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Netgraphs: A Graphic Representation of Adjacency Matrices as a Tool for Network Analysis

Varghese P. George
Thomas J. Allen

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MASSACHUSETTS
INSTITUTE OF TECHNOLOGY
50 MEMORIAL DRIVE
CAMBRIDGE, MASSACHUSETTS 02139

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In recent years, sociologists and analysts concerned with organizational behavior have increasingly turned to networks to represent relationships within and among social systems. Such networks are generally based on what is known as adjacency matrix, which can be mathematically defined as a square matrix $A = [a_{i,j}]$ (Chartrand, 1977; Harary et al., 1965). In this matrix, there is one row and one column for each node of the network, and the entry $a_{i,j} = 1$ if a directed line connects the node i to the node j, while $a_{i,j} = 0$ if the nodes are not connected. For both sociological and organizational analyses, "who-to-whom" *communication* matrices are a frequently used (Rogers and Kincaid, 1981) type of adjacency matrices. In some situations, adjacency matrices may represent more complex interactions, embedding a broad spectrum ranging from simple links of friendship to links based on more intricate social choices.

The conceptual underpinnings of network analyses go back to Cooley (1902) at the turn of the century. Theoretical focussing was helped along by Simmel (1955) . But it was Moreno's research from early 1930s (Moreno, 1978), which developed into what became known as *sociometry*, that provided the greatest impetus to the formation and the growth of the field known today as network analysis. The basic analytic tool of Moreno's sociometry is the sociogram, which is used to represent relationships, usually among people. In the typical sociogram, each node represents a person and the branches of the network represent some form relationship between two nodes.

Due to the difficulty in generating and understanding large sociograms, this form of analysis has been generally restricted to small social systems. Mathematicians such as Harary and colleagues (1965) and Flament (1963) made substantial contributions to solving this problem through the introduction of techniques for network reduction and simplification. Nevertheless, the basic problem of graphically representing relations among a large number of entities remained. Worse yet, once the graphic image was achieved it became impossible to understand the relationships in what often resembled a dish of spaghetti. Many a graduate student labored long hours to produce *by hand* these spaghetti-like graphic outputs of somewhat suspect interpretive value. Alternatively, networks can be represented by their matrices and a number of different graphic techniques have been developed to enhance such representations.

Sociometry and Sociograms

Sociometry was developed, principally by Moreno, as a technique (Moreno, 1978; Moreno and Jennings, 1960; Northway, 1967; Rogers and Kincaid, 1981) for measuring, what he called, 'statistics of social configurations'. The 'configurations' are based on 'choice-relations' among the individuals in a selected group. Depending on the researcher's inquiry, such relations may be characterized by anything ranging from 'playing together at recess' for school children, to 'communicating' for members in an organization. Moreno and his students developed indices for measuring concepts such as cohesion, prejudice, status and leadership. In elementary analysis of sociometric configurations, simple ratios were employed (Nehnevajsa, 1960) to evaluate the relative position of individuals within a population, the relative position of subgroups within a population, as well as relative standing of groups.

Typically, however, the sociometric data were presented as sociogram, a graphic scheme for representing such data. Individuals are represented by small circles in sociograms, and relations (most often, communication) by appropriate lines with arrows connecting the circles. Allen (1964) was among the first to use this technique to represent communication relationships among individuals in large organizations. One of his networks, showing the communication network in a geographically dispersed organization is shown in Figure 1. Needless to say, since this diagram was drawn manually, the configuration shown was not achieved at the first pass. It usually takes several attempts before achieving a coherent diagram of this size.

By Moreno's own claim, it was the sociogram that enabled the development of sociometry (1978) :

> The closest approximation to an official start of the sociometric movement occurred on April 3-5, 1933, when the Medical Society of the State of New York exhibited a few dozen sociometric charts during its convention at the Waldorf Astoria Hotel. These charts became, by mere chance, the showpiece of the scientific exhibits; a large number of physicians, neurologists, psychiatrists and sociologists stopped in to see them and to read in the criss-cross of red, black and blue lines the unveiling of the social forces which dominate mankind. ⋯ In the days to follow all the large newspapers, led by the New York *Times*, carried headlines, stories, editorials, pictures of sociograms, and sociometric cartoons, throughout United States. ⋯ Since then sociometry and its derivatives and extensions, social microscopy and group dynamics, group psychotherapy, roleplaying and interaction research, psychodrama and sociodrama, have retained their fascination for the general public and have matured to a widely known and respected school of thought.

Motivation for an Alternate Graphical Scheme

For all their historic significance, and hyperbole from Moreno, sociograms have serious problems. The information in sociograms of small groups is manageable, but as the size of the population increases, the diagrams become very crowded, and the information contained in them less decipherable. It also becomes painfully more difficult to draw the diagrams. Rogers and Kincaid (1981) write:

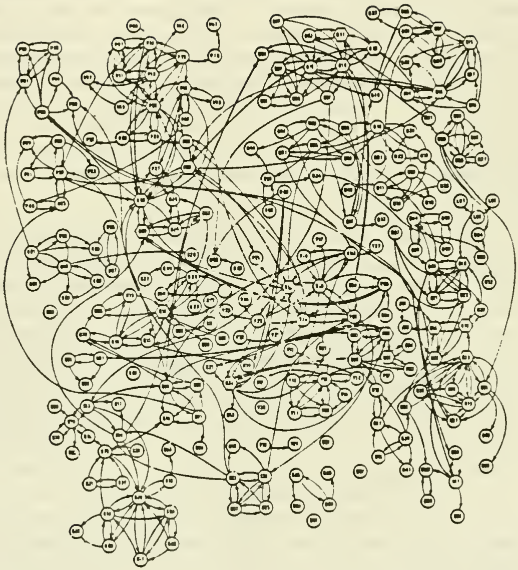


Figure 1: Sociogram Showing Communication Network in a Geographically Dispersed Organization. (Allen, 1986).

