INTRODUCTION

This volume grew out of a conference on methods of research in social networks. The conference was sponsored by the University of California, Irvine, Research Program in Social Network Analysis. It was held in Laguna Beach, California, in the spring of 1980.

Many of the scholars who were active in social networks research attended the Laguna Beach conference. They are listed on pages *vi* and *vii*.

Participants were broadly representative of a range of perspectives in networks research. No attempt was made to load the roster with proponents of one or any small set of viewpoints. Obviously, there is a bias towards participation by those working or—at that time—visiting on the West Coast. This bias was based on economic considerations; the budget was limited. But in any case, care was taken to assure a sampling of divergent views on current problems in network study.

Participants were asked to prepare drafts of papers on topics of general methodological interest to those working in the area of social networks research. The group met and explored alternative conceptions of key problems in this area of research. Finally, after two days of discussion, the broad outline for this volume emerged. It was conceived as a state of the art statement of research problems and methods from the varying perspectives of those assembled.

Individuals and pairs working in collaboration staked out areas for exploration and report. Drafts of chapters and revisions were prepared. Finally, the three editors undertook the task of tying it all together into what we hope is a reasonably coherent volume.

Although no one planned it that way in advance, this book has five sections. They arise from the major types of problems addressed in the book

ıich can logically be ordered as stages or processes in social structural or twork analysis.

I. Network Representations. What are the fundamental modes by ıich social structural phenomena are to be represented? What is the nature the units of social structure? What are the basic types of relations between ɜm? What are the processes that affect these units and their relations over ne? The choice of a mode of representation thus implies a phenomenogical orientation, as well as a methodological strategy. The latter includes oice of representational models, measurement axioms, and the like.

II. Network Boundaries. How do we set the limits to a network or cial structural problem, and how does the choice of boundaries limit the itability of various models or methods? The problem might also include e question of the boundaries of the elementary units related in the network.

III. The Structure of Relations. How are the relations of a network ɜfined and measured? What is their structure and content? These are ɜntral foundational problems distinctive to the networks approach. How is e type of measurement related to the detection of structure? What are the ɔpropriate probabilistic or deterministic models for structural analysis?

IV. Implications of Relational Structure. A central feature of network ıalysis is the ability to represent the ways in which the relational structure f a network impacts on system actors. This may include impact on the ıvironment of the actors, the positions of the actors, or the actors ıemselves (i.e., on their attributes or relations).

V. Clustering and Positioning of Actors. How are actors clustered in a ɔcial network into groups or cliques? Such clusters are formed on the basis f social relations within the group in contrast to those outside. How does ıis clustering idea differ from the idea of positions or roles in the social ɜructure, based on patterns of relations with occupants of other roles? What re the preconditions and consequences of actors' occupancies of groups or liques as opposed to roles?

I. Network Representations

Network representations utilize elements and their relations. The lements are not all necessarily of the same type: they may be individuals, ɛts of individuals, groups, organizations, activities, or some combination ıereof. The relations are not all necessarily of the same type: they may be ɛflexive (one element relations), dyadic (two element relations), or polyadic

(multi-element relations) for elements of a single type. Relations among two or more different types of elements may also be examined. There are many different types of network representations in common use. In all of its varieties, the network approach is quite general. There are, however, common features and issues which run through these varieties.

Types of empirical, graphic, or mathematical representations of networks are often interchangeable. For example, isomorphic mappings can be defined among (1) concrete actors and their social relations, (2) points and edges in one or more graphs of the network, (3) matrices in which rows or columns are related by cell entries, and (4) various abstract algebraic structures.

Chapter 1 sets the groundwork for network analysis of systems of dyadic relations. Freeman reviews the intuitive antecedents for network study and systematically builds a formal representation for the study of social structure, including temporal processes. Isomorphisms between graph, matrix, and algebraic representations are explored as they relate to the phenomenology of systems of elements and dyadic relations. He defines this field as currently conceived and sets the range of tasks for developing a coherent perspective.

Chapter 2 presents a broad overview of a general structuralist perspective for the study of social networks, incorporating polyadic as well as dyadic relations. Foster and Seidman discuss polyadic relations as different types of subgraphs defined on subsets of actors or elements. Drawing on their own rich lines of anthropological and mathematical research, they go beyond problems of representation to present a unified set of concepts and tools for structural analysis. Their vocabulary is strongly graph-theoretic, but they also show some of the isomorphisms between the graph and algebraic representations.

The differences in the phenomenology and methods of Chapters 1 and 2 may be of considerable interest to those who adopt a structuralist perspective. Consider, for example, shared fields of interaction between multiple actors, such as co-participation in specified social contexts, groups, or roles. In the framework of Chapter 1, group memberships might, for example, be represented as attributes of actors. From the somewhat different perspective of Chapter 2, groups might be viewed as a second kind of node which interconnect subsets of actors, which might imply a phenomenological difference between group memberships and other attributes (e.g., age, sex) which merely categorize (but do not necessarily interconnect) subsets of actors. The frameworks of representation here are, in one sense, interchangeable, but one frame of reference might be more natural and more

roductive to work with substantively or analytically. Often, new and roductive approaches are preceded by such shifts of perspective. In this ase, Foster and Seidman are attempting to capture the richness of nthropological concepts of social structure. Out of their perspective has rown a number of new and fruitful mathematical concepts and procedures or structural analysis.

