Longitudinal Social Network Studies and Predictive Social Cohesion Theory

The present proposal links researchers from different countries working on projects concerned with developing a new scientific theory of social cohesion using novel means of representation and analysis of large-scale network structures. The goal is a rigorous scientific theory of dynamic social evolution not in terms of stages but open ended networked social processes. Subprojects and their orientations fall under the following headings: (l) a theory of dynamic evolutionary processes of stabilization and change in modern and traditional social structure including the emergence of institutions and differences in individual participation in institutional activities; (2) study of kinship, marriage, and exchange with emphasis on cooperation, competition, and material flows that affect class formation and wealth distribution; (3) studies of social class; and (4) studies of elites. Many of these studies are historically embedded community and regional studies, including new studies such as those on co-emergence of state and capital markets in Florence (with John Padgett) or networks of elites in Mexico (Jorge Gil). Another purpose of the proposed grant is to further cooperation in the sharing of methods and of theoretical strategies on projects directly related to anthropology, including dimensions commonly absent from purely sociological network studies. This general project is one that seeks to combine cultural and structural approaches, the better to understand aspects of network structure as important intervening variables in the transmission or shift in cultural patterns under diverse economic and historical conditions.

I. Representation and Analysis of Network Structure

The present orientation is derived from social network, anthropological and sociological theory, and seeks to understand the central influence of networked processes on societies, cultural systems and groups, using analytic methods of networks and ethnography. It derives from the PI's long experience in working with cross-cultural and comparative network data. Network studies build their theoretical findings on network representations of social interaction and accurate ways of representing various aspects of social structure. This includes new ways of representing kin and marriage systems, computer visualization techniques, and devising more rigorous ways to represent relations than possible using more traditional genealogical charts. These allow us to explore simultaneously personal networks versus the wider multiplicity of an extended view of networks of networks. We build on methods developed for P-graph analysis (see p.13), which capture central elements in the structure and changing patterns in linkages between families in large-scale communities. Use of new concepts in graph theory for the study of cohesion (bicomponents, p.5) provides exact models for measuring network effects on actors or shaping actors' behavior in numerous dimensions of social life. An advantage of this network approach is that even in large populations it provides exact boundary conditions for social groups hypothesized to be cohesive. In exploring such structures we can specify fundamental aspects of how and when people form or relink relations and understand how such formations relate to the expected or emergent institutional forms of a population. Shifting boundaries and within-boundary densities are compared through time and hypotheses can be compared across cases about within-boundary sizes and densities that trigger structural transformations. Our studies include concern both with cultural schema of networks and social relations as well as relations between individuals and their behavioral dimensions. From such material we study not only network boundaries, but also the structure and direction of relations, shifts in the nature of ties, and the structure of relations in multiple network systems.

The capacity to perform such analyses and to conceptualize them at the most general level has been the result from the l970s forward of collaborations between sociologists, anthropologists, mathematicians and others. The PI has been involved with this aspect of development of representation systems for the last two decades, working with others on various projects in the United States and Europe, especially France and Germany and with considerable support from the Minister of Technology in France and through the Humboldt Foundation in Germany. Many of the models of the actual studies and analytic techniques for these data are readily available on the web site of the PI.

II. Theoretical and Conceptual Background

Society, as a network of networks, consists of processes involving people and the material and symbolic elements networked with each other and their environment. Some of the central questions of this proposal can be addressed in terms of such networks. Why do people coexist in *groups* in the first place? In network terms, how do cohesive *components* arise that operate as emergent units in organizing human activities? In defining a relatively stable group that has some stable or predictable features vis-à-vis other groups, what makes a set of interpersonal linkages *cohesive*? What makes an interpersonal *contact*, which may be coincidental, into a *connection* in a cohesive network, a network in which the structure and dynamics of connections have important consequences for social, economic or political outcomes? What is it that makes a *network* cohesive in the sense that it affects institutional and social-cultural arrangements? What are some of the predictable *consequences* of network cohesion?

The key conception in this project – successfully tested in six of our longitudinal case studies – is that it is not simply *single connections* that count in having "cohesive effects" but the way that connections are redundantly or mutually embedded and reinforced in robust aggregations in the circuitry of the network. In a series of links cumulating over time, such circuitry is not only clustered in locally dense aggregations but through the redundancy and reinforcement properties of multiple independent pathways that form robust feedback and self-reinforcing circuits and connect smaller and denser clusters into larger cohesive units.

