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Social Structure from Multiple Networks. I. Blockmodels of Roles and Positions[1]

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Networks of several distinct types of social tie are aggregated by a dual model that partitions a population while simultaneously identifying patterns of relations. Concepts and algorithms are demonstrated in five case studies involving up to 100 persons and up to eight types of tie, over as many as 15 time periods. In each case the model identifies a concrete social structure. Role and position concepts are then identified and interpreted in terms of these new models of concrete social structure. Part II, to be published in the May issue of this *Journal* (Boorman and White 1976), will show how the operational meaning of role structures in small populations can be generated from the sociometric blockmodels of Part I.

During the past decade, the network metaphor has become increasingly popular with social scientists;[2] it has even penetrated the conservative

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[2] Network metaphors date back at least to Simmel (1950, 1955; first published in 1908) and the so-called formal school of German sociologists. Simmel emphasized the ubiquity of social networks based on "the actual similarity of [individuals'] talents, inclinations, activities, and so on" (1955, p. 128) and which cross-cut the categorical attributes of persons. Von Wiese, strongly influenced by Simmel, stressed the multiplicity of types of social ties and the analytic desirability of reducing network structures. If the "constantly flowing stream of interhuman activity" were halted in its course for one moment, von Wiese (1941, pp. 29–30) suggested, we would observe

precincts of economics (Boorman 1975; Marschak and Radner 1972; Schelling 1971; see also Leijonhufvud 1968). Sociologists' and anthropologists' attempts to develop the metaphor into operational concepts have taken two directions. One has emphasized the paths or "threads" in a single network: the manner in which long chains of contact wind their way through large social systems (Milgram 1967; Pool and Kochen 1958; Rapoport 1963; Coleman 1964; Hunter and Shotland 1974; White 1970*a*, 1970*b*; Lee 1969; Granovetter 1973, 1974). The second has emphasized the "knittedness" of interconnections within a network and the overlaps between multiple (many-stranded) types of networks for a given population (typically small; see Theoretical Background section, below). Our operational concepts follow the second tradition but are consistent with the first.

After demonstrating the utility of these concepts as applied to five case studies, we redefine the classic concepts of role and position so that they apply to concrete, observable interactions, ordered by a new framework. We take as given the incidence of each of several distinct types of tie across all pairs in a population (see for example figs. 1 and 3 below). Ties of each given type are treated as a separate entity (a matrix). Each is a separate network to be contrasted with other such networks, rather than merged with them to form a complex bond between each pair of actors. This analytic segregation of network types is basic to our framework. From it, aggregation emerges as a concept with dual aspects: actors are partitioned into structurally equivalent sets within each network; simultaneously, though, networks are mapped into a set of images that can be specifically interpreted for specific populations. The resulting "blockmodel" is a view of social structure obtained directly from aggregation of the relational data without imposing any a priori categories or attributes for actors. Our fundamental argument is that the enormous variety of concrete social structures is reflected in the variety of possible blockmodels; furthermore, blockmodels provide tools for ordering this diversity.

The essential phenomenon portrayed in network imagery, we argue, is the *absence* of connections between named individuals. The logical symmetry between ties that are "present" and ties that are "absent" (i.e., all others) has encouraged proponents of graph theory to overlook the

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"an apparently impenetrable network of lines between men. There is not only a line connecting A with B, and B with C, etc., but C is directly connected with A, and, moreover, A, B, and C are enclosed within a circle. Not only is there *one* line connecting A with B, and not only *one* circle in which they are both enclosed, but there are many connecting lines. . . . A static analysis of the sphere of the interhuman will . . . consist in the dismemberment and reconstruction of this system of relations. Outside this network, above and below it, there can be nothing that is social, unless we leave the plane of empirical observation."

social asymmetry that exists between social action and its complement (Harary, Norman, and Cartwright 1965; cf. Simmel 1950, pp. 311–16).[3]

This paper and its forthcoming companion, Part II, present no models of processes over time; there are neither predictions of other behavior nor explications of a stochastic process of tie formation and dissolution that would sustain an observed blockmodel. In this paper the arguments for a blockmodel as a picture of social structure are specific to the context of, and the data available for, each case study.[4] Yet blockmodels provide a natural framework for discussing various types of structural change: numerous changes in individual ties can still be consistent with an unchanged structural pattern; changes in the "circulation" of actors among the structurally equivalent sets can still reflect the same structural pattern for a given network, and changes in network patterns can occur and yet leave sets of actors unchanged.

The next section of this paper examines the broad theoretical underpinnings of our research. The second major section presents definitions and the methods of analysis. The third section exhibits analyses based on five case studies. The fourth section provides an interpretation of "role" and "position."

THEORETICAL BACKGROUND

Insightful expositions of recent work on network interrelations are those by Mitchell (1969, chap. 1) and Barnes (1972). While we use them as central references, we want to state one fundamental disagreement. Both see network analysis to date as, at best, an eclectic bag of techniques (Barnes 1972, p. 3) for studying the details of individuals' variability around some basic ordering by categories and concrete organizations (Mitchell 1969, p. 10). We would like the reader to entertain instead the idea that the presently existing, largely categorical descriptions of social structure have no solid theoretical grounding; furthermore, network concepts may provide the only way to construct a theory of social structure.

Perhaps *the* major thrust of classical social theory was its recognition of the historical dissolution of categorical boundaries for social relations, whether the change was perceived as a transition from status to contract (Maine), from *Gemeinschaft* to *Gesellschaft* (Tönnies), from mechanical

[3] Recognizing that the "holes" in a network may define its structure was a primary substantive motivation for the work reported here. There are obvious analogies with homology theory in algebra (Hilton and Wylie 1960), though the relevant mathematics is quite different.

[4] In addition, White (1974*b*) has calculated probabilities for the occurrence purely by chance of the simplest blockmodels.

to organic solidarity (Durkheim), from traditional to means-rational orientation (Weber), or from ascribed to achieved status (Linton). In our view, the major problem with postclassical social theory has been that its concepts remain wedded to categorical imagery. All sociologists' discourse rests on primitive terms—"status," "role," "group," "social control," "interaction," and "society" do not begin to exhaust the list—which *require* an aggregation principle in that their referents are aggregates of persons, collectivities, interrelated "positions," or "generalized actors." However, sociologists have been largely content to aggregate in only two ways: either by positing categorical aggregates (e.g., "functional subsystems," "classes") whose relation to concrete social structure has been tenuous; or by cross-tabulating individuals according to their attributes (e.g., lower-middle-class white Protestants who live in inner city areas and vote Democrat). Both methods have "often led to the neglect of social structure and of the relations among individuals" (Coleman 1958).[5] In contrast to the standard wisdom, there is a growing list of empirical findings regarding the effect (and frequency) of "accidents" and "luck" in the actual functioning of societies: the transmission of useful information among scientists (Menzel 1962), the attainment of general economic success (Jencks et al. 1972), and the location of desirable jobs (Granovetter 1974; see also Boorman 1975). These findings force us to ask whether the stuff of social action is, in fact, waiting to be discovered in the network of interstices that exist outside the normative constructs and the attribute breakdowns of our everyday categories.

Overall Social Structure

Nadel's *The Theory of Social Structure* (1957), one of the few pieces of sustained analytical exegesis in sociology, inspired the work (White 1963; Lorrain and White 1971) from which these papers grew. His focus was the interrelations of roles. In dealing with role "frames" and their interlock,[6] he confronted the interaction of cultural systems and concrete social structure, a topic on which we spend little time. However, we do develop, in a limited context, two of Nadel's most important ideas. First, social structure is regularities in the patterns of relations among concrete entities; it is *not* a harmony among abstract norms and values or a classi-

[5] There are some exceptions to these tendencies, e.g., reference-group theory (Merton 1959, pp. 281–86), and Znaniecki's (1940) embedding of "role" concepts in "social circles"; nevertheless, there is a remarkable lack of attention to aggregation as a central problem for sociological theory. Leijonhufvud's (1968, chap. 3) critique of neoclassical economics for avoiding similar questions is relevant here. See also Green (1964) for a more orthodox review of economic aggregation concepts.

[6] This topic, of course, entails the attendant complexities of interrelating the multiple perspectives of actors in actual societies.

fication of concrete entities by their attributes. Second, to describe social structure, we must aggregate these regularities in a fashion consistent with their inherent nature as networks.

The cultural and social-psychological meanings of actual ties are largely bypassed in the development. We focus instead on interpreting the patterns among types of tie found in blockmodels. Our sole assumption here is that all ties of a given observed type share a common signification (whatever their content may be). From these patterns, we develop below (and in Part II) operational concepts of role and position.[7]

In our view "position," in the concrete sense of office in a formal organization or membership on a committee, is a concept quite independent from "role." The blockmodels of this paper can be said to identify positions, but only in an elementary sense. In Part II we extend the analysis to encompass multiple *egos* and, thence, role *structures*; we hope also that this extension can describe, in the language of Mitchell (1969, pp. 45–49), the existence and interrelations of "institutions."

At best, blockmodels can make only a partial contribution to the analysis of formal organizations as structures of offices. The network metaphor is unavoidable in developing models of formal organization, even of the simplest kind (Williamson 1970, chap. 2). However, fundamentally new developments of the metaphor are needed, such as that proposed by Friedell (1967) and that implied by the argument of Cohen and March (1974).

Analyzing systems of formal organizations will require still further developments of network imagery, and these cannot be divorced from models of elites and the ways in which they may control large social systems through the structure of network access. Recent work on director interlocks (e.g., Levine 1972) and on advisory systems (Mullins 1972), as well as formally analogous models of interlocks in dual individual-position systems (Breiger 1974*b*; Bonacich 1972), may point in the right direction.

One practical reason for the caution of Mitchell and Barnes in using network concepts was the lack of satisfactory methods for aggregating networks among individuals. A related reason was the paucity of research on networks among nodes that represented collectivities and organizations. There are few systematic analyses of networks among such nodes (but see Fortes 1945, Mayer 1960, and Savage and Deutsch 1960); however, engineering and operations research have huge descriptive and normative

[7] Our stress on relationships among patterns suggested to one of our referees an analogy to Lévi-Strauss's work on "meaning." He thereby credited us with too much and too little. We use that term without the rich ethnographic insight of Lévi-Strauss; however, we do discuss the falsifiability of an ideal-type pattern and (White 1974*b*) its null expectation. In our view, the delineation of concrete social structure should be analytically divorced from symbolic and cultural analysis.

literatures on flows within networks (see Ford and Fulkerson 1962) that may prove suggestive (see White 1973).[8]

Both Mitchell and Barnes emphasized "anchored" networks (networks seen from the perspective of a particular member), because they wanted to show how network concepts illuminate the manipulative activities of concrete persons in real situations. Their conceptual approach differs from our observer viewpoint in this paper and the multiple-ego viewpoint of Part II. In particular, they merged different types of tie and inferred a complex, overall quality from the multiplex bond between the anchor person and each of his contacts.[9] In contrast, we argue for the value (from the observer's viewpoint) of treating the network based on each analytically separable type of tie as a separate entity. Furthermore, Mitchell and Barnes paid more attention to the different facets of meaning measured for each type of tie; they also stressed the importance of rich observation by a participant observer as, for example, in Kapferer's work (1972).[10] In contrast, we argue, following Durkheim, that a theory should be developed only in terms of the overall structure that is the context for particular transactions. We cite as evidence Boorman's (1975) model of job information exchange, noting that his results regarding stability and optimality were obtained from postulates of a very simple, overall network structure.[11]

Mitchell and Barnes treated sociometry, especially balance theory, with some disdain.[12] Although many powerful analyses of data have used a variety of sociometric concepts (see, e.g., the excellent survey articles by Glanzer and Glaser [1959, 1961]), many of the data are from experimental "groups" and other populations aggregated within a sociological vacuum. Moreover, with the crucial exception of the analyses by Davis, Holland, and Leinhardt (see Part II), balance theorists have had little

[8] Both this paper and Part II deal wholly with data on individuals, but our motive for developing the methods reported here was partly that we think they will be fruitful for analyzing data on networks among collectivities (see Breiger, Boorman, and Arabie [1975] reanalyzing data of Levine [1972]).

[9] But note the lament of Mitchell's colleague Boissevain (1973, p. xi) that "the problem of handling multiplex or many-stranded relationships remains, in spite of the increasingly sophisticated analytical apparatus provided by network analysis."

[10] Kapferer went even further, attempting to develop an exchange theory for transactions between pairs in a network.

[11] We believe that blockmodels, which represent static structure, will be a useful framework for developing social exchange theory. Ekeh's (1974) recent review of "the two traditions" in social exchange theory urged the importance of interaction between restricted exchange (Homans) and generalized exchange (Lévi-Strauss). Blockmodels seem a natural context for such a merger.

[12] Mitchell (1969, p. 7) ventured so far as to term balance theory, the most interesting analytic development in this tradition (see e.g., Harary et al. [1965, chap. 13]), "a toy of the lecture-room theoretician."

stomach for actual data. Yet we think Mitchell and Barnes too hasty. Our own approach owes much to sociometry, particularly its encouragement of systematic data reports in contrast to rich intuitive observation, and blockmodels include various forms of balance theory as special cases (see Part II).

Contrasts with Sociometry

Sociometry's most common goal for a single type of tie was the identification of cliques (or similar configurations) of tightly clustered individuals; a secondary goal was chains of connectivity. The clique concept embodies the root idea of aggregation by relations rather than by attributes that is indispensable to blockmodels. Sociometry's other major goal (most notable in balance theory) has been to interpret the interpenetration, or overlap, among different types of tie.

We now draw five contrasts between sociometry and blockmodels. The first two are prompted by the restrictive nature of the clique concept. First, persons not in cliques are usually disregarded (i.e., treated as outside the effective sociometric system). In contrast, blockmodeling requires searching for a complete partition, such that sets of persons can be structurally important regardless of whether the sets resemble cliques. Second, even when (as in MacRae 1960) cliques are defined as we define structurally equivalent sets (i.e., by similarity in ties to third parties rather than by choices of one another), the clique imagery is retained and is often allowed to limit the interpretation. In blockmodels, on the other hand, partitioning of individuals is only one side of a dual problem; the other is to interpret the pattern formed on the one or more networks by the partition.[13]

The third contrast is in use of spatial imagery. Most sociometry deals with only one type of tie, sometimes an overall type constructed from separate kinds of data. Several investigators (e.g., Laumann and Pappi 1973) eschew the crudity of clique description, preferring instead to view the population as embedded in some abstract space (usually Euclidean). Even ordinal measures of similarity between pairs can be converted into quantitative measures of location and distance through some variant of multidimensional scaling (Shepard 1962; Kruskal 1964*a*, 1964*b*; McFarland and Brown 1973; Arabie and Boorman 1973; Shepard 1974). Cliques, as well as many other sociometric concepts (e.g., connectivity), can then be expressed in terms of locations and distances within the space. In contrast, blockmodels assume no such spatial embedding. Presumably each

[13] Basic to our work has been our desire to conceptualize many ideal-type patterns, each suggestive of a different form of social organization, and to perform tests that reveal which (of all conceivable patterns) actually *exist* in a population.

network, each distinct quality of tie, requires its own space, whereas blockmodels are able to sidestep this matter. Perhaps a more basic question, though, is whether *any* spatial representation is suitable for a network, since the essential feature of social networks may well be the sharp breaks in patterns—the "holes" in the networks.[14]

The fourth contrast concerns boundaries. Sociometry usually takes as given some split between the population studied and the rest of the world (i.e., it assumes a clearcut enclave). However, Barnes emphasized the artificiality of this presupposition and urged instead a distinction between the finite "reach" of network effects and the notion of a sharp boundary around a particular set of people (1972, p. 16). In two of the case studies below (the biomedical and the Firth-Sterling), we argue that blockmodels apply to networks among people who are embedded in a larger world and who thus comprise an "open" population.