> But while Jacob Moreno provided communication scientists with a measurement tool (sociometry) of great usefulness even today, his main data-analysis technique of drawing sociograms was limited to a network with a maximum size of 80 to 100 individuals. Even then, drawing of a sociogram is a highly arbitrary and time consuming task.

Rogers and Kincaid go on to point out that a major problem, "is that the sociogram may be wrong. An infinite number of sociograms can be constructed from one set of network data, each of which may convey a *different* picture of communication structure. There is no objective, standard procedure for drawing sociograms. ... After several decades of scholarly interest in Moreno's sociometric approach in the 1930s and 1940s, including the launching of the scientific journal *Sociometry*, Moreno's approach became passé among social scientists."

Unfortunately, due to their graphic complexity sociograms have not been amenable to computer analysis. While sociograms may be less common now, network approaches to social science research have become increasingly more popular. In the sections that follow, we present the concept, some examples, and a few standard procedures for a *computer-based* graphic scheme for representing networks. The scheme will allow the representation and interpretation of very large networks. We have labelled the output Netgraphs, and they will, as we shall see, allow introduction of several interpretive dimensions into the network representation. But first we will briefly review some of the historical roots of similar schemes.

GRAPHIC TECHNIQUES FOR REPRESENTING MATRICES AND NETWORKS

Over the years a number of interesting graphic techniques have been developed to represent networks of various sorts. Most of these were created by social scientists to represent the types of interpersonal and intergroup relationships discussed earlier in the paper. Several interesting approaches have been developed by physical and biological scientists, however, to meet particular needs in their areas of work.

Examples from the Physical and Biological Sciences

In the study of the molecular structure of ribonucleic acid (RNA), Kneser (1988) describes the following problem:

> One wishes to represent information about the probabilities that various (base) pairs (i, j) from a sequence of length n over a finite alphabet occur. It is important to be able to locate accurately from the display how probable it is on a logarithmic scale. ...
>
> ...
>
> A succinct way of doing this is by drawing black boxes of varying sizes accurately positioned with lower left corners forming the square matrix of probabilities.

In Figure 2, we reproduce Kneser's diagram. By using the size of the darkened square in each cell of the matrix to represent the magnitude of the probabilities, Kneser produces visually striking graphic representation. Numbers in the cells would not communicate the information as effectively.

A similar need arises in the analysis of mechanical structures using finite element method.[1] The primary objective of such analysis is to calculate stresses and deflections in structures. The finite element method involves discretization of a given structure into a network of finite elements ('mesh') to make computations tractable (Everstine, 1987; Weaver Jr. and Johnston, 1984).[2] The key numerical problem that arises in finite element analysis is to solve large sets of linear algebraic equations of the form, $\mathbf{Ax} = \mathbf{b}$, where the vector $\mathbf{b}$ and the square matrix $\mathbf{A}$ are known, and the unknown vector $\mathbf{x}$ is sought. $\mathbf{A}$ is usually known as the stiffness matrix. In most applications $\mathbf{A}$ is 'sparse', that is, contains mostly zeroes. Locations of the nonzero elements depend solely on the ordering of the unknowns. Such ordering, in turn, corresponds to the sequential selection of grid-point labels of the mesh.

Algorithms for solving the linear sets of equations work most efficiently on stiffness matrices with small 'bandwidths', that is, with nonzero elements clustered around the main diagonal. Therefore, several schemes that indicate how the grid-point labels of a finite element mesh may be appropriately re-sequenced have been developed (Everstine, 1987). Notice, of course, that

[1] The authors thank Dietmar Harhoff for bringing this example to our attention.

[2] Although the original applications were in the field of solid mechanics, its usage has spread to many other fields with problems of similar mathematical nature.

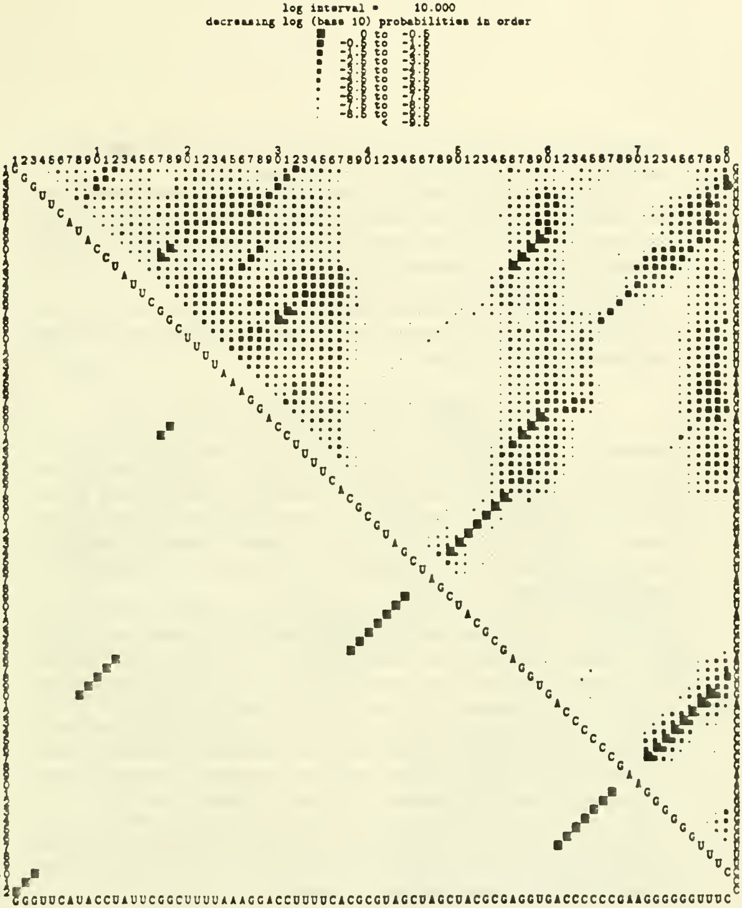


Figure 2: Partition Function Probabilities of Bindings. (From a problem in the study of the molecular structure of RNA.) (Kneser, 1988).

problems before and after such re-sequencing are identical, but after the re-sequencing, the stiffness matrix **A** has smaller bandwidth.

