did the average group. "Transmitters" did the opposite. "Isolate" groups sent and received less. (Each of these roles can also be differentiated according to its having higher- or lower-than-average levels of communication within each group, resulting in eight network roles.) Using the fourfold role typology, analysis indicated that Groups 0 (service)

and 9 (unaffiliated) are consistently "carriers" of information. Task groups generally remain isolates after perhaps a few periods as carriers or receivers, while nontask groups shift from the role of isolate through transmitter to carrier or receiver. In general, an electronic information-based environment is entropic and it is difficult for a group to sustain the role of carrier; it is highly unlikely that a task-oriented group can sustain this role.

Application of MDS to Computer Conferencing Data

Previous analysis of the data (Rice, 1982) found the relations among the groups to be best modeled as reciprocal.² Thus matrix S can be treated as symmetrical, which is required for most MDS programs. Therefore, the directional frequencies of interaction were entered into both the upper and lower triangles of the 24 matrices, one for each month.

Two scaling approaches were used. In the first approach frequencies (similarities) were used instead of distances (dissimilarities). Scaling the frequency matrices is the same as using similarity data, rather than dissimilarity data, to scale psychological stimuli (Shepard, Romney, & Nerlove, 1972). This operation has a number of advantages. First, connectedness is scaled positively. Second, it is simpler than using distance matrices. Third, it does not alter the dimensionality of the network space. Fourth, when there is no theoretical criterion for the selection of a function that transforms similarities into dissimilarities, the direct scaling of the frequencies avoids arbitrary choices that necessarily affect the analysis. Its major disadvantage is that the greater the frequency of interaction among two nodes, the farther apart, rather than closer, the nodes are in the network's space. Graphic interpretation of such data is difficult.

In the second approach, the matrix of social distances, S' was used. All elements in the off-diagonal were subtracted from 655, the largest intragroup frequency of communication at any time period. However, because the largest frequency of intergroup communication was 405, this transformation added a constant (250) to all values in the sociomatrices. As a result, it altered the dimensionality of the coordinates and the value of a number of descriptive indicators. These matrices, once transformed into distances, were then entered into Galileo. Results from both approaches will be compared when appropriate.

RESULTS

Centrality

Table 12.1 presents the centralities of each group for each month. Groups 0 and 9 are the most central, or closest to the origin. At nearly

Table 12.1 Centrality of Groups at 24 Monthly Intervals

Month	0	1	2	3	4	5	6	7	8	9
2	421.7	440.6	441.4	440.5	440.9	440.2	441.4	441.4	441.4	423.6
3	421.1	441.8	437.5	438.9	433.4	442.1	443.0	443.0	443.0	421.9
4	407.5	442.8	437.4	440.2	431.2	441.7	443.7	443.7	443.7	417.2
5	397.4	444.9	434.4	430.2	431.9	438.7	445.8	445.8	445.8	410.4
6	399.2	444.0	423.3	423.3	434.4	439.0	447.0	447.0	447.0	399.5
7	399.4	443.7	434.2	432.3	429.4	441.5	445.9	445.9	445.9	407.3
8	396.9	445.0	436.0	430.9	427.0	441.3	446.1	446.1	446.1	407.6
9	399.3	445.8	433.5	436.6	424.0	436.3	446.1	446.1	446.1	408.6
10	403.2	443.3	435.1	437.6	438.9	437.4	444.7	444.7	444.7	411.7
11	401.4	444.8	433.3	434.2	433.7	437.4	445.7	445.7	445.7	405.7
12	397.3	445.7	437.5	440.0	437.7	442.0	440.3	444.0	444.0	402.6
13	392.7	447.1	439.1	438.3	435.7	440.7	440.7	442.9	442.9	396.3
14	377.2	449.1	437.0	440.5	436.7	439.3	443.5	441.7	441.7	486.5
15	388.1	447.6	437.0	440.7	436.5	441.0	444.3	442.1	442.1	391.1
16	389.2	450.8	435.1	436.7	430.7	440.2	445.1	442.5	442.5	369.9
17	386.0	448.7	439.5	430.3	437.7	440.8	441.8	442.9	442.9	391.1
18	385.9	449.3	439.4	429.8	436.5	442.0	444.6	442.5	442.5	388.0
19	386.0	449.9	438.4	438.1	436.8	440.9	443.0	442.7	442.0	379.5
20	384.8	449.3	434.4	440.5	434.8	444.4	444.7	443.7	442.3	379.6
21	391.4	443.4	435.6	437.7	434.1	444.9	444.9	444.9	444.9	391.6
22	379.1	443.2	433.4	441.4	431.6	442.3	445.9	444.9	443.4	385.8
23	369.8	442.4	433.2	442.5	433.8	444.1	448.6	444.5	432.8	374.7
24	370.9	447.6	432.6	442.1	435.8	444.3	449.3	445.8	426.4	373.7
25	412.5	439.7	438.7	441.1	438.4	441.0	443.5	440.8	436.6	418.9

