

# Developing Theory and Ethnographic Applications for Explanations of Emergent Structure and Network Dynamics

**PI Douglas R. White**

## TABLE OF CONTENTS

<b>Project SUMMARY</b>	<b>1</b>
<b>Project DESCRIPTION</b>	<b>3</b>
<b>I. Objectives</b>	<b>3</b>
<b>II. Rationale</b>	<b>3</b>
<b>III. Conceptual Perspective</b>	<b>3</b>
<b>Modeling Strategies, Patterns and Mathematical Theorems,         and Working Hypotheses</b>	<b>4</b>
<b>Heuristics for Theorizing Dynamic Evolution of Coherence         among Formal Patterns</b>	<b>7</b>
<b>Dynamics</b>	<b>9</b>
<b>IV Measurement: Detecting Patterns in Networks</b>	<b>9</b>
<b>V. Hypothesis Tests on Social Transformations</b>	<b>10</b>
<b>VI. Modeling and Hypothesis Testing: Research Problems and Questions</b>	<b>11</b>
<b>Problem 1: Cohesive Unity</b>	<b>11</b>
<b>Problem 2: Exchange Balances and Multilevel Graphs</b>	<b>12</b>
<b>Problems 3/4: Bundling and Scaling</b>	<b>13</b>
<b>Problem 5: Distributive Transformation</b>	<b>14</b>
<b>VIII. Developing Methods for the Integration     and Extension of Network Results</b>	<b>14</b>
<b>Cohesive Groups, Cohesive Roles, Cohesive Blockmodels</b>	<b>14</b>
<b>VIII. Research Schedules and Deliverables</b>	<b>17</b>
<b>IX. Key Personnel and Training</b>	<b>17</b>
<b>Current and Project PUBLICATIONS and References CITED</b>	<b>18</b>
<b>BIOSKETCHES:</b>	<b>23</b>
<b>Douglas R. White (PI)</b>	<b>23</b>
<b>Frank Harary (Consultant)</b>	<b>24</b>
<b>S.E. van der Leuw (Consultant)</b>	<b>27</b>
<b>BUDGET</b>	<b>28</b>

## Developing Theory and Ethnographic Applications for Explanations of Emergent Structure and Network Dynamics

### SUMMARY

**This research will produce (1) a series of anthropological monographs analyzing long-term field site data that the PI and collaborators have developed, (2) documentation for other researchers to use these and other project datasets, (3) new methodology for the social sciences, (4) a book oriented to theory and models in this area of scientific research, and (5) training of graduate and undergraduate students in anthropological research, and their participation in publications. The explanatory and methodological network analysis framework developed in this work will focus on social dynamics and emergent social phenomena of central interest to anthropology and sociology. These include emergence of, and changes in: instructional structures, class structures, kinship structures, patterns of violence and armed conflict, modes of conflict resolution, social cohesion and lines of division, patterns of exchange and major social transformations resulting from tipping point phenomena (phase transition) in social networks. The principal mathematical models employed and developed for the study of structure and structural emergents are graph theoretic, network-based, and algebraic, to which we add principles of dynamical systems analysis that the PI has developed in collaborative work with other scientists and social scientists at the Santa Fe Institute. Collaborative work with graph theorist and logician Frank Harary (project consultant), which has been critical to the success and output of the previous NSF award, is even more central to the present proposal: The aim of the joint methodological work, deliverable in book format, is the integration of coherent scientific principles applicable to the network dynamics of social interaction and explanation of emergent phenomena. This work focuses on four key areas of network modeling (cohesive blocking, graph and network homomorphisms, and role-activity analysis) that will be integrated through in a new set of formal cohesive-conditional models, the results of which are succinctly summarized and theorized through concept lattice analysis. The project will also involve synergetic collaboration on substantive and theoretical problem areas (analysis of cohesion, exchange and multilevel systems, scaling and distributive or tipping phenomena) that overlap with those of a European Union research project (consultant S.v.d.Leeuw, PI) that focuses on a complementary set of longitudinal fieldsite and historical/ archaeological databases. In addition to the book on modeling network structure and dynamics, each of the four substantive monographs on the long-term field studies will explain different aspects of the methodology for the analysis of network structure and dynamics and the theoretical principles for relating network analysis to fundamental social processes.**

## Developing Theory and Ethnographic Applications for Explanations of Emergent Structure and Network Dynamics

### Project DESCRIPTION

**I. Objectives.** The goal of the proposed research is a conceptually integrated theory of networks involving development and application of explanatory frameworks deployed and tested in a series of long-term field sites in which the PI is one of many collaborators engaged in study (including graph theory consultant Harary, and students in training). It is part of a larger research project involving collaborators at the Santa Fe Institute (social scientists John Padgett, Walter Powell, Sander van der Leeuw and David Lane; and biologist Geoffrey West) working on network and complexity theory as applied to a broad set of contemporary issues.

**II. Rationale.** The past 35 years have seen a massive development of tools for network analysis, spurred by anthropologist Clyde Mitchell (1969) and sociologist Harrison White (et al. 1976), and burgeoning applications to ever-wider sets of problems in the social sciences. The trajectories of social network analysis in the two disciplines were very different, however. In anthropology, where it was introduced in the 1960s as a collateral tool to institutional and cultural analysis, the network paradigm did not become a central contributor to theory, as in sociology.<sup>1</sup> Still, even in sociology, the development of methodology (Scott 1991, Wasserman and Faust 1994) has far outstripped that of an integrated theory of networks that situates explanatory principles in a common conceptual framework, and the lack of such developments is noted in both disciplines.<sup>2</sup> The proposed research also provides the network component of a project that is anthropological in content, “The Information Society as a Complex System” (ISCOM), submitted by Drs. David Lane (University of Modena), Geoffrey West (Oxford) and Sander van der Leeuw (Nanterre) to the Information Society Technologies Programme (IST 01-07-2A; [www.cordis.lu/ist](http://www.cordis.lu/ist)) of the European Union.

**III. Conceptual Perspectives.** One of the key ingredients of scientific explanation and the testing of theory is the development of models that relate first principles (e.g., interaction, structure) to a diversity of observable outcomes (e.g., as a function of simpler processes and parameters). Network theory, in so doing, attempts to make explicit how social and cultural phenomena emerge out of interaction by measuring, across observable networks of communication and of social and instrumental relations, events and activities, and ideally, through time, different kinds of emergent structure. **Appendix Table A** shows some of the network concepts applicable to various literature streams in different domains of

---

<sup>1</sup> Unlike sociology, which defined and forged ahead with social networks as a theoretical paradigm (Mullins 1975, Berkowitz 1982, Burt 1982) on a par with “heavy-duty approaches such as structure-functionalism, Marxism, and ethnomethodology” (Wellman 2000:4), interest in networks largely died out in anthropology once those experimenting with the approach in the 1960s and early 1970s turned from problems of fluid social structure to the study of transactions, ritual enactment, symbolic action, and contemporary themes of cultural anthropology. Anthropologists with a cognitive focus narrowed their studies to the shared components of egocentric cognitive constructions in relation to observed behavior, studies that unfortunately didn’t recapture the interests of the field at large.

<sup>2</sup> Even within INSNA, the International Network of Social Network Analysis, in spite of “explosive growth of interest, ...membership hasn't commensurably grown in size” and as Wellman (2000:7) noted, despite “ready availability and easy use of heavy-duty methods... and...the participation of so many smart people, our work has not cumulated enough or developed enough integrated theory. Why is it that many people with network analytic sensibilities do not participate? When I ask, they tell me that our methods are too hard and our scope is too narrow. Or else, they think that only a metaphoric ‘network’ sensibility is enough. I wonder how to reach out to them so that a broad, rigorous structural analytic perspective flourishes.” Although members meet annually, and INSNA members are the major producers of new methodology, there has been little development of a conceptually integrated theory.

social theory. They are listed in abbreviated form with major concepts under various theoretical headings, each followed in the table by network-based measures of each aspect of social structure, the principal authors associated with each method, and a classic anthropological or sociological author associated with each. It is within this scaffolding of diverse theoretical concepts and associated measures that the present research takes shape in concentrating on a few central modeling strategies that are crucial for theoretical integration. One of the goals of the proposed research is to study how these different models relate to one another, and how they can be used in combination both to build a general framework of interrelated models useful for formulating network theory, and to help to test some of the hypotheses derived from network theory. The middle column in Table A lists the typical kind of mathematical model used for a particular concept. As will be seen, the project PI and consultant Frank Harary (a principal logician of social networks and founder of the mathematical field of graph theory) are heavily involved in the development of such models. Those we have selected for special attention are the pattern principles that are numbered in Table A. The first four of these are listed in **Table 1** below. Coupled with the modeling of fundamental interaction processes, these are some central types of models that allow structural emergents to be measured and hypotheses to be tested about processes, interactions and outcomes.