Graphic schemes that show the effectiveness of such re-sequencing are also available. In Figure 3 we have reproduced a picture (Everstine, 1987) that shows location of nonzero terms in a stiffness matrix before and after automatic grid-point re-sequencing. Numerical metrics cannot as effectively bring home the image of reduced bandwidth.

The similarity between the two schemes discussed above and the scheme for networks will become clearer in the next section. We first turn to similar examples from social sciences.

Examples from Social Sciences

Lievrouw et al (1987) reported a study of the social network of biomedical scientists specializing in lipid metabolism research. In Figure 4 we have reproduced their diagram showing the 'who-to-whom network matrix for the sociometric roster data collected from the members of the lipid metabolism cluster.' Note the similarity with Kneser's scheme. Instead of squares of varying sizes, Lievrouw et al have used discrete *geometries* to highlight variation in cell values of the matrix.

During Moreno's time itself, a graphic portrayal of the matrix was proposed. Forsyth and Katz (1960), frustrated that 'the sociogram must be built by a process of trial and error, which produces the unhappy result that different investigators using the same data build as many different sociograms as there are investigators,' proposed a scheme to rearrange the matrix[3] *manually* to highlight dominant configurations ('sub-groups') and to graphically present the rearranged matrix as a 'schematic impression.' Borrowing some data from Moreno's work, Forsyth and Katz presented a corresponding sociogram and schematic impression of the matrix (Figures 5 and 6).

Such a schematic impression of a matrix was sometimes referred to as a 'sociomatrix.' In any event, Moreno did not seem to be favorably impressed by the technique. He maintained that, except for one-sided choices or rejections, the matrix offers difficulties. He argued:

> Already pair relations are hard to find, but when it comes to more

[3] In this case, the matrix consisted of choices, rejections and blanks. One may consider this as equivalent to a (0/1/-1) matrix.

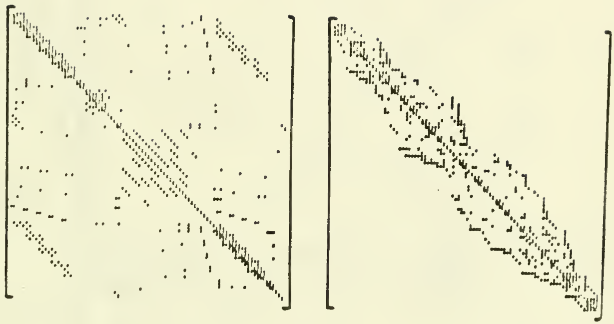


Figure 3: Location of nonzero terms in a stiffness matrix (N=87) before and after automatic grid-point re-sequencing. (Everstine, 1987).

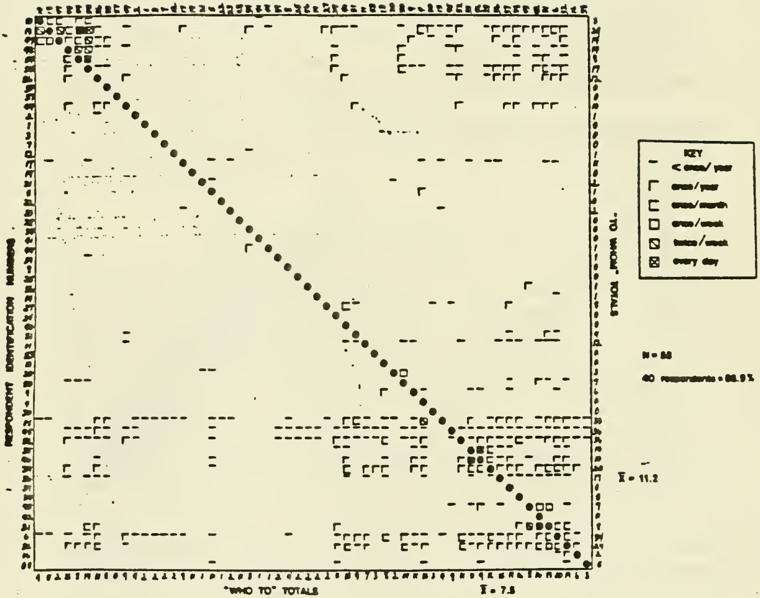


Figure 4: Who-to-whom Matrix of Scientific Communication among Biomedical Scientists Receiving NIH Grants in Lipid Metabolism, 1983. (Lievrouw et al., 1987).

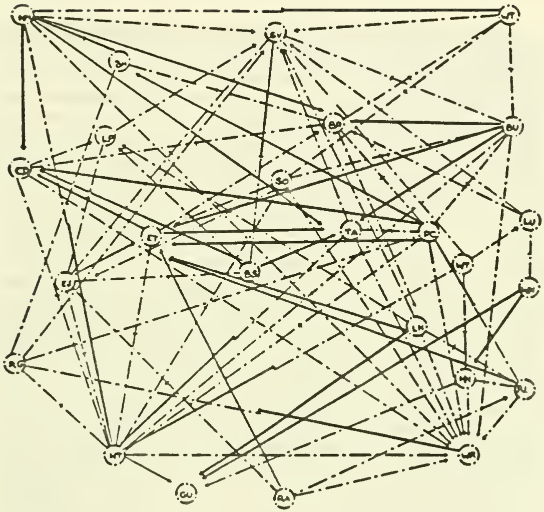


Figure 5: Sociogram Showing the Structure of a Cottage Family. (Forsyth and Katz, 1960).