The fifth contrast involves a basic methodological issue. Moreno's original emphasis on concrete diagrams of ties among individuals was sound. As sociometric analysis "advanced," though, it became more and more wedded to approximations by indices (of which spatial embeddings and triad inventories [Holland and Leinhardt 1976] are among the most sophisticated). Balance theory initially signaled a reversal of this trend; however, as soon as it became clear that no real data sets were "balanced" in the classical sense, researchers began an unrewarding search for indices of the degree of deviation from classical balance (see, e.g., Flament 1963). We argue, instead, that sociological analysis needs explicit models of the structures in observed populations, *not* measures or statistical indices of deviations from some convenient ideal structure. Blockmodels were developed to meet this need.

METHODS: PHENOMENOLOGY AND ALGORITHMS

Structural Equivalence and Blockmodels

Consider ties of one type, from one person to another, arrayed as a square matrix, with a row *and the corresponding column* of the matrix assigned to each person in the population. Create a separate matrix for each type of tie. Figure 1 presents three kinds of tie among biomedical researchers specializing in the neural control of food and water intake (Griffith, Maier, and Miller 1973). An entry of X means that a tie is "present"; a blank space, that a tie is "absent." The left-hand matrix represents all ties of mutual personal contact. The other two matrices

[14] Breiger et al. (1975) compared blockmodels with multidimensional scaling solutions in considerable detail for several sets of data (using both the MDSCAL and INDSCAL algorithms); they argue that there is agreement between results obtained by the various approaches.

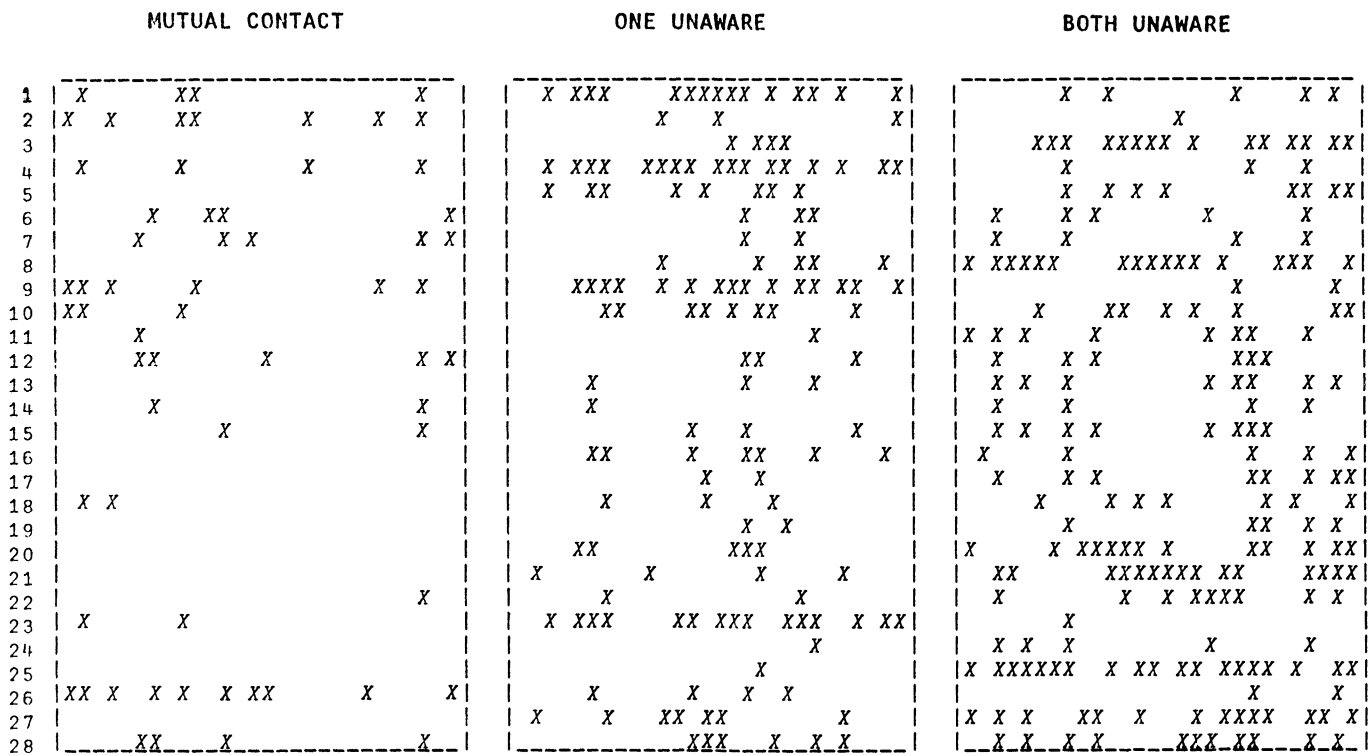

FIG. 1.—Incidence of ties of three types among 28 biomedical scientists in a research network. Source: Griffith, Maier, and Miller (1973). Asymmetric and reciprocal "unawareness" reported separately. Alphabetical listing by surname; numerical row and column labels as shown in left margin.

represent "unawareness of man or his work," distinguishing pairs of individuals who reciprocate "unawareness" (the right-hand matrix) from pairs in which only one individual indicated an "unawareness" tie (the middle matrix). Only an arbitrarily chosen subset of 28 members of the full sample ($N = 107$) is included.

Blockmodeling begins with weakening and extending the algebraic concept of "structurally equivalent" actors in a network (Lorrain and White 1971). A self-consistent search procedure is used to partition a population into sets of structurally equivalent actors—*blocks*. In each data matrix, we rearrange the row and column of each individual, so that the members of a block are grouped together. We also use the term *block* for a rectangular submatrix in which ties of the given type from members of one block to members of another block are reported. (The context will specify which of the two meanings is intended.) Attention is focused particularly on blocks which have no, or very few, instances of ties: these are termed *zeroblocks*.

Look ahead to figure 3, in which the 28 persons in figure 1 have been partitioned into four blocks. (For example, the first block has five members: individuals numbered 9, 26, 23, 4, 1.) The rows and columns for individuals have been rearranged so that each of the three matrices can be seen as 16 blocks displaying ties from one of the four sets (blocks) of individuals to another. For example, in each matrix of figure 3 the upper left block reports any ties among the first five individuals; adjoining it on the right is the block reporting any ties *from* these five *to* the second set [block] of six individuals; and so on. There are eight zeroblocks in the left matrix, five in the middle one, and four in the right-hand one. The pattern of zeroblocks in this figure is interpreted in the next section, where case studies are discussed.

A *blockmodel* is a hypothesis about a set of data matrices: it specifies for each matrix which blocks will be zeroblocks when some common partition of the population is imposed on all the matrices (as in fig. 3). A blockmodel consists of a square binary matrix, called an *image,* for each type of tie. Each image has a row and a corresponding column for each block (in fig. 3, the top panel of three 4×4 matrices shows an image for each type of tie). The ordering of blocks within the blocked matrices is arbitrary, as is the ordering of members within a block.

Five ideas are basic to blockmodels. First, structural equivalence requires that members of the population be partitioned into distinct sets, each treated homogeneously not only in its internal relations but also in its relations to each other such set. Second, the primary indicator of a relation between sets is not the occurrence but the absence of ties between individuals in the sets. Third, many different types of tie are needed to portray the social structure of a population. Fourth, the nature of a type of tie is inferred from the pattern, in a given population, of all ties of that type.

The fifth idea embodies our basic claim about aggregation. A model of social structure requires specifying, for each pair of sets on each type of tie, whether or not a zeroblock exists. Thus, a given set—a "block" in our terminology—may be debarred, by the model, from ties of one type with several other blocks, and from ties of a second type with a different collection of other blocks, and so on.

Bonds and Segregation

Suppose the networks for a given population satisfy a particular blockmodel hypothesis. When these matrices are rearranged and partitioned accordingly, those blocks which are not zeroblocks are usually not completely filled with ties. They have a speckled appearance because choices from members of the row block to members of the column block are interspersed with blanks showing no ties. There are several reasons for this situation. First, if the data are sociometric responses, then the number of responses per person is usually limited to an arbitrary number that is normally insufficient to yield solid blocks of entries. If an observer infers ties (instead of asking the subjects about them), he will be unable to monitor all possible pair interactions continuously; thus he may miss brief occasional contacts that are, in fact, enough to maintain a tie (if not to originate it). At any given time, chance fluctuations (who has been talking to whom, etc.) may determine which particular ties are coded as present.

Second, aside from limitations in data collection, the persons being studied may not be motivated to report all their ties. At some times, they may even wish to conceal some ties from others, or even from themselves—hence also from any investigator. The act of revealing a tie—one's asymmetric contribution to a pair connection—is a tactical decision in an ongoing situation.[15]

Third, there is no need for a person to maintain every tie to all individuals who belong to his own or another block, even though the number of ties between (or within) these blocks may be considerable. Maintaining a tie requires time and energy; in addition, it makes a claim on another person's attention. Blockmodeling requires that ties of a given type from any person in one block to any person in another be equivalent in structural significance; however, not everyone need choose to mobilize all such ties all the time (White 1974*a*).

Finally, the *population* need not be a natural group in mutual face-

[15] This theme is further developed in Schelling (1960). That self-censorship actually occurs is further suggested by the Firth-Sterling Corporation data analyzed below.

to-face contact, all of whose members are automatically acquainted with one another. It may be a contact network in which a particular person may never even have heard of half the others, as in figure 1. Blockmodels are wholly applicable to such cases.

The blockmodel hypothesized for a set of matrices is an interrelated set of inferences from those data to an aggregated pattern of ties among certain sets of persons. The memberships of these sets (the blocks) are influenced by each other through the incidence of ties of every type across the whole population. *Bonds* is the term[16] assigned to those blocks which are not zeroblocks, even though many or most of the entries are blanks.

Sociometric stars and other concepts that try to capture individuals' popularity have no direct analogue in blockmodels.[17] Segregation of choices, as between boys and girls in grammar school classrooms (Bjerstedt 1956), has often been noticed in sociometric analyses. This phenomenon can be described by zeroblocks in a blockmodel, but has apparently been investigated only for a priori categories of persons, such as male and female. With reference to less extreme forms of segregation, think of zeroblocks (such as those in the mutual contact matrix of fig. 3) as marking the boundaries of choices by subgroups. Because individual popularity depends on the size and composition of the group or unit under consideration, it may be argued that this class of sociometric concepts depends logically on blockmodels (or some closely related apparatus) for delimiting the boundaries of such units. *Within* the top left block of the figure 3 mutual contact matrix, for example, it is apparent that the first individual (#9) is most popular (he is chosen by each of his blockmates) while the second individual (#26) receives fewer choices. This fact is masked, however, in the unpermuted data of figure 1, which shows individual #26 receiving more choices overall than individual #9.

Images from Reciprocity and Reflexivity

Much of sociometry emphasizes the distinction between a reciprocated tie and an asymmetric tie (Davis 1970). This distinction is used in blockmodeling, but usually between blocks and not between individuals. On the other hand, reflexivity is merely a technical question in sociometry, whereas in blockmodels the existence of diagonal entries for a given image involves a crucial substantive question. In sociometry there are

[16] Breiger et al. (1975) used the term "1-block" instead of bond.

[17] Connectivity in a sociometric graph may depend crucially on a single tie between two individuals and is therefore hard to relate to blockmodel ideas (compare also the concept of a sociometric "bridge" suggested in Granovetter 1973). Holland and Leinhardt (1973) explored the sensitivity of sociometric models to measurement error in sociometry, but they came to unjustifiably pessimistic conclusions.

only four possibilities for any pair of individuals on a given type of tie: reciprocal, null, or one-way (two possibilities). In contrast, blockmodels permit 16 images on two blocks; these are shown, and fixed labels assigned, in figure 2. In sociometry, three of the four possibilities are structurally distinct; in blockmodeling, 10 of the 16 images are distinct (see fig. 2).

In the blockmodels for five of our case studies, images E and V (and F and W) occurred frequently and are substantively important. V can capture, in a crude 2×2 pattern, the structure of a hierarchy as usually idealized: ties of deference extended within each block to one's immediate superiors are also observed from the lower to the higher blocks in the hierarchy. In contrast, image Y can be seen as aggregate deference accorded *only* by persons in the lower block *only* to persons in the higher block. Call E the "hangers-on" pattern. It suggests differential standing, but in a different way. Here the second block is not internally coherent but is part of an overall deference structure. The E image suggests a distinction between the center and the periphery.

Images P and N represent pure reflexivity and pure symmetry, respectively. Sociometric balance theory may be expressed by these two images: positive binding within each of two cliques (reflexivity—P) and hostility between the two cliques (symmetry—N). Element C singles out one clique from the remaining isolated individuals. If the type of tie represented here has negative connotations, then either C or D shows a concentration of hostility within a subset.

Images H and T are patterns for perceptions held by members of both blocks: all ties from both blocks go to one block. Images S and G show people split into a passive block on the one hand and an active block that does not discriminate between itself and the passives in ties of the type under study. The usual forced-choice procedures for gathering sociometric data would preclude discovery of patterns S and G.

The Aggregation of Blocks

The image of a blockmodel may be portrayed to any desired degree of refinement by combining blocks to achieve a "coarser" image (one with a smaller number of rows and columns) or by further splitting the existing blocks to achieve a "finer" (larger) image. Any blockmodel on three blocks, for example, can be collapsed formally into a blockmodel on two blocks by combining any two of the blocks. Since the order of blocks is arbitrary, there are $(2^{n-1} - 1)$ ways to collapse an n-block blockmodel into possible blockmodels on two blocks.[18] Of course, the rule for collapsing

[18] Each of the original data matrices reports information only about ties of that type for all pairs in the population. Permuting the rows (and corresponding columns)

must require that if any one of the refined blocks being combined into a coarse block is a bond, the coarse block must also be a bond. Often two blocks are not sufficient to capture even the gross patterns in a blockmodel for a case study.[19]

Observe that each bond in the *C,F* pair of images for two blocks is also a bond in the *E,F* pair: even when the number of blocks is the same, one blockmodel may be a refined (i.e., more demanding) version of another. In principle, one can construct an inclusion lattice[20] of blockmodels, on a given number of types of tie, beginning with those on two blocks and then extending the lattice to three and more blocks. In practice, the possible blockmodels are far too numerous for this to be useful. For example, there are 104 single images with three blocks, which are distinct under permutation of blocks.

Formally, the pair of images *C,F* is simply a more demanding version of *V,F,* but (as will become apparent) the social structures described have quite different qualities. Blockmodels provide a framework for making substantive judgments and interpretations; they supply a set of formal answers. However, the solution must be proposed, as well as validated, on substantive grounds.