This project will test a series of new theoretical models concerning social networks and group dynamics, particularly the new conception and methodology of how to bound or frame *in network terms* the contribution of social and cultural capital and their role in social and institutional change. The project will develop for broader use a sharable database of worldwide anthropological and historical case studies. These studies analyze existing data on human groups, including large populations in which we observe internal and outside links and internally linked or overlapping groups, sometimes numbering in the hundreds. In the past five years, and drawing from earlier field studies, the PI has studied large-scale human social organization by focusing on social network structure and dynamics, typically at the level of communities or stratified populations such as classes or elite groups. The principal focus is on networks of concrete linkages between individuals and concrete transactions such as the transfer of resources. Many of these transactions are symbolically coded as involving individual rights in the corporate assets of groups or in terms of relations of exchange. Cultural self-conceptions of groups have material effects in governing how and which transactions are performed. Study of these effects has been the focus of theories of social exchange. The objective here, however, is to get to a level of analysis underlying groups in the aggregate into the processes of interpersonal relations that govern their formation and dissolution. How do interactive processes – including decentralized social interaction – lead to different social, cultural, institutional, and group configurations?

The present project offers a distinctive contribution to the rapid evolution of network analysis since the 1950s (summarized methodologically in **Wasserman and Faust** 1994), one that is of significance both for social theory and applied research. It provides a novel means of connecting micro-analysis and theories of the middle range with testable hypotheses at the macro level. Concepts of cohesion, in spite of decades of network research, are still defined in ways that, by stressing high *density* of ties, are applicable only to relatively small groups. Hence in the study of social class, elites, marriage systems, or societal scale social organization, the older tools of networks research are incapable of formulating and detecting patterns of large-scale network or group cohesion. Even the blockmodeling of abstract patterns of "roles" in social networks – a literature to which the PI has also contributed a generalized methodology better suited to community level studies – is no substitute for the study of more delocalized patterns of cohesion.

Elite studies conducted by network methods, for example (e.g. **Knoke** 1990), identify local clusters within connected networks of low density and conclude that large-scale cohesive groups are absent, hence they can have no structural effects. As a result of a methodological bias, these studies are forced to support a pluralist model of interest groups (with attendant problems of identifying the bases of group affiliation in rational choice) rather than one of emergent groups and influences, more consistent with what is known today about network criticalities in influence patterns. Studies of corporate interlocks, as for example in **Burt** (1982,1983), raise the possibility of oligopolistic practices. But because what is measured as cohesive subgroups are localized and locally densified clusters of actors or relations, these studies do not investigate the effects of more delocalized or decentralized forms of cohesion. The problem of "network externalities" in economics and institutional economic history largely surfaces only under the narrowest conceptions of the interdependencies of complex technological interfaces, not the social interfaces among human actors.

The same is true in the study of social class. Even in the best of network studies of entire communities (e.g., **Laumann** 1973), the methodology produces a necessarily pluralistic interpretation of interlinked but only locally cohesive subgroups, with "class" as either an analytic construct or a cognitive mapping by actors rather than a potentially cohesive group with boundary criteria that are predictive of forms of cooperative social action concerted on a larger scale. The only "organizations" that are held to count are the formal or corporate organizations. The present project focuses on more delocalized patterns of large-scale cohesion, using new concepts of cohesion that the PI has developed, but consistent with **Tilly**'s (1998) claim:

> "that an account of how transactions clump into social ties, social ties concatenate into social networks, and existing networks constrain solutions of organizational problems clarifies the creation, maintenance and change of categorical inequality."

In the study of marriage systems the situation is similar. We have on the one hand a set of anthropologists and social scientists who argue for society and social structure as a "system of rules," but behavioral patterns in network studies of marriage are either taken to be "too complicated" to study or understand, or else are analyzed in terms of small-scale or only locally cohesive groups. What is missing?

> "The merit of studying networks of actual social relations lies in the attention this draws to the frequency with which idealized structural components stressed by the structural-functionalists – such as kinship, political, religious, and economic subgroups – are *ignored* in the daily interactions of people. Network analysis is thus to be seen as a solvent for the boundaries of these observer-defined and overly reified groups…" (Laumann, Marsden and Prensky 1992:62).

The studies in this proposal focus on how group cohesiveness – in production, reproduction and exchange – is concretely grounded in networked connections. Our study is of large-scale networks, which are typically of low density. The hypotheses that follow the sections below on sample, methodology and measurement of large-scale cohesion, concern the relation of a theory of social cohesion to problems of social class, elites, marriage systems, and large-scale social organization generally. After the general framework of the projects is discussed, I show how our existing evidence fits a number of hypotheses using the core measures and methodological conceptions. I also look at tests of our structural models of cohesion against other variables associated with cohesion in large groups, such as operational criteria for social solidarity (as in Lindenberg 1998) being developed in the reemergent group dynamics tradition. There is strong preliminary support both for the general and many of the specific hypotheses, meriting further study.