Note: Underlined values indicate isolates, or groups not on the system at that time period. Values are relative to highest intergroup communication frequency plus one. Because the matrix cell values have been transformed by a factor of 655, the table values have meaning only relative to one another.

every month, Group 0 is the most central node, as befits its service role. Nearly all systemwide "Broadcast" messages emanated from this group and were sent to all other members. All users could send comments or requests for help to this group. It was truly an information "carrier." The random group, 9, was the most central in the remaining periods, even exceeding Group 0 in months 16, 19, and 20. Members of Group 9 were "unaffiliated," so they were independent members of the system as a whole, free to exchange messages with any other user.

In general, the nontask groups were more central than the task groups, supporting their prior categorization into the role of carrier. Group 8 was the only exception, often becoming as central as nontask groups. It is at first not clear why this should be so. The group was very focused on its task, and exhibited high levels of sending messages within the group. However, it was very active relative to the whole system, and sent more messages throughout the system than did many of the other groups. The communication exchanges within the group were not considered by the MDS approach, whereas they were explicitly modeled in the prior analysis (Rice, 1982). Therefore, the heavy systemwide communication is not analyzed relative to the group's heavy internal communication. Thus it appears as a central group relative to other groups. The other task groups are least central and indeed were categorized as information isolates by the prior analysis. These results reject the null Hypothesis 1, no difference in centrality of task versus nontask groups. Further, they indicate that groups focusing on the system as a whole environment will be most central to the system's network.

Connectedness

Table 12.2 presents the two indicators of system connectedness. The first indicator of connectedness, the trace of the communication distance matrix, is inversely related to connectedness. The second, the trace of the frequency matrix, is a direct measure of connectedness. Since the participants knew that many of the conferences were ending at the end of month 25, use of the system began to decrease before then. As a result, data from month 25 were dropped from further analysis.

Both indicators were plotted against time. Connectedness appeared to increase over time. There was no evidence of nonlinear trends. Therefore, time-series analyses were not performed. Rather, each indicator was regressed separately on time. For communication distance, $R^2 = .80$, $b = -.3, 150$, $p < .001$; for communication frequency, $R^2 = .78$, $b = 429$, $p < .001$. Examination of residuals did not reveal any additional pattern. Thus there was a significant and large linear increase in connectedness over time. The null version of Hypothesis 2 may be rejected.

Table 12.2
Connectedness of Network at 24 Monthly Intervals

Month	Connectedness:	
	Inverse Connectedness: Trace of Matrix of Distances	Trace of Matrix of Frequencies
2	1,912,942.8	1546.8
3	1,899,942.5	1646.9
4	1,892,836.8	2521.3
5	1,873,427.2	3406.4
6	1,863,521.5	4960.6
7	1,873,365.0	3996.4
8	1,871,554.2	4477.0
9	1,870,964.2	4215.0
10	1,883,379.7	3237.4
11	1,875,145.2	4496.3
12	1,874,990.5	6145.2
13	1,862,680.9	5888.3
14	1,844,001.1	9999.5
15	1,857,397.2	7483.0
16	1,828,973.0	8857.8
17	1,847,636.0	7538.3
18	1,842,895.6	7783.9
19	1,837,735.7	8695.1
20	1,842,339.6	9518.4
21	1,856,089.0	6693.4
22	1,838,332.3	7805.0
23	1,827,824.1	14393.5
24	1,821,040.8	12130.9
25	1,894,242.7	1421.3

Dimensionality

Using the matrices of frequencies resulted in a two-dimensional solution for all time periods.³ These two dimensions accounted for virtually all (99 percent) the variance in the coordinate space. The mean correlations among the respective dimensions between adjacent time periods were .999 and .740. The amount of variance explained and the high correlation among the loadings on the dimensions indicate that the network's structure at the system level was relatively stable over time.