Two Algorithms

For the cases studied to date, up to half the blocks have been zeroblocks. Intuitively, it is surprising to find any partition of rows and columns for a set of arbitrary matrices which fit a blockmodel containing many zeroblocks, but in principle there could be many. The number of possible partitions is astronomical. G. H. Heil has devised an efficient computer algorithm for constructing all assignments (if any) of men to blocks for which the rearranged data matrices obey the given blockmodel. This algorithm, called BLOCKER, is described in detail elsewhere (Heil and White 1974).

In carrying out BLOCKER, one can identify persons whose assignment to one or more particular blocks in the blockmodel effectively determines the placement of many other persons. Such individuals may be

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does not change the information. After a partition is imposed, the blocked matrix for a given relation contains the same pair data as before. The use of blockmodels can be urged on the purely methodological grounds that they permit flexible aggregation which retains this permutation invariance (see White 1974*a*).

[19] True for the biomedical and the monastery cases examined below. In contrast, the essential patterns, and thus qualities, in the Newcomb fraternity *can* be described by a pair of images (*V,F*).

[20] Szász (1963) provides relevant lattice-theoretic background. When building such a lattice, the order of blocks is obviously significant in comparing matrices.

Z	$\begin{matrix} 0 & 0 \\ 0 & 0 \end{matrix}$		
C	$\begin{matrix} 1 & 0 \\ 0 & 0 \end{matrix}$	D	$\begin{matrix} 0 & 0 \\ 0 & 1 \end{matrix}$
X	$\begin{matrix} 0 & 1 \\ 0 & 0 \end{matrix}$	Y	$\begin{matrix} 0 & 0 \\ 1 & 0 \end{matrix}$
P	$\begin{matrix} 1 & 0 \\ 0 & 1 \end{matrix}$		
N	$\begin{matrix} 0 & 1 \\ 1 & 0 \end{matrix}$		
G	$\begin{matrix} 1 & 1 \\ 0 & 0 \end{matrix}$	S	$\begin{matrix} 0 & 0 \\ 1 & 1 \end{matrix}$
H	$\begin{matrix} 1 & 0 \\ 1 & 0 \end{matrix}$	T	$\begin{matrix} 0 & 1 \\ 0 & 1 \end{matrix}$
E	$\begin{matrix} 1 & 1 \\ 1 & 0 \end{matrix}$	F	$\begin{matrix} 0 & 1 \\ 1 & 1 \end{matrix}$
V	$\begin{matrix} 1 & 0 \\ 1 & 1 \end{matrix}$	W	$\begin{matrix} 1 & 1 \\ 0 & 1 \end{matrix}$
U	$\begin{matrix} 1 & 1 \\ 1 & 1 \end{matrix}$		

FIG. 2.—The 16 possible 2×2 binary matrices. Grouped into 10 rows, one for each set that is equivalent under permutation of the two blocks. The letter labels used here and in the text are applied only to these matrices (never to designate other images or to data matrices).

termed *crystallizers*: they resemble sociometric stars in importance, not because of the number of choices they receive but because of their strategic, "structural" position in the overall matrix following from the hypothesized model. Other persons are allowed multiple, alternative assignments by the BLOCKER algorithm; these are termed *floaters*. They are somewhat analogous to the sociometric isolate, who receives few or no choices.[21]

The number of different blockmodel hypotheses, even with just two or three blocks and just two types of tie, is so large that some other approach is desirable for initial exploration. Breiger has developed a hierarchical clustering algorithm that partitions men into possible blocks and then finds a blockmodel by inspecting the data matrices rearranged according to the partition.[22] It is called CONCOR; its formal behavior is analyzed in Breiger et al. (1975); some mathematical properties are described in Schwartz (1974).

The difference between the two algorithms is as follows. CONCOR produces from raw data an assignment of individuals to blocks, and thence suggests a blockmodel hypothesis. BLOCKER demands a blockmodel hypothesis and derives from it any assignment of men to blocks that satisfies the hypothesis for the given set of data matrices. Matrix entries in any numerical form can be direct input to CONCOR, whereas each tie must be coded as either 0 or 1 before BLOCKER can be used. Substantive judgment is required in both: in CONCOR, on when to stop the further splitting of blocks; in BLOCKER, on what blockmodels constitute appropriate hypotheses.

BLOCKER searches for pure zeroblocks; an assignment is rejected for a blockmodel hypothesis if even one tie thereby appears in any zeroblock. CONCOR partitions the population in a way that may be intuitively characterized as yielding sharp contrasts in densities of ties between different blocks. The image suggested by CONCOR can be refined by varying the cutoff level of tie density below which a block is coded as a zeroblock.

[21] See Appendix A for more specific information about the assignment of men to blocks.

[22] Specifically, given k matrices, each of size $n \times n$ and reporting ties among a population of n actors, a two-dimensional matrix (M_0) with $k \times n$ rows and n columns is formed by "stacking" each of the k matrices one above the other, taking care to preserve column ordering. (Alternatively, the $2nk \times n$ array of each matrix and its transpose may be formed.) The $n \times n$ correlation matrix (M_1) of product-moment correlation coefficients among columns of M_0 is then formed. This process is iterated (M_{j+1} is the matrix of correlations among all pairs of columns of M_j) until a limit matrix is obtained, which may be permuted to yield a bipartite division of the actors (columns) into exactly two subsets (blocks) of sizes s and $n - s$. A refinement to any desired number of blocks may be obtained by creating a new array M_0 with $k \times n$ rows and s columns, $k \times n$ rows and $n - s$ columns, etc. In their detailed description of the algorithm, Breiger et al. (1975) include extensions and comparisons with multidimensional scaling and hierarchical clustering methods in the literature. We wish to thank A. Tagg of the University of Surrey for calling our attention to the anticipation of this algorithm in McQuitty and Clark (1968).

The image required by BLOCKER can be refined by following the inclusion lattice for images.

In the theory and interpretation of blockmodels, neither BLOCKER nor CONCOR is indispensable. It is possible, though laborious, to find and test blockmodel hypotheses by simply inspecting many permutations of the data matrices.

FIVE CASE STUDIES

This section reports five case studies on which we tested blockmodels. Four concern adults in work situations; only one (the Firth-Sterling Corporation management) included all of the population's relevant authority figures. Two are panel studies using at least four time periods. Four of the populations are primarily face-to-face groups of fewer than 20 members, and one is a subsample from a larger sample ($N = 107$). Four are exposed to normal turnover in members. All five include systematic data on individual attributes. All the populations are twentieth-century and American. This section concludes by illustrating the use of blockmodels with overtime data for two of the studies.

For four of our case studies (all but the biomedical research network), detailed independent analyses are presented in the original studies of the interactions. These discussions have informed our search for blockmodel hypotheses used as input to BLOCKER and are also used to validate some of our findings. We cite here five general findings from the case studies which illustrate this validation of the blockmodels and also additional insights obtained. (1) CONCOR, a mechanical search algorithm not dependent on our perceptions of the "meaning" of the data, produces a partition of individuals into blocks which is *equivalent* at the three- or four-block level of refinement to the identification of major groupings in the original study of the interactions, in all four cases for which such comparisons may be made (see results reported below and in Breiger et al. 1975). This strong finding suggests the validity of our approach to network aggregation. (2) Even though many of our hypotheses which are tested by BLOCKER are informed by our reading of the original studies, blockmodels constructed across several different types of social relation in each study are valuable in portraying the overall social structure. (3) BLOCKER partitions for coarse (two- and three-block) models agree with the partitions independently derived by CONCOR. (4) In each case study, we suggest additional interpretation (based on a finer partition of individuals into blocks and/or a consideration of the patterns of relations brought out in the blockmodel) which goes beyond the analyses of the original accounts. (5) The case of the biomedical research network, for which a detailed analysis of the interactions among the population's members does not exist, illustrates the utility of blockmodels as an exploratory procedure in searching for structure when the only available clues consist of reports of interaction among pairs of individuals.

A Biomedical Research Network

Data.—Griffith et al. (1973) identified 173 scientists studying the neural control of hunger and thirst. Of these, 107 responded to Griffith's questionnaire. In more than half the possible instances (as fig. 1 shows) one respondent was unaware of another, as can be expected in an open population.

Blockmodel.—In order to apply BLOCKER to these data, each entry in the matrices must be coded in binary form. Only a reciprocated choice on "mutual contact" was regarded as strong enough by itself to prevent a zeroblock; thus symmetric choices on mutual contact were coded *"X"* and the rest coded "blank." "Unaware of" is not like other, substantive, types of tie, so unreciprocated choices on it were treated as a distinct type of tie, with reciprocated choices constituting a third type. A blockmodel hypothesis, stated in the top panel of figure 3, for these three types of tie was developed by systematically exploring intuitively plausible blockmodels. At the left in figure 3 is the partition—the unique assignment (defined in Appendix A)—of men to blocks that BLOCKER yields when the data are tested against the hypothesis. The bottom panel shows the data matrices with rows and columns blocked in conformity with this partition: inspection shows the blockmodel is confirmed.

Interpretation.—Interpret the blockmodel in status terms. (Blocks are ordered from high to low status.) On symmetric "mutual contact," the bottom two blocks are connected neither internally nor to one another, and the bottom block has no connections with any block, including itself. The bottom block belongs to the population only in the cultural sense that it has no asymmetric unawareness of the block that is obviously the leading set of researchers. *No* block has asymmetric unawareness ties to the top block; yet that block has asymmetric unawareness entries to each of the others; we might call this a snob effect.

Further tests.—CONCOR was applied (not shown here) to the data matrices for "mutual contact" and "unaware." Its first split of the 28 men yielded a partition similar to BLOCKER's: the first two groups in the latter became one group, and the last two a second, except for two interchanges. After two more splits, the partition was

$$(1\ 4\ 9\ 23\ 2\ 10\ 26)\quad(24\ 19\ 12\ 14)\quad(6\ 7\ 28\ 11\ 15\ 13\ 16)\quad(18\ 22\ 3\ 5\ 8\ 17\ 20\ 21\ 25\ 27). \qquad [1]$$

The extreme blocks are close to those of figure 3; the middle two are

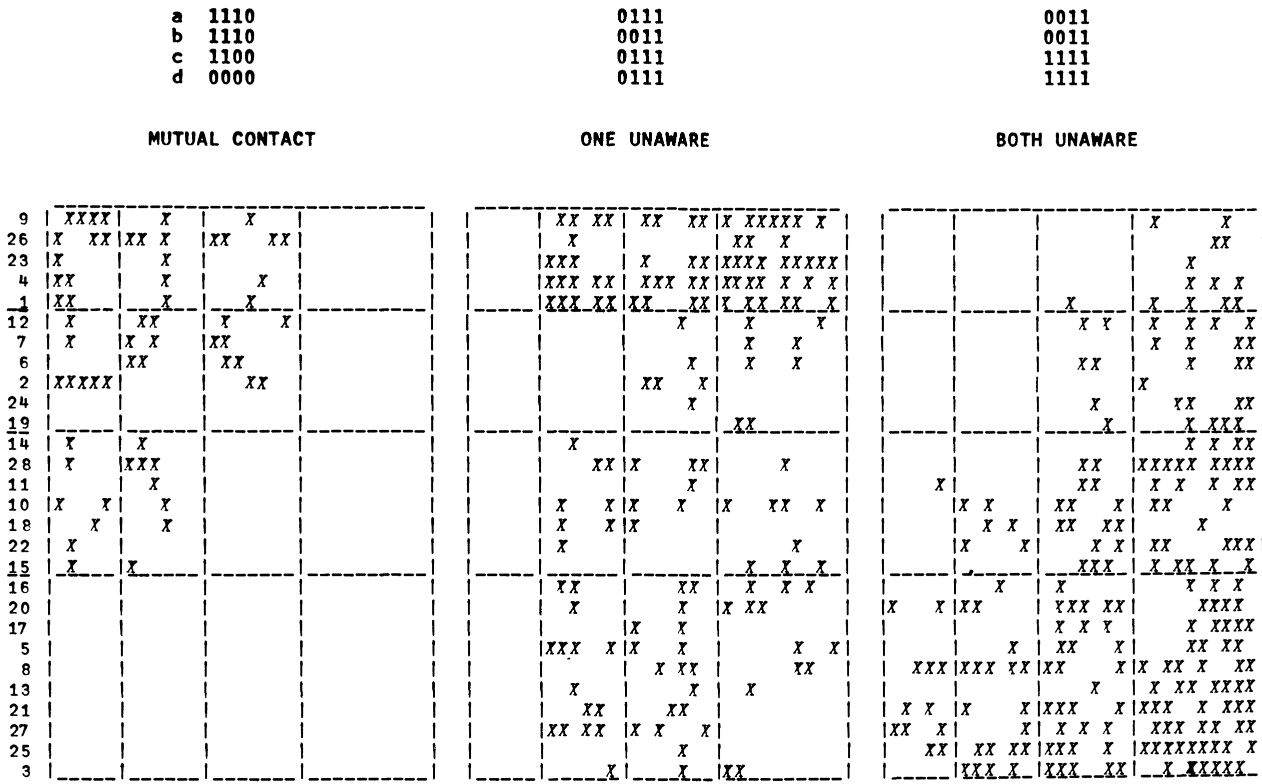

FIG. 3.—Blockmodel for biomedical network: images and blocked data matrices. In the left margin are letter labels for blocks and the rearranged numerical labels for individuals from fig. 1.

more mixed. For all three types of tie, we constructed a blockmodel from the CONCOR partition by defining a zeroblock as any block with less than a specified fraction of the average density of entries for the given type of tie. For any cutoff fraction between 1/10 and 1/2, the resulting blockmodel was very close to that of figure 3.

Each of two additional arbitrarily chosen sets of 28 persons (not overlapping with each other or with the first) was then blockmodeled in exactly the same way, again using CONCOR. The two resulting blockmodels were close to each other and to the blockmodel in figure 3. Although the full sample of 107 had not yet been simultaneously partitioned (see Breiger 1976), we inferred that in the larger study both the blockmodel pattern and the block memberships would correspond with the results reported for these subsamples. Everyone in the network knows the top dogs (block *a*), but although these top dogs collaborate with some researchers in lower strata, they appear to remain ignorant of most lesser mortals. Members of block *b* appear to be very active researchers, aware of one another. Unlike those in the bottom block, members of the third block (*c*) are not just on the sidelines; they frequently see at least some researchers in higher blocks. Clearly, the complete interconnectedness of a face-to-face group or other community is not necessary for the coherence of this social structure. Neither these blocks nor (more importantly) the global pattern of relations over the network would emerge from counts of individual "popularity" or from conventional clique analysis.

A Monastery in Crisis

Data.—Sampson's (1969) detailed account of social relations in an isolated American monastery should become a classic. During a 12-month period, much of it in residence as an "experimenter on vision," Sampson developed an extraordinary variety of observational, interview, and experimental information on the monastery's social structure. Toward the end of his study, a major blowup in the monastery culminated in a mass exodus of members by expulsion and resignation.