III. Network Analysis Sample: Sources, Size, Quality

The database consists of 11 longitudinal and 9 potential restudy fieldsites by ethnographers, plus 16 historical studies from archival or published sources – the first time such as sample has been assembled with fully computerized data. The planning for the longitudinal field study sample was funded by Wenner-Gren and brought together in 1986 many of the anthropologists engaged in such studies (Foster 1979) into a cooperative "Linkages" project. An NSF project in 1987-89 for the Gwembe Tonga fieldsite funded development of a prototype methodology. Funding for internationally collaborative aspects of the project were funded by a 1993-95 NSF grant, "Network Analysis of Kinship, Social Transmission and Exchange: Cooperative Research at UCI, UNI Cologne, CNRS Paris," and by the A. von Humboldt Stiftung for the PI and its Transatlantic Cooperative Program. Mellon Grants in Anthropology and Demography funded work in 1995-96 with James Lee on the Qing historical archives and in 1997-99 with Robert Kemper and Eric Widmer on the Tzintzuntzan field site. Table 1 shows some of the characteristics of the sample as listed and classified in Table 2.

Data Source	A	B	C	D	Totals	**Data Quality**	A	B	C	D	Totals	**Data Status**	A	B	C	D	Totals
FW Fieldwork	1	8	1		10	Ex Excellent	6	9	1	2	18	Co Computerized	4	7	4	6	21
FWL Longitudinal	4	5	1		10	VG Very good	1		3	3	7	Co* Computerized and completed	2	3	1	1	7
Historically based:						Gd Good	1	3	2	3	9						
AR Archives	2		2	5	9	Po Poor (being Restudied)		1			1	C2 Computerized and offered (C2*)		1			1
BK Book(s)	1		2	3	6								1				1
MX Mixed				1	1	Gr Groups				1	1	IP In Process	1	2	1	2	6
Totals	8	13	6	9	36	Totals	8	13	6	9	36	Totals	8	13	6	9	36

Table 1: Characteristics of the Longitudinal / Historical Sample (by Type of Study: A=Cohesion, B=Marriage Systems, C=Class, D=Elites)

The median sample size of our studies (excluding one pilot case of a corporate interlock study using a mixture of our methods and those of Breiger) is 2,800 marriages, or upwards of 5,000 individuals, with an upper range of 50,000 (ca. 90,000 individuals). How is it possible to do network analysis on such large populations, and are the data of sufficient quality to support such analyses? Only in the last 12 months have such large-scale network analyses become possible (and now routine), thanks to the work of the PI (discussed below) and the computer science team of Batagelj and Mrvar (1997). The principal network that we analyze at a population scale is that of kinship and marriage. The quality of such data depends upon family reconstruction from census and archival sources, which is a standard technique in the historical sciences, and upon genealogical interviews or linked censuses, which are standard techniques in ethnographic research. Ratings of data quality by the PI, in Tables 1 and 2, show a judgment of excellent data quality in half the studies, and very good or good in all but one case (rated "poor" because of population disruption, but being restudied to improve the data base). These cases are selected from a larger set of 150 case studies to be among the best that are available, given regional representation, for possible longitudinal studies of human populations. The ten ethnographic longitudinal studies include one of the most extensive longitudinal field studies carried out in Europe (Brudner 1969, Brudner and White 1997), two studies – one of a nomadic and another of a village group in the same area – by leading ethnographers of Turkey (Stirling 1998; see also Johanson and White 1998), two classic studies of Gwembe Tonga villages (ethnographers Colson and Scudder), two Mexican villages (studied separately by Foster and Kemper and by White, Brudner and Nutini), Goodenough's study of the Chuukese in Micronesia, Mead's computerized database for Pere village, Manus, and Chagnon's computerized database for the Yanomamo. Data quality is excellent in each of these cases. The PI has been directly involved in eight of these ten cases (all but the Stirling and the Chagnon databases), either with the fieldwork (Tlaxcala, Austria) or in computerization and making the data available. Further, the PI has been involved in processing the data from seven of the ten other ethnographic studies (all but the studies by McCall, Hans Fischer and Kronenfeld) which are not longitudinal but which provide good or excellent retrospective genealogical data at a population level. The present project represents one of the principal efforts in anthropology to make longitudinal research databases available to the social sciences, and the only current attempt to apply network analysis on a large scale to available population-level data from ethnographic and historical studies (Table 2).