	LF	RL	HN	TA	WR	PC	HT	BU	SO	WT	SV	LP	ES	BS	ET	RA	WT	GU	HM	WN	LU	BR	JH	RG	CD
LR	X	+			+						+	+			−			−							
RL	+	X	+		+	+									−										
HN		+	X		+												−	+							
TA				X	+	+	+				+														
WR					X																			−	
PC		−		+	+	X	+	+							−							+	−	+	−
HT				−	+	+	X	+	+				+		+		−	−	−					+	+
BU				−	+	+	+	X	+	+	+				−							−			
SO					+		+	+	X	+			+		+										
WT								+	+	X	+								−			+			
SV								+			X		+	−			+								
LP											+	X	+												
ES							+				+	+	X	+	−	+									
BS				−							+	+	+	X											−
ET				−			+		+						X							+			−
RA		+			+								+		−	X									
WT			+				+				+						X				+				
GU																		X							
HM				−	+		+			+	+								X			−	−		−
WN			−															−		X	+				
LU											+									+	X	+			
BR	+					+				+												X	+		+
JH																			−			+	X	+	
RG					+	+	+				+												+	X	
CD					+		+					+										+			X

Figure 6: "Schematic Impression of Matrix" Showing the Structure of a Cottage Family. (Forsyth and Katz, 1960).

> complex structures as triangles, chain relations, and stars, the sociogram offers many advantages, direct visibility and better opportunities for precise observation. (Moreno, 1960).

As we discussed earlier, one of the more serious complaints against the sociogram is its lack of precision. In general, there are so many triangles, chain relations and stars in any reasonably sized network, that an investigator can highlight some arbitrary ones and mistakenly assume that the right ones have been uncovered. Second, Moreno also did not at all concede the difficulties in drawing the sociograms as the sample size increased. Obviously, he did not seem to think it mattered much. In fact, his group churned out large sociograms with apparent ease. The father of sociometry held back his blessings, and graphic representation of matrices never really became popular among the proponents of sociometry.

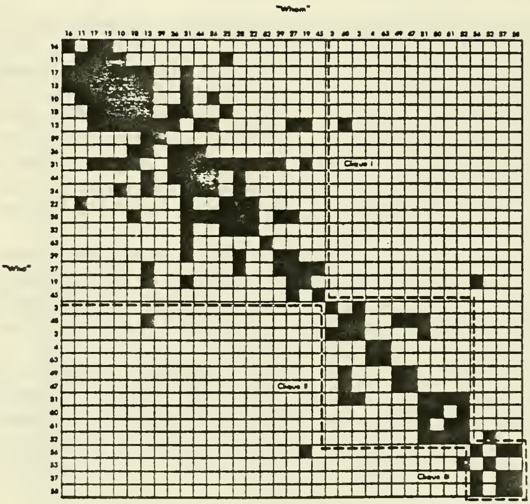
Nonetheless, in recent times there has been a renewal of the attempt to use matrix-based graphic schemes. Rogers and Kincaid (1981) for example, used a diagram (Figure 7) which shows a village communication network in matrix form. Such diagrams, while showing network structure very clearly, still suffered from being manually generated.

To our knowledge, the only other computer-generated, matrix-based graphic scheme is created using Burt's (1989) network analysis program called *Structure Assistant*. The design procedure in the program helps to 'construct' social structures using a Monte Carlo routine. A screen image of the sociometric choice matrix is also generated. A sample image is reproduced in Figure 8.[4]

NETGRAPHS — THE BASIC CONCEPT

To understand the basic concept underlying Netgraphs, consider the adjacency matrix. The rows and columns identically represent the same individuals in a sample. That is, the individual in row_i is the same as the individual in $column_i$, for all i. The cells containing 'zero' signify absence of contact between the individuals in the respective rows and columns, and similarly, cells containing 'one' signify contact. On a large square lattice, Netgraphs

[4] We understand from William Richards that he is in the process of adding a matrix-based graphic scheme to his NEGOPY program.



Note: The four isolates have been dropped from this matrix, in order to show more clearly the clique structure.

Figure 7: Who-to-whom Communication Matrix for Interpersonal Communication About Family Planning in Village A. (Rogers and Kincaid, 1981).

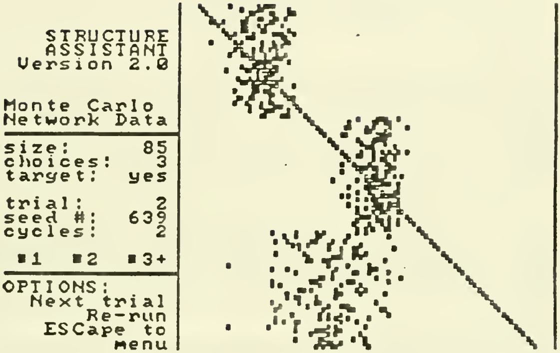


Figure 8: Screen Image of Sociometric Choice Matrix. (Burt, 1989).

simply record the 'ones' (that is, the contacts), wherever they appear in the matrix, as minuscule filled ('lit up') squares. In other words, the complete picture will look like a large square grid that is selectively filled in to indicate contacts, very much like that produced by Burt (1989) and Rogers and Kincaid (1981). Obviously, it is very easy to use computers to display and print selectively filled square lattices. Given an adjacency matrix, the scheme is quite easily implemented in any computer with minimal graphics capabilities.