II. Network Boundaries

Chapter 3 examines problems of specifying units of analysis in the tudy of social networks. In particular, Laumann, Marsden, and Prensky fix ur attention on questions concerning specifying boundaries of human ollectivities. This is not a new problem in sociology, but it gains fresh nsights when viewed from a structural perspective. They also lead us to onsider problems of the suitability of various classes of structural models in ne context of varying kinds of group boundary specifications.

III. The Structure of Relations

In Chapter 4, Batchelder explores some of the ramifications of neasurement theory for the study of social relations and networks. The heory of measurement has developed for the most part in mathematical sychology. But it turns out to have considerable power when it is focused n networks problems. The most striking results, perhaps, are those that ear on the appropriateness of various classes of structural models in the ontext of varying measurement axioms.

Statements about network structure require invariance across ransformations of the measurements which are compatible with the neasurement scales. Batchelder's major contribution is to show the nplications of different measurement scales for such invariant statements bout transitivity, reciprocity, and cliqueing.

Chapter 5 by Strauss and Freeman gives a broad perspective derived rom probability theory on the structure of relations in a network. Their reatment organizes and gives coherence to a wide range of older specific etwork models in the light of modern stochastic theory. Finally, they wind p with an examination of a set of quite general and powerful contemporary erspectives all derived from log-linear analysis.

In Chapter 6, Burt and Schøtt develop a model designed to begin to come to terms with a very difficult problem: the content of social relations. Most network researchers seek to uncover clusters of actors. They stress structural patterns and seemingly avoid any discussion of relational content at all. In this chapter an elaborate device for exploring clustering among relations is introduced.

Chapter 7 by Boyd provides empirical and algebraic methods for analysis of the structure of relations. Here the set of primary relations is expanded to include the semigroup of all compound relations. Results from the theory of semigroups are used to contribute to our understanding of network structures. Boyd solves the difficult problem of how to construct meaningful semigroups from empirical network data. He also shows how the semigroup can be homomorphically decomposed to show subsystems of relations in equilibrium.

Boyd, like Batchelder in Chapter 6, examines the problem of level of measurement of social relations. Here, however, he asks how different kinds of measurement—Boolean versus real valued relations—and different kinds of composition of relations, as in Boolean versus ordinary matrix products, affect the detection of different kinds of structural properties in semigroups of relations. He decides in favor of real valued measures and operations in order to reveal the kinds of equilibrium subsystems in which he is interested.

There is also a close connection between Chapters 6 and 7. Burt uses correlations between different primary relations to analyze questions of content. Boyd uses correlations between primary and compound relations in a semigroup to analyze questions of relational structure.

IV. Implications of Relational Structures

In Chapter 8, Bonacich questions how homomorphisms of a network semigroup—preserving properties of the structure of relations—can be interpreted in terms of graph homomorphisms which either collapse sets of relations or sets of actors in the orginal network. Four approaches are suggested, none of which provides a complete solution to the question. The approaches are shown to be appropriate to different kinds of structural representations, and each applies under different conditions. Many of these problems of the relation between semigroup and graph homomorphisms have not yet been solved mathematically.

Boyd, in the previous Chapter, also discusses how the structure of ılations in a semigroup has important consequences for the types of ɔsitions occupied by actors.

Doreian's Chapter 9 uses the recently developed method of network ıtocorrelation to solve problems of estimating how the attributes of system ɔtors may be affected not only by their other attributes (as in regression ıodels), but by the attributes of other actors with whom they interact in a ɛtwork.

Foster and Seidman, in Chapter 2, are also concerned with the question f how relational structures constrain or facilitate decisions taken by system ɔtors. In their approach, however, they are able to define a great variety of ıtra-unit (i.e., subgraph level) and inter-unit relational structures.

V. Clustering and Position of Actors

The cliquing and clustering of subgroups of actors has a long history in ɔcial network analysis. Only in the last decade or so has the more general roblem of the equivalence of positions of actors been addressed. Thus, in rder of generality, we now have three concepts of positioning: (1) *cluster quivalent* sets of actors are those who have more relations within the cluster ıan with sets of actors in other clusters; (2) *structurally equivalent* sets of ctors are those who have the same (or similar) relations with other actors, egardless of how they are internally related; (3) *regularly equivalent* sets of ctors are those who have the same (or similar) relations with one or more quivalent actors.

A sociological clique is a kind of cluster where relations are within the luster are dense. Cliques represent a special case of structural equivalence. Cliquing however, is a "group" concept based on internal connectedness, vhile structural equivalence is partly a "role" concept based on general ɔatterns of external connectedness. Regular equivalence, on the other hand, s more purely a role concept. Regular equivalence implies nothing about loseness of connections among actors, while connecting paths between tructurally equivalent actors are always of length no greater than two.