Table 2: the 36 Research Sites	**PIs (see key for country, university)**	***UCIStudent/ PostDoc/* Faculty**	**Topic**	**Collaborator (see key)**	**Data Source**	**Data Quality**	**Sample Size**	**Data Status**
1-8 A. Analysis of Cohesion Patterns (8 case studies): includes marriage systems and classes or elites								
Florence, Italy 13-15C	Padgett*1,SFI	*D.Watts(SFI)*	Cohesion	White	AR	Gd	10,000	Co
Turkish Nomads	Johansen(Ge)	White	Cohesion		FWL	Ex	1,600	Co*
Turkish Village	Stirling(E)	M.Fischer*10	Cohesion	White	FWL	Ex	3,000	C2*
Tzintzuntzan(M) &Mig	Kemper*2	White	Cohesion	Widmer(Sw)	FWL	Ex	7,000	Co
Tlaxcala(M)-Belen	White/ Nutini	Brudner	Cohesion	*Schnegg*(Ge)	FWL	Ex	2,000	Co
Tlaxcala(M)Villages	White/ Nutini	Brudner	Cohesion	*Schnegg*(Ge)	FW	Ex	4,000+	IP
Warren Co., Tenn.	A.Turner	*R.Salmo*	Cohesion	White	BK	Gd	8,000	Co
Corporate Interlock	Breiger*9	*Han*9*	Cohesion	John Roberts Jr.	AR	Ex	60+	Co*
9-20 B. Analysis of Marriage Patterns (13 case studies)								
Omaha(N)	Dorsey[+]	*Thompson*	Omaha System	Barnes(E)*8,White	FW	Gd	1,800	Co
Fanti(N)	Kronenfeld*11	White	Omaha System		FW	Ex	2,200	C2
Chuukese(P)	Goodenough*7	*Skyhorse*	Crow System	White	FWL	Ex	1,900	Co
Gwembe 1 (Z)	Colson*4	*Fitzgerald*	Crow System	White	FWL	Ex	4,000	IP
Pere Manus(Ne)	Mead[+]	*Anthro.stu.*	C-I-H System	White	FWL	Ex	2,800	Co
Groote Eylandt(Aus)	Rose[+]	Bearman (1997)	General Exch	White	FW	Ex	360	Co*
Pul Eliya, Sri Lanka	Leach[+]	*R.Johnson*	Dravidian Syst	White/Houseman(F)	FW	Ex	180	Co*
Amazonian societies	e.g., Chagnon	White	Dravidian Syst	Houseman(F)	FWL	ExGd	2,000	Co*
Gwembe 2 (Z)	Scudder*3	*Fitzgerald*	Iroquois System	*Sam Clark*7*	FWL	Ex	2,000	Co*
Wam, New Guinea	H. Fischer(Ge)	*Anthro.stu.*	Iroquois System	White	FW	Gd	600	Co
Rapanui(P)	McCall(Aus)	*J.Hess*	Marriage Systm	*M.Colima*(S)	FW	Po?	1,200	Co
Ndembu(Z)	V.Turner[+]	*Anthro.stu.*	Marriage Systm	White	FW	Gd	140	Co
Beti, Cameroons©	Houseman(F)	White	Marriage Systm		FW	Gd	3,000	IP
21-27 C. Analysis of Social Class Patterns (6 case studies)								
Feistritz (Au)	Brudner	White	Class		FWL	Ex	2,400	Co*
Guatemala	*Casasola*	White	Class	D.Bell,Freeman	AR	VG	9,000	Co
Bevis Marks(E)	Berkowitz*6	*Fitzgerald*	Class	White	BK	Gd	2,200	Co
Sawahan Indonesia	Schweizer(Ge)	White	Class		FW	VG	400	Co
Drame, Slovenia	White		Class	Batagelj/*Mrvar*(Sl)	AR	Gd	14,000	Co
Nord-Pas-de-Calais(F)	White	*K.Dalzell*	Class	J.M. Dupriez(F)	BK	VG	20,000	IP
28-36 D. Analysis of Elite Patterns (9 case studies)								
American Presidents	White, *Skyhorse*	StephanNorris	Elites	R.Grannis*9	BK	Gd	1,400	Co
Mexican Presidents	Jorge Gil(M)	*Alcántara*	Elites	Schmidt(M),White	MX	Ex	2,000	Co
Spanish Elites	N.Pizarro(S)	*Reyes Herero(S)*	Elites	Breiger*9	AR	Gr	12,000	Co
French Public Health	Gribaudi(F)	*Christofoli (F)*	Elites	White	AR	VG	8,000	IP
Geneva Scientists	Widmer(Sw)	*Fitzgerald*	Elites	White	AR	VG	3,000	Co
Norfolk Gentry(E)	Bearman*5	*Fitzgerald*	Elites	White	BK	Gd	5,000 ?	IP
Old Testament; Semitic and Arabic Lines	R.Grannis*9	*B.Jester*	Elites	White	BK,AR	Gd	4,000 12,000	Co
European Royalties	White	*B.Jester*	Elites	White	AR,BK	Ex	8,000	Co
Qing Imperial Lineage	James Lee*3	*J.Stern*	Elites	D.Ruan(UCI)	AR	VG	50,000	Co*

Graduate students or Post-Docs marked in *italics* throughout the tables. (See APPENDIX Table 2a for Notes to Table 2).

IV. Principal Hypotheses and Scientific Contributions

We are interested in the emergence in large social networks, of social cohesion not as an abstract property of an entire system but as a property of particular subsets of individuals, subsets that have predictably different behaviors than other subsets. A cohesive group, for example, might be able to mobilize and exert control over resources – material, social and cultural capital, including property, material goods, political or religious offices, etc. – in ways that tend to exclude outsiders. Members of such a group, in addition, might exhibit characteristic behaviors of mutual support or altruistic "solidarity" towards one another as opposed to outsiders. Beyond the obvious and well studied application of this idea to small groups, gangs, factions, etc., we are interested here in cohesiveness that might exist in unexpected ways in social groups on a much larger spatial and numerical scale.