Scaling the matrices of distances did not result in as simple a solution. The two largest dimensions accounted for an average of only 15.2 percent and 11.7 percent of the variance in the network across time periods. The mean correlations among the respective dimensions between adjacent time periods were only .69 and .58 ($F = 18.2, 11.3$, respectively; $p < .005$). Because of the lower percentage of variance explained and the lower correlations among the dimensions, all further analysis compared the network's coordinate spaces generated directly from the matrices of

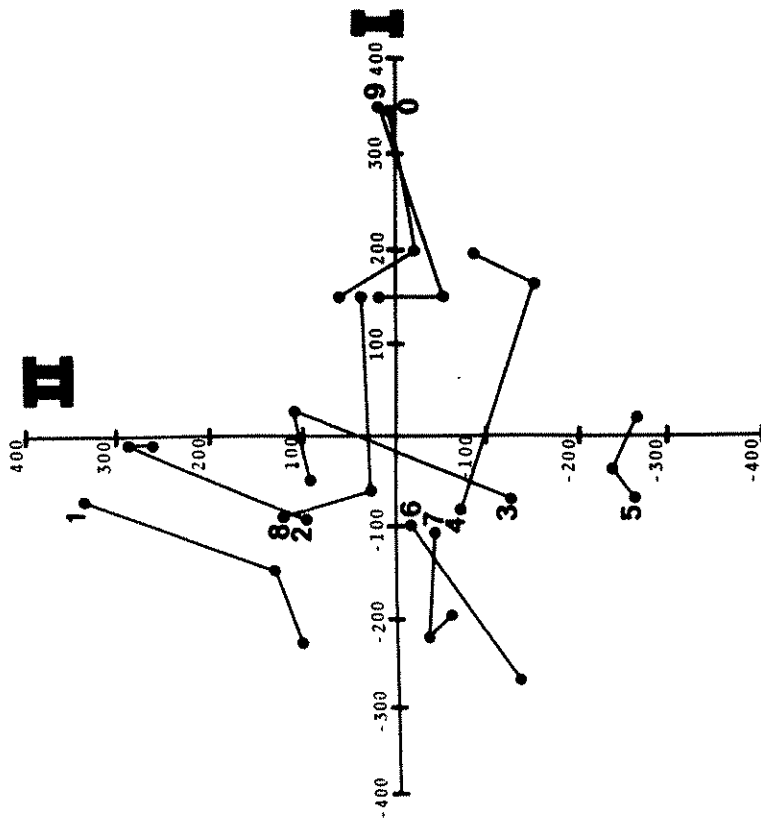


Figure 12.1. Motion of groups over time, based on matrix of social distances. Position at month 2 is closest to group number; 25.4 percent of variance explained at month 2. Position at month 13 is middle point of line segment; 26.8 percent of variance explained at month 13. Position at month 24 is end point of line segment; 28.2 percent of variance explained at month 24.

frequencies rather than from the matrices of distance. However, for graphic purposes, months 2, 13, and 24 of the communication distances have been plotted in Figure 12.1. The two dimensions in Figure 12.1 account for only 25 to 28 percent of the variance in network structure (see note 3). Therefore, conclusions about how the network changed should not be based upon this representation. Figure 12.1 does indicate that the network became more connected. Again, Groups 0, 8, and 9 appear to move toward the origin, while the task groups (except 8) identified as increasingly more information isolated by Rice (1982) drift away from the origin. Nontask groups 2, 3, and 4 cut across the central area of the space, remaining carriers of information and relatively central to the system.