This is the basic approach that Netgraph takes. In its most fundamental form it is a set of computer programs which converts an adjacency matrix to a graphic representation.[5] Once that capability was developed, however, it became apparent that the power of the programs could be enhanced considerably if a capability to permute the rows and columns of adjacency matrix was built into them.[6]

The first suggestion, therefore, is to permute the rows and columns of the adjacency matrix based on a key variable (such as a demographic variable, a metric of physical or organizational distance, types of different roles, different cliques, etc.) and to provide a grid for the Netgraph to visually delineate the 'different values' of the variable. The grid is just to clearly demarcate the 'boundaries'.

One particular feature of the Netgraphs presented in this paper is included just to simplify programming. Normally for matrices, the element $a_{1,1}$ of matrix A is written on the *top left hand corner*, with other elements following to the right and below. It might have been helpful if this configuration could be followed in Netgraphs as well. But the available graphical routines made it much simpler to represent the element $a_{1,1}$ at the *bottom left hand corner*, with other elements following to the right and above. Thus in all the examples that follow, the graphical representation of adjacency matrices have been 'rotated' by 90 degrees. This does not detract in any way from

[5] In its present form, our programs are written in APL for an IBM Personal Computer, and are capable of handling adjacency matrices of the order of 32000.

[6] Marsden and Laumann (1984) identify three broad types of models used in network analysis: topological ('role-based'), graph theoretic ('clique-based') and spatial ('social distance- based'). In the examples that follow the reader will notice that the authors' approach leans more towards the spatial model, and therefore is most directly and simply amenable to certain reordering schemes we are about to propose. However, we believe that the scheme can be easily adapted to both the topological and graph theoretic approaches.

their effectiveness.

Figure 9 is a Netgraph based on an adjacency matrix with rows and columns reordered on the basis of individuals' age.[7] The outer square is the envelope of the full matrix. The squares along the diagonal represent communication among members in their 20s, 30s, 40s, and 50s respectively. The rectangles in the off-diagonal represent "inter-age group" communication. Note that, because of the symmetry, "30s-to-20s" communication is identical to the "20s-to-30s" communication.

To further aid in understanding a network, the adjacency matrix can be 'sorted.' For example, the columns and rows of a communication matrix may be permuted on the basis of the number of individuals with whom any given individual communicates. In other words, the row and column for the highest communicator is positioned in the lower left hand corner of the Netgraph, the next highest is assigned the next row and column above and to the right, and so on. Note that such sorting was not done in Figure 9. The reader may contrast that with the examples that follow.

In Figure 10 we present a Netgraph based on a sorted adjacency matrix. The person on the left bottom corner is the highest communicator. Others, as we move to the right and above, have progressively fewer communication partners.

Such sorting by number of contacts yields several valuable results. First, it usually brings about an order ('high' to 'low') to the data being presented. Second, it provides a quick visual impression about (degree-based) *individual centralities* and *group centralization*. Finally, by pulling the high communicators to one corner, it becomes easier to get a visual sense for the *connectivity* of a group as well.

[7]Appendix provides information on the data and research method. All the Netgraphs in this paper are based on a *single* communications matrix of approximate order of 500, variously manipulated to highlight different refinements.

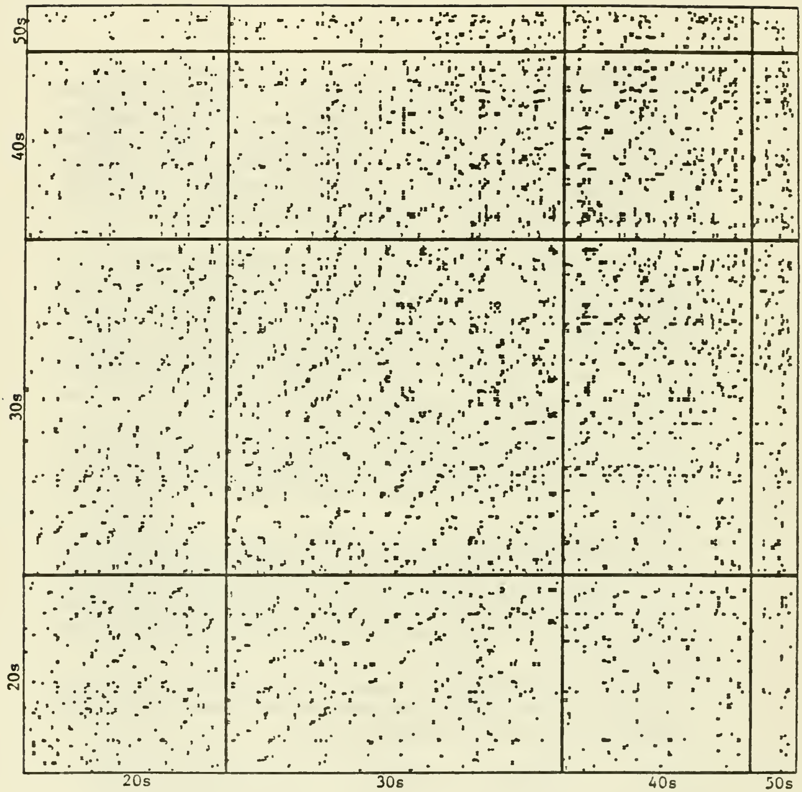


Figure 9: Netgraph — Ordered by Age.