	<b>Pattern 1</b>	<b>Pattern 2</b>	<b>Pattern 3</b>	<b>Pattern 4</b>	<b>Pattern 5</b>
	<b>Cohesive Blocks</b>	<b>Graph Homomorphisms</b>	<b>Blockmodel (Informal Roles)</b>	<b>Centrality / Topology</b>	<b>Role/Activity Structure (Formal Roles)</b>
<b>Coherence</b>	Group Blocking	Exchange and Opposition	Analogous Positions	Nodal / Ngbhd Properties	Allocated Positions
<b>Relations</b>	Multiple	Single	Multiple		Tripartite*
<b>-- Within Sets</b>	Connectivity	Disconnection	Similarity		HxH social PxP formal TxT task seq.
<b>-- Between “</b>	Inclusion	Connection	Similarity		HxP PxT TxH
<b>Structure</b>	Hierarchy	Partition	Partition		H/T=H/P x P/T
<b>Equivalence</b>	(None:overlap)	Coloring	Regular		Multiple
<b>Overlap</b>	Minimum	None	None		
<b>Reflexivity</b>	n.a.	Disallowed	Allowed		

\* Opposition is associated with the balance theorem, exchange with the clustering theorem.

\*\*H=Humans, P=Positions, T=Tasks (Oeser and Harary 1964, 1979)

**Table 1: Formal Patterns in Networks (as elements in our study of coherent integration)**

**Modeling Strategies, Patterns and Mathematical Theorems, and Working Hypotheses.** One of the crucial ways to identify network properties that are likely to have sociological or anthropological consequences is to identify those concepts that are characterized by theorems that express the relation between the **global structure** of the subgraphs identified by these concepts, within larger networks, and processes that involve **local traversal** between the nodes of the same networks or subgraphs. **Patterns 1 and 2, cohesion and balance**, are complementary topological properties that define robustness of groups, on the one hand, and structures of opposition and exchange between groups, on the other. In each case the relevant theorems link structure to traversal, or global to local aspects of a single measurement concepts. For the identification and measurement of subgraph cohesion, the subject of our previous NSF research award, the identity of structure and traversal as a provable equivalence between the following two measures is stated in **theorem 1**:

1. A subgraph  $S$  of a network or graph  $G$  is  $k$ -connected when the minimum node cut set size  $?(u,v)$  separating any nonadjacent  $u,v$  pair of nodes in  $S$  equals  $k$ . This defines robustness of subgroup structure by relative invulnerability to disconnection by removal of  $k$  nodes.

2. Any pair of nodes  $u,v$  in  $S$  is joined by at least  $k$  *node-independent*  $u-v$  paths. This defines the minimum level of multiplicity or redundancy of independent traversals between nodes.

A maximal subgraph  $S$  having these (equivalent) properties is called a *k-component* of  $G$ .

Research under our previous award established that the  $k$ -components of social networks provided an operational basis for defining topologies of cohesive groups whose boundaries and inclusive hierarchies (since a group that is cohesive at level  $k$  is potentially embedded in larger groups of successively declining cohesion) predicted a host of expected downstream consequences of social cohesion in the contexts represented by a series of ethnographic and historical datasets. We have abundant evidence that the type of **cohesion** that is measured in social networks by node rather than edge connectivity [9] (team member project publications are given throughout in square brackets; see Project Publications) is fundamental to identifying robust groupings of elements in social and cultural systems, and that the identification of such groupings – with a high internal connectivity through multiple pathways – may play a key part in constructing an integrated network theory. **Pattern 2 (balance** in partitions of connected networks, Harary 1953, and its generalization in graph coloring or clusterability) is the essential basis for understanding exchange (Gregory 1982). Harary (1953) defined *balance* or *sidedness* as it applies to a signed graph, which is a set of  $V$  vertices or nodes, together with edges or unordered pairs in  $V \times V$ , in which each edge has either a positive or negative sign as follows. The equivalence of global and local definitions as whether a signed graph  $G$  is sided or balanced is stated in his **theorem 2**:

1. The nodes of  $G$  can be partitioned into two sets (sides) such that every negative edge joins nodes from different sets and every positive edge joins nodes from the same set.
2. All paths joining any pair of nodes in the graph have the same sign, where the sign of a path is computed as a product of signs on its edges.

These two statements, for example, provide a computable social model of a 2-sided marriage network with a Dravidian cross-parallel distinction defined in terms of the network [14]. Statement 1 gives a global characterization of a 2-sided structure, and statement 2 a local view in which any two persons,  $X$  and  $Y$ , can determine their cross/parallel status if they are in any way related. Our discovery [2][3][5] of sided networks in cognatic societies throughout South Asia and Lowland South America led to major breakthroughs in understanding the relation between cultural rule systems, empirical marriage networks, and kinship terminologies such as the Dravidian type [14]. One link between balance and cohesion to be studied in our proposed research is shown by an **illustrative hypothesis (1)**: the more cohesive and the smaller the diameter of a marriage network in a system with Dravidian terminology, the easier the local rule of sidedness is to apply, and the more likely is a global structure of sidedness in the marriage network. Another is the link between the hierarchical topology of cohesion and exchange relations between members of cohesive groups, taking into account the position of actors exchanged (in the case of recruitment processes) or doing the exchange in the hierarchical cohesion structure. An **illustrative hypothesis (2)** is that in some social systems, the level of cohesion obtained by players in groups engaged in exchange is proportional to the levels of exchange in which they are engaged, at least to the extent that cohesion mobilizes local resources for external exchange. A test dataset for this hypothesis will be the affiliation networks of teams coded in The Baseball Archive (<http://www.baseball1.com/statistics/>) from 1863-2001, and the exchange relations studied will be the exchange of players and managers (see Problem Area 2). In this case the sidedness structure does not apply, but we may find use for equivalent global/local and structure/traversal definitions as to whether a signed graph  $G$  is *clustered* (where exchange relations are coded negative) as stated in Harary's **theorem 3**:

1. The nodes of  $G$  can be partitioned into  $n$  sets such that every negative edge joins nodes from different sets and every positive edge joins nodes from the same set.
2. No cycle joining any pair of nodes in the graph has a single negative sign.

The second statement in the exchange of players study expresses the obvious fact that you don't trade players on your own team, but the clustering model at the global level can establish whether there are  $n$  sets of teams where trade is between but not within sets, and the analysis of directional trades can be used to study whether there is a global topology to the exchange structure and how it is related to the

cohesion structure (various positive relations can be used to define the cohesion structure, such as players who have played together previously on a different teams, etc. We will also be studying how to model cohesion when heterogeneous relations are involved.)

A third area of modeling where our approach to cohesion will be bought together with balance (sidedness) and clustering in exchange relations is the development of mathematical theorems about conditional graph homomorphisms and substantive hypotheses we think can be developed in this area. Consider the two-sided exchange relations, for example, between sellers and buyers of a product. Flow of information about prices and quantities is enhanced when the relations are overlapping, and the robustness of distribution of such information is a function of the cohesiveness (as already defined) of the trading relations. A graph homomorphism uses such theorems as 2 or 3 (graph coloring) to generate a reduced graph of sets of players having potential exchange relations. A graph homomorphism that is conditional on cohesion can be constructed so as to find a series of maximal reductions not of all the nodes but those for which exchange relations also satisfy various levels of cohesion. One might identify, in this way, a series of concentric cores of a market system in which the cohesiveness levels of players as a structural property are linked to a traversal property (robustness of distribution of pricing and quantity information in the market). Such models have great potential for modeling structure and dynamics in social systems.

Working off the set of key network approaches in Table 1, we want to push our integrative approach further to include two of the principal structural approaches to networks, **Pattern 3**, blockmodeling or positional equivalence and analogic structures (Lorrain 1974, Lorrain and White 1981), and **Pattern 4**, centrality and centralization (Freeman 1979), and to include two approaches that are not in common use. Of the latter, the first is the **topological** approach, which seeks to identify the locally varying neighborhood properties of networks (unaltered by elastic deformations), and the second is the **role/activity analysis (Pattern 5)** of Oeser and Harary (1964, 1979) which links networks of people, tasks and positions. Pattern 3 – the logic of analogy – has been show to be fundamental to thought, narrative structure, the situatedness of intelligibility (Hofstadter 1985, and Fauconnier and Turner 2000), and the recognition process in social identity, role, and attributed motivation and reputation (H.White 1992). Pattern 5, which includes task and role specialization and division of labor is the basis of formal organizations, office holding and the allocation of responsibility. Pattern 4, along with topology, is among the modalities (see Heuristics) by which other patterns are integrated, and we are researching a topological formulation in which to embed our modeling of cohesive hierarchies. In addition, we want to study as Pattern 6 what we call distributed transformation, the result of reweighting of network elements, the tipping of network structures into a redistribution of elements that for example may once have been centralized.

With respect to patterns 3 and 5, blockmodeling and role structure, our **working hypothesis (3)** for theoretical and mathematical integration is that, as with patterns 1 and 2, conditional cohesion acts as an identifier of discretely bounded units and as an intensifier (through robustness and local-global linkages) of the substantive effects of patterns discernable in role systems of whatever sort. In blockmodeling, for example, which is a very widely used method of network analysis in sociology, there is a classical problem of structural equivalence blockmodels being too strict (in looking for matrix partitions where the subrectangles are all uniform), regular equivalence blockmodels being too loose (in looking for matrix partitions where the subrectangles are all zero or have at least one uniform nonzero in each row and column), and density blockmodels being too ill-defined or sloppy. A conditional connectivity blockmodel would identify the hierarchical levels of intensification of positions and their interlocks with other positions in terms of the k-connectivities (cohesion) of the subrectangles. The proposed form of blockmodeling would thus be based in **k-cohesive equivalence** (every blockmodel is a homomorphic mapping of a network according to such equivalence sets: White and Reitz 1983, Reitz

and White 1989). A similar reformalization is envisioned for Oeser and Harary's role/activity structure analysis methods.