Table 12.3
Rate of Change, and Change in the Rate of Change, in the Structure of the Network; Actual and Predicted Values

Months	Change in Rate of Change		
	Actual ^a	Comparison ^b	Predicted ^c
2-3	-1.49	-	-
3-4	-4.97	1	3.48
4-5	-10.80	2	5.83
5-6	-55.47	3	44.67
6-7	-56.84	4	1.37
7-8	-88.91	5	32.07
8-9	-75.03	6	-13.88
9-10	-38.77	7	47.56
10-11	-86.33	8	83.28
11-12	-169.94	9	-12.96
12-13	-156.98	10	87.89
13-14	-244.87	11	-50.07
14-15	-194.80	12	-14.00
15-16	-180.80	13	6.00
16-17	-186.78	14	-3.06
17-18	-183.72	15	4.61
18-19	-188.33	16	30.81
19-20	-219.21	17	-57.01
20-21	-162.20	18	7.21
21-22	-169.41	19	146.88
22-23	-316.29	20	-62.97
23-24	-253.32	-	-
24-25	230.13	-	-

a. The overall change was negative (except in interval 24-25) because there was greater change on the imaginary dimensions than on the real ones. Please see notes 1 and 3.

b. The comparison interval is between sets of rates of changes. For example, comparison 1 is the difference between the rate of change of months 2 and 3 and the rate of change of months 3 and 4.

c. Prediction values are calculated from equation 3. Text explains how the equation attempts to fit the actual data.

Change in Network Structure

The coordinates of the nodes (the network structure), which resulted from the frequencies of interactions, were next compared by means of a least-squares rotation (Woelfel et al., 1979). The total difference in position on all dimensions (or distance moved) for the nodes between adjacent points in time are shown in Table 12.3. They are plotted in Figure 12.2.

Table 12.3 and Figure 12.2 show an increase in the overall monthly rate of change in the network. A linear regression with monthly intervals as the independent variable suggested that the network's structure did not stabilize over time ($R^2 = .80$, $a = -.24$, $b = -12.6$, $F = 88$, $p < .001$), despite the high correlations between dimensions across time. Autocorrelation

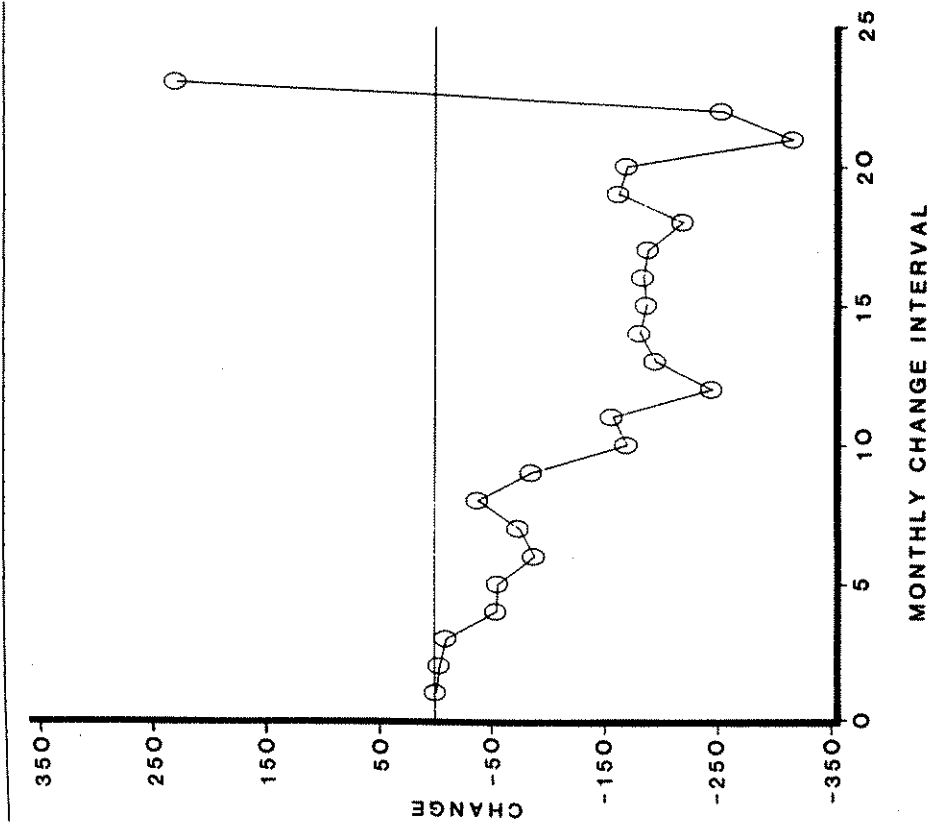


Figure 12.2. Overall change (O) in network structure over 24 months. See Table 12.3 and accompanying note.

procedures were not applied to describe the change in the network for three reasons: (1) There was no apparent periodicity. (2) We were working with change scores. Removing the linear trend through the use of change scores makes the system stationary (Krull & Paulson, 1978). In this case autocorrelation procedures need be applied only if there is significant measurement error. Because these data are accurate measures of users' communication on the EIES system, we felt that the application of autocorrelation procedures was unnecessary. (3) There were not a sufficient number of points in time to justify the analysis.