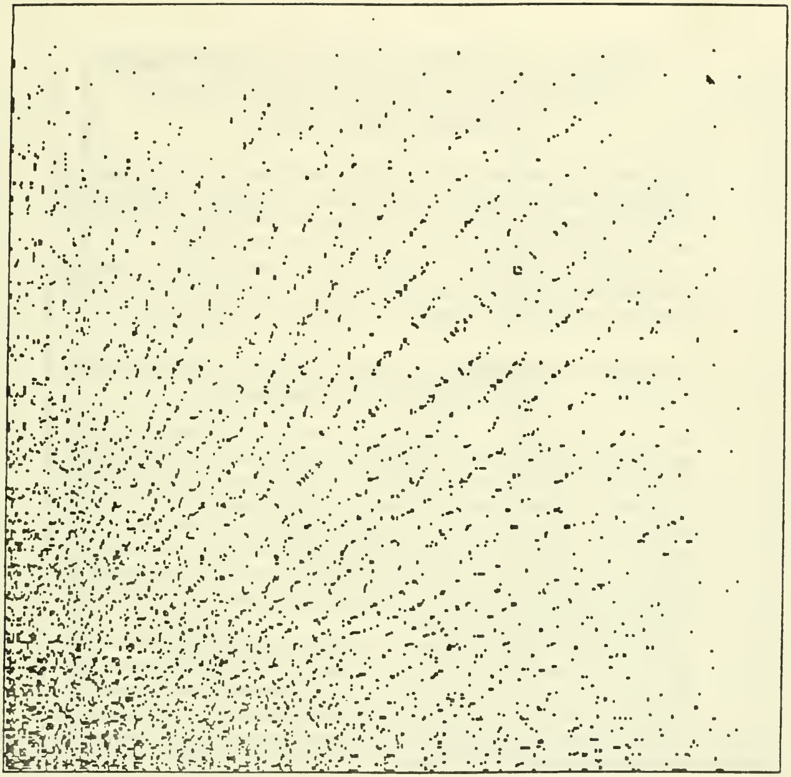


Figure 10: Netgraph — Sorted by Number of Communication Partners.

MORE EXAMPLES OF NETGRAPHS SHOWING ORGANIZATIONAL COMMUNICATION

In the selected examples of Netgraphs of organizational communication that follow, we have incorporated *simultaneously* the refinements suggested so far: *first* sorting the adjacency matrix based on number of communication partners, then permuting them and providing delineating grids.

There are several substantive organizational issues that will become apparent from the Netgraphs that follow. We will only touch upon the most significant among these to highlight the effectiveness of the diagrams.

Netgraph Showing the Impact of Physical Separation on Organizational Networks

In Figure 11, we present a *multiply* ordered Netgraph. The rows and columns are reordered based on sites, buildings, floors, and wings. The grid for wings is not drawn, just to avoid clutter. Note the powerful effect of physical separation on communication networks. Within floors the effect of separate wings is clearly discernible. Note also the pattern of communication of the occupants of the seventh floor of the second building in site number 3. Their communication cuts across floors, buildings and even sites. This is not surprising, since the top floor of the tall building was occupied by project managers and internal consultants.

We find also that the highest communicators <u>within</u> the lowest structural group (in this case, wings) are the ones most likely to communicate <u>across</u> such groups. And, within such groups, high communicators coalesce into identifiable clusters. That is, the highest communicator has a higher probability of communicating with the next highest than with individuals lower in the spectrum.

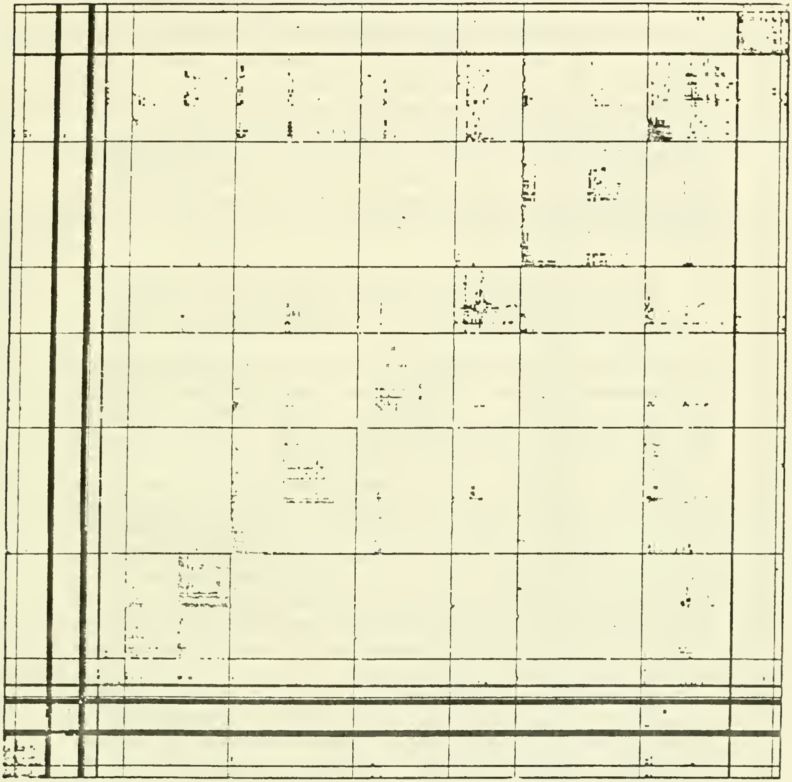


Figure 11: Netgraph — Ordered by Sites, Buildings, Floors and Wings.

Netgraph Showing the Impact of Hierarchical Structure on Organizational Networks

In Figure 12 we have reordered the columns and rows twice, along two levels of organizational hierarchy: 'sections,' and 'departments'.

In Figure 9 it seemed that the sample was reasonably well linked. But figures 11 and 12 clearly show that the sample is actually severely fragmented. Notice also that the "communication clusters" consist of small numbers of people. Our observations in the previous section with respect to high communicators (on clustering of high communicators and their 'boundary' spanning patterns) are valid in this section as well.

SUGGESTIONS FOR ADDITIONAL ENHANCEMENTS TO NETGRAPHS

The reader will note that in figures 11 and 12 two colors, red and yellow, are used to represent contacts.[8] The contacts were coded as follows. If one of the two members of a pair was a manager, the contact is coded red. All others pairs are coded yellow. This shows clearly the central position of managers in networks, as well as their boundary spanning roles.