Sampson defined four sorts of relation—Affect, Esteem, Influence, and Sanction—on which respondents were to give their first three choices, first on the positive side and then on the negative. Figure 4 shows these choices for his fourth time period, before the blowup but after a new cohort of novices had settled in. For example, novice #3 liked novice #1 best, and therefore a 3 (representing highest choice) is entered in the intersection of the #3 row and the #1 column of the top left matrix (an entry of 2 means second choice and a 1 means third choice). We assign each monk a number from 1 to 18 (roughly in their order of joining the monastery—the same order Sampson used). We give each of the eight positive and

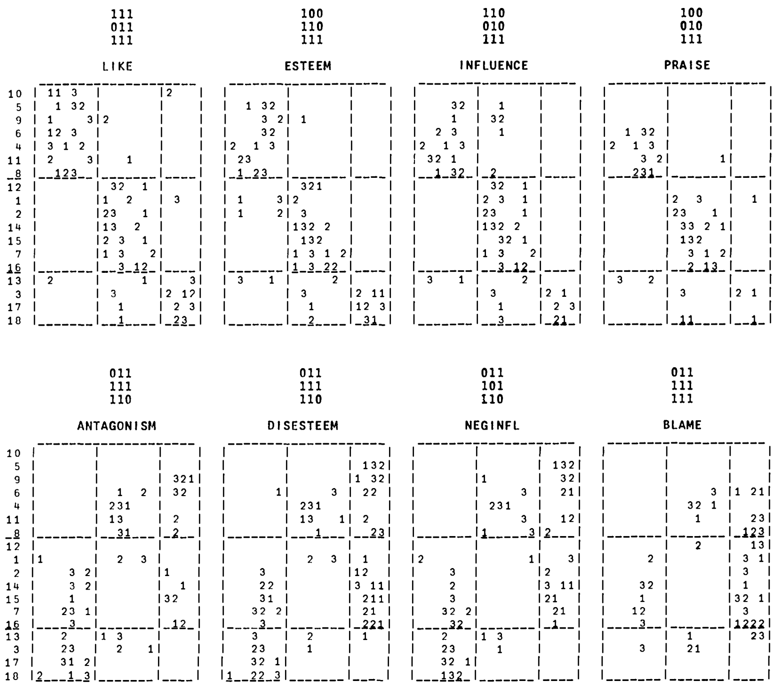

FIG. 4.—Blockmodel for the monastery, time 4: images and data matrices. In the latter, 3 stands for first choice, 2 for second, and 1 for third on each type of tie. Source: Sampson (1969).

negative relations a distinct name. In all of our case studies we use "Like" and "Antagonism" for positive and negative affect, respectively.

Blockmodeling.—CONCOR was applied to all eight matrices of figure 4.[23] This algorithm is not explicitly concerned with locating zeroblocks; data of all three choice rankings are processed by it. After two splits the partition into three blocks was

$$(10\ 5\ 9\ 6\ 4\ 11\ 8)\quad (12\ 1\ 2\ 14\ 15\ 7\ 16)\quad (13\ 3\ 17\ 18). \qquad [2]$$

This partition was then imposed on the eight data matrices (the results are shown in fig. 4). We assumed that in a population of 18 persons, only the top two choices were strong enough to invalidate a zeroblock (establish a bond), so each block which contained no entry greater than 1 was

[23] Slightly different results are reported in Breiger et al. (1975) because they, like Sampson, summed plus and minus entries to combine the eight types of tie into four matrices for CONCOR input. Our choice is perhaps preferable because it makes less strong measurement assumptions; see also n. 24 below.

represented as a zeroblock. The resulting blockmodel is shown in the top panel of figure 4.

To apply BLOCKER, which requires binary input data, values of 2 and 3 were coded as 1, the rest as 0. When the blockmodel shown in figure 4 was tested on the data using BLOCKER, the unique assignment found was *exactly* that derived from CONCOR! Direct inspection of figure 4 confirms this finding (note that third choices, coded as 1, should be ignored).

In the image for esteem, the three blocks are ordered in a complete linear hierarchy, which is certainly plausible in a monastery. The bottom block has a bond to itself and to each of the higher blocks on every kind of positive relation; yet it also has reciprocated bonds with both of the other blocks on all four negative relations. Liking bonds are universal with one exception: the second block does not match its esteem bond for the first with a liking bond. The two top blocks exchange no positive sanction ("praise" in fig. 4); however, the first block, top on esteem, concedes influence to the second.

Refinements and interpretations.—If we return to the CONCOR approach and raise the cutoff density for zeroblocks to half the average density, the resulting blockmodel is

$$\begin{array}{cccc}
\begin{matrix}1&0&0\\0&1&0\\0&1&1\end{matrix} & \begin{matrix}1&0&0\\0&1&0\\0&1&1\end{matrix} & \begin{matrix}1&1&0\\0&1&0\\0&1&1\end{matrix} & \begin{matrix}1&0&0\\0&1&0\\0&0&1\end{matrix} \\
\text{Like} & \text{Esteem} & \text{Influence} & \text{Praise} \\
\\
\begin{matrix}0&1&1\\1&0&1\\1&1&0\end{matrix} & \begin{matrix}0&1&1\\1&0&1\\1&0&0\end{matrix} & \begin{matrix}0&1&1\\1&0&1\\1&0&0\end{matrix} & \begin{matrix}0&1&1\\1&0&1\\0&0&1\end{matrix} \\
\text{Antagonism} & \text{Disesteem} & \text{Neg. Infl.} & \text{Blame}
\end{array}$$

The Like image is identical with Esteem, and Disesteem with Negative Influence. As in the previous blockmodel, the top two blocks exchange negative bonds of all four types, but there is only one kind of negative bond from the bottom block to the second block. The concrete social structure suggested is much the same for either version: a top-esteemed block unambivalently positive toward itself, in conflict with but conceding influence to a second, more ambivalent, block, to which is attached a block of losers.

For this small population, further refinement of the partition by mechanical application of algorithms is not justified, but hints in Sampson's historical account and inspection of the matrices suggested a refinement of the partition into five blocks, with each of the two left blocks in [2] being split as:

(10 5 9) (6 4 11 8) (12 1 2) (14 15 7 16) (13 3 17 18). [3]

This is the ordering of rows and columns used in figure 4. BLOCKER, applied as before, verified that this partition provided the unique assignment for a certain blockmodel; the question is: Does the blockmodel make sense? Consider first the esteem image from BLOCKER in this refined blockmodel (the lines show divisions into the blocks of [2]):

	a	*b*	*c*	*d*	*e*
a	0	1	0	0	0
b	1	1	0	0	0
c	0	1	1	0	0
d	0	0	1	1	0
e	1	0	1	1	1

(Recall that this image fits the data with 2's and 3's coded 1 and all other entries 0.) Name the blocks from top to bottom and from left to right *a, b, c, d, e*. In brief, within the old top block, *a* is now a hanger-on to *b;* within the old second block, *d* defers to the core block *c*. It was *c,* but not *d,* that esteemed the initial top block, and then it only esteemed the core (*b*). Moreover, it was the hanger-on, *a,* who conceded influence to the initial second block, but only to its core, *c*. (The old bottom block of losers remains the same; it [*e*] esteemed only the hangers-on [*a*] of the old top block.)

The other images in the refined blockmodel can be read from the data matrices in figure 4. All four positive images confirm the hangers-on and deference structures within the former blocks. There are three more liking bonds than esteem bonds, but except for this fact and the special asymmetry in esteem and influence among the top blocks (already mentioned), the four positive images are almost identical. The refinement of negative bonds is simpler: in each of the four negative images there are reciprocal bonds between *b* and the bottom three blocks (*c, d, e*) but almost none to *b*'s hangers-on (*a*). And the loser, *e,* though receiving many or all types of negative bonds from the other four blocks and reciprocating to both *a* and *b,* sends no negative bond to *d;* however, *e* sends all four types of negative bond to *d*'s masters (*c*).

Comparison with Sampson's analysis.—Both the blockmodels for three blocks and that for five blocks can be compared with Sampson's own analysis. Sampson (1969, p. 370) posited a definite clique structure for the monastery at time T4, on the basis of sociometric graphs (drawn from the data shown in fig. 4), his own observation, and his interpretation of events and personal attributes. His Young Turks are led by monks 2, 1, and 12 (in descending order of leadership), with 14, 15, 7, and 16 as followers. His Loyal Opposition is led by 4, with 5 a popular member, 6 and 11 as members, and 9 less fully attached. He saw three Outcasts: 3, 17, and 18. The other three monks (10, 8, and 13) wavered between the two cliques, which he described as being in intense conflict.

Both CONCOR and BLOCKER agreed on the split into three blocks (shown in fig. 4). Sampson's Loyal Opposition is wholly contained in the first block; the Young Turks are exactly the men in the second block; the Outcasts are wholly contained in the third block. Sampson's Waverers 8 and 10 are in the Loyal Opposition block, whereas Waverer 13 is in the Outcast block.

Our refined five-block blockmodel splits the Young Turks exactly as did Sampson, with 1, 2, and 12 as leaders; however, the first two blocks split the Loyal Opposition differently, as well as enlarging it. Monk 5 is changed from Sampson's "socio-emotional leader" (p. 360) to membership in the Loyal Opposition's hangers-on block. Sampson earlier observed (p. 322, n. 32): "His [monk 5's] circumspect aloofness from interpersonal conflicts served to preserve his relatively high ranking on most measures throughout the study, but as a consequence, his influence on others was more that of a detached role model than a framer of opinion or action." And Waverer 8 is in the leading block (*b*) of the Loyal Opposition according to the blockmodel.

The pattern of relations given in figure 4's blockmodel—the eight images on three blocks—accords with Sampson's basic contention of a fight between the Loyal Opposition and the Young Turks. The blockmodel reports strong ambivalence within the Young Turks—simultaneous positive and negative bonds of many types—but none within the enlarged Loyal Opposition; all of these reports accord with the detailed statements in Sampson's analysis. The blockmodel makes three further important assertions: the Young Turks are conceded top position in a linear hierarchy of the three blocks on influence, while the enlarged Loyal Opposition is conceded top spot in a hierarchy on esteem. Third, the bottom block has but one internal type of bond which is negative; it also receives Like bonds from above, as well as the negative bonds that its members return in kind: this implies that the bottom block is a meaningful social unit in a sense different from that of Sampson's "pseudo-group."

Bits of evidence in Sampson's detailed textual account support these further assertions; for example, monk 13 nominates, and is the only man to vote for, 3 as chairman of an important meeting (p. 354).[24] Our

[24] Monk 13 is placed in the Loyal Opposition by Breiger et al. (1975) because of the way they apply the Breiger algorithm; see n. 23 above. Yet when they did a multidimensional scaling analysis for comparison, using Kruskal's MDSCAL algorithm,

assertions contradict some of Sampson's summary statements, but this fact per se is not as important as the fact that blockmodeling has permitted us to move *beyond* the picture Sampson drew—beyond the kinds of inferences that are technically feasible from sociometric diagrams. The blockmodel on five blocks necessarily differs from Sampson's conclusions; it analyzes units finer than his factions but ignores the distinctive behavior of individuals that he emphasized. Until the matrices for earlier time periods are taken up below, the main support for the refined blockmodel is the consistency across images of the pattern within each faction.

One week after the period to which these data refer, an explosion started. The Superior and the Novice Master, together with the handful of senior monks (none of them included in the sociometric population of the 18 monks in training), decided in their regular review process to expel monks 2, 3, 17, and 18. The reasons given by the senior staff were, for the latter three, that they were "too immature" and had "personality problems," while monk 2 was considered "too independent, questioning and arrogant" (Sampson 1969, p. 373). Only monks 1, 2, and 3 of the 18 had been to college and were candidates to be full clerical monks; they were older and restless even under the drastically reduced discipline their seniors had instituted a year earlier, before their arrival and that of monks 10 through 18.

Almost at once, monk 1 voluntarily departed. Then, within a week, monks 16, 15, 14, and 7 left, in that order. A few days later, 13 and 8 left, also voluntarily. A month later still, monk 10 left. Of the six remaining from the 18, note that four had been there in the old days before the change of discipline, and five were in the Loyal Opposition. A puzzle in both Sampson's picture and the blockmodel is why monk 12 remained. Otherwise the blocks found in building the refined blockmodel from pure sociometric data fit the initial departures perfectly: monk 1 followed his blockmate immediately, and the next wave of four was precisely the block asserted to be their subsidiary; only after them did monk 13 leave, and he preceded the two from the Loyal Opposition.

Cliques and Strata in the Bank Wiring Room

Data.—Homans's (1950) classic account of the Bank Wiring Room suggested a six-block blockmodel;[25] only after assessing this hunch will we apply the two algorithms in the usual way. The original monographic treatment (in Roethlisberger and Dickson 1939; hereafter abbreviated as

monk 13 was placed substantially closer to other Outcasts, a placement consistent with our present blocking.

[25] This is a slight simplification of an earlier blockmodel on seven blocks, reported in White (1974*a*). Inspector I3, a separate block there, has been combined with the third block (Wiremen W2 and W5).

R-D) is itself a classic. A production section that wired switchboard banks in a Western Electric plant was transferred to a separate room; for a year men shared this room with an observer who, with other researchers, repeatedly interviewed the 14 men, monitored official records, and so forth.

The observers reported *their* judgment of the incidence of five types of tie[26] (shown in the matrices of fig. 5). Two are the familiar Like and

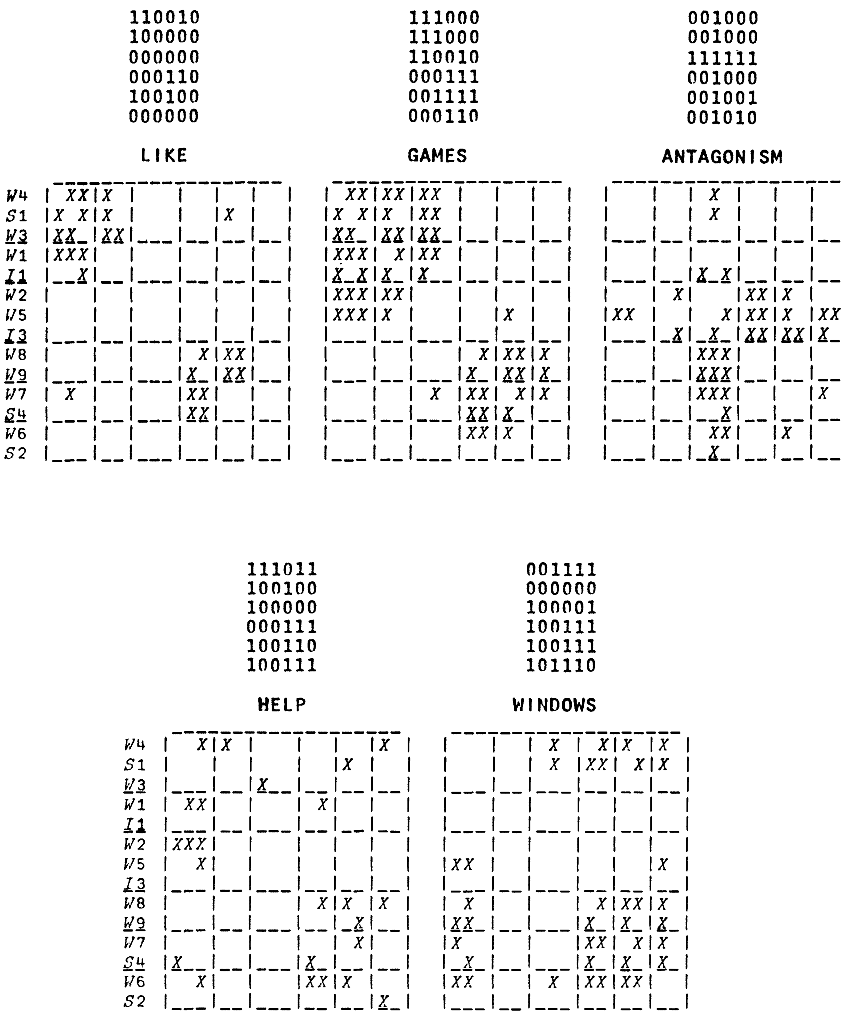

FIG. 5.—Blockmodel for the Bank Wiring Room: images and data matrices

[26] An additional type of tie is not reported here because it could be received only by soldermen.