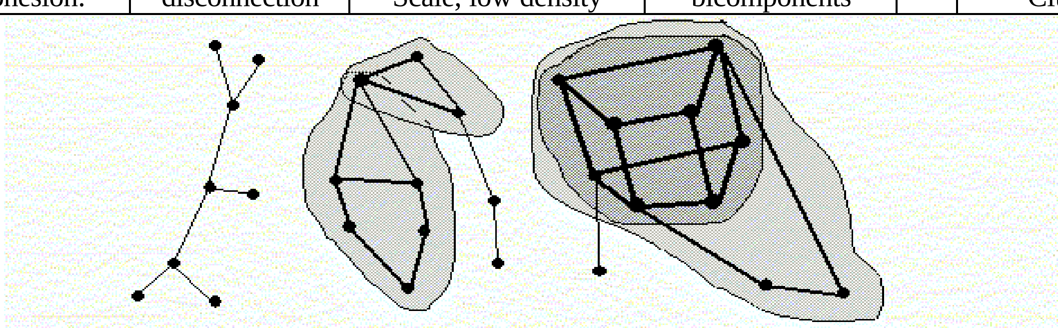
Five kinds of scientific knowledge (see also http://eclectic.ss.uci.edu/~drwhite/pgraph/advances.html) may result from such studies: (1) principles of network structures and processes in large scale social organization (e.g., how common risks and values operate in conjunction with material social relations to stabilize networks in terms of the way connections are formed through loyalties, mutual aid, etc.), (2) theories that operate fractally in that they apply to "complexity" in social systems within a range of different scaling levels, (3) underlying regularities in emergent phenomena in terms of the conditions of emergence of the holistic properties of emergent units, (4) how observed variables interact in emergent phenomena (i.e., from detailed study of each individual case and comparisons among them), (5) what kinds of criticalities hold, within what thresholds, for major structural transformations. To conduct such research meaningfully, it is crucial to observe each system or population over time, because it is only there that we will see periods of relative stasis – oscillatory dynamics of small scale near-equilibrium processes – as opposed to periods of radical transformation (phase transition). One of our hypotheses about the generic properties of phase transitions – although they might occur with respect to very different surface features, different types of institutions, etc. – is that they will typically occur at the relatively low network densities identified in the complexity sciences as critical for self-organizing systems (see Waldrop 1992).

V. Detailed Methodology and Hypotheses, and Preliminary Results from Case Studies

As discussed below, we test six specific facets of a theory of integration by differential modes of connectivity as it applies to a sample of 36 case studies of social networks.

Methodology and Hypotheses, 1: Bicomponents. This project uses a series of new concepts of social integration, based on different modes of connectivity in network components, and tests for their effects, in a series of longitudinal case studies. We hypothesize that the set of boundaries of social groups defined by differential connectivity, as defined below, are correlated in turn with predicted features of social cohesion: core members, for example, have much higher participation in the community institutions of central public significance. This provides construct validation for the theory and predictions from network structure to emergent social phenomena. As a first step in the study of large-scale cohesion, the methodology builds on previous work by the PI on forms of large-scale social integration based on multiple connectivity, in which every pair of nodes is connected ("relinked") by multiple independent paths. Within a social network, a multiply connected (bi-, tri-, …, k-) component is a maximal set of nodes (maximal meaning not the largest such set, but one that cannot be expanded further and still have the property in question) in which every pair is connected ("relinked") by multiple (2, 3, ..., k) independent paths. Table 3 and the graphs and definitions that follow illustrate the properties of these concepts. To illustrate the definitions, each of the three disconnected graphs above is a component. There are three bicomponents, two within the middle and one in the rightmost component. The one tricomponent is within the bicomponent of the rightmost (1-) component. These concepts define nested subsets.

Table 3:	Level of Connectivity generating bounded subgroups: 1-, bi-, tri-, k-connectivity				
Concepts of Cohesion	1-Connected (1-) component	2-Connected bicomponent	3-Connected tricomponent	...	k-Connected k-component
Scale of Cohesion:	Vulnerable to disconnection	Potentially Large Scale, low density	Clustered within bicomponents	...	Hierarchically Clustered



Three disconnected components, three bicomponents (light gray) and one tricomponent (gray)

Definition 1: A (1-) component of a network or graph is a maximal set of nodes and arcs such that every pair of nodes is connected (three disconnected components above). Definition 2: A bicomponent of a network or graph is a maximal set of nodes and arcs such that every pair of nodes is connected by two or more independent paths (three light gray subgraphs). Definition 3: A tricomponent of a network or graph is a maximal set of nodes and arcs such that every pair of nodes is connected by three or more independent paths (dark gray subgraph). General Definition 4: A k-component of a network or graph is a maximal set of nodes and arcs such that every pair of nodes is connected by k or more independent paths (no examples above for k>2). Why are such concepts needed?