The use of color adds a third dimension to the graph. The basic unit of analysis in the graph is a pair (of individuals or organizational units). Pairs can have many characteristics. Characteristics of pairs are derived from corresponding individuals either sharing or not sharing certain characteristics. For example, both members of a pair could be managers or engineers, or one might be a manager, the other an engineer. These three types of a pair can be assigned different colors, thereby showing the different patterns that develop for communication among managers, communication among engineers and communication between the two types.

It does not take very much imagination to think of many possible applications. One could examine communication patterns at and between different hierarchical levels, among and between different professions (eg. hardware and software engineers) and so on. The analysis is constrained only by the

[8]Color printers, particularly of the dot-matrix type, are now fairly cheap. Also, color copying has become fairly common. Use of color should be reasonably accessible to most researchers. Publishing color graphics is still very difficult.

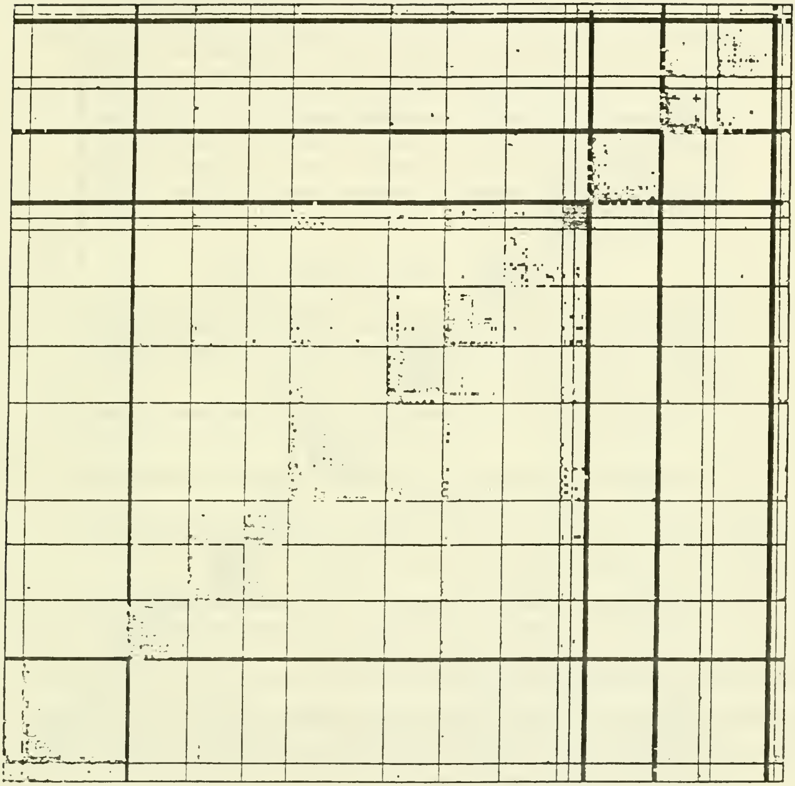


Figure 12: Netgraph — Ordered by Sections, and Departments.

number of colors available for printing. Still another dimension can be added by emulating the approach of Kneser, or of Lievrouw, and using different geometries as well as colors to distinguish different kinds of pairing.

The addition of color and geometry allows the presentation of several values on each of four dimensions, all in a single display. The reader should remember, however, that additional dimensions can be handled also by multiple presentations of the basic, ordered two dimensional array. It may not be also necessary to use more than two dimensions at a time. For example, we could have reordered the adjacency matrices of figures 11 and 12 one more time using a 'manager/non-manager' variable to highlight the roles of managers in the Netgraphs.

An Example Using Multiple Colors

In Figure 13 we have a different version of Figure 11 with multiple colors which will help in examining communication patterns among several types of people at several different geographic locations. The color coding is according to the following algorithm based on a job classification.[9]

1. If either in a pair making contact is a manager, the contact is represented in red.

2. If neither is a manager, and if either is a quality assurance person, the contact is represented in yellow.

3. If neither is a manager nor a quality assurance person, and if either is a software engineer, the contact is represented in green.

4. If neither is a manager, a quality assurance person nor a software engineer, and if either is a trainee, the contact is represented in blue.

5. Else, the contact is represented in black.

The reader will agree that by carefully choosing variables (such as job classification), and the *sequence* of the algorithm that does the color coding, it should be possible to highlight the influence of demographic variables on patterns and configurations in a network. In Figure 13, for example, we find

[9] The sequence of the algorithm is crucial.