Antagonism, but three others report context-specific types: "Games" is the designation for a kind of affectionate horseplay (including "pinging" the upper arm); "Help" (with production tasks) is our name for a second type; "Windows" reports chronic quarrels over opening windows. The observers saw these as stable interaction patterns established when the section had settled down. In all types but Help, each tie is reciprocated. A man need not "send" any ties of a given type. When applying BLOCKER, each tie reported as present was coded "1."

In addition to two inspectors (called hereafter I1 and I3, after Homans), there were nine wiremen (numbered from W1 to W9 by position in the room from front to back) and three soldermen (S1, S2, S4). Layout was fixed: W1–W3 were assisted by the solderman at the front of the room, S1; W4–W6 by S2; and W7–W9 by S4; I1 and I3 shared inspection of banks from the middle team.

Interpreting all the kinds of evidence, R-D, followed by Homans, concluded that the social structure was based on two cliques, located mainly in the front and the back of the room, respectively. They listed the members in the front as W1, W3, W4, S1, and I1, and those in the back as W7, W8, W9, and S4; but they also saw nuances within each group and discussed other individuals as fringe members. At other places in their accounts, they emphasized that individuals have differential standing or prestige in the informal social structure. To us, their account strongly suggested a hangers-on pattern within each clique as well as strata cutting across the cliques.

Developing a blockmodel.—Games ties were described as friendly, and for both them and Like ties the hangers-on pattern (the E element within the clique) seems appropriate. But Games ties were much more numerous than Like ties, so it seemed likely there should be more men in a core group on Games than in a core group on Like. Like and Games between them thus should differentiate each clique into three blocks. Antagonism was concentrated on, and within, the set of men whom both R-D and Homans judged to be, at best, marginal to the cliques, and who would appear in the bottom blocks of the two cliques. These three types of tie suggested a blockmodel for six blocks on Like, Games, and Antagonism; it was not clear what pattern to expect on Help or on Windows, except that the latter should be concentrated in the back of the room. This approach suggests not only the images but also the memberships of at least the higher blocks.

The initial blockmodel was adjusted by inspection of the actual choices; it is shown in the top panel of figure 5 as the first three images. The data, also shown in figure 5, fit this blockmodel: BLOCKER indeed yields the unique assignment shown (see Appendix A). Two important points should be made. This partition is consistent with—indeed a refinement of—Homans's cliques. The partition is

(W4 S1 W3) (W1 I1) (W2 W5 I3)
(W8 W9) (W7 S4) (W6 S2). [4]

Furthermore, each of the three images is close to our first guess for it. Nested hangers-on patterns over Like and Games, for each clique, are shown, together with one symmetric bond joining the cliques. All Antagonism ties are within or with the bottom block in each clique; in addition, the front clique's marginal men receive most of the negative bonds from both the front and the back cliques. The bonds in the last two images in figure 5 (Help and Windows) were simply read from the data matrices upon which the given partition was imposed.

Testing the blockmodel.—When CONCOR is applied to all five data matrices, the first split is *exactly* between the first three blocks and the last three. When each of the two sets of blocks is routinely split, the result is

(W4 S1 W3 W1 I1) (W2 W5 I3)
(W8 W9 W7 S4) (W6 S2), [5]

again perfect conformation to boundaries in the full six-block blockmodel! CONCOR first distinguished between the cliques and then, within each set positively bound together, distinguished strata. A blockmodel on these four blocks can be aggregated from the one on six blocks in figure 5 by taking the logical union of the first two rows and the first two columns, and then doing likewise for the fourth and fifth rows and columns.

One can also emphasize the differentiation into strata as the overriding feature, rather than the split between cliques. Suppose we combine the first and fourth blocks of figure 5, the second and fifth, and the third and sixth. When unions of the corresponding rows and columns are computed, the five images become

L			*G*			*A*			*H*			*W*		
1	1	0	1	1	1	0	0	1	1	1	1	1	1	1
1	0	0	1	1	1	0	0	1	1	1	0	1	1	1
0	0	0	1	1	0	1	1	1	1	1	1	1	1	1

When this blockmodel was applied by BLOCKER to the five data matrices, we obtained a single solution: the top block is the union of the first and fourth blocks of figure 5, and so forth.

The analyses of the Bank Wiring Room in R-D and in Homans are the basis for the blockmodel and so can hardly be cited as independent evidence.

Test based on reasons for work stoppage.—In the original report, Roethlisberger and Dickson (1939, pp. 428–32) stated that the bank wiring department allowed the nine wiremen to claim allowances for unusual work stoppages "beyond their control." Wiremen frequently claimed more time allowances than were necessary (contrary to the intent of the wage-incentive scheme) because they were willing to trade some loss of income for some gain in security (expressed as uniformity in output curves). Each time a wireman claimed a time allowance, he was supposed to give the reason for the delay. R-D coded 12 classes of reasons and then cross-tabulated the claims by reason and wireman. Generalized attitudes need have little relation to specific position in a particular population, but context-specific attitudes such as these reasons should be affected by one's position and should, hence, resemble those of others in equivalent positions.

In this cross-tabulation, each wireman has a column and each reason a row. We used CONCOR to split the wiremen on the basis of their respective columns of counts.[27] The result is

$$(\mathrm{W1\ W2\ W3\ W4\ W5})\quad(\mathrm{W6\ W7\ W8\ W9}). \qquad [6]$$

It is at once apparent that the split is precisely that between the blocks of the front clique and those of the back (see [4] or [5]). In particular, the marginal members W2, W5, and W6, whom Homans did not place, are each grouped with the wiremen from the appropriate upper blocks.

In only two of our case studies did the population have specific job assignments, and only the Bank Wiring Room also had fixed locations. Let us return to the six-block partition given in figure 5. We already know that joint membership in a block follows neither from having the same one of the three jobs nor from having different jobs. Sayles (1958, a monograph on industrial work groups) criticized the earlier literature for giving too much independent importance to dynamics in small groups as such; the keys to social structure and process, he argued, were kinds of job and the flow of work imposed among jobs. At first sight, it seems that our analysis provides a counterexample; however, close examination shows that the split between cliques is as important a determinant of the six blocks as is the division among strata, and the cliques clearly emerge from the layout of the room. Similarly, for all types of tie except Antagonism, the pattern of bonds between blocks depends on the clique split as much as on strata.

Newcomb's Second Fraternity

Data.—Newcomb (1961) analyzed two experiments in which 17 previously unacquainted male undergraduates lived together in a fraternity-

[27] See Appendix B for further details.

style house, expenses paid. They were subject to observation and required to supply many self-reports, including a complete rank ordering of the other 16 by "favorableness of feeling" during each of the 16 weeks of the experiment. Newcomb reported only measures of association for the rank orderings (which contributed only indirectly to his account of the social-psychological dynamics). Here we take polar types of tie (Like and Antagonism), abstracted from the rank order for the last week of the second experiment, and suggest a blockmodel for three blocks. The individual-level data were described by Newcomb's associate, Nordlie (1958), who developed an independent interpretation that is more explicit than Newcomb's. Individuals are numbered as in Nordlie's Appendix A, as are ranks (from 1 for most favorable to 16 for least; no ties permitted). (The parallel first experiment will be discussed in Part II.)

Developing a blockmodel.—In a population of this size, the top two ranks were believed to represent strong friendship choices; the bottom two, strong antagonism. There is a scapegoat in this group (man 10), who received one of the bottom three choices of each of the other 16 persons. For application of BLOCKER, the top two choices were coded as Like ties; the bottom three, as Antagonism ties. There seemed to be a top group that disdained the others, so the *V,F* blockmodel (for two blocks) was hypothesized. The result was a split of men into blocks for which Like and Antagonism satisfy the blockmodel; men 13, 9, 17, 1, 8, 6, and 4 were in the top block. This is the only split that yields a solution, and it stipulates two floaters (men 2 and 5) who can be placed separately or together in either block (see also Appendix A).

An obvious refinement is a split of the bottom block into (1) losers and (2) a stratum not internally antagonistic and ambivalently oriented to the top block of seven: the blockmodel is

$$\begin{array}{ccc} 1 & 0 & 0 \\ 1 & 1 & 0 \\ 1 & 1 & 1 \\ & \text{Like} & \end{array} \qquad \begin{array}{ccc} 0 & 0 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 1 \\ & \text{Antagonism} & \end{array}$$

Developing a blockmodel.—BLOCKER, using this model, yielded the following: a second block (men 7, 11, 12, 2) and a bottom block (14, 3, 10, 16, 5, 15); the top block is unchanged, but the two floaters are now more restricted.

CONCOR was then applied to the complete rankings (each rank treated as an integer) to yield three blocks. These were identical with the three blocks BLOCKER yielded from the top two and bottom three choices. To define the blockmodel, we state a *cutoff density* (the highest average density of "choices" in a block that permit it to be coded as a zeroblock for that type of tie).[28] With the top two ranks defined as Like choices and the bottom three as Antagonism, for any cutoff density below one-fifth the average density on that type of tie, the resulting blockmodel is the same as the one presented above. When the cutoff density is raised further, the first bonds to disappear are the bottom block's positive bond to itself and its negative bond to the second block.

Comparison of the blockmodel with Nordlie's interpretation.—Nordlie's (1958, pp. 67–77) study of "sugbrouping" yields an assignment of men to "clusters" for week 15 that is entirely consistent with our blockmodel. For each pair of men, Nordlie computed the rank correlation coefficient of the choices *sent* by each to the 15 others, excluding themselves. This matrix of "intra-pair agreement" was then clustered as described by Nordlie (1958, pp. 70–71) to produce subgroups of nonoverlapping membership and a residue of men assigned to no cluster. Nordlie discovers five subgroups for week 15 of the second experiment: (1, 5, 6, 8, 13), (2, 4, 17), (7, 11, 12), (3, 14), (15, 16). Men 9 and 10 are not assigned. Each of the five subgroups is contained within a single block of our three-block blockmodel, if the two floaters (men 2 and 5) are allowed either of their assignments.

Nordlie does not distinguish Like and Antagonism, and he does not go on to examine and interpret concrete patterns of ties among his clusters. The blockmodel above suggests a combination of balance theory (in some form) with hierarchy as the forces at work.

Management Conflict in a Company

Data.—This section develops a blockmodel on eight types of tie specifically relevant to the business activities of the 16 top managers (in 1958) of Firth-Sterling, a company with about 2,000 employees producing specialty alloy and abrasives products for industrial use (for a full description of the data, see White 1961). The blocks and patterns fit well with independent evidence (White 1960, 1961) of chronic conflicts over research and development of new products (the prime management issue in a company whose product line turned over every few years in the era of the R&D fever). Managers are numbered as in the original report (White 1961, table 1): 1–5 are R&D managers; 6–8, sales managers; 9 and 10, production managers; 11 and 12, executives; and 13–16, top staff managers; in addition, 6, 9, and 12 are vice-presidents, and 11 is the president (a

[28] It would not be satisfactory to use average rank order in a block in place of density of choices. The former measure averages Like and Antagonism choices numerically. Ambivalence would be excluded; in contrast, a blockmodel permits a given image to contain both a bond on Like and a bond on Antagonism.

man of elite social and business standing brought into the ailing company a few years earlier).

Developing a blockmodel.—With such ties, there were no precedents for hypothesizing a blockmodel. CONCOR was applied to the data matrices for all eight detailed types of relation (the seven reported by White [1961, p. 192], with choices on the fifth type—Respect for Knowledge and Respect for Decisions—separated into two matrices). The partition into three blocks found[29] was

(11 9 13) (2 4 6 7 8 1 15) (5 10 12 14 3 16). [7]

Since each choice had been carefully considered by the respondents, the cutoff density chosen for zeroblocks was zero (i.e., a single choice in a block prevented its being coded as a zeroblock). The top panel of figure 6 reports our blockmodel on three images: Similar Business Policy, Personal Friendship, and Uncomfortableness. The blockmodel was obtained by imposing the above partition onto the matrices for these relations. The bottom panel shows the resulting blocked matrices. (Obviously—

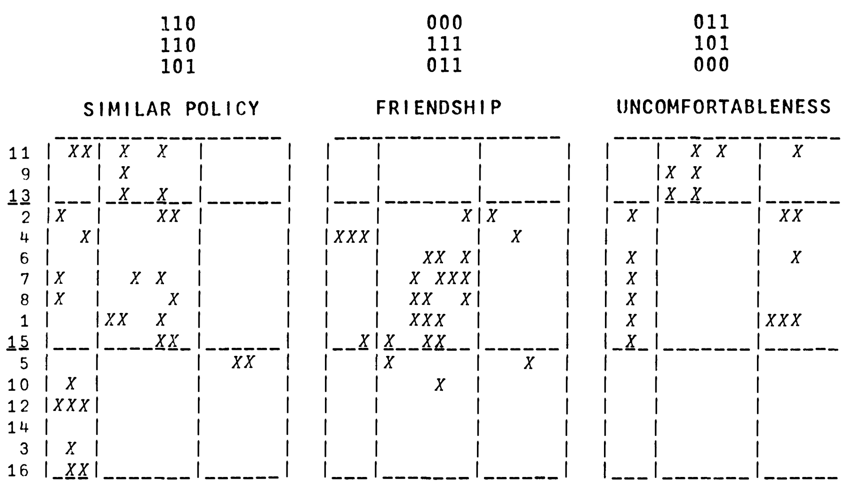

FIG. 6.—Blockmodel for Firth-Sterling management: images and data matrices. Source: White (1961).

[29] Following the usual procedure, all eight 16 $\times$ 16 data matrices were first "stacked" into a 128 $\times$ 16 array. It was then found that two of the 16 columns in this array—those for men 8 and 16—consisted solely of zeroes. As the product-moment correlation is undefined for vectors with no variance, these two columns were removed and CONCOR was applied to the remaining 14 columns. Men 8 and 16 were then placed arbitrarily into blocks. When BLOCKER was applied to test fig. 6's model against the data shown there, men 8 and 16 appeared as the only "floaters." We note that no other columns contain zero variance in any of the data matrices for the five case studies.

an implication of the zero cutoff density—this partitioning matches that produced by BLOCKER for this blockmodel.)