There is a fourth approach to the positioning of actors, where elationally equivalent sets of actors are those who have similar patterns of nternal and external relations, without regard to whom the external relations ıre with. This represents a "local" rather than a "global" approach of regular

equivalence to social roles. The chapters in this section deal with all four concepts of position.

Before discussing the chapters in this section, we might note that Foster and Seidman, in Chapter 2, provide a generalization of the ordinary concept of cliques and maximally complete subgraphs. They also provide a general discussion of the concept of position in a network, in graph-theoretic terms. A subgraph has an intrinsic structural feature as a function of its self-contained relations. It has a positional characteristic as a function both of internal relations and those with outside elements. A clique or cluster is thus defined positionally. Structural equivalence and regular equivalence, as role concepts, are also defined positionally.

In Chapter 10, Mitchell applies both cliquing and structural equivalence algorithms to Kapferer's Zambian data, before and after a labor dispute, on shop-floor networks. He examines the extent to which these analyses, as well as graph theoretic measures based in reachability and distance, support and refine Kapferer's hypotheses about the structure and shifts of patterns in the network.

In Chapter 11 a new algorithm (MAPCLUS) for finding overlapping subsets is applied to matrices of structural equivalence coefficients from two classic sociometric data sets: the Bank Wiring Group, and the Sampson Monastery. Arabie and Carroll's results are similar in spirit to the representations discussed in Chapter 2 for overlapping subsets and those of Chapter 10 on "islands." The algorithm could be applied to any of the three main types of positional problems above: (1) to find overlapping cliques, using as input the raw relations of a symmetric graph; (2) to find overlapping positions of structural equivalence, as exemplified here; or (3) to find overlapping roles, using as input the regular equivalence coefficients of Chapter 13.

Arabie and Carroll also note the difficulties of the classic clique-finding problem of finding maximally complete subgroups of a graph. The problem is NP-complete, and is thus likely to continue generating a plethora of competing algorithms. MAPCLUS, on the other hand, uses a computationally tractable procedure. It differs from other clustering techniques in allowing implicit overlap, and providing explicit tests of goodness-of-fit.

Chapter 12 examines the problem of finding non-overlapping clusters of structurally equivalent points in a network. In the resulting blockmodel of patterns of relatedness between sets of equivalent points, Heil shows how to measure goodness-of-fit as a departure—towards high or low density

ocs—from expected density under the null hypothesis. Using the fit easure, he develops a procedure (COBLOC) for evaluating successive gglomerations of points, resulting in a family of blockmodels. He xemplifies the approach using the Bank Wiring Room data and shows nprovements in the COBLOC approach as compared to earlier ockmodeling methods.

Chapter 13 takes the third approach to positions in a network, based on global" role structures. Reitz and White generalize the blockmodeling pproach to capture broader intuitions about the nature of such roles. They evelop two new types of blockmodels based on positional equivalences that apture patterns of single-link and multiplex connectivities so that positions n the network correspond to actor/counterpart relations in a system of nterconnected roles. Unlike the structural equivalence approach, they do ot require that equivalent actors are identically related to other actors, but nly that they have the same relations with some actors in counterpart quivalence sets.

Thus, Reitz and White extend the network representation developed in hapter 1, but introduce a number of new structural concepts and definitions o represent the roles occupied by actors. They follow the strategy of hapter 2, moreover, in drawing on anthropological research on role tructures and attempting to formalize this richness in mathematical terms. hey present a number of new theorems about the hierarchical ordering of ositional equivalences (of types 2, 3, and 4 above), their uniqueness roperties, and connectivity properties. They show the implications of each ype of equivalence for inducing homomorphic images of the semigroup of elations on a graph. This part of the chapter is closely related to Chapters 7 nd 8, dealing with relational semigroups. In connection with Bonacich's uestion, Reitz and White completely specify the conditions for graph homo - norphisms to induce semigroup homomorphisms or isomorphisms, and they rovide tools for opening up new lines of research on graph and semigroup tructure.

Reitz and White introduce measures of regular equivalence and an lgorithm for finding regular blockmodels based on regular equivalence oefficients. Their example shows the difference between the abstract pproach to role regularity and the approach based on structural equivalence.

Chapter 14 provides a probabilistic model for evaluating both local nd global aspects of role structure. Marsden asks three types of questions bout roles or subgroups: (1) what are the internal relations within the ategory; (2) what are the types of relations by which category members are onnected to other members of the total network (e.g., isolate, receiver,

transmitter, carrier); and (3) do relations in the network differ depending on the position occupied by an external transaction partner? Like Chapter 5, they provide an integrated set of log-linear statistical models for the evaluation of these questions in network data sets. The approach is exemplified using data on interorganizational relations in a midwestern community.

All of the papers in this last section build on solutions to problems in the previous sections: a representation must be chosen, boundaries to the problem must be set, and relations must be measured. Clustering of actors is often implied by certain aspects of relational structure. A symmetric and transitive relation, for example, will cluster actors into equivalence sets (cliques). Clustering and positional problems thus come late in our ordering of the logical priorities of network analysis.