**Heuristics for Theorizing Dynamic Evolution of Coherence among Formal Patterns.** Other goals of the research include development of a process model of relational coherence: how do elements assort and cohere and synchronize in a (complex) social system? Structural coherence is a heuristic concept we use to express how these different formal aspects of the mathematical structure of sociocultural phenomena are embedded in real-world material, spatiotemporal, cognitive and communicative processes.

A guiding **hypothesis (4)** is that the engines of structural coherence are coupling processes generated by the **synchronization** and **bundling** of tasks and activities – behaviorally, cognitively and communicatively – within a field of social action. A related goal is to articulate this theory in terms of networked processes and emergent structures, with the six patterns numbered in Table A, as detailed in Table 1, being the principal formal patterns that we will investigate. Some of the insights of complexity theory are articulated within this framework and generate the following kinds of **heuristic hypotheses** that, while given below in statement form, are best considered as research questions, which we still have to refine in terms of the most appropriate language in which specific hypotheses can be formulated:

1) **Structural catalysis** (catalysis refers to the regulation of processes through slowing down or speeding up their temporal rates or contracting/diffusing their temporal scales) is the emergence of shared perception, language, and auto regulatory communication, which, as agents or actors learn to recognize such emergent patterns, alter rates of specific types of interactions because actors use these recognitions strategically. Since our **patterning principles 1-5** are locally recognizable by actors (see theorems 1-3 above; other theorems will be provided) but also (by these same theorems) have global structural and traversal consequences for networks, they are prime candidates to examine the effects of structural catalysis, which presupposes the emergence of a perceptible formal pattern in a social field.

2) **Tipping points** (Gladwell 2000) occur in historical trajectories where, although networks are still composed of the same types of relations, the way that the relations or flows are distributed across formal structural patterns (and functions) is dramatically altered (this is related to our **Pattern 6, distributed transformation**, the result of reweighting of network elements, the tipping of network structures into a redistribution of elements that may once have been centralized). Structural catalysis may alter which kinds of relations are utilized as the basis of grouping and/or as the basis of exchange. Similarly for how relations are distributed in the logic of analogy/identity and the logic of allocation.

3) **Interdependence** among the four of the pattern principles in Table 1 occurs in **pairings** (see Figure 1): the grouping logic of relational solidarity is paired with an exchange logic between groups (our **hypothesis (3)** is that the extent of interlock is partly a function of the level of cohesion or conditional cohesion in both networks – see above); and the analogous-positions logic in a behavioral system is paired with the formal or organizational activity allocation logic (with interlock again partly a function of the level of conditional cohesion in both networks). Pairing principles come out of balance and clustering and other principles, interlocked by level of structural cohesion.

4) **Modalities** by which the pairs of pattern principles (1 and 2; 3 and 5) are articulated include **segmentation** (as in homomorphic equivalence classes) and **crosscutting** integration (as in cohesive blocking and set intersection). Further, if the pairings are in perfect alignment they are more likely to neatly segment and/or segregate a social field (and its perceptual and communicative superstructures); if they are in misalignment they **crosscut** and thereby integrate a field through overlap, association and attendant ambiguity.

5) **Morphogenesis** as an aspect of coherence results from the fact that the segmentary versus crosscutting patterns, among others, have very different and very severe implications and consequences (they strongly affect the path dependence of evolution and historical trajectories). The PI's dissertation (White 1969) established through comparative ethnographic analysis that morphogenic coherence

occurs between the degree of crosscut integration in a social structure and the degree of cooperativity required in the labor processes. One of his student's dissertations (Grannis 1998) established the same for urban systems: the greater the segmentation of transport and communication systems into tree-like structures with cul-de-sacs, the lower the social integration and cooperativity, as measured by various indices; the greater the crosscuts, the more integration and cooperativity.

6) **Bundling** of activities, in ways that satisfy easily executable behavioral routines, is a necessary feature of spatiotemporal and sociocognitive (shared information) systems. Goodenough (1963 Ch. 10) develops this into a principle of cultural organization and dynamics. Morphogenic and network pattern principles come to bear on this fundamental organization problem. Coherence in expressive behavior, because of activity and cognitive constraints similar to those that require bundling, also requires high coherence in coordinate mapping with the labor domain. Hence:

7) **Polarity reduction** occurs between activity and cognition, and between expressive and task behavior (one has to see the films of Alan Lomax to recognize the coherence between them) as they are brought into coherent interdependence. In this process, for example, significant low frequency activities (e.g., mortuary ceremonies) are brought into resonance or synchronization with high frequency ones (e.g., daily or seasonally recurrent activities).

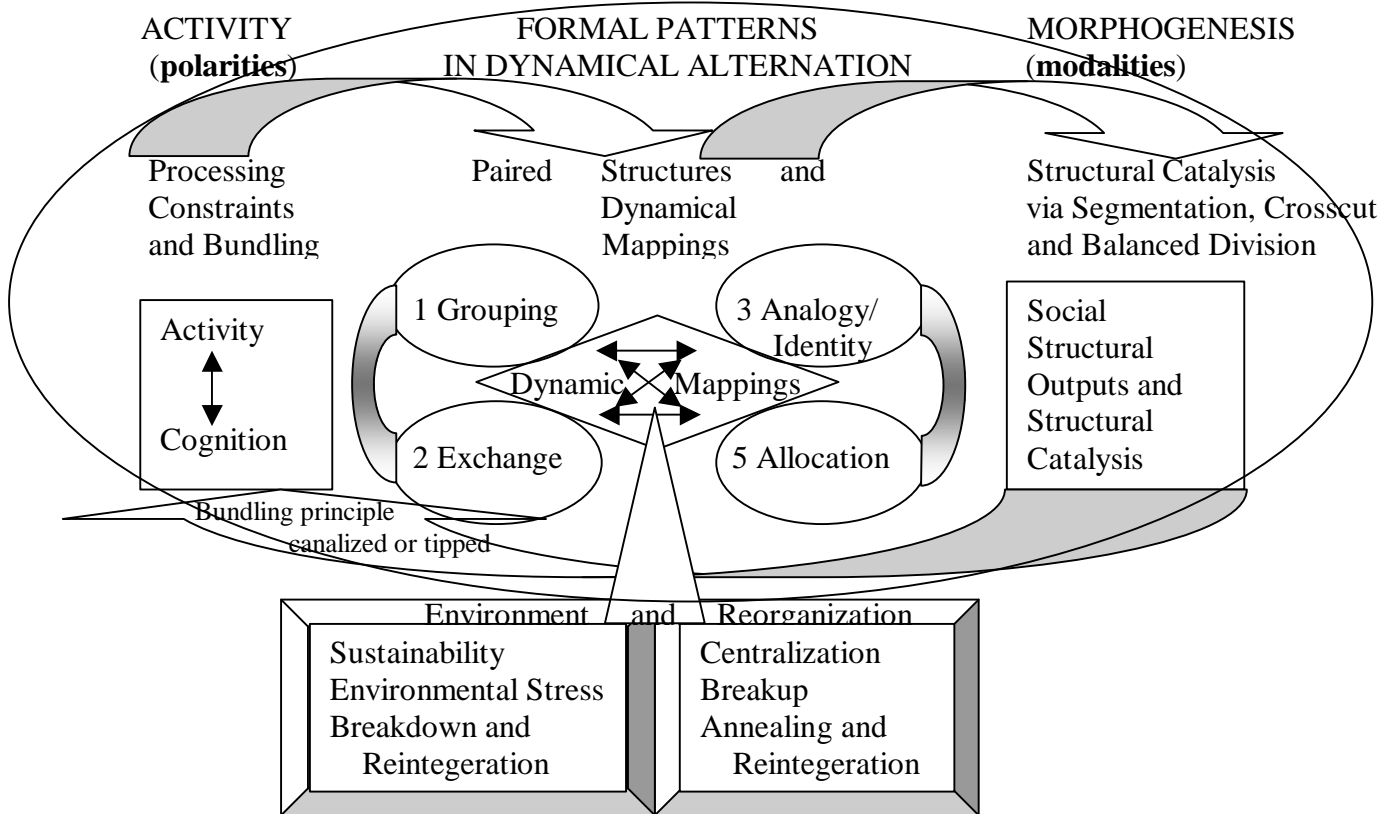
8) **Structural catalysis** again (the emergence from a perceptible formal pattern of a field of perception, language, and auto regulatory communication) plays a role in bundling and polarity reduction. For example, analogous conceptual structures (pattern principle 3) map onto diverse activity sets, and 'unify' them culturally. Similarly, formal principles of political, organizational and task allocation (pattern principle 5) require synchronization through structural catalysis of principles of recruitment, succession and inheritance with activity and auto regulation processes.

9) From smallest details up to the largest of abstract patterns of activity, **structural catalysis** is at work on different spatiotemporal and sociocognitive scales, that is, in a temporal and spatial spectrum, and in a social and cognitive spectrum of process. This is what dynamicists Iberall and Soodak (1978) call the stack of 'factory day' processes that make up the spectra of activities of any complex system, subject to near-equilibrium material and energetic constraints on repetitive activity cycles.

10) The two sets of pattern principles (1&2 vs 3&5) are articulated by dynamic mappings some of which involve further individuated network attributes such as centralities and diversity in other attributes that serve as the basis for recruitment, etc.