Included in both the Policy and Uncomfortableness matrices of choices are guesses about the question "who . . . might single you out . . . ?" (for each relation). Guesses were requested in order to increase the scope of choices, especially on uncomfortableness. Indeed, 19 of the 27 guesses coincided with direct choices, while few were reciprocated (an indication that these were surrogate choices rather than realistic perceptions of others' choices). Every guess that did not coincide with a choice fell into one of the 10 bonds shown in the images; none fell into any of the eight zeroblocks.

Interpretation.—We now turn to a substantive examination of the blockmodel, considering first the division of men into blocks. The partition is neither into departments nor into formal ranks. When CONCOR was applied twice more (to split the two big blocks), then men 4 and 15 were separated out within the left-hand block; and men 3, 16, and 5 were split from the rest of the right-hand block (see [7]). These five blocks, ordered as in the permutation shown above, correspond exactly to the grouping of managers by their attitudes to R&D (inferred from their questionnaire responses, interviews, and actions in specific conflicts over R&D [White 1960, 1961]). Indeed, the permutation classifies managers by degree of hardheadedness toward R&D. The Executive Vice-President (12), the Treasurer (14), and the Director of Abrasives Production (10) were utterly skeptical. The Personnel Manager (16) and the two R&D managers concerned with alloys (3 and 5)—the more routine side of production, in which only routine development was carried on—were close seconds. All three Sales Managers, plus the overall coordinator of R&D (1) and the man (2) who ran the most speculative research project, were most optimistic and favorable to R&D. The President's Trouble Shooter (15, in charge of expediting some new products) and manager 4 (a respected engineer with several inventions that he was trying to produce by a job shop operation) were favorable but not optimistic about results. In the middle were the President (11), the Vice President for Production (9), and the Accountant (13), in the observer's opinion the most realistic persons of the entire group; all three were acutely aware both of the poor record of Firth-Sterling's R&D and of the crucial importance (for the company's image and borrowing capacity) of having an R&D program.

The blockmodel on the three main blocks with the three specific images makes equal sense. In figure 6 the block of 11, 9, and 13 is put on top, consonant with its obvious preeminence in the eyes of all. It exchanges policy bonds with the Sales block (the middle block in the partition [7]) and receives a policy bond from the hardheaded block; in addition, each block has a policy bond to itself. On Personal Friendship, the top block sends no bonds, and it is not chosen by the hardheaded block (a fact showing the realism of the latter); whereas the Sales block, in the most vulnerable position on R&D, claims bonds to all three blocks. There is no Uncomfortableness bond within any block. The top block and the Sales block are uncomfortable with each other, and each is ill at ease with the hardheaded block. The latter had repeated specific clashes with the Sales block (it seems likely, from the interviews, that the hardheads were simply unwilling to reveal specific negative choices for any reason).

We have not reproduced here the matrix of choices on "the managers with whom you have the most dealings." The image for these objective choices would contain only bonds, no zeroblocks. Indeed, if the densities of choices are computed by block, the results are

(11 9 13)	:	.50	.14	.11
(2 1 6 7 8 4 15)	:	.57	.17	.12
(3 16 5 10 12 14)	:	.33	.10	.10.

The striking feature is the homogeneity of entries within columns. Everyone claims most dealings with the President's block, next most with the Sales block, and least with the hardheaded block; but in this small population of top managers, each block shows some heavy contacts with managers in each other block.

Blockmodels over Time

Blockmodels also make sense out of data describing social structure over time. The possibilities are numerous. Blocks can be stable over time, with the blockmodel changing. On the other hand, a blockmodel may be stable, with the blocks' memberships changing as roles and positions rotate among individuals (of course, we would need independent confirmation of such changes). Or there can be complete stability, at least for the coarse partitions into blocks together with associated blockmodel images. Successive observations of choices existed for two of the cases analyzed above, the monastery and the fraternity. The results are quite similar.

The fraternity data.—The stability of both the blockmodel and the blocks, after the first few weeks of maneuvering, is the main result for the fraternity. We imposed the three-block partition found for the final week on the data for each earlier week. We also computed the density of the top two choices in each block for each week (number of choices divided by number of cells in which choices could occur); we then computed the density for the bottom three choices. Figure 7 shows the results of this procedure for selected weeks: 0, 3, 5, 8, 13, 15. The development seems clear. In the initial week, the blocks show little variation in density; thus, there is little justification for asserting that the three blocks exist as distinct

WEEK	LIKE			ANTAGONISM		
	.21	.18	0	.14	.18	.31
0	.14	.25	.05	.29	.08	.12
	.10	.20	.10	.24	.12	.17
	.25	.07	.04	.02	.21	.33
3	.20	.15	0	.25	0	.20
	.20	.08	.06	.21	.12	.20
	.28	.04	.02	.02	.07	.43
5	.11	.42	0	.11	0	.37
	.21	.08	.03	.14	.04	.37
	.29	.04	.02	0	.10	.43
8	.14	.33	0	.07	0	.42
	.20	.12	.03	.07	0	.50
	.31	.04	.02	.02	.07	.43
13	.10	.42	0	.03	0	.46
	.21	.08	.03	.02	.12	.43
	.33	0	0	0	0	.50
15	.10	.42	0	.07	0	.42
	.20	.12	.03	.05	.04	.50

FIG. 7.—Newcomb's second fraternity: density of choices in each block, for selected weeks. Partition of men into blocks: (13 9 17 1 8 6 4) (7 11 12 2) (14 3 10 16 5 15). Blocks are taken from the blockmodel tested and sustained on data for week 15.

structural entities. By the third week, though, a pattern is clearly discernible; the top two blocks clearly show no internal antagonism, and the third is clearly at the bottom of a three-part hierarchy. Then, by at least the fifth week, not only the final blocks but also the final blockmodel have emerged with remarkable clarity. Thereafter the stability is marked. Now if either BLOCKER or CONCOR is applied to the data for an intermediate week, much the same blocks and blockmodel are found, whereas neither a clear blockmodel nor clear blocks emerged from their application to data for the first two weeks.

This conclusion has little interest if men are simply repeating the same choices week after week; the argument in our section on methods was that men should be expected to change their choices over time, but within the confines of blocks that contain bonds. For example, take choices made by the top block. In week 0, these seven men made 14 Like choices (top two ranks); eight were of different persons from those whom each chose in the final week. Of these eight choices, five created bonds not predicted in the coarse V,F model (that is, the bonds were from the top block to the other block of 10 men); three added to the existing bond. By chance, one would expect an outcome like this: 10/17 in the forbidden block and 7/17 in the block allowed according to the Like image.

In order to complete this example, we repeated the comparison with week 15 for each week in turn. Define a *change* for week i to be a choice in week i that is not matched by a choice in week 15. We then summed changes for weeks 0–4 and compared them with changes summed for the 10 weeks 5–15.[30] Data for the first five weeks show as many changes of individual Like choices (38) as were made in the last 10. In the first five weeks, 60% of the changes fall in the zeroblock—exactly the chance expectation—but in the last 10 only 34% of the (relatively fewer) changes are in the zeroblock of the week 15 model. When parallel counts were made for Antagonism choices (the bottom three ranks), a similar picture emerged: 45% of the early weeks' choices differed from those of week 15, compared with 22% for the late weeks. For the early weeks, exactly the chance expectation (40%) fell in the zeroblock in the F image, while only 14% of the (relatively infrequent) changes in late weeks lay in this forbidden block. There is some indication, then, that individuals' choices continue changing even after a blockmodel has stabilized; in addition, after week 4, the changes—both for positive and for negative ties—conform much better to the final blockmodel.[31]

The monastery data.—Sampson claimed that, during the period to which his data refer, groupings emerged within the monastery and polarization developed among them; blockmodeling does not show such clear-cut changes over time. At period T1, before the new cohort of novices arrived, monks 4, 5, and 6 were the core men, with 9 and 8 more peripheral; 7 was isolated, but immediately became friendly with monk 16 in the new group. By T2, according to Sampson's observation, monks 1 and 2 stood out as the most respected in the whole group of 18. Then incidents multiplied as traditional discipline surfaced (even though in much milder form): for

[30] No data were collected for week 9.

[31] In further work (not reported here) on both fraternity experiments, we distinguished five blocks in the late weeks. The pattern within the top block reported in the text, when split, is stable, but the personnel assigned to each half "circulate" over time. Within the split top block, the elements E and S are the images on Like and Antagonism: a hangers-on pattern reinforced by common rejection of the lower half.

example, some new novices were shocked when shown the waxed whip for the Order's traditional mortifications. About period T3, monk 2, without explicit disapproval from the officials, instigated meetings of the novices to discuss their routine. In the formal vote for chairman of the meeting, he received 11 votes while monk 1 received three (only monk 4 was not present).

Our analysis of change is confounded by the fact that the sociometric data used here are retrospective from T4. Thus the data for periods T2 through T4 show only moderate changes. Even when the refined partition into five blocks is imposed upon the earlier data matrices, the counts in blocks are quite uniform across time periods. The sums of weighted choices, by block, for Like are shown in the top panel of figure 8.

Like:

T2					T3					T4				
2	12	0	3	1	2	10	4	0	2	4	11	2	0	2
11	5	6	2	0	10	12	1	1	0	9	14	0	1	0
3	0	8	5	2	1	3	11	4	0	0	0	11	4	3
0	2	15	9	0	1	0	16	9	0	0	0	16	8	0
2	0	10	2	10	2	0	5	1	16	2	0	5	1	18

Antagonism:

T2					T3					T4				
0	0	0	0	6	0	0	0	0	6	0	0	0	0	6
0	1	2	8	13	0	1	16	0	6	0	0	13	4	9
4	7	0	1	6	3	10	0	0	5	1	5	2	3	1
1	7	0	0	17	3	12	0	0	10	0	15	0	0	9
4	15	4	1	0	0	19	5	0	0	2	17	6	1	0

FIG. 8.—Monastery data: sums for Like (top panel) and Antagonism (bottom panel) choices over three time periods. (Individual choices contribute either +3, +2, or +1 to the sums, depending on tie strength.)

Since the same block memberships are used for each period and the blocks are of nearly uniform size (with either three or four members), it was unnecessary to convert to a density measure. It is clear that the blocks from T4 also stand out as distinctive units at the earlier periods (i.e., the groupings existed from the beginning). Certainly there is a consistent decline in Like between the top two blocks (roughly, Sampson's Loyal Opposition) and the middle two (the Young Turks); however, the buildup of liking within the bottom block (which Sampson dismissed as the Outcasts) is equally striking. So also is the increasing focus of liking ties within the Loyal Opposition (largely from ties withdrawn from the other blocks) upon their leaders.

The parallel sums for Antagonism are shown in the bottom panel of figure 8. Again, the five blocks are discernible at the earlier periods. The only notable pattern changes are the concentration of antagonism from the leaders we identify in the Loyal Opposition upon the Young Turks' leaders (these Loyal Opposition leaders, in turn, are increasingly disliked by followers within the Young Turks).

Much the same changes over time are seen in the other three positive types of tie and in the negative types. Even the refined partition into five blocks yields sharp discrimination in the two earlier periods. Sampson gave careful instructions for the retrospective choices, reminding each respondent of a salient event marking that period. But it is impossible to validate them as faithful representations of perceptions at T2 and T3.

We noted in the section on methods that constraints on data collection, random fluctuation in social relations, and the differential maintenance and concealment of ties over time give rise in a natural way to "speckled" blocks (bonds) that are only partly filled with choices. Our model allows for changes in the novices' ties over time, but our hypothesis was that such changes would generally confine themselves to bonds and would not affect zeroblocks (as defined by the blockmodel for period T4). If choices for T2 and T3 are really just surrogates for T4, they should fall within the bonds specified by the blockmodel of T4; the same outcome should also hold if they are truly for a different period but the same blockmodel is hypothesized. According to the "top-two, bottom-two" cutoffs used in applying BLOCKER, among the 25 blocks in each image, about half are zeroblocks. Of the 131 choices on the four positive types of tie at T3, a third (43 choices) do not coincide with some choice at T4. Of these 43, 11 created bonds within zeroblocks. For negative types of tie, the corresponding figures are: 128 choices, 48 T3 discrepancies from T4, and 7 entries falling at T3 into blocks which are zeroblocks at T4. To put this another way, of the 2,183 *entries* that are zero in the eight data matrices for T4, the majority (59%) are in *zeroblocks;* however, of the cells that are zero at T4 but not at T3, four-fifths (80%) are confined at T3 to blocks that are bonds in the T4 blockmodel. If T2 is compared to T4, the figures for positive ties are: 130 choices, 62 discrepancies; 20 of the latter appear in zeroblocks of the T4 blockmodel. For negative ties the figures are 121, 69, and 17, respectively.

The implications seem simple and agree in general with the Newcomb analysis above: the Sampson blockmodel is largely stable across time with respect to both blocks of men and images, and it emerged quickly after the population was constituted. To bring out the significance of these conclusions, it is worth drawing a contrast with evolution in a more classic sense. There is little support here for a naive borrowing of ideas from biological evolution, where natural selection is classically viewed as producing its results gradually on a time scale of many generations (Mayr 1963; Levins 1968). Instead, the picture conveyed, at least by these data, is one of "saltationist" evolution, where adaptations arise rapidly and with finality (Ford 1955). To take another parallel, this finding is in part consistent with the economists' view of a system of actors who maximize profits or utility effortlessly and instantaneously, though with the crucial difference that no explicit maximizing behavior has yet been identified.

IMPLICATIONS: CONCRETE SOCIAL STRUCTURE

Sociologists have long been tortured by their inability to specify clearly the meaning of two fundamental terms, "role" and "position" (see the excellent brief review by Catton [1964, pp. 936–43]). All agree that no cogent theory of social structure can dispense with the concepts these terms try to capture (one reason Mitchell [1969] is so soft-spoken about networks is that they seem conceptually remote from role and position). Part of the trouble, we submit, is the lack of generally applicable operationalizations: no matter how cogent the prose discussion of role and position (or cognate terms), the sense of insight fades as the writer (or his reader) tries to apply them to various concrete social structures.[32]

We now suggest that the purposely neutral terms employed until now —block and blockmodel—provide operational definitions for the substantive concepts of role and position. We then suggest a way to interpret concrete social structures in these terms. We require three primitive terms:

(1) *claim*—the generic term for each instance of a tie from one member of a population to another. Claims may be made either by the members themselves (as in the biomedical scientists' data) or by an outside observer (as in the Bank Wiring Room data).

(2) *type of tie* (abbreviated *toft*)—a network of all claims of a specified type. The meaning of "type" is initially (and explicitly) left

[32] The study by Gross, Mason, and McEachern (1958) of the school superintendency is one of the very few systematic applications of such concepts to concrete situations. Because they deal with explicit offices in explicit formal organizations, they bypass the derivation of positions from networks of relations (at the cost of other conceptual difficulties). In our terms, they moved directly to the interpretation of types of tie, using data on perceptions of rights and duties among counterpart offices; in addition, they were aided by pooled data from different concrete populations that are, by definition, parallel in organization.

open, the postulate being that a *shared* meaning is accorded each type throughout the population.

(3) *population*—the set of persons or other actors whose claims are reported. Its membership is the choice of the investigator; it need not be restricted to a natural enclave or a set in which each actor knows most of the others.