An examination of the changes reveals an initial slow rate of change for months 2 to 5, which accelerated between months 5 and 9. The differences became smaller for months 9 to 11, suggesting that the structure of the

network stabilized during these time periods. Three additional groups, 6, 7, and 8, entered the network at month 12. As a result, the rate of change increased between months 11 and 12. The reciprocity model did not fit the data well at this time either (see Rice, 1982). This high rate of change continued throughout the next year and the greatest change occurred between months 22 and 24. The rate of change in the structure of the network, however, stabilized between months 14 and 19 before oscillating and rising at the end, suggesting that the network may have reached an equilibrium at this level of interaction. These rates of change indicate a shifting of levels of communication within the coordinate space rather than of the pattern of communication, so they do not reflect the stability of the fit of the data to the reciprocity model discussed earlier (Rice, 1982, p. 936).

These results suggest that over time the rate of change in the network structure (specifically, the total of the coordinates of the groups in multidimensional space based upon the number, sender, and receiver of electronic messages) increased. There was an initial slow rate of change, which then accelerated, oscillated, accelerated, and showed a period of stability before accelerating at the end. This result of course rejects the purely stable system of Hypothesis 3, but is an implication of system "shocks."

Accelerations in the Structure of Network

We have discussed several measures of the stability of the system's network. Centrality increased over time. Connectedness also increased. The dimensions were highly stationary over time. But the amount of change in the nodes' locations on the coordinates did increase over time. Each of these measures a different aspect of network structure and takes a different level of complexity into account. Those measures based upon aggregates of individual nodes' characteristics showed significant change across time periods. Those measures that were based upon the system as a whole, however, showed a relatively stable network. This generalization supports the results in the prior analysis (Rice, 1982), and specifies Hypothesis 3. The final analysis of network stability tests equation 3 against the data.

There appears to be a pattern in the rate of change in the system that is a function of how many and which groups were active participants and of the length of that participation. To examine this pattern further, the changes in the rate of change in the nodes' positions (acceleration) were analyzed. The accelerations of the nodes' coordinate values are presented in Table 12.3. Table 12.3 reveals an oscillating rate of change. The specific periodicity is unclear, however. (For this and other reasons noted above, time-series procedures were not applied.) Generally, the oscillations increase in amplitude with the most volatile changes occurring for

accelerations between months 21 and 23. At that time, Group 1 entered the system. The greatest changes in the network occurred when groups entered the system, shifting from "isolates" to network participants. Current users would begin to receive messages from new users, generating another round of exploration, evaluation, and reciprocating of valued linkages. The network's structure changed to accommodate the new members, and as a function of the new members' participation.

Table 12.3 also reveals a period of stability around months 16, 17, and 18, or comparisons 13, 14, and 15. No groups entered or left the network and sufficient time passed for the interaction patterns to have stabilized. Had the EIES system ended at this point, the data suggest that the network had achieved an equilibrium state or converged on a stable structure. This pattern of change would correspond to an underdamped oscillation (Barnett & Kincaid, 1983; Kincaid et al., 1983).

The next analysis, therefore, tested how well the accelerations in Table 12.3 fit equation 3. Only the first 15 accelerations were used because at that point the network seemed to have stabilized. The nonlinear regression algorithm used in this analysis attempts to describe the data best according to the parameters of the given function (equation 3). Because of the generality of equation 3, reflected in its large number of parameters, any sinusoidal function that best fits the data, not only an underdamped oscillation, may result. The program provides the coefficients for the parameters that best describe the data.