11) Within the group-level hierarchies of cohesion and adhesion there is room for further variability at the individual and subgroup level, including **centralization and** variability in relative centrality of nodes or subgroups (**Pattern 4**). Centrality structures are constrained, however, by levels of cohesion and adhesion. A star pattern of maximal centralization, for example, can occur where adhesion is high but cohesion is low, whereas high cohesion (which entails high adhesion as well) places a limit on centralization.

12) In fluctuating environmental interactions, coherent systems may breakup, and their resilient components reconfigure in **redistributed transformations (Pattern 6)**.



**Figure 1: Process Model of Relational Coherence between Statics and Dynamics**

**Dynamics.** Figure 1 above summarizes the heuristic hypotheses and puts them in a dynamical context. In addition to tipping points in the assortment of relations across formal structural patterns, one of the principal sources of dynamical instability occurs in the variable ways that the coarser grouping and group exchange formal patterns are mapped onto the more nuanced logics of analogy and allocation. Arrows within the large circle in this diagram reflect temporal processes, numbers and labels within the smaller circles represent the types of patterning we have identified in principles 1-5, the diamond represents potential for shifting ways in which these patterns are mapped into or across one another, and the large triangle from the environmental and reorganizational boxes up to the diamond is intended to represent (1) the influence of stresses or breakdowns that occur in environmental or demographic sustainability and external pressures; and (2) stresses towards reorganization, including centralization (or conversely, breakups that often lead to fragmentation and decentralization).

**IV. Measurement: Detecting Patterns in Networks.** Cohesive blocking is a new methodology, developed under the previous NSF award [9], one that is crucial to theorizing about clusters of meaningfully related elements such as people in social groups, items in a material culture, or concepts in a symbolic world. As in theorem 1, a  $k$ -connected (or  $k$ -edge-connected) block in a graph of relationships is a maximal set of nodes in which no pair can be disconnected by removal of fewer than  $k$  nodes (or edges). Node and edge connectivity define cohesive and adhesive blocks in networks, respectively. A  $k$ -cohesive block is also a maximal set of nodes where every pair has  $k$  or more paths that are node-independent (with no intermediate nodes in common). White and Newman[12] give a fast algorithm to compute all such paths for large networks. Nine project-related publications [1-3,6,7,11,13-15] show the predictive consequences of the measures of cohesion or adhesion for substantive variables in ethnographic and sociological studies under the previous NSF award.

As shown in Table 1, while in cohesive blocking connections are grouped *within* sets, graph coloring is a homomorphism (generating color equivalence as a partition of nodes; edges can also be partitioned by similar principles) that goes in the opposite direction to observe the organization of equivalence sets when connections are limited to those *between* sets. Like colorings (and unlike cohesive blocks), blockmodeling is a homomorphism that generates a partition of nodes into nonoverlapping sets, but without the constraints of graph colorings (which cannot put two connected nodes in the same equivalence set). Sociological block modeling (Lorrain and White 1970, White, Boorman and Breiger 1975) is to the concept of role (analogous or similar position emerging out of a system of relations) what cohesive and adhesive blocking is to that of group.<sup>3</sup> In the next phase of research we will generalize cohesive blocking to the study of role structure as developed by Oeser and Harary (1964, 1979), where we try to find tasks that cohere with one another, people who cohere with tasks, and coherence among formal roles (algebraic products of people by positions and positions by tasks) as opposed to emergent ones (people by people and people by tasks). Table 1 again shows some of the ways in which these approaches differ. No one as yet has shown how these different aspects of network modeling might be unified around an integrated sociocultural theory, mathematically well formulated, of the socially interactive basis of cognition and the coherence of human behavioral systems (see Hutchins 1996; Moore 1998; Goodenough Ch. 10 1963). At the mathematical level, our research steps will be to establish a common formal language for comparison and integration of these four approaches, then to formally restate each model in the common language of graph theory, and finally to work on the formal conditional relationships amongst them (as we have done with connectivity and conditional density in developing the methodology of cohesive blocking [9], see Harary 1984). The next stages, discussed below, are to develop a substantive theoretical framework of hypotheses that allow us to measure and integrate the formal aspects or dimensions of these models in relation to empirically testable applications.

**V. Hypothesis Tests on Social Transformations.** Testing of hypotheses using our databases under the previous NSF award largely relied on static correlational tests in which we found that the new measures of cohesion have a broad range of predictive consequences. The present research shifts to include dynamics. As we learned from our time series network analysis of the evolution of cooperative ties in the worldwide biotechnical industry [13], the longitudinal analysis of network structure and dynamics in relation to social and economic transformations is challenging but has high scientific payoffs in terms of understanding the linkages between structure and dynamics. In the biotech study we treat (as **hypothesis 5**) the feedback the relation between local decisions of corporations to form cooperative ties with others, (**hypothesis 6**) how this produces differences in degree distributions (in numbers of ties) between corporations, (**hypothesis 7**) the effect of different types of degree distributions (exponential, power-law) on network topology, and (**hypothesis 8**) the existence of cohesive units in the network topology on the local decisions of corporations to form cooperative ties. Where find huge statistical effects for (9), for example, in addition to preferences for diversity of ties, supporting our overall emphasis on effects of cohesive structures and connectivity. We also identify models of tipping points or phase transitions in which connectivity is statistically implicated in the longitudinal transformations of the industry, and identify some of the effects of congruence or incongruities (Figure 1) between different pattern principles. What we learned from this study will be applied to our other longitudinal projects.

**VI. Modeling and Hypothesis Testing: Research Problems and Questions.** In the previous NSF research, parts of this framework were used successfully to analyze network data in a variety of field

---

<sup>3</sup> The concept of regular equivalence (network homomorphism) as developed by White and Reitz (1983, Reitz and White 1989) is an explicit formulation of blockmodeling that fits ethnographic applications, by finding more general positional analogies outside the context of small group studies.

settings: our Austrian village study (Brudner and White 1997), the Tlaxcalan village study [1][W1], the Turkish nomad study [6][7], etc. In the process of diffusing the framework through methodological workshops, the PI was also invited to join three major research projects that had extensive historical or time-series data: the European “**Society as a Complex System**” and **Archaeomedes projects** (settlement and communication structure) of van der Leeuw (1998) and others, **the Florentine elites and banking project** (Padgett 1993, 2001), and **the Biotech industry project** (Powell and [13]). The PI's work on the latter project, as noted, has provided a paradigm for applying our process models (Fig. 1) to other longitudinal databases. Each of these projects is associated with the Santa Fe Institute for the study of complex systems where the PI has been part of research working groups for the last three years. Having established the usefulness of the formal analysis of cohesive and adhesive structures as a component of systems integration, the present research is able to turn to the problems of dynamics in terms of how the grouping principles fit into a larger framework of theoretical and substantive problem areas.

**Problem 1: Cohesive Unity.** What are the large as well as the smaller scale cohesive bases of cooperativity in social systems? What kinds of stable platforms for social, political and cultural organization (including knowledge bases) are formed on the basis of cohesive units? Data provided by ethnographer Johansen (Johansen and White 2002; White and Johansen ms.) on the social networks of Turkish nomads has given us excellent ethnographic material for an analysis of multilevel cohesive groupings that will serve as a model for other anthropologists wishing to follow this type of study. In addition to finishing the book on **Network Cohesion among Turkish Nomad** (White and Johansen ms. Deliverable, **Book 1**), collaborations will continue on the applications that can be characterized by the following research questions:

- 1.1 Can cohesion predict the resilience and productivity of research groups? (Mark Newman – Santa Fe Institute – and the PI)
- 1.2 Can cohesion predict psychological attachment to school in adolescent friendship networks? (James Moody– Ohio State – and the PI)
- 1.3 Can cohesion predict emergence of medical institutions in 19<sup>th</sup> C. Paris? (Maurizio Gribaudo – EHESS– and the PI)
- 1.4 Can cohesion predict collusion in business networks? (James Moody– Ohio State– and PI)
- 1.5 Does social class cohesion exist in American colonial families ancestral to the U.S. Presidents? (NSF REU undergraduate Jon Sepe– UCI– and the PI)
- 1.6 Can cohesive intellectual and institutional networks predict the sites of emergence of modern scientific practices in Geneva? (Eric Widmer– University of Geneva – and the PI)
- 1.7 How does distributive cohesion affect electronic communication networks? (James Moody– Ohio State– and the PI)
- 1.8 Does exclusion from (or lack of) cohesive groups predict characteristics patterns of violence? James Moody just submitted a paper to AJS on weapon carrying among adolescents. Students who are not members of the largest cohesive component are more likely (odds ratio of about 2) to carry weapons to school, which is a possible lack-of-socialization effect stemming from not being part of the substantive community. The ethnography of the Siriono provides another potential case study of this phenomenon.
- 1.9 Do cohesive subgroups predict the lines of fragmentation of groups under pressure to segment [9]? This and question 1.8 can also be addressed in other cases in our database.

The absence of cohesive units in a connected system does not imply lack of organization but simply a different form of organization (organizational units connected in tree-like networks) known as segmentation. The PI and Michael Houseman (ms. Deliverable, **Book 2**) are rewriting a book on Polynesian examples of segmentation in Tikopia and Anuta, where exogamous patrilines are segmented with the occurrence of internal marriages. Our analysis of these two cases offers an explanation as to how segmentation can fit with balanced forms of exchange similar to dual matrimonial organizations or moiety-like systems.