The data are a set of networks: for each toft, the claims issued by each person regarding all others in the population are reported as a binary matrix. Most commonly the data will be sociometric, and then the claims cannot be considered to be acknowledged by the targets. With respect to claims, the choice of jurisprudential language is not accidental: Blockmodels may have natural applications to the analysis of complex lawsuits, and they seem particularly adapted to handling counterclaims and crossclaims in multiple party litigation (e.g., *Lasa per L'Industria del Marmo Societa per Azioni v. Southern Builders, Inc.*, 45 F.R.D. 435 [W.D. Tenn. 1967], *reversed,* 414 F.2d 143 [6th Cir. 1969]).

Blockmodels as Roles among Positions

A blockmodel is a hypothesis, a representation proposed for the social structure that exists in the population's claims. Three terms can be used to describe a blockmodel:

(4) *position*—each of the sets into which the population is partitioned is a position. The technical term "block" is a synonym for this substantive concept.[33]

(5) *bond*—a nonzero entry from one position to another in the image for a toft.

(6) *image*—the report, in the form of a binary matrix, of the bonds on a given toft among all positions.

By its definition, a blockmodel is a *simultaneous graph homomorphism* in mathematical terms (Heil and White 1974). Mapping the population into positions requires mapping each data graph matrix simultaneously onto the corresponding image. By the definition of a homomorphic mapping, there is no bond from one position to another if and only if there is no claim from any member of the first position to any member of the other position. Thus, in the terms used earlier, each image is fully specified from its zeroblocks when the persons in a data matrix are partitioned into positions.

[33] We agree with Catton (1964, p. 942) that there has been an evolution toward clarity about these concepts. Our definitions can be seen as operationalizing those proposed by Larsen and Catton (1962) after their thoughtful analysis of the literature: "position . . . location of a person or a category of persons in a set of social relationships . . ."; "role . . . a pattern of collectively held expectations which define appropriate behavior for persons in a given social position."

The theoretical content of a blockmodel hypothesis, then, is a transformation of individual claims into a statement of social bonds (i.e., ties within and among positions). Reflexivity (the existence of "self-choices" or unity entries on the diagonal of a matrix) now emerges as a major substantive question about each position, rather than (as in sociometry) a mere technicality of presentation for a claims matrix. We argue (and further elaborate in Part II) that a bond has truly social content—is "received" by the target position as well as "sent" by the row position—whether or not there is a reciprocal bond on that toft from the target to the sender position.

Not only have we left open the actual semantic content of the claims on a toft; we have also not specified the general nature of tofts. One or more of the tofts might refer to rights, another to duties, another to contracts, another to evaluations, and so on through the long list of general natures proposed in various analyses of roles (once again, legal applications are obvious). It seems to us worthwhile to define position and role within as abstract and flexible a cultural framework as possible, so that the cultural content of the social structure becomes a question for empirical research rather than a matter of definition. Sustained analysis of social structure, we reiterate, requires keeping the two sides of the analysis as distinct as possible.

Our next definition is abstract in cultural terms but specific to the population and its positions in the blockmodel:

> (7) *role set*—a pair of vectors for all blockmodel images: one the ordered set of rows for that position, the other the columns for that position.[34]

Thus a role set is simply a statement of bonds sent and bonds received, by a position, on all the tofts. Observe that a position's bond (or lack of one) to itself on each toft is part of its role set. There is no need to report the role set for each position as a pair of vectors because the set of images for the blockmodel is a complete inventory of the role sets for all positions.

Arrays

Without further data, a blockmodel cannot be validated. One simple form of validation is to establish stability, or coherent change, in the blockmodel over time, as was done in the previous section. Another is to test the existence of bonds on a given toft by means of direct observations on inter-

[34] This definition is compatible with Merton's usage (1959, p. 369). A person's "status set," in Merton's terms, includes his positions in distinct blockmodels for the different populations and contexts in which he participates. In a given blockmodel an individual is indistinguishable from other members of his position; his individuality rests in his unique "status set."

actions or flows of a suitable kind. A third involves assessing the homogeneity of persons in a position with regard to suitable characteristics.

The key words are "coherent" and "suitable": validation requires substantive judgment as well as further data. Even if, with minimal substantive argument, one became convinced that a blockmodel was a valid description of a given concrete social structure, there would still be a feeling of incompleteness. The remaining question is whether the roles among positions cohere in some intelligible way in an overall structure. In Part II we propose methods for answering this question from the perspective of persons in various positions: in brief, we propose criteria for role structures (cf. Nadel 1957).

One may also search for an overall interpretation of the blockmodel from an observer's perspective. Does every toft have substantive interpretation such that the positions can be seen as an *array*[35] intelligible on each toft? Perhaps the simplest example would be the blockmodel *V,W;* that is, the images

$$\begin{matrix} 1 & 0 \\ 1 & 1 \end{matrix} \quad \text{and} \quad \begin{matrix} 1 & 1 \\ 0 & 1 \end{matrix}$$

Where the first toft has connotations of deference, and the second of domination, one interprets the first position as the superior of the second. Or, one could begin with no knowledge of the imputed quality of the tofts but with attribute data for the individual members: for example, the fact that members of the second position shared higher standing in various other contexts and populations. Then one would infer that the second toft had the quality of deference and the first connoted domination.

As we have seen in the case studies, one must usually work with a wide variety of clues as to possible standings of positions and qualities of tofts. As more case studies are analyzed, we can hope that regularities will emerge, clarifying what sort of array is to be found in what context. "Context" must include what tofts one can and does elicit as data.

An array can take many forms, as the case studies show. The linear hierarchy or partial order is only one class of possibilities, though an important one. The array may indicate hierarchy though all bonds are reciprocated: see, for example, the Bank Wiring Room blockmodel on like and antagonism, which is a refinement of an *E,F* blockmodel, not a *V,W* one. And the hierarchical array suggested for Newcomb's fraternity is a refinement of a blockmodel with both symmetric and asymmetric bonds, namely, *V,F*.

[35] We are tempted to include "status" in this term, since many writers give it connotations we intend for "array" (see Zelditch 1968); but the confusion would be great because "status" is commonly restricted to the context of vertical rankings.

Classic balance theory suggests the P,N array as the concrete social structure seen by an observer. Here there is no question of hierarchy; instead, we have the familiar idea of rigid polarization into two opposing parties.

If one finds the blockmodel C,D on a pair of tofts, it suggests that there is no array (no overall social structure on that population); the population falls into two unrelated cliques, each of which responds only on its "own" toft. On the other hand, the blockmodel X,Y suggests a highly integrated structure; for example, let X mean "seeks as husbands" and Y mean "seeks as wife," and partition the population by sex.

There are 57 distinct pairs of images on two positions; but we do not speculate about the significance of each one. The case studies illustrate how the investigator is usually led toward discriminating more than two positions in his blockmodel hypothesis. Taxonomies of multiposition blockmodels,[36] and taxonomies of tofts, must be evolved as the empirical base is widened; in addition, careful attention must be given to the many relevant conceptual analyses in the literature.[37] Some developments along these lines will be a byproduct of Part II.

CONCLUSION

After placing our work in the context of other network analyses of social structure, we defined operational concepts and methods and then presented examples. The concept of a block—a set of persons structurally equivalent with respect to other such sets across several types of relation—has led to the development of blockmodels for varied relations in five quite different populations. The examples illustrate the reliability and robustness of both the algorithms and their results. The blockmodel for each example was interpretable as an abstract pattern among a few aggregate units that characterized the more detailed interaction among a larger population of individuals. Independent evidence available for four of the populations supports those blockmodels. Furthermore, in each case, the blockmodel identified regularities in relational structure that had not been proposed previously. In the two instances for which data were available, we discovered that changes over time were consistent with the blockmodels. We then interpreted familiar concepts in role theory within our conceptual framework. In Part II we propose ways to test for and describe role

[36] François Lorrain and Joseph E. Schwartz have prepared taxonomies, from the observer's viewpoint, of blockmodels on two positions for pairs of tofts, and on three positions for one toft.

[37] Breiger (1974*a*) showed how typologies of community power structures may be translated into blockmodel hypotheses and thus actually become open to disconfirmation.

structures, a more complex level of overall integration that need not accompany regularities of the concrete sort described here.

The approaches we have described are applicable to open network populations (e.g., a contact network composed of biomedical researchers) as well as to the small, closed groups that are the traditional preserve of sociometric investigators. Blockmodel applications to a third class of populations—those comprising groups as varied as informal associations and corporate boards of directors—are reported elsewhere (Breiger et al. 1975).[38] This broad applicability results from the ability of blockmodels to address the problematic issue of locating the boundaries of social interaction. In our view, large, loosely bounded, "open" populations are particularly interesting subjects for blockmodeling. We suggested that our sample of 28 scientists (from Griffith's 107 respondents) reflected the structural pattern evident in the larger population. This claim deserves serious scrutiny: if it is upheld in future work, network analysis can be generalized to the study of populations far larger than those studied by earlier network techniques.

Even if evolutionary or discontinuous changes of structure can be identified and congruence with personal and cultural perceptions established, models of structure are not sufficient unto themselves. Eventually one must be able to show how concrete social processes and individual manipulations shape and are shaped by structure. A natural next step, then, is to identify how flows of information and other transactions relate to images and their change. One fundamental problem here is that many social settings may admit not just a single equilibrium outcome, but multiple alternative equilibria, with which particular equilibrium is reached depending in part on accidents of early interaction (compare the earlier comments on the Newcomb fraternity data; compare also Simon's [1957] model of Homans's theory of small groups). In turn, the interesting questions may bear on what external forces may cause a social structure to pass from one equilibrium configuration to another. A number of quite distinct traditions of model building seem to be converging on this same set of problems, including Schelling's work on "tipping" phenomena (1971) as well as models of the genetic evolution of social behavior (Boorman and Levitt 1973; Boorman 1974).

There is an important limitation in the viewpoint urged thus far. As we stated in the very first paragraph, connectivity properties in networks receive only tangential attention. The contrast between weak and strong ties should be a major factor in connectivity analyses for large populations

[38] L. Groeneveld (1974) also reports such an analysis. He found blockmodels, for three successive time periods, among 34 program units (containing both staff and advisors) of the National Science Foundation. The five tofts used were objective measures of mobility, authority, and interlock among these supra-individual "nodes."

(Rapoport and Horvath 1961; Granovetter 1973; Boorman 1975). Blockmodels as developed thus far deal chiefly with strong ties, whether in open-network populations or in small enclaves. It may be harder to find nontrivial blockmodels for weak ties (e.g., sociometric choices in casual or temporary groups such as those used in social psychological experiments).[39]

Connectivity has also been a major concern in sociometric studies of closed populations. Overlaps among cliques often have been used (e.g., Coleman 1961; Young and Larson 1965) to indicate structure (although there is no agreed-upon or powerful way to model overlaps). Blockmodels impose a partition of a population into disjoint blocks or positions (except for floaters—see Appendix A). Clique overlap is captured only by the device of cross-cutting partitions (as in the Bank Wiring Room). We focus instead on modeling overlaps between independent networks and on aggregating multiple networks while retaining their network character (the incidence of "holes" as zeroblocks). The practical tradeoff is between developing statistical measures of clique overlap (e.g., Alba 1973) on the one hand, and on the other hand interpreting aggregate patterns across multiple networks. New techniques may provide new vistas. Of particular promise is a new nonhierarchical clustering model now in the process of development by Arabie and Shepard (Arabie and Shepard 1973; Shepard 1974). The idea underlying this model is one of allowing arbitrarily given proximity data to define their own lattice of overlapping clusters in a natural and unconstrained way.

Finally, we need to enlarge the base of case studies. We particularly need data from which we can learn how new recruits to a population merge with, or change, the structure reflected in a blockmodel. In the terminology introduced earlier, when will a new recruit become a "crystallizer," and when a "floater"? When will his initial ties of various types relegate him to a block that is marginal to the structure? Is the E pattern, on specified tofts, the normal context for indoctrination or socialization into an open network population? Is the V,F array (on positive- and negative-affect ties, respectively) characteristic of clustering and deference within stable small, closed groups? Only with a broader empirical base can general regularities be sought.

[39] Observation of troops and packs of primates and other vertebrates is beginning to result in systematic reports of network ties among individual animals (e.g., Struhsaker 1967; Schaller 1972; see also the analysis of Struhsaker's data in Arabie and Boorman 1973). If we were to find blockmodels fitting such data, they would suggest to us that these ties are of strength (durability, intensity) comparable to strong ties among humans and that individuality is as pronounced among animals as among people (see Wilson 1971, p. 459). Since individuality seems much more muted or even nonexistent among insects and other invertebrates, we presume that the network models discussed in this paper are less appropriate for analyzing such populations.

APPENDIX A

Floaters and Crystallizers

In each case study reported in this paper, BLOCKER yields a unique assignment of men to blocks, subject to two limitations. First, an assignment is termed unique even though one or more men can each be in two or more blocks, for the given unique assignment of the rest of the population; however, these "floaters" must be specified. The extreme example is a man with no ties of any type, who can therefore be in any block simply because he is irrelevant; it would be misleading to create a different overall assignment for each of his possible locations. Second, the minimum number of men any block can contain must be specified; otherwise, for example, a vacuous solution with no men in some block would have to be counted. The acronym for this parameter, MIN, is used hereafter to designate the minimum block size thought appropriate for a given population and blockmodel. For convenience, the two specifications are reported together here for each case study:

Study Author	# Blocks	MIN	Floaters: Man i between or among Blocks J
Griffith, Maier, and Miller	4	5	23 between 1 and 3 19 and 24 among 2, 3, or 4 Any man in 4 may also be put in 3
Sampson (1)	3	3	None
(2)	5	3	None
Roethlisberger et al. (1)	6	2	8 among blocks 1, 4, and 6 13 between 1 and 2
(2)	3	4	1, 9, 12, 13 between 1 and 2 8 between 1 and 3
Newcomb	3	4	2 between 1 and 2 5 between 1 and 3
White	3	3	8 and 16 among all three blocks

For a detailed analysis of assignments and floaters, see Heil and White (1974).

APPENDIX B

Attributes and Blocks in the Bank Wiring Group

In the dual manner elaborated by Breiger (1974*b*), reasons can also be regarded as "individuals," the cross-tabulation transposed, and CONCOR applied again. (First, though, in order to equalize the influence of different wiremen on the result, the column of counts for a wireman was converted to percentages.) The partition of reasons into three sets was (1 4 5 10) (7 8 9 11) (2 3 6 12), with reasons numbered according to the order in which they are listed in the source (table XXIX there). The sum of counts in the original matrix between each of a set of reasons and each of the men on one side of the split above is

16	23
3	106
33	43

where the top row is the left set of reasons, etc. The wiremen in the back clique usually cited reasons from the second set; the wiremen from the front, almost never. These reasons, 7, 8, 9, 11, associated with the wiremen W6, W7, W8, W9, include "Waiting for Solderman" and "Waiting for Inspector," but not "Waiting for Trucker." Roethlisberger and Dickson (1939) noted that the "waiting" class of reasons is highly subjective and "includes reasons which placed the blame for delays upon people instead of upon things" (p. 431). This maximal taking advantage of discretion, coupled with resentment at equals and superiors (soldermen and inspectors, not truckers), fits in with the tendency to fight over windows within the back clique (see fig. 5) and conforms with R-D's finding that the back clique "resented any show of superiority more than the others did because they were in the most subordinate position" (p. 523). Reason 9 is somewhat a technicality, as wireman W9 was assigned to making repairs (p. 432). Reason 11 is not discussed in the source (see p. 432).