Hypothesis 1 a. The mere existence of connections among a set of individuals in a large group – the emergence of giant connected components in network evolution (p.7: Hyp.2) – is not sufficient to create social cohesion or solidarity. Multiple connectivity (existence of multiple paths between all pairs of actors in a social group) entails less vulnerability of a multiply connected component to disconnection, multiple independent channels of communication, and multiple paths for the exertion of social pressure, social sanctions and self-reinforcing feedback loops in patterns of social action. Multiple paths of connection between people are a form of redundancy and constitute one of the structural forms in which social capital is organized in social groups (the other being the branching out of tree-like connections to reachable nodes).

1 b. Biconnectivity is a source of emergent, potentially decentralized social cohesion that can occur (with observable effects) at low density in (the bicomponents of) relatively stable social networks. The mechanism is the potential for self-amplifying or positive feedback circuits. Thus, energy, information or resources can be more effectively circulated or redistributed in higher k-components. Further, the higher the redundancy of connectivity, the less vulnerability to disconnection. For any connected graph Menger's theorem states that its maximal connectivity equals the minimum node removal for disconnection.

1 c. This is especially true for relations that have very high "currency" or life-support salience, such as relations of political influence, property transmission, kinship and marriage connections, and stability of group membership. High currency ties are of such importance that they must often be more decentralized in their distribution than more clustered ties such as friendship. A decentralized network with biconnectivity of high currency ties can have a higher scale of cohesiveness than more locally cohesive clusters; and it may have more cohesive effects than a centralized network.

1 d. Hence social class, elites, wealth-transmission, marriage systems and residential stability are especially likely to *correlate with bicomponent boundaries* and to show additional *evidence of cohesion*, such as differential rates of participation in community institutions and officeholding, differential rates of migration, differential mobility and educational attainment, differential occupational specializations, political influence, etc. This is not an effect of centrality since nodes on the perimeter of bicomponents are not necessarily less central in the overall graph (e.g., in the graphs above there is a node, the most central in its component, that connects two bicomponents).

1 e. In a large network with sufficient (but often low) density, a giant bicomponent may be the source of cohesive participation in core institutional arenas of the group (although not everyone biconnected by high-currency relations will have high cohesion). Bicomponents are not closed unto themselves but may radiate ties outward in tree-like connective patterns, possibly 1-connected to other bicomponents. In a network with a giant bicomponent, if we distinguish those 1-connected to the giant component, and those not connected at all, this gives rise to a three-part structure that will constitute one of our structural variables for testing hypotheses about effects of connectivity:

1 the giant biconnected core
2 its periphery, 1-connected to the giant core
3 the margins, in separate 1-components

Our hypotheses predict that various measures of cohesion will correlate with this ranked 3-part variable. Since bicomponents are unique, we can identify bounded social groups of potentially large-scale and low density that have significant implications for societal organization in terms of different aspects of cohesion, such as: formation of social classes, participation in key institutions and political offices, and large-scale social groupings that may affect the transmission of property and distribution of resources.

Tests of Bicomponent Correlations and Effects: Pilot Studies and Expected Results. Eight field studies analyzed to date allow tests of the main hypotheses. The fact that hypotheses about cohesion are supported in different ways in different cases is explained in the second to fourth sets of hypotheses below.

Kaingang (Brazil). the ethnography of a displaced foraging group shows support for the bicomponent hypotheses as a negative case. Here, the kinship and marriage network has no large bicomponent, no marital relinking whatsoever. This correlates with almost total lack of cohesion evidenced in extensive factionalism, feuding, murder and Jules Henry's (1941) account of the fear of connecting or reconnecting between distantly linked groups.

Tlaxcala (Mexico). A single egalitarian social class structure in rural villages correlates with virtually complete integration of villagers – except for very recent immigrants – into two cross-cutting bicomponents of kinship and *compadrazgo ties*. For *compadrazgo,* 81% of the members of the civil and religious councils belong to the giant bicomponent, as compared with only 14% of nonmembers. For kinship, 78% of the members of the civil and religious councils belong to the giant kinship bicomponent, contrasted with 46% of nonmembers (White, Schnegg, Brudner and Nutini 1999a, 1999b).

Tzintzuntzan (Mexico). For married persons, 84% of those who emigrate to work in the Us and return belong to the giant bicomponent, while only 57% of those who stay in the US and 67% of those who never went to the US are bicomponent members. Thus we can predict that migrants who marry into the bicomponent – either before or during migration – tend to return from the U.S. to Tzintzuntzan. Patterns for migration to Mexico City are similar but even more dramatic (Widmer, White and van Kemper 1999).

Feistritz Farmers (Austria). Farmstead heirs tend to belong to the kinship bicomponent (est. over 80%) while of the farmstead buyers and other village residents only 31% and 8%, respectively, belong to the bicomponent (Brudner and White 1997).