**Problem Area 2: Exchange Balances and Multilevel Graphs.** Complementary to the formation of social, political, and territorial groups is the process of establishing exchange relationships between them. Unlike transactions carried out within a group, cross-boundary relations take on the possibility of exchange or opposition. Graph homomorphisms, like the coloring of territorial maps of polities, preserve the distinctness of groups connected by such cross-boundary edges. To our knowledge, the relationship between cohesive connectivity groups in networks (where the ‘positive’ or in-group relations are of interest) and the partitioning or colorings of nodes by graph equivalence, where ‘negative’ out-group or exchange relations are involved, has only begun to be studied [9]. This combined approach allows the study of competition and trade-offs between solidarity (in-group) and exchange (between group), and the emergence of complex divisions of labor induced by cohesive hierarchies. A key idea here is that cohesive groups are nested in hierarchies according to the degree of cohesion, so that exchange colorings may operate at different hierarchical levels. A second related idea is that the hierarchical or embedded relationship of different units or subgraphs is such that we may usefully consider modeling complex systems as multilevel graphs where lower-order graphs are embedded in the nodes of higher-order graphs (Harary and Batell 1981). Collaborations will continue on applications characterized by the following research questions.

2.1 Do bundlings or divisions of labor in each of our case studies always have the spatially concentric patterns related to community cohesion observed by White and Burton (1987) for preindustrial societies and for industrial societies by Smith and White [22]? - and are the flexibilities observed in terms of task switching (rebundling of activities) a special case of our general hypothesis of exchanges operating at the boundaries of cohesive hierarchies, only in this case changing role/task allocations in the cohesive hierarchy itself?

2.2 Does cognatic sidedness (graph theoretic 2-colorings of matrimonial exchange networks), as discovered in scores of societies in Amazonia (Houseman and White 1998a) and Dravidian South Asia ([3], [14]), predict a series of other ‘balanced-sides’ characteristics of these same societies (e.g., Dravidian kinship terminology, characteristics forms of political organization, leadership, conflict, and family structure)?

2.3 Do the ‘moiety-graph’ characteristics of network structures that permit more efficient information exchange in community problem solving (demonstrated in mathematical theorems and simulations by [9]) predict greater likelihood of cooperative problem-solving outcomes in a range of task-structured situations?

2.4 Does the competitive exchange structure of organized sports, both in games and player exchange (baseball database study, 1863-2001), produce hierarchical cohesion structures and “tiers” of player exchanges? (UCI student Tom Moliterno—with advice from the PI— will also be using multilevel graphs of teams and their organizations at one level and player exchanges between teams at the next, movements of teams between cities at a yet higher level.)

2.5 Do the two forms of sociocultural osmosis promoted by cohesive solidarity and exchange reduce levels of violence and potential terrorism? (possible rfp response by economist Halbert White and associates and the PI).

**Problem Areas 3 and 4: Bundling and Scaling.** When social, physical and communicative processes are connected in a network in which costs and outcomes can be optimized under time and channel capacity constraints, small random or exploratory perturbations allow the material and energy allocations to drift towards an optimized network configuration. A **structural prediction hypothesis (9)** is that sequential sets of **more cohesively equivalent** nodes (see above) are more likely – proportionally to the cohesion level – to develop a coherently optimized role structure. Role structures become templates for organizing bundled sets of activities and actors, and are extended in social and cognitive systems into analog models of regular equivalence (White and Reitz 1983) where the mapping of the template onto a new domain preserves the structure of linkages. Bundling principles provide dynamical processes partly responsible for construction of stable platforms or multi-unit systems of organization.

A second principle closely related to bundling in constructing multi-level platforms of network organization is that of *scaling*, which is again related to the distribution of capacities of individual nodes and channels in a network and in turn to the distribution of nodes and channels across a spatial or network topology. Biology has recently made massive progress with the scaling approach (West 1999). One of the key sociological insights of Powell, White, Koput and Owen-Smith [13]), using a scaling approach, is that the processes by which the network is populated with actors (recruitment, persistence, disappearance) and by which actors grow their links to others (e.g., individual level decisions) tend to be determinant of the overall network topology (Albert and Barabasi 2001), from which the social and legal institutions of the industry emerge. Parallel to the structural couplings of theorems 1-3, discovery of detailed micro-macro dynamic couplings such as these are a central contribution of scaling approaches.

Armed with principles of bundling and scaling, we are prepared to analyze complex systems in ways that overlap with the European Union ISCOM (Information Society as a Complex System) Project, and to provide that project an infrastructure of network analysis. Some of the correspondences between our projects and the European projects are listed below.

Scaling in urban systems (ISCOM problem 1) – our test questions will be:

3/4.1 Can changes in settlement hierarchies already well described in the Archaeomedes project in a 2000-year database for Southern France (Rhône Valley: van der Leeuw et al. 1998) be predicted from network analysis of changing cohesive hierarchies and centralities in transport networks? (Sander van der Leeuw– Nanterre– project Archaeomedes– and the PI).

3/4.2 Do the cohesive boundaries of neighborhood streets in urban areas, uninterrupted by major thoroughfares, predict homogeneity of social attributes better than other methods? (Grannis– UCLA– and the PI).

3/4.3 Do cohesive densities of elite marriage networks such as we have for Nord Pas-de-Calais, France, mapped into a geographic spatial structure, allow a fractal scaling of urban social and class structure? (Hervé Le Bras–Ecole des Hautes Etudes-Sciences Sociales, Paris– and the PI).

Organization into competence networks (ISCOM problem 2) corresponds to our question:

3/4.4: Does what we call bundling, for which we have a number of network analytic methodologies and modeling, predict the emergence and consequences of role systems in datasets for which we have appropriate ethnographic information?

Scaling in corporations (ISCOM problem 3). Our Santa Fe Institute project on Network Dynamics in the evolution of collaborative ties in the Biotech industry is nearing its first publication [13], and poses a series of questions listed above in **section V**.

Network diffusion and the dynamics of innovation (ISCOM problem 4).

3/4.5 What are the effects of cohesion and degree distribution scalings (as in.5 above) as elements of network topologies on diffusion of knowledge and technology (in biotechnology [13] and other industries) and the dynamics of innovation?

Markets and distributed control networks (ISCOM problem 5).

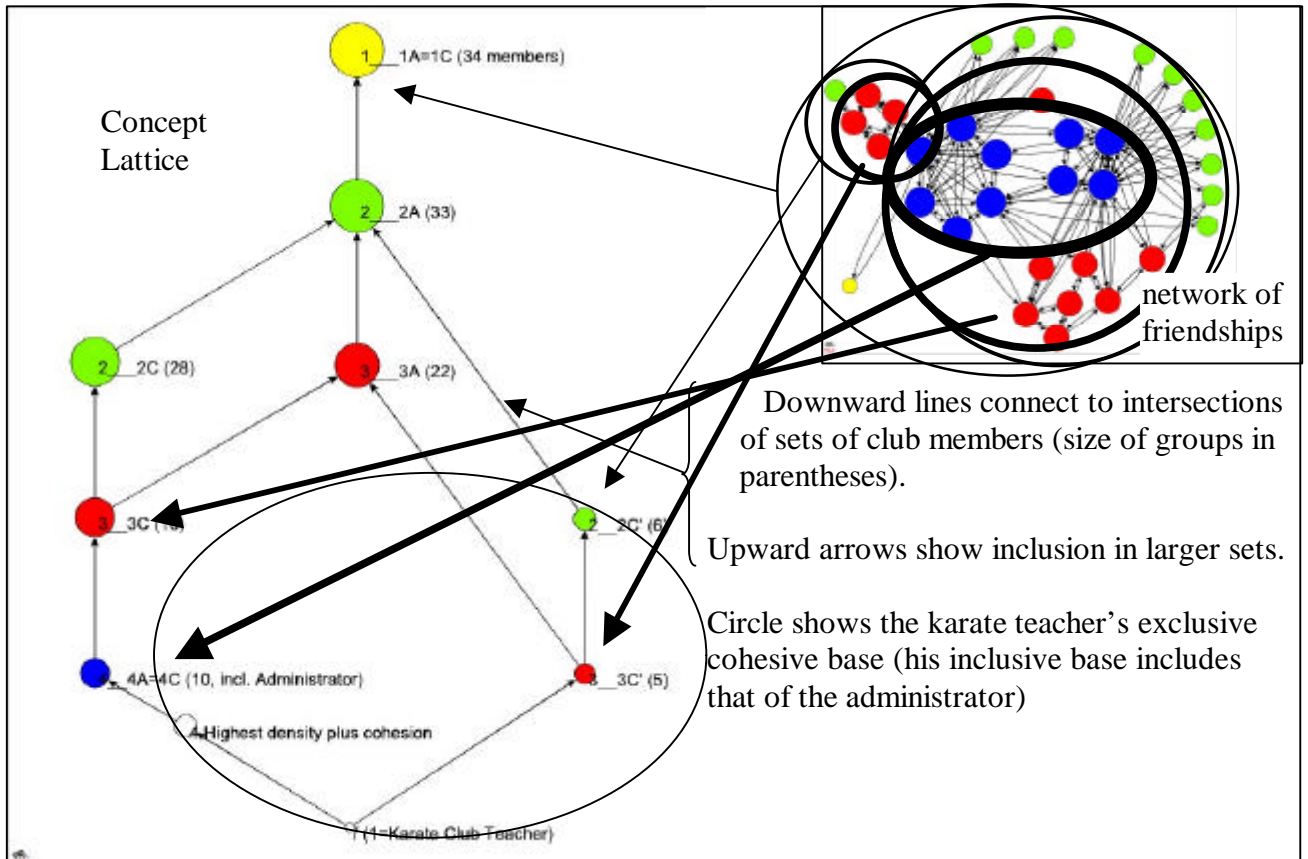
3/4.6 In the processes by which networks are generated – by the addition/deletion of actors and ties – in economic systems and markets, is there a relation between differences in the distributional scaling of these processes (exponential versus power-law, for example, as results of older-survivors-flourish versus rich-get-richer processes), type of market (level playing ground versus oligopoly), and different types of self-organizing distributed control?