If the back clique's reasons tended to fall into an imputed "resentment" category, the front clique's reasons indicated "playing the game" or perhaps a "craftsman's ethic." In roughly one-fifth of all instances of time allowances for the front clique, its members gave no reason at all, while the comparable figure for the back clique was 8%. Mostly, the reasons of the front clique are objective, as R-D define that term (e.g., cable reversals were detected by inspectors' tests). However, they label "defective wire" and "defective solder" as *subjective* reasons. It may be argued that these reasons are different from those in the "waiting" class (reasons 6, 7, 8) in that they represent a "professional" judgment.

REFERENCES

[NOTE.—The unpublished Ph.D. dissertations cited may be obtained in microfilm copies from University Microfilms, Ann Arbor, Michigan.]

Alba, R. D. 1973. "A Graph-theoretic Definition of a Sociometric Clique." *Journal of Mathematical Sociology* 3 (1): 113–26.

Arabie, P., and S. A. Boorman. 1973. "Multidimensional Scaling of Measures of Distance between Partitions." *Journal of Mathematical Psychology* 10 (May): 148–203.

Arabie, P., and R. N. Shepard. 1973. "Representation of Similarities as Additive Combinations of Discrete, Overlapping Properties." Paper read at Mathematical Psychology Meetings, Montreal, August 1973.

Barnes, J. A. 1972. "Social Networks." Addison-Wesley Module Publications 26. Reading, Mass.: Addison-Wesley.

Bjerstedt, A. 1956. *Interpretations of Sociometric Choice Status*. Lund: Gleerup.

Boissevain, J. 1973. Preface to *Network Analysis: Studies in Human Interaction,* edited by J. Boissevain and J. C. Mitchell. The Hague: Mouton.

Bonacich, P. 1972. "Techniques for Analyzing Overlapping Memberships." Pp. 176–85 in *Sociological Methodology 1972,* edited by Herbert L. Costner. San Francisco: Jossey-Bass.

Boorman, S. A. 1974. "Island Models for Takeover by a Social Trait Facing a Frequency-dependent Selection Barrier in a Mendelian Population." *Proceedings of the National Academy of Sciences, USA* 71 (11): 2103–7.

———. 1975. "A Combinatorial Optimization Model for Transmission of Job Information through Contact Networks." *Bell Journal of Economics* 6 (Spring): 216–49.

Boorman, S. A., and P. R. Levitt. 1973. "A Frequency-dependent Natural Selection Model for the Evolution of Social Cooperation Networks." *Proceedings of the National Academy of Sciences, USA* 70 (1): 187–89.

Boorman, S. A., and H. C. White. 1976. "Social Structure from Multiple Networks. II. Role Structures." *American Journal of Sociology,* in press.

Breiger, R. L. 1974*a*. "Blockmodel Analysis of Elite Structures." Paper presented at the M.S.S.B. Conference on Elites, Harvard University, October 1974.

———. 1974*b*. "The Duality of Persons and Groups." *Social Forces* 53 (December): 181–90.

———. 1976. "Career Attributes and Network Structure: A Blockmodel Study of a Biomedical Research Specialty." *American Sociological Review,* vol. 41 (February), in press.

Breiger, R. L., S. A. Boorman, and P. Arabie. 1975. "An Algorithm for Clustering Relational Data with Applications to Social Network Analysis and Comparison with Multidimensional Scaling." *Journal of Mathematical Psychology* 12 (August): 328–83.

Catton, W. R., Jr. 1964. "The Development of Sociological Thought." Pp. 912–50 in *Handbook of Modern Sociology,* edited by Robert E. L. Faris. Chicago: Rand McNally.

Cohen, M. D., and J. G. March. 1974. *Leadership and Ambiguity: The American College President*. New York: McGraw-Hill.

Coleman, J. S. 1958. "Relational Analysis: The Study of Social Organizations with Survey Methods." *Human Organization* 17 (Winter): 28–36.

———. 1961. *The Adolescent Society*. New York: Free Press.

———. 1964. *Introduction to Mathematical Sociology*. New York: Free Press.

Davis, J. A. 1970. "Clustering and Hierarchy in Interpersonal Relations: Testing Two Graph Theoretical Models on 742 Sociograms." *American Sociological Review* 35 (October): 843–52.

Ekeh, P. 1974. *Social Exchange Theory*. Cambridge, Mass.: Harvard University Press.

Flament, C. 1963. *Applications of Graph Theory to Group Structure*. Englewood Cliffs, N.J.: Prentice-Hall.

Ford, E. B. 1955. "Rapid Evolution and the Conditions Which Make It Possible." *Cold Spring Harbor Symposia on Quantitative Biology* 20: 230–38.

Ford, L. R., Jr., and D. R. Fulkerson. 1962. *Flows in Networks*. Princeton, N.J.: Princeton University Press.

Fortes, M. 1945. *The Dynamics of Clanship among the Tallensi*. Oxford: Oxford University Press.

Friedell, M. F. 1967. "Organizations as Semilattices." *American Sociological Review* 32 (February): 46–54.

Glanzer, M., and R. Glaser. 1959. "Techniques for the Study of Group Structure and

Behavior: I. Analysis of Structure." *Psychological Bulletin* 56 (September): 317–32.
———. 1961. "Techniques for the Study of Group Structure and Behavior: II. Empirical Studies of the Effects of Structure in Small Groups." *Psychological Bulletin* 58 (January): 1–27.

Granovetter, M. S. 1973. "The Strength of Weak Ties." *American Journal of Sociology* 68 (May): 1360–80.

———. 1974. *Getting a Job: A Study of Contacts and Careers.* Cambridge, Mass.: Harvard University Press.

Green, H. A. J. 1964. *Aggregation in Economic Analysis.* Princeton, N.J.: Princeton University Press.

Griffith, B. C., V. L. Maier, and A. J. Miller. 1973. "Describing Communication Networks through the Use of Matrix-based Measures." Mimeographed. Philadelphia: Drexel University, Graduate School of Library Science.

Groeneveld, L. P. 1974. "Bureaucracy and the Organization of Science: A Structural Analysis of the National Science Foundation." Ph.D. dissertation, Department of Sociology, University of Indiana.

Gross, N., W. S. Mason, and A. W. McEachern. 1958. *Explorations in Role Analysis.* New York: Wiley.

Harary, F., R. Norman, and D. Cartwright. 1965. *Structural Models: An Introduction to the Theory of Directed Graphs.* New York: Wiley.

Heil, G. H., and H. C. White. 1974. "An Algorithm for Constructing Homomorphisms of Multiple Graphs." Unpublished paper, Department of Sociology, Harvard University.

Hilton, P. J., and S. Wylie. 1960. *Homology Theory: An Introduction to Algebraic Topology.* New York: Cambridge University Press.

Holland, P. W., and S. Leinhardt. 1973. "The Structural Implications of Measurement Error in Sociometry." *Journal of Mathematical Sociology* 3 (January): 1–27.

———. 1976. "Local Structure in Social Networks." In *Sociological Methodology 1976,* edited by David R. Heise. San Francisco: Jossey-Bass, in press.

Homans, G. C. 1950. *The Human Group.* New York: Harcourt, Brace & World.

Hunter, J. E., and R. L. Shotland. 1974. "Treating Data Collected by the 'Small World' Method as a Markov Process." *Social Forces* 52 (March): 321–32.

Jencks, C., et al. 1972. *Inequality: A Reassessment of the Effect of Family and Schooling in America.* New York: Harper & Row.

Kapferer, B. 1972. *Strategy and Transaction in an African Factory.* Manchester: Manchester University Press.

Kruskal, J. B. 1964*a*. "Multidimensional Scaling by Optimizing Goodness of Fit to a Nonmetric Hypothesis." *Psychometrika* 29 (March): 1–28.

———. 1964*b*. "Nonmetric Multidimensional Scaling: A Numerical Method." *Psychometrika* 29 (June): 115–59.

Larsen, O. N., and W. R. Catton, Jr. 1962. *Concept and Sociology.* New York: Harper & Row.

Laumann, E. O., and F. U. Pappi. 1973. "New Directions in the Study of Community Elites." *American Sociological Review* 38 (April): 212–30.

Lee, N. Howell. 1969. *The Search for an Abortionist.* Chicago: University of Chicago Press.

Leijonhufvud, A. 1968. *On Keynesian Economics and the Economics of Keynes: A Study in Monetary Theory.* London: Oxford University Press.

Levine, J. H. 1972. "The Sphere of Influence." *American Sociological Review* 37 (February): 14–27.

Levins, R. 1968. *Evolution in Changing Environments.* Princeton, N.J.: Princeton University Press.

Lorrain, F. P., and H. C. White. 1971. "Structural Equivalence of Individuals in Social Networks." *Journal of Mathematical Sociology* 1 (January): 49–80.

McFarland, D. D., and D. J. Brown. 1973. "Social Distance as a Metric: A Systematic Introduction to Smallest Space Analysis." Pp. 213–53 in *Bonds of Pluralism: The*

Form and Substance of Urban Social Networks, edited by Edward O. Laumann. New York: Wiley.

McQuitty, L. L., and J. A. Clark. 1968. "Clusters from Iterative Intercolumnar Correlational Analysis." *Educational and Psychological Measurement* 28 (Summer): 211–38.

MacRae, D. 1960. "Direct Factor Analysis of Sociometric Data." *Sociometry* 23 (December): 360–71.

Marschak, J., and R. Radner. 1972. *Economic Theory of Teams.* New Haven, Conn.: Yale University Press.

Mayer, A. C. 1960. *Caste and Kinship in Central India: A Village and Its Region.* Berkeley: University of California Press.

Mayr, E. 1963. *Animal Species and Evolution.* Cambridge, Mass.: Harvard University Press.

Menzel, H. 1962. "Planned and Unplanned Scientific Communication." Pp. 417–41 in *The Sociology of Science,* edited by Bernard Barber and Walter Hirsch. New York: Free Press.

Merton, R. K. 1959. *Social Theory and Social Structure.* 2d ed. Glencoe, Ill.: Free Press.

Milgram, S. 1967. "The Small World Problem." *Psychology Today* 1 (May): 61–67.

Mitchell, J. C., ed. 1969. *Social Networks and Urban Situations.* Manchester: Manchester University Press, for Institute of Social Research, Zambia.

Mullins, N. C. 1972. "The Structure of an Elite: The Public Advisory Structure of the Public Health Service." *Science Studies* 2 (January): 3–29.

Nadel, S. F. 1957. *The Theory of Social Structure.* London: Cohen & West.

Newcomb, T. M. 1961. *The Acquaintance Process.* New York: Holt, Rinehart & Winston.

Nordlie, P. G. 1958. "A Longitudinal Study of Interpersonal Attraction in a Natural Group Setting." Ph.D. dissertation, University of Michigan.

Pool, I. de S., and M. Kochen. 1958. Unpublished manuscript on contact networks. Cambridge: Massachusetts Institute of Technology.

Rapoport, A. 1963. "Mathematical Models of Social Interaction." Pp. 493–579 in *Handbook of Mathematical Psychology, Vol. II,* edited by R. D. Luce, R. R. Bush, and E. Galanter. New York: Wiley.

Rapoport, A., and J. W. Horvath. 1961. "A Study of a Large Sociogram." *Behavioral Science* 6 (October): 280–85.

Roethlisberger, F. J., and W. J. Dickson. 1939. *Management and the Worker.* Cambridge, Mass.: Harvard University Press.

Sampson, S. F. 1969. "Crisis in a Cloister." Ph.D. dissertation, Cornell University.

Savage, I. R., and K. A. Deutsch. 1960. "A Statistical Model of the Gross Analysis of Transaction Flows." *Econometrica* 28 (July): 551–72.

Sayles, L. R. 1958. *Behavior of Industrial Work Groups.* New York: Wiley.

Schaller, G. B. 1972. *The Serengeti Lion.* Chicago: University of Chicago Press.

Schelling, T. C. 1960. *The Strategy of Conflict.* Cambridge, Mass.: Harvard University Press.

———. 1971. "Dynamic Models of Segregation." *Journal of Mathematical Sociology* 1 (July): 143–86.

Schwartz, J. E. 1974. "An Examination of Iterative Blocking Algorithms for Sociometry." Unpublished paper, Department of Sociology, Harvard University.

Shepard, R. N. 1962. "The Analysis of Proximities: Multidimensional Scaling with an Unknown Distance Function." *Psychometrika* 27 (1): 125–40; 27 (2): 219–46.

———. 1974. "Representation of Structure in Similarity Data: Problems and Prospects." *Psychometrika* 39 (December): 373–421.

Simmel, G. 1950. *The Sociology of Georg Simmel.* Translated and edited by Kurt H. Wolff. New York: Free Press.

———. 1955. *Conflict and the Web of Group-Affiliations.* Translated by Kurt H. Wolff and Reinhardt Bendix. New York: Free Press.

Simon, H. A. 1957. *Models of Man.* New York: Wiley.

Struhsaker, T. T. 1967. "Social Structure among Vervet Monkeys (*Cercopithecus aethiops*)." *Behaviour* 29 (1): 83–121.

Suppes, P. 1960. *Axiomatic Set Theory*. New York: Van Nostrand.

Szász, G. 1963. *Introduction to Lattice Theory*. New York: Academic Press.

White, H. C. 1960. "Management Conflict over Research and Development: A Case Study." Ph.D. dissertation, Department of Sociology, Princeton University.

———. 1961. "Management Conflict and Sociometric Structure." *American Journal of Sociology* 67 (September): 185–99.

———. 1963. *An Anatomy of Kinship*. Englewood Cliffs, N.J.: Prentice-Hall.

———. 1970*a*. *Chains of Opportunity*. Cambridge, Mass.: Harvard University Press.

———. 1970*b*. "Search Parameters for the Small World Problem." *Social Forces* 49 (December): 259–64.

———. 1973. "Everyday Life in Stochastic Networks." *Sociological Inquiry* 43 (Spring): 43–49.

———. 1974*a*. "Models for Interrelated Roles from Multiple Networks in Small Populations." Pp. 52–102 in *Proceedings of the Conference on the Application of Undergraduate Mathematics in the Engineering, Life, Managerial and Social Sciences*, edited by P. J. Knopp and G. H. Meyer. Atlanta: Georgia Institute of Technology.

———. 1974*b*. "Null Probabilities for Blockmodels of Social Networks." Unpublished paper, Department of Sociology, Harvard University.

Wiese, L. von. 1941. *Sociology*. Edited and annotated by F. H. Mueller. New York: Oskar Priest.

Williamson, O. E. 1970. *Corporate Control and Business Behavior*. Englewood Cliffs, N.J.: Prentice-Hall.

Wilson, E. O. 1971. *The Insect Societies*. Cambridge, Mass.: Harvard University Press.

Young, R. C., and O. F. Larson. 1965. "A New Approach to Community Structure." *American Sociological Review* 30 (December): 926–34.

Zelditch, M., Jr. 1968. "Status, Social." *International Encyclopedia of the Social Sciences* 13:250–56.

Znaniecki, F. 1940. *The Social Role of the Man of Knowledge*. New York: Columbia University Press.