Bevis Marks Synagogue (London). The large kinship bicomponent contains almost exclusively members of the trades and clerical occupations while the smaller separate bicomponents contain members of managerial and financial occupations (Fitzgerald and White 1997).

Guatemalan Elites. Those families in the kinship bicomponent of 18th century marriages are highly correlated with (1) families judged by a panel of Guatemalan historians to be the prominent families of this century and (2) the families whose members succeeded to political office (Casasola and Alcántara 1999).

Geneva Scientists. Some sampling designs show a giant kinship bicomponent with disproportionate numbers of scientists from prominent specialties, such as physics (Widmer, Sutter-Widmer, Sigrist and Fitzgerald 1999).

Turkish Nomads. Of married resident nomad clan members, 90% belong to the kinship bicomponent, and 95% of those who marry women of another nomad tribe belong to the giant 1-component. Those who marry villagers belong to the giant 1-component and overwhelmingly tend to emigrate (Johansen and White 1998).

Expected Results: Other Studies. In each of the other studies in this project, some kind of correlation between bicomponents and indicators of cohesion is expected. The specific forms of cohesion, however, are hypothesized to depend on different patterns of local interaction within the network.

Methodology and Hypotheses, 2: Phase Transition - Emergence out of Network Criticalities and Local Interactions. Phase transitions in large low-density networks are one of the classical areas of theories in theories of complexity and self-organizing systems. Hence we will want to introduce some ideas about self-organizing systems: In the study of social behavior, as in the burgeoning field of complexity sciences, networks of interaction are crucial foci of study on the frontiers of research, and their study may provide crucial advances to anthropological theory. Social systems are as delicate and subject to bifurcations or instabilities as any other living system. Among the large array of scientists now working in complexity research there is an hypothesis that the type of variability that we see in biological and cultural systems may not be explainable exclusively by Darwinian selection of random genetic permutations by their direct behavioral consequences but from selection of self-organizing properties as well Nor is it sufficient simply to add to our theoretical framework idealized tendencies to equilibrium adaptations such as are hypothesized by neoclassical economics or by that variety of evolutionary biology that tries to explain all organism behaviors as direct adaptations in species-environment interactions. Rather, it is specific patterns and forms of self-organizing interactions that prove critical in understanding complex systems, the variability of their structural configurations, and the real-world effects that follow from these configurations.

For networks with a large number of nodes in which edge density increases over time, there exists a critical density threshold for the transition to a giant multiply connected core. This occurs discretely when an edge is added that merges two smaller bicomponents, for example, into a single giant bicomponent that includes most of the connected nodes in the network. Dynamic evolution of 1-connectivity and biconnectivity (and higher order connectivities having both global "giant component" effects and localized interaction effects) can give rise to phase transitions in network configurations. Hence, in a longitudinal study of a network, as in (1 e), there may come a point where the nodes partition dynamically into (1) a giant bicomponent in which every pair of nodes is connected by 2 or more independent paths, (2) a periphery of nodes connected to the core by a single path, and (3) marginals unconnected to the core.

Hypothesis 2 a. Longitudinally, new kinds of social coalitions are likely to occur after the giant bicomponent appears, partitioning the network into the giant bicomponent, the periphery, and the margins. If emergent features appear that are associated with the bicomponent (such as evidence of cohesion) the evidence may support the hypothesis of a criticality transition. This is not likely to occur until the giant bicomponent is stable for some period of time (as in the cumulating edges of kinship and marriage linkages in a context of social densification), and its redundancies accumulate to counteract dissolution by subtraction of nodes or edges. Further edge densification adds to the redundancy and robustness of the giant bicomponent.

2 b. A second criticality transition may occur in terms of more localized transitions after the edges the giant bicomponent partitions further into (4) a giant tricomponent in which every pair of nodes is connected by 3 or more independent paths, and (5) the remainder of the bicomponent.

Expected Results for Phase Transition Hypotheses. Four of our case studies have sufficient longitudinal data from some "startup" condition to test phase transition hypotheses. Longitudinal dynamics can also be compared to simulation models, listed under cases 5 and 6 below.

1. 13-15th century Renaissance Florence, co-evolution of states and markets. The PI is invited to the Santa Fe Institute to apply the project methodology and theory to phase transitions described by Padgett (1998) for the transformation of family and banking systems and the birth of the modern financial market via banking institutions that emerge out of family ownership in Renaissance Florence, 1200-1500. Data on 10,000 marriages are being converted into p-graph format (see p.13) so that network k-components and local interactions such as marital relinking patterns can be computed and compared over time. The earliest period of corporate patrilineages and family-run banks as non-transferable "patrimony" correspond to the invention of hereditary last names and low density tree-like kinship structures with tree-like marriage alliances between them. With depopulation in the 14thC due to bubonic plague, the lineage trees were thinned, and marriage alliances as well as other relations became the basis for locally cohesive clusters (multiple small bicomponents) expressed in new forms of business partnerships in guild-type configurations. As families subsequently grew rapidly and intermarriages proliferated (1349-1378), we hypothesize that a density transition to giant bicomponent cohesiveness occurred among a large set of families and that the phase transition favored decentralized alliances in a dispersed social class configuration among the *popolani* nobility (1380-1433). In the last period (1434-1494), however, we hypothesize that the contrast between "structural holes" in the network and the emergence of locally densified tricomponents provided the key competitive edges for the dominance of the Medici family.