**Problem Area 5: Distributive Transformation**, corresponding with ISCOM problem 6, *The long term*. The ISCOM project is focused on specific social transitions observed in European datasets, as well as between different archaohistorical regimes. Our project has developed complementary datasets on which to draw as exemplars for theoretical modeling and hypotheses testing that derive from ten long-term anthropological field sites: Tlaxcala and Tzintzuntzan field sites in Mexico[W1][W2][21], Scudder and Colson's Gwembe Tonga in Zambia, Brudner's Gailtal valley in Austria [B], Johansen's Turkish nomads[6][7], Stirling's (1998) Turkish village, Leach's Pul Eliya in Sri Lanka[2], Goodenough's Chuukese in Micronesia[20], Dorsey's Omaha in Nebraska, Mead's Pere Manus village. Where possible, the ethnographic field and census data is supplemented by archival data (Tlaxcala, Tzintzuntzan, Gailtal valley), and each dataset also contains extensive or complete genealogical datasets for entire communities, often supplemented by other social network data. Because of the time depth of these studies (from 40 to 500 years), it is possible to study social transformations and developmental processes in relation to network structure and dynamics.

In addition to longitudinal field site datasets developed in computerized form over the last 15 years as part of our "linkages" project (to which this is a successor project), we have archival or historical data on the following populations, over long time periods, with extensive network and attribute data (data sources or collaborators in parentheses):

1. American political elites, 17-18<sup>th</sup> century (White and undergrad REU Jon Sepe).
2. Nord-pas-de-Calais bourgeoisie, 19-20<sup>th</sup> century (White and Le Bras).
3. Mexican political elites, 20<sup>th</sup> century (Alcantara [17] dissertation 2000; Gil et al.1999).
4. Norfolk, England, local elites 18<sup>th</sup> c. (Bearman; and Fitzgerald [17] dissertation).
5. Public health networks and institutions in Paris, 19<sup>th</sup> century (Gribaudo).
6. Colonial Guatemalan elites, 18-19<sup>th</sup> century (Casasola [16] dissertation 2001).
7. Florentine elites, Italy, 13-15<sup>th</sup> century (Padgett 2001).
8. Qing Imperial Lineage, Beijing, 16-19<sup>th</sup> century (Lee and Feng 1999).

**VII. Developing Methods for the Integration and Extension of Network Results.** The proposed next stage of the research develops and applies a mathematical modeling framework as part of a general theoretical integration of network approaches as applied to a wide range of subjects in anthropology and ethnohistory. For example, the network structure used by White and Harary [9] to illustrate the methodology can be summarized in a new way (for easier integration with other approaches) using a concept lattice (Ganter and Wille 1999): Figure 2 shows all cohesive and adhesive blocks in a network of friendships (see inset) among karate club members (Zachary 1975a,b). The nodes in this lattice represent sets of individuals and their memberships in inclusive hierarchies of groups defined by cohesive and adhesive blocks in the network, some of which overlap – as indicated by the lowermost node of the lattice, in which the downward intersections are those among groups. Size of nodes in the lattice reflects the size of each group (those circled in the network diagram in the upper right inset), and upward arrows show inclusions of smaller groups in larger ones. To visualize the groups in this figure, take any node on the diagram and draw an oval that includes the node and all those linked to it by downward lines (inversely to arrows). Each of nine such groups includes the bottom node, representing the karate club teacher. Each group is labeled with a number that gives its node or edge connectivity, followed by A for an adhesive block or C for a cohesive block (in parentheses are the sizes of groups). There are four concentrically tighter adhesive blocks (1-2-3-4 in the A series), but two divergent hierarchies of cohesive blocks, each several layers deep (1C-2C-3C-4C and 1C-2C'-3C' in the two series). In this case 1A=1C(=1C') includes the entire group, which can be disconnected by removal of the teacher (hence its status as 1C for 1-cohesive) or by removal of the link between T and 12 (hence 1A for 1-adhesive).



**Figure 2: The concept lattice of cohesive and adhesive blocks of a network of friendships (inset) among karate club members**

The structure seen in Figure 2 is a concise display of the sociologically meaningful groups on the basis of their network ties.<sup>4</sup> By definition, a  $k$ -cohesive block is contained in a  $k$ -adhesive one, and the hierarchies of blocks are severely constrained by the fact that any two with connectivity  $k$  will have no more than  $k-1$  nodes in common.<sup>5</sup> Hence we can read from the figure that while 2C and 2C' intersect by downward lines at the lowermost node, their intersection can contain only a single node (the karate teacher). We can easily grasp from a correct reading that the teacher is the only person who is a member of all the groups and that his social support exceeds that of administrator, who belongs to 7 blocks but not to the densest 4-block within 4C nor to 3C'- 4C' (these are indexical of the teacher's autonomy, as they include students at a site not supervised by the administrator). This might help to explain why the teacher is the one who initiates a conflict with the administrator over his salary. White and Harary [9] also show how the group structure displayed in the figure (and in finer detail) predicts the lines of cleavage by which the club fragments into two parts. The dynamics of dropping ties when

<sup>4</sup> Concept lattices can also show clique structure (Freeman 1996) but cliques can only intersect, which makes it difficult to identify more inclusive groupings. The same is true for overlaps of group membership (Freeman and White 1993), which also fail to capture cohesiveness in large networks. The latter has been shown to have sociologically important predictive consequences for social classes, business alliances, ethnicity and political organization (Moody and White [9]).

<sup>5</sup> White and Harary explain how this is consistent with Menger's Theorem that  $k$  or more node-independent paths between two nodes implies they cannot be disconnected by removal of fewer than  $k$  nodes, and node removal removes edges while edge removal does not remove nodes.

members are forced to choose between leaders also play a role in prediction. This interplay between structural moments and dynamic effects of social interaction in predicting outcomes constitutes one of the main foci of this research.

Cohesive structures may apply not just to social networks but also to all kinds of networks (symbolic, material, multipartite), and we will experiment in the next research period with other types of networks using ethnographic materials from our case studies. What is exciting here is that the hierarchical nature of cohesion (with limited overlaps) is ideal to represent emergent properties of systems that are quasi-classificatory, with ‘exemplars’ of hierarchical elaborations of associated concepts, but that also contain ‘anomalies’ as crosscuts across categories. This takes us back to the debates of ethnoscience of the 60s and 70s but in an entirely new way, one that is open to new discoveries of emergent properties.

**Cohesive Groups, Cohesive Roles, Cohesive Blockmodels.** The first major methodological contribution of this project, in our previous NSF funding, was to effectively solve the problem of detecting and bounding groups in networks at different levels of cohesion, and in showing that this measure of cohesion (k-components; node connectivity) has broad predictive consequences for foundational questions in social systems ([9], [11]). A second contribution, that of the paragraph above, is in embedding levels of k-component cohesion in a concept lattice to get a coherent and precise description for network structures that are simultaneously hierarchical and overlapping. Three additional methodological innovations will be explored in the proposed research; to recapitulate:

1. **Cohesive blockmodeling.** Blockmodeling, one of the principal methods for identifying structural positions (structural or regular equivalence) in social (1-mode) or bipartite (2-mode) networks, suffer from the following defects. Methods based on structural equivalence are too strict (they equate only those with ties to the same others), and when relaxed to provide density parameter, suffer from the vagaries of how network densities are unevenly distributed in relation to potential structural positions. Methods based on regular equivalence are too loose, since they only require single-link ‘parallel’ lines of network transmissibility through successive blocks, and they are subject to the vagaries of unequal distributions of degree (number of edges) for different nodes relative to the blocking. We will investigate **conditional blockmodels** based on connectivity, which provide hierarchically stacked levels of robustness to the block structure of social roles, analogous to that found for social groups in our earlier work. The results of conditional blockmodeling will also fit very compactly into a **concept lattice** integration of research findings across different datasets. These blockmodels will provide precise structural contours to the role structure of networks, whether 1- or 2-mode, and will add precision to testing heuristic and predictive hypotheses in different datasets, as described above.

2. One useful feature of this methodological innovation is that for 2-mode network data (e.g., affiliation networks: individuals by groups), the same software that efficiently computes concept lattices for 2-mode data (Burmeister’s 1996 ConImp and Diagram programs) outputs a successor list that can be used to identify each of the k-component blocks.

3. A second feature is that 1-mode overlapping clique structures can be immediately embedded analytically in the lattice hierarchy of k-component blocks.

