Network Analysis and Social Dynamics

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Abstract

Network analysis, an area of mathematical sociology and anthropology crucial to the linking of theory and observation, developed dramatically in recent decades. Methodological developments are recounted that make possible a theoretical synthesis of social network theory in relation to understanding of social dynamics.

The past 35 years saw a massive development of tools for network analysis, spurred by anthropologist Clyde Mitchell and sociologist Harrison White, 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.[1] Still, even in sociology, the development of methodology (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. My discussion will focus on application of explanatory frameworks in an emergent network theory as used by research collaborators (including myself and graph theorist Frank Harary) in a series of long-term field sites. The aspects of the project I will discuss are integrated through a NSF grant in which I am PI and Harary is the consultant.[2]

1 Conceptual Perspective.

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 parameters or measures). Network theory, in so doing, attempts to explicate 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. **Table 1** shows some of the network concepts applicable to domains of social theory. Coupled with the modeling of fundamental interaction processes, they are designed to allow for structural emergents to be measured and to test hypotheses about processes, interactions and outcomes.

Concepts and some numbered principles	Network Aspects	Measures of Network Structure	Methods Authors	Classics
A Solidarity	Intragroup	**Pattern 1**		
Group (1)	A’ **Cohesion**	k-connectedness	Harary & D.White	Lewin
Culture	A” Consensus	1-dimensional covariance	Romney & Batchelder	Tylor
Moral econ.	A’’’ Affect	k-balance	Harary, Davis	Heider
B Soc.Relations	Intergroup	**Pattern 2**		
Economy (2)	B’ **Exchange**	graph homomorphism	Harary	
Amoral econ	B” Conflict	graph homomorphism	Harary	Simmel,Coser, Gluckman
Law	B”’ Mediation	Conditional homomorph.	Simmel	Lévi-Strauss, Nadel
C Specialization	Activity	**Patterns 3-4**		
Position (3)	C’ **Str. Equiv.**	Structural homomorph.	H.White	Homans
Analogy (3)		regular. homomorph., overlap lattice	White&Reitz Ganter & Wille	Merton, Goodenough
Specialty (4)	C”’ **Div of Labor**	task allocation homomorph.	Oeser &Harary	Durkheim
D Inequality	Ordination	**Pattern 5**		
Centrality (5)	D’ Influence	betweenness	Freeman	Bavelas
Supervisory authority	D” Power	triadic interlock	J.Davis, D.White	Nadel
Hierarchy	D”’ Authority	levels measure	Reitz	Lewin
E Redistributed Transformation		**Pattern 6**		

Table 1: Networks Concepts in the Literature Streams of Social Theory

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[1] 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.

[2] NSF grant #BCS-9978282, “Longitudinal Network Studies and Predictive Cohesion Theory,” 1999-2001.

The middle column in Table 1 lists the typical kind of mathematical model used for a particular concept. As in the Table, Frank Harary (a principal logician of social networks and founder of the mathematical field of graph theory) and I myself as project PI and consultant, respectively, are heavily involved in the development of such models. How these different models relate to one another is a current focus of our research interest. How can they be used in combination both to build a general framework of interrelated models useful for formulating network theory, and to help test some of the hypotheses derived from network theory?

2 Dynamics

Figure 1 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 that are discussed below.

3 Potentials for Integration of Theory and Measurement

3.1 The Dynamical Evolution of Coherence among Formal Patterns.

One of the goals of the present research is to develop a process model of relational coherence: how do elements assort and then cohere and synchronize in a (complex) social system (see also Watts 1999a,b)? A central heuristic construct for us is the use of "structural coherence" 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. Our guiding hypothesis 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 1, as detailed in Table 2, 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:

3.1.1 Structural catalysis

Catalysis is regulation of processes through slowing down or speeding up their temporal rates or contracting/diffusing their temporal scales. Structural catalysis refers to the emergence of shared perception, language, and auto-regulatory communication, which requires or presupposes the emergence of a perceptible formal pattern of a social field such as the four pattern principles in networks of relations. E.g.: **Pattern 1** (**cohesion** measured by multiconnectivity, White and Harary 2001) is fundamental to the grouping principle. **Pattern 2** (**balance** measured within partitions of connected networks, Harary 1953) is an essential basis for understanding exchange (Gregory 1982 H.White 2002). **Pattern 3** (**positional equivalence and analogy**, Lorrain 1974, Lorrain and White 1981) is fundamental to thought, narrative structure, the 'situatedness' of intelligibility (Hofstadter et al. 1985, and Fauconnier 1997), and the recognition process in social identity, role, and attributed motivation and reputation (H.White 1992). **Pattern 4** (**specialization and division of labor**) is the recognized basis of formal organizations, office holding and the allocation of responsibility. **Pattern 5** (**centralization**, Freeman 1979) is one of the modalites (see below) by which other patterns are integrated.

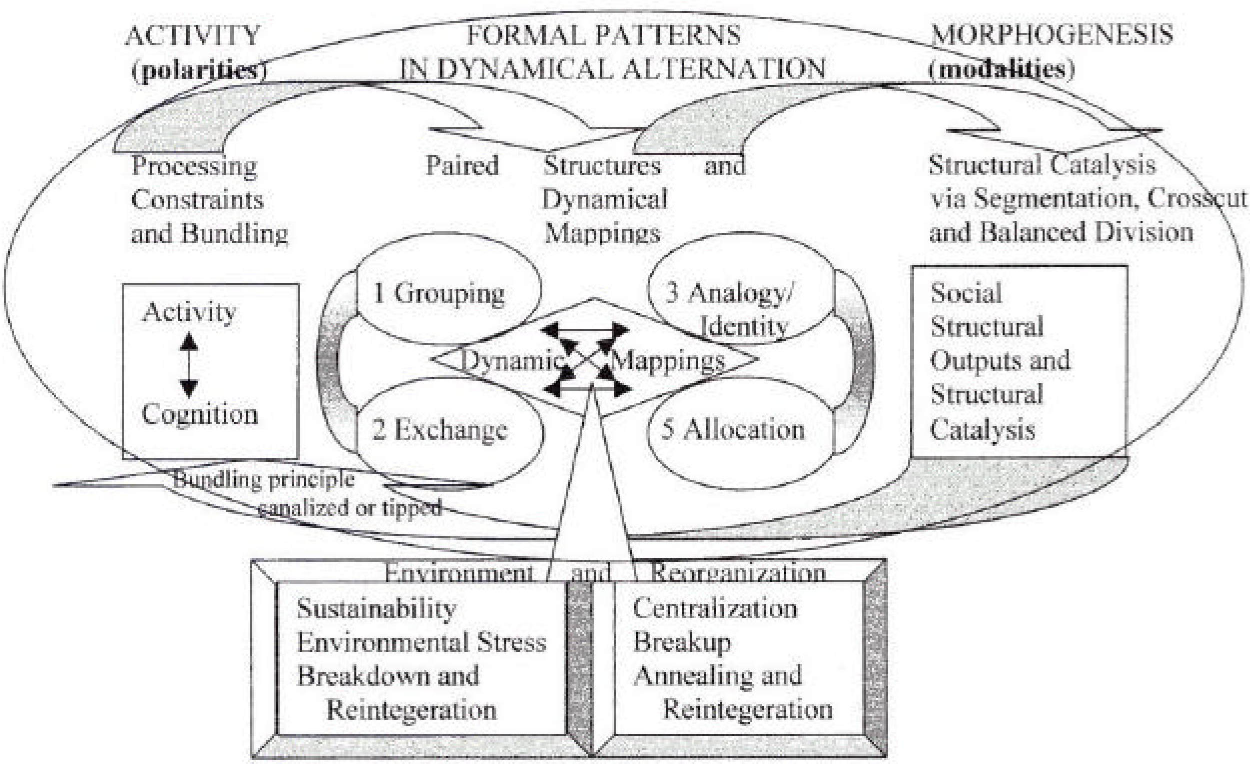

Figure 1: Process Model of Relational Coherence between Statics and Dynamics

3.1.2 Tipping points

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 are distributed across formal structural patterns (and functions) is dramatically altered. **Pattern 6** (**distributed transformation**) is 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.