Attempts to fit the accelerations to equation 3 were unsuccessful. The oscillations did not decrease in size in spite of the stable period. The predicted values represent a stable sinusoidal pattern. *M*, the dampening constant, was approximately zero. The curve did not follow the peaks and valleys in the data closely. The predicted values are presented with the data points in Table 12.3 and graphed in Figure 12.3. There was no explicit periodicity in the data, although with fewer than 20 data points this would not be likely. Further, as the oscillations increased in size rather than decreased prior to eventual stabilization, the pattern of residuals steadily increased until the final few points, when they became quite small. While the network stabilized, the changes induced by the entry of Groups 6, 7, and 8 at month 12 prevented the changes from becoming small. Thus the data could not be described accurately as an underdamped oscillation.

Change in System Network

Summarizing the results on network stability, we have found that there are two levels of network stability—measures based upon aggregates of network nodes, and measures based upon the network as a whole. There was ongoing activity and increase at the aggregate level (centrality, connectedness, sending messages, and change in coordinate totals) but

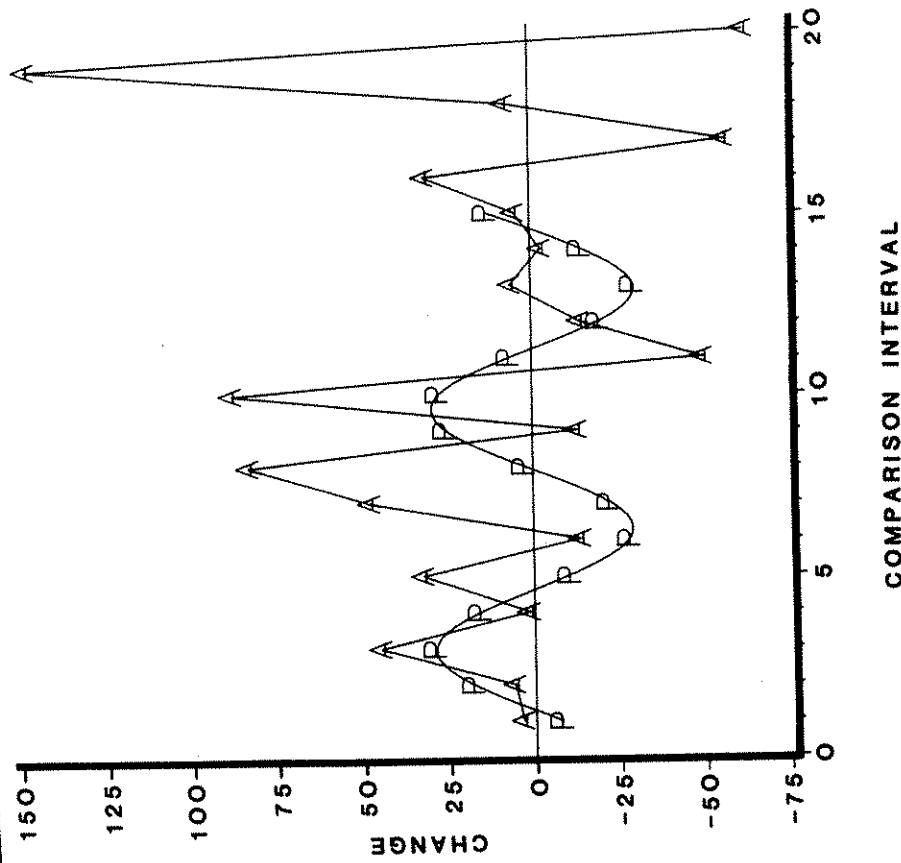


Figure 12.3. Change in rate of overall change in network structure over 24 months, actual (A) and predicted (P) values. See Table 12.3 and accompanying note.

relative stability at the system level (dimensional loadings and reciprocity). However, the model presented in equation 3 of the pattern of the rate of change was not supported by the data.

DISCUSSION

In the research reported here, network indicators of centrality, system connectedness, and structure of the network were derived directly from a multidimensional scaling program applied to data representing two years' worth of interaction among users of a computer conferencing system.

These data were analyzed over time to describe how the network changed. This particular social network, comprising 10 research groups, or about 700 persons, displayed a linear increase in connectedness over time. Relationships among specific groups quickly became and remained relatively stable, with a substantial proportion of interactions involving two groups. These two groups consisted of a set of consultants who serviced the other users, and a set of otherwise unaffiliated users who roamed freely through the electronic space.