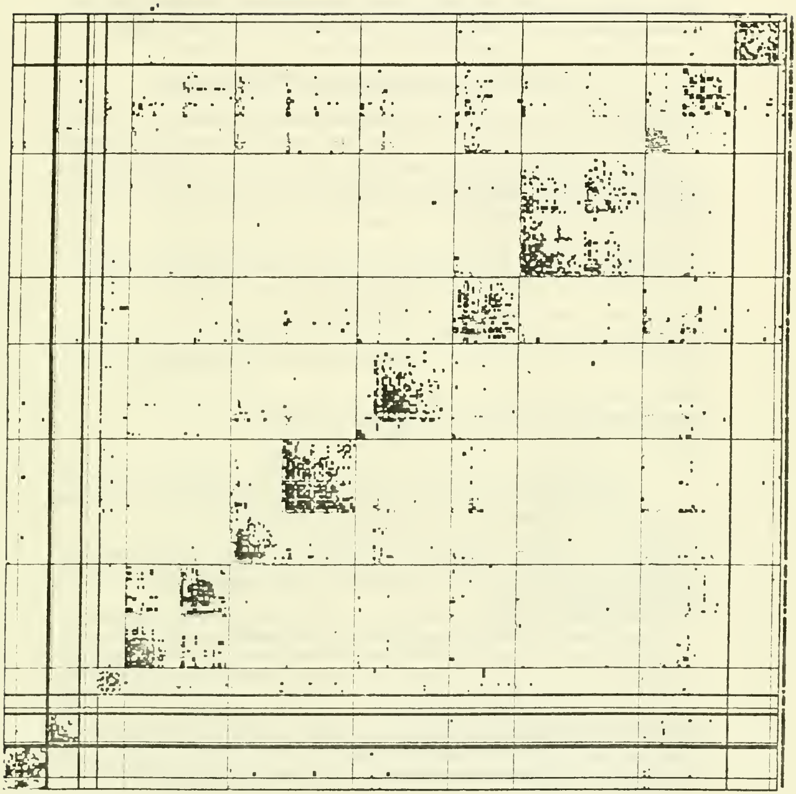


Figure 13: Netgraph Showing Impact of Physical Separation — Multiple Color Codes for Contacts, Based on Job Classification of a Selected Member in Each Pair.

that managers, quality assurance persons, and trainees are predominant partners in those communications that cut across geographical boundaries.[10, 11]

Using Three Dimensional Netgraphs

Though we do not have a three dimensional Netgraph yet for the reader, we believe that such diagrams could be very useful. For example, we could use the third dimension to represent the strength of ties. Configurations revealed in such Netgraphs will be valuable. CAD software may be adapted for generating such diagrams.

THE NETGRAPHS AS AN ANALYTIC TOOL

In this section we summarize the various uses of Netgraphs as an analytic tool.

Uses in Exploratory and Diagnostic Analyses

Considering the state of the art in the field, we expect most uses to be for exploratory and diagnostic analyses. The following is mostly a brief revisit to some of the more significant applications.

[10]Of course, we would have arrived at the same conclusion using multiple passes with just two colors, or, with just one color, using additional reordering of the adjacency matrix with a job classification 'key.'

[11]Notice that in Figure 13 we pre-assign a color simultaneously for (every element of) row_i and $column_i$ in a selected order. That is, first managers rows and columns are assigned red, next QA persons' are assigned yellow and so on. One difficulty with this scheme, of course, is that it is impossible to distinguish between communication among a particular type and communication between two types. For example, in the Figure 'manager to manager' communication as well as 'manager to non-manager' communication are both coded red. To somewhat alleviate this problem, an interested reader may use the 'color bar' on the side of the Netgraph in Figure 13. The bar exactly codes the job type of each individual. This helps in distinguishing 'intra' and 'inter' types of contacts. The best solution, of course, is to color code each contact instead of entire rows and columns. At this time, such a procedure would unacceptably increase the execution time of the computer routines.

- *Visual Estimation of Connectivities, Centralities and Centralizations.* The diagrams are visually revealing regarding three parameters of common interest: connectivities of groups (from the area covered by the little squares), centralities of individuals (from comparing the number of little squares for each individual) and centralizations of groups (from the dispersion of the rest from the highest communicator).[12]
- *Macroscopic Analyses.* Since the diagrams can easily be drawn for very large matrices, network analysis can be done now on large groups. In addition to opening up the field for macroscopic analyses, the diagrams serve as a visual "micro-macro" linking tool. In this context, unlike the sociograms, this graphical scheme helps in several ways. The sparsity of a large communication matrix is immediately brought home. We have uncluttered, and therefore easily comparable, segments of intra- and inter-group communication in the same diagram.
- *Applicability to Various Strategies in Network Analysis.* Earlier we mentioned the topological, graph theoretic and spatial models in the network approach (Marsden and Laumann, 1984). Though our own examples principally belong to 'spatial models,' Netgraphs can be used equally well for other models as well.
- *Bridging Demography, Structure and Networks.* By carefully selecting the nature and sequence of reordering, and color coding of contacts, we can study how demographic variables and structural parameters influence networks. We can also *control* for a selected variable. For example, we can try to answer questions like: Are *high* communicators managers or people with long tenures?

Uses in Prescriptive Mode

We anticipate that Netgraphs will be used effectively in a prescriptive mode as well, particularly in organizational design. They help draw up specifications based on appropriate communications requirements.

[12]All parameters are 'degree-based.' Centrality measures based on 'betweenness' and 'closeness' can not be as easily gleaned from Netgraphs.

Desired levels of interaction may be prescribed using these diagrams. By retaining the representation of the entire organization, the groups, and even the individuals, and highlighting the distance among them, the diagrams aid in balancing competing requirements, and in pointing to areas that require special attention. Since actual behavior can also be represented in such diagrams, they enable verification, and redesign, if necessary.

In summary, a Netgraph is a pictorial representation of networks that keeps the unit of analysis at the level of each individual (node) while retaining comparative information with regard to all other relevant individuals (nodes). It enables us to understand the structural and demographic influences on networks. It aggregates and delineates data, thereby helping in visually estimating some crucial network parameters. For the same reason, they can also be used in prescriptive modes. And, unlike sociograms, once simply programmed, computers will do *all* the work in generating them, no matter how large the sample.

NOTE ON THE DATA USED IN THE EXAMPLES

The analyses were carried out on reported communications using several different channels (face to face, telephone, written, electronic mail, etc.) from approximately 500 applications software professionals of a large, international computer firm. The data were collected using traditional, written, individual surveys, in 1984. At that time the firm had not yet made operational its electronic mail facilities. So the data do not include the electronic channel. Standard, and well documented (Eveland, 1985; Knoke and Kuklinski, 1982; Rice and Richards, 1985), techniques were used to obtain the *adjacency* (0/1) matrices representing communication networks.

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