3.1.3 Interdependence

Interdependence among the four pattern principles in Table 2 occurs in **pairings** (see Figure 1): the grouping logic of relational solidarity is paired with an exchange logic between groups (which are not however automatically solidarity); and the analogous-positions logic in a behavioral system is paired with the formal or organizational activity allocation logic (but these two logics are not necessarily well coordinated). Pairing principles come out of balance theory as a principle of structural cohesion.

3.1.4 Modalities

Modalities by which the pairs of pattern principles (1 and 2; 3 and 4) are articulated are 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.

3.1.5 Morphogenesis

Morphogenesis as an aspect of coherence results from the fact that the segmentary versus crosscut patterns, among others, have very different and very severe implications and consequences (they strongly affect the path dependence of evolution and historical trajectories). 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. Grannis (1998) established the converse 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.

3.1.6 Bundling

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 the 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:

3.1.7 Polarity reduction

Polarity reduction occurs between activity and cognition, and between expressive and task behavior –one has only see the films of Alan Lomax (1976) 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).

3.1.8 Structural catalysis

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 4) require synchronization through structural catalysis of principles of recruitment, succession and inheritance with activity and auto regulation processes.

1. 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.
2. The two sets of pattern principles (1&2 vs 3&4) 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.
3. 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 5**). 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.
4. In fluctuating environmental interactions, coherent systems may breakup, and their resilient components reconfigure in **redistributed transformations** (**Pattern 6**).

3.2 Measurement: Detecting Patterns in Networks

Cohesive blocking is a methodology recently refined by White and Harary (2001) 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. 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). Nodes versus 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 (2001) give a fast algorithm to compute all such paths for large networks. The predictive consequences of measures of cohesion or adhesion for substantive variables in ethnographic and sociological studies have been shown for social class (Brudner and White 1997), leadership and group solidarity (Johansen and White 2002), group segmentation in conflict (White and Harary 2001), and attachment to school (Moody and White 2001), for example.

As shown in Table 2, 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 ed by similar principles) that goes in the opposite direction to observe the organization of equivalence sets when connections are limited to those *between* sets. Homomorphisms such as colorings are complementary to lattice structures (such as cohesive blocking hierarchies, which do not result in partitions) as principles in graph theory. Like colorings (and unlike cohesive blocks), block modeling 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. 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 2 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). 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.

	Pattern 1	**Pattern 2**	**Pattern 3**	**Pattern 4**
	Cohesive Blocks	**Graph Homomorphisms**	**Blockmodel (Informal Roles)**	**Role Structure (Formal Roles)**
Coherence	Group Blocking	Exchange Opposition (Balance, Clustering)	Analogous Positions	Allocated Positions
Relations	Multiple	Single	Multiple	Tripartite*
--Within Sets	Connectivity	Disconnection	Similarity	HxH social PxP formal TxT task seq.
--Between Sets	Inclusion	Connection	Similarity	Bipartite maps
Structure	Hierarchy	Partition	Partition	H/T=H/P x P/T
Equivalence	(None:overlap)	Coloring	Regular	Multiple
Overlap	Minimum	None	None	
Reflexivity	n.a.	Disallowed	Allowed	

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

Table 2: Formal Patterns in Networks (as elements in the study of coherence)

4 Some problems being investigated

***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?

***Problem 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 (White and Harary 2001). 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).

Problems 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 is that sequential sets of structurally equivalent nodes – connected to the same others – will tend 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 (regular equivalence) models where the mapping of the template onto a new domain preserves the structure of linkages (White and Reitz 1983). 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 related to the distribution of capacities of individual nodes and channels in a network in relation 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 (2001), using this 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).

***Problem 5*: Distributive Transformation**, the long term: 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.

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