**VIII. Research Schedules and Deliverables.** Under the last NSF award, the PI, Consultant Harary and longitudinal ethnographer Lilyan Brudner conducted a series of training workshops to introduce the new methodologies for network analysis (especially the cohesion/adhesion methodology and the methods for longitudinal demographic and network analysis) in a variety of forums where we are carrying out research collaborations: the Institute of Ethnology at Cologne, the Systems Analysis group (IIMAS) at UNAM in Mexico, the Max Planck Institute for Demographic Studies at Rostok, the Ecole des Hautes Etudes en Science Sociales (EHESS) and the National Institute for Demographic Studies (INED) in Paris, the Santa Fe Institute for complexity studies, and the Sociology Departments at Columbia and Geneva. The structure of the current project is a different one, focusing now on the production of books

and new datasets from our longitudinal and other field sites to be made available to other researchers. To facilitate the completion of manuscripts, the PI has arranged a reduced-salary sabbatical for the spring quarters of 2003 and 2004 (and, if the grant is extended into a third year, 2005). This will allow an uninterrupted 6½ months each year for writing. The salary for the PI is thus not an additional summer salary, but a salary that compensates for the reduced salary (an option of the UC system that allows longer periods of sabbatical). While the topics of this research are intellectually far ranging, as the research progresses the publication strategy is to focus on case studies and well defined models in which we learn significant substantive findings that are applicable to a generalizing science.

One outcome will be the writing of a co-authored book with Harary, **Structural Models in EthnoSociology**, focusing on structural models for social networks, replete with quantitative case study examples from ethnographic field studies. Following the listing of structural models in Table A, the book will deal first with models for the emergence of social groups and their characteristics; then of the emergence of various kinds of economies of exchange, conflict and mediation; then that of specialized tasks, positions and analogical structures that are generated across multiple domains; the emergence of inequalities, and last the distributed transformations of social systems. A sequel, **Dynamic Models in EthnoSociology**, with Mark Newman of the Santa Fe Institute, is envisioned.

**Deliverable case studies**, in terms of book publications and documented datasets, include:

**Book 1: Network Cohesion among Turkish Nomads**, with Ulla Johansen.

**Book 2: Emergent Dualities: Segmentary Structure and the Balance Principle in Polynesian Kinship Networks**, with Michael Houseman (in revision for Cambridge Press).

**Book 3: Invisible Government: Belen, since the Revolution**; with Schnegg, Brudner & Nutini.

**Book 4: Cultural Kinetics: A House-system in an Austria Farming Village, 1511-2001** w/ Brudner.

**IX. Key Personnel and Training.** Frank Harary, who developed the mathematical foundations of **Graph Theory** (1969, in print), is key to project success, as in the previous round of NSF research. M.A. level anthropologist Paukszat, attracted by our workshops in Cologne, will do an Irvine Anthropology PhD while working on the project (funded for 2002 by the DFG). Her project tasks will include data analysis and co-authorships on the longitudinal field sites in addition to documenting datasets for web publication and making them operational for analysis. She will undertake rigorous training in longitudinal network analysis. Prof. van der Leeuw's participation as consultant is essential to expansion of the project to European field sites, and to applications to common problems involving modeling complex systems. Small research stipends will be available to graduate and undergraduate participants and trainees.

**X. Significance of the Research.** A measure of cohesion developed in the previous NSF grant was subjected to critical testing and found to have the predicted consequences for emergence of institutions such as social participation, adherence to social norms, and the formation of social classes, lines of segmentation, where conflicts occur at the boundaries of differentially cohesive groups, and distinctive patterns for occurrence of violence. In this research we combined our approach to cohesion – robust structure – with other network approaches to provide the basis for an integrated theory of network that can lead to understanding not only of static social structures and institutions, but of network dynamics that leads to both gradual sociocultural changes and punctuated social transformations. This integrated approach to large as well as small-scale studies of social networks provides a key ingredient to the development of longitudinal ethnographic as well as historical studies of social processes. Among these processes are the formation of social institutions critical to societal maintenance and development. By enhancing a grounded theoretical approach to anthropology and history, development and training in new methodology, archiving and analysis of cumulative databases, and publication of new grounded theoretical approaches, we hope to enhance the capabilities of anthropology and social sciences generally to engage with complex problems of contemporary social research.

**Project Publications of the Research Team:**A. Web and CD-ROM Publications

- [W1] White, Douglas R., Michael Schnegg, Lilyan Brudner. 1999. **The Invisible State: Radial Cohesion in Tlaxcala, Mexico.** <http://eclectic.ss.uci.edu/~drwhite/cases/decentralized.html>
- [W2] Kemper, Robert V., Eric Widmer, Douglas R. White. 2000. **From Tarascan Empire to Craft Production: A longitudinal research web-site (Tzintzuntzan, Mexico).** <http://eclectic.ss.uci.edu/~drwhite/tzintzun/> <http://www.santafe.edu/tarasco>
- [W3] White, Douglas R. 2000. **Computational Anthropology, Informatics and Related Sciences.** <http://eclectic.ss.uci.edu/~drwhite/center/cac.html>

B. Book Chapters, Books, and Articles

- [A] White, Douglas R. 1997. Structural Endogamy and the Graphe de Parenté. *Informatique, Mathématique et Sciences Humaines* 137:107-125.
- [B] Brudner, Lilyan A. and Douglas R. White. 1997. Class, Property and Structural Endogamy: Visualizing Networked Histories. *Theory and Society* 25:161-208.
- [1] White, Douglas R., Michael Schnegg, Lilyan A. Brudner and Hugo Nutini. 1999. Networked Integration: Multiple Connectivity and its Crosscutting Boundaries in Tlaxcalan Kinship and *Compadrazgo*. To appear in, Jorge Gil and Samuel Schmidt, eds. *Social Networks: Theory and Applications*. Mexico, D.F.: UNAM Press.
- [2] Houseman, Michael and Douglas R. White. 1998a. Network Mediation of Exchange Structures: Ambilateral Sidedness and Property Flows in Pul Eliya. In T. Schweizer and D. R. White, eds., *Kinship, Networks and Exchange*. Cambridge: Cambridge University Press. Pp.59-85.
- [3] --- 1998b. Taking Sides: Marriage Networks and Dravidian Kinship in Lowland South America. Pp. 214-243, in Maurice Godelier, Thomas Trautmann, and Franklin E. Tjon Sie Fat, eds., *Transformations of Kinship*. Smithsonian Institution Press.
- [3a] White, Douglas R. and Thomas Schweizer. 1998. Kinship, Property and Stratification in Rural Java. In T. Schweizer and D.R.White, eds., *Kinship, Networks and Exchange*. Cambridge: Cambridge University Press. Pp.36-8.
- [4] White, Douglas R., Vladimir Batagelj and Andrej Mrvar, 1999. Analyzing Large Kinship and Marriage Networks with Pgraph and Pajek, *Social Science Computer Review* 17:245-274.
- [5] White, Douglas R. 1999. Elementary Simulation of Marriage Systems. *Journal of Artificial Societies and Social Simulation* 2(3). <http://jasss.soc.surrey.ac.uk/2/3/5.html>
- [6] White, Douglas R., and Ulla Johansen. 2001. *An Introduction to Network Analysis of Genealogy and Politics: Social Dynamics in a Nomadic Society*. Altamira Press.
- [7] Johansen, Ulla, and Douglas R. White. In Press. Long-term Ethnography and the Collaborative Study of Social Dynamics in a Nomadic Clan in Southeastern Turkey, *Chronicling Cultures: Long-term Ethnographic Research*, eds. Robert V. Kemper and Anya Royce, Altamira Press.
- [8] Harary, Frank and Douglas R. White. 2001. P-Systems: A Structural Model for Kinship Studies. *Connections* 24(2):15-25, journal of the International Network for Social Network Analysis.

- [9] White, Douglas R., and Frank Harary. 2001. The Cohesiveness of Blocks in Social Networks: Connectivity and Conditional Density. *Sociological Methodology* 31 (2001). London: Blackwell (for the American Sociological Association).
- [10] White, Douglas R., and Frank Harary. In Press. Collective Geodesics and Co-evolution: A Graph Theoretic Model. *Advances in Complex Systems*.3.
- [11] Moody, James, and Douglas R. White. In review. Social Cohesion and Embeddedness: A Hierarchical Conception of Social Groups. *Santa Fe Institute Working Paper* 00-08-049, <http://www.santafe.edu/sfi/publications/Working-Papers/00-08-049.pdf>.
- [12] White, Douglas R., and Mark Newman. In review. A Fast Algorithm for Node-Independent Paths. *Social Networks*.
- [13] Powell, Walter W., Douglas R. White, Kenneth W. Koput and Jason Owen-Smith. In process. Evolution of a Science-Based Industry: Dynamic Analyses and Network Visualization of Biotechnology, for submittal to *American Journal of Sociology*.
- [14] White, Douglas R., Michael Houseman. In process. Sidedness, 60 Million Strong: Where exceptions make the rules. American Anthropological Association Annual Meeting 2001. Washington, D.C.
- [15] White, Douglas R. In process Emergence, transformation and decay in socio-natural systems. In *Emergence, Transformation and Decay in Socio-Natural Systems*, eds. Sander van der Leeuw, Uno Svedin, Tim Kohler, Dwight Read.
- C. Student Dissertations and Articles
- [16] Casasola, Silvia, 2001. *Prominence, Local Power and Family Networks in Santiago de Guatemala: 1630 –1830*. Ph.D. Dissertation, School of Social Sciences, Irvine (Linton Freeman, Chair).
- [17] Alcántara-Valverde, Narda. 2000. *Kinship and Friendship Networks in Mexican Politics: Between Elite Interlocking and Faction Formation*. Ph.D. Dissertation, School of Social Sciences, Irvine (Douglas R. White, Chair).
- [18] Casasola, Silvia, and Narda Alcántara. 1999. Elite Family Networks in 18<sup>th</sup> Century Guatemala. To appear in, Jorge Gil and Samuel Schmidt, eds. *Social Networks: Theory and Applications*.
- [19] Fitzgerald, William, and Douglas R. White. 1998. Class Differentiation and Structural Endogamy in the Bevis Marks Synagogue, London. Manuscript.
- [20] Skyhorse, Patricia. 1999. Adoption as a Strategy on a Chuukese Atoll. *The History of the Family* 3:429-439 (also thesis in preparation, Douglas R. White, Co-Chair).
- D. Project Postdoc Collaborations
- [21] Widmer, Eric, Douglas R. White and Robert van Kemper. 2001. Structural Endogamy and Labor Migration in Tzintzuntzan, Michoacan. Manuscript. University of California, Irvine.
- [22] Smith, James, and Douglas R. White. 2001. Implicational Structures in the Industrial Division of Labor. Manuscript. University of California, Irvine.