The structure of the network derived from scaling the frequencies of interaction was two-dimensional. Over time, the structural relations of the network as a whole changed at an increasing rate. This increase is consistent with the pattern of diffusion or adoption of other innovations. The rate of change was nonmonotonic. It started slowly, then accelerated and stabilized. It again accelerated as Groups 6, 7, and 8 entered the network and then stabilized only to reaccelerate near the end of the 24 months when Group 1 reentered the system.

The model presented as equation 3 did not fit the pattern of the rate of changes in the nodes' locations. The change scores did not reach an equilibrium. There are three reasons this may have been the case. First, the system continued to oscillate; the rate of change in the nodes' positions on the coordinates did not dampen. Second, there were exogenous factors that inhibited the equilibrium. As described here, this would be new nodes entering the network or new information from the environment. Third, the length of time was too short for the dampening process to occur. In this case, there were too few points in time between the point when Groups 6, 7, and 8 entered the system and when Group 1 joined the network.

Methodological implications indicate some necessary fine-tuning when applying network analysis. The first specification is how the relational measures are constituted. Systemwide measures that were aggregates of individual relational measures showed ongoing change; results using these measures indicate an unstable system. However, systemwide measures that were direct relational measures indicated relative stability in the system. Thus, even though both kinds of measures are relational, or network variables, they in fact measure different conceptions of the network. The second specification involves whether measures of within-group relations are considered as well as the more typical cross-group relations. Results of this analysis compared to a prior analysis (Rice, 1982) indicate that while the primary conclusions are the same, one group was described quite differently because its extensive within-group interactions were not taken into account by scaling procedures. Both of these specifications call for multimeasure, multimethod approaches to network analysis such as the analyses by Barnett, Bales, and Day (1985).

We might, at this point, step back from the specific empirical analyses of this chapter to sum up the larger conceptual framework. We accept the

traditional notion of a social system as a collection of actors who compete for resources by means of a (usually) acceptable set of mechanisms that facilitate or constrain those relationships. Here, actors are groups of researchers and agency personnel. Resources consist of information rather than material, energy, or keys to the executive washroom. The mechanism is an electronic information environment (a nationwide computer conference) rather than a physical environment such as meetings or an economic environment such as a product market. Constraints such as physical appearance or proximity are removed, while constraints such as capacity for processing information are heightened. The effects of some personal traits such as charisma or verbal persuasion are removed, while equality of participation is heightened. Relationships are represented explicitly by electronic messages and positions in information networks (such as "carrier" or "isolate") rather than by exchange of money or elevation of position. We simply argue that a new environment will in some ways lead to new patterns of social structure (the need for reciprocation to maintain an information-rich position early on, or a system more vulnerable to impacts of new entrants) and in some ways continue to reflect typical patterns (increased connectedness over time, more stable system structure than individual structure).

SUMMARY

This study examined changes in the patterns of interaction among members of a social network, using Galileo, a metric multidimensional scaling program, and computer-monitored data on communication. The network consisted of ten groups engaged in a computer conference over a 24-month period. The results indicate that the network's connectedness and groups' centrality increased over time. Some system-level measures of network structure showed stability across the time periods. The rate of change stabilized at some time periods, but when new groups entered the network there was a change in the rate of change in the structure of network. Definitions of measures of the structure of networks, and the assumptions of the methodologies used to analyze them, must be specified to avoid misinterpretation of network analyses.

NOTES

1. We do not discuss here the importance of non-Euclidean space in network analyses using multidimensional space, due to page limitations and reviewers' preferences. However, Riemannian space, imaginary dimensions, and network intransitivity are discussed in a companion paper (Barnett & Rice, 1985) and elsewhere (Barnett & Woelfel, 1979; Woelfel & Barnett, 1982).
2. Many MDS analyses of networks arbitrarily force the matrices to be symmetrical—by averaging, adding, or dropping values between nodes. Because the model of reciprocity in

the prior analysis fit the present data exceedingly well, we have empirical and theoretical grounds for treating matrix S as symmetrical.

3. The second dimension was imaginary. As explained in note 1, analyses of imaginary dimensions—evidence of non-Euclidean structure in the network—are discussed in Barnett and Rice (1985).

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