**References CITED**

- Albert, Reka, and Albert-Laszlo Barabasi. 2001. Statistical mechanics of complex networks.  
submitted to *Reviews of Modern Physics*.
- Burmeister, Peter. 1996. Formal concept analysis with ConImp: An introduction to the basic features. Darmstadt: TH Darmstadt.
- Berkowitz, Stephen D. 1982. *An Introduction to Structural Analysis: The Network Approach to Social Research*. Toronto: Butterworth.
- Burt, Ronald. 1982. *Toward a Structural Theory of Action*. New York: Academic Press.
- Fauconnier, Gilles, and Mark Turner, 2000, *The Way We Think*. UCSD: CogSci.
- Freeman, Linton C. 1979. Centrality in social networks: Conceptual clarification. *Social Networks* 1:215-39.
- Freeman, Linton. 1996. Cliques, Galois Lattices, and the Structure of Human Social Groups. *Social Networks* 18:173-187.
- Freeman, Linton and Douglas R. White. 1993, Using Galois Lattices to Represent Network Data. *Sociological Methodology* 1993, pp. 127-146, Peter Marsden, ed.
- Ganter, Bernard, and Rudolf Wille. 1999. *Formal Concept Analysis: Mathematical Foundations*. New York: Springer Verlag.
- Gil Mendieta, Jorge, Samuel Schmidt, Jorge Castro, and Alejandro Ruiz. 1999, *La Red Política de México: modelación y análisis por medio de la teoría de grafos*. México, D.F.: IIMAS, Universidad Nacional Autónoma de México. Data Base REDMEX.
- Gladwell, Malcolm. 2000. *The Tipping Point*. Boston: Little Brown and Company.
- Goodenough, Ward, 1963. Chapter 10, Forecasting Social Change, *Cooperation in Change*. New York: Russell Sage.
- Grannis, Richard. 1998. The Importance of Trivial Streets: Residential Streets and Residential Segregation. *American Journal of Sociology* 103:1530-64.
- Gregory, Chris A. 1982. *Gifts and Commodities*. New York: Academic Press.
- Harary, Frank. 1953. On the notion of balance in a signed graph. *Michigan Mathematical Journal* 2:143-46.
- Harary, Frank. 1984. Conditional Colorability. *Graph Theory Singapore 1983*. Lecture Notes in Mathematics 1073:127-36.
- Harary, Frank and M.F. Batell. 1981. What is a system? *Social Networks* 3 (1981) 29-40.
- Hofstadter, Douglas R., Daniel C. Dennett, Doug Hofstadter. 1985. *The Mind's I* New York: Bantam Books
- Hutchins, Edwin. 1996. *Cognition in the Wild*. Cambridge: MIT Press.
- Iberall, Arthur, and Harry Soodak. 1978. Physical basis for complex systems – Some propositions relating levels of organization. *Collective Phenomena* 3:9-28.
- Lee, James, and Wang Feng. 1999. *One Quarter of Humanity: Malthusian Mythologies and Chinese Realities, 1700--2000*, Harvard University Press,
- Lorrain, François. 1974. Social structural, social classification, and the logic of analogy. In Paul Ballonoff, ed., *Mathematical Models of Social and Cognitive Structures*. Urbana: University of Illinois Press.

- Lorrain, François, and H.C.White. 1981. The structural equivalence of individuals in social networks. *Journal of Mathematical Sociology* 1:49-80
- Mitchell, J Clyde (ed.). 1969. *Social Networks in Urban Situations*. Manchester: Manchester University Press.
- Moore, Alexander. 1998. *Cultural Anthropology: The Field Study of Human Beings*. San Diego: Collegiate Press.
- Mullins, Nicholas. 1973. *Theories and Theory Groups in Contemporary American Sociology*. New York: Harper and Row.
- Oeser , O. A., and Frank Harary, 1964. A Mathematical Model for Structural Role Theory, II, *Human Relations* 17: 3-17.
- .1979. Role Structures: A description in Terms of Graph Theory, in *Role Theory: Concepts and Research*, B. J. Biddle, Ed. New York: Robert E. Krieger Publishing Company, 1979, pp. 92-102.
- Padgett, John. 2001. Organizational Genesis, Identity and Control: The Transformation of Banking in Renaissance Florence. In, *Networks and Markets*, James E. Rauch and Alessandra Casella, eds. New York, NY: Russell Sage Foundation.
- Padgett, John, and Christopher J. Ansell. 1993. Robust Action and the Rise of the Medici. *American Journal of Sociology* 98:1259-1319
- Reitz, Karl and Douglas R. White. 1989. Rethinking the Role Concept: Homomorphisms on Social Networks, pp. 429-488 in *Research Methods in Social Network Analysis*. L. C. Freeman, D. R. White, A. K. Romney eds., George Mason Press
- Scott, John. 1991. *Social Network Analysis*. London: Sage.
- Stirling, Paul. 1998. *45 years in the Turkish Village*. <http://lucy.ukc.ac.uk/Stirling>
- Van der Leeuw et al. 1998. *Archaeomedes: Archéologues et géographes en vallée du Rhône*. Paris: Anthropos.
- Wasserman, Stanley and Katherine Faust. 1994. *Social Network Analysis: Methods and Applications*. Cambridge: Cambridge University Press.
- West, Geoffrey B. 1999. The Origin of Universal Scaling Laws in Biology. *Physica A* 263: 104-120.
- Wellman, Barry. 2000. Networking Network Analysts: How INSNA (the International Network for Social Network Analysis) Came to Be. *Connections* 23(1): 1-31.
- White, Douglas R. 1969. *Networks and Cooperation: Decision Making among North American Indians*. Ann Arbor, MI: Dissertation Reprints.
- White, Douglas R., M.Burton, and L.Brudner. 1977. Entailment Theory and Method: A Cross-Cultural Analysis of the Sexual Division of Labor. *Behavior Science Research* 12:1-24
- White, Douglas R. and Karl P. Reitz,.1983. Graph and Semigroup Homomorphisms. *Social Networks* 5:193-234.
- White, Harrison C. 1992 *Identity and Control: A Structural Theory of Social Action*. Princeton: Princeton University Press.
- White, Harrison C., Scott A. Boorman, and Ronald L. Breiger. 1976. Social structures from multiple networks, I. Blockmodels of roles and positions. *American Journal of Sociology* 81:730-799

Zachary, Wayne W. 1975. *The Cybernetics of Conflict in a Small Group: An Information Flow Model*. Unpublished M.A. Thesis, Department of Anthropology, Temple University.  
 —. 1977. An Information Flow Model for Conflict and Fission in Small Groups. *Journal of Anthropological Research* 33:452-73.

**APPENDIX 1: LITERATURE STREAMS**

Concepts and some (numbered) pattern principles	Network Aspects	Network Measures of Structure	Methods Authors	Classics
<b>A Solidarity</b>	Intragroup	<b>Pattern 1</b>		
Group (1)	A' <b>Cohesion</b>	k-connectedness	Harary&D.White	Lewin
Shared culture	A'' Consensus	1-dim. covariance	Romney&Batch.	Tylor
Moral topologies	A''' Affect	balance theorems	Harary, Davis	Heider
<b>B Soc.Relations</b>	Intergroup	<b>Pattern 2</b>		
Economy (2)	B' <b>Exchange</b>	graph homomorp.	Harary	
Amoral econ	B'' Conflict	graph homomorp.	Harary	Simmel, Gluckman
Law	B''' Mediation	cond. homomorp.	Simmel	Lévi-Strauss, Nadel
<b>C Specialization</b>	Activity	<b>Patterns 3 &amp; 5</b>		
Position (3)	C' <b>Str. Equiv.</b>	str. homomorph.	H.White	Homans
Analogy (3)	C'' <b>Role Equiv.</b>	reg. homomorph., concept lattice	D.White&Reitz Ganter & Wille	Merton, Goodenough
Specialty (5)	C''' <b>Div of Labor</b>	task alloc.homom	Oeser &Harary	Durkheim
<b>D Inequality</b>	Ordination	<b>Pattern 4</b>		
Centrality (4)	D' Influence	Betweenness	Freeman	Bavelas
Sup.authority	D'' Power	triadic interlocks	J.Davis, D.White	Nadel
Hierarchy	D''' Authority	levels measure	Reitz	Lewin
<b>E Redistributed Transformation</b>		<b>Pattern 6</b>		

**Table A: Networks Concepts in Domains of Social Theory**