2. Geneva Scientists. 18th century startup densifies into a "patrician scientific community" linked and relinked by marriage and kinship bonds.

3. American Presidents. 19th century startup densifies into a Yankee elite network, excluding the southern Presidents.

4. Guatemalan Colonial Elites. 17th century densification (after the conquest, a new elite emerges from 1630 to 1773) into a property-holding elite that is highly over-represented on the 8-16 member city council of the capital city of Santiago.

5. Random graphs as baseline comparisons. One of the key topics of graph theory that supports the study of low-density transitions in network structure is that of network evolution (Palmer 1985). As simulated longitudinal networks grow by the random addition of edges among a fixed set of nodes, large connected components begin to appear, and at quite low density these connected components begin to grow exponentially. A critical transition in graphical evolution is where a single giant component appears, one encompassing many times the number of nodes as the next largest component, and starts to swallow up most of the nodes in a network. This criticality point is discrete in the sense that two small components may suddenly merge into one by the addition of a single edge. We can also find the expected size of the giant component, if any, that will have occurred in almost every random graph as a function of the number of nodes and edges. In a programming language like Mathematica (Wolfram 1996) we can write the formulae for giant components from the findings of mathematical graph theorists (Palmer 1985, Bollobás 1985).

6. Random graphs with demographic controls. As described in White (1999), I will be developing further Monte-Carlo simulation techniques for simulating randomized-marriage models in network studies of marriage systems. The method allows controls for observed demographic features, such as population and differential generation, sibset and lineage size and structure, and different types of marriage prohibitions. The network model of population structure includes parent-child and marriage links from which generations are calculated. Within each generation, marriages of parents and marriages of children are kept as fixed points, but the bonds between them are reshuffled. To keep patriline or matriline structure, daughters or sons, respectively, are redistributed to spouses, who keep their lineage affiliations. To keep only sibship structure and randomize both patrilines and matrilines, both sons

and daughters are redistributed to marriages. When redistribution is done, various Monte Carlo options are possible: random assignment, or random under various constraints, such as prohibitions against sibling marriages or against various types of cousin marriages. Comparing the Monte Carlo simulations against the actual marriage network allows assessment of whether observed marriage patterns represent a statistical departure from marriage frequencies that would be expected from random assortment under demographic constraints. Results are decomposed into a multilayered model of marriage rules as departures from randomness. These methods have been successfully applied to three case studies: Pul Eliya-Sri Lanka, Dukah hamlet-Indonesia, and Feistritz-Austria.

Methodology and Hypotheses 3: Local Interactions and Global Structure – 1 Social Class and Radial Cohesion. Having a giant connected component that includes the great majority of people in a locality or social setting is a helpful prerequisite of social integration. As noted above, biologists and geneticists have found that connectionist models of low-density criticality are crucial to explaining many different types of phase transitions of the biological systems that they study. Network or structural models of this sort are predictive of emergent phenomena or transitions to new structural arrangements that alter the properties of the entities observed and their interactions. Criticality is not strictly determined, however, by the formulas for random processes, such as random graph evolution. Rather, criticality is a non-linear phenomena, not only in the sense of exponential processes, but in terms of departures from randomness that are less predictable because they emerge out of the details of local interactions: Products of multiply-interacting variables introduce bifurcations where small differences in initial or local conditions can magnify into very different outcomes.

Under what conditions are redundantly relinked or multiply connected sets of actors integrated, where ties between them are cross-cutting rather than organized into locally cohesive structures? This is one of the questions that the current research will attempt to answer. As a first step we can examine the lack of local clustering, by defining radial cohesion.

Radial cohesion is a specific case of a biconnected group with low overall density and an absence of local clustering. It is very common in kinship and marriage networks where marriage even with distant kin is prohibited but is otherwise rare in other kinds of relations – found so far in only one of our cases – but its existence supports the idea that locally dense "proximal cohesion" is not the only form of cohesion. A first hypothesis for our study of complex societies concerns cohesion in bicomponents.

Hypothesis 3 a. The combination of features in radial cohesion is hypothesized to contribute to high levels of large-scale cohesion. Random or radially cohesive structures with a bicomponent are likely not to break up into divisive subgroups because they lack local or "proximal" cohesion within smaller subgroups. Prime examples of radially cohesive groups in complex societies are structurally endogamous groups formed by long cycles of marriages relinking consanguineally extended families. Such groups may be radially rather than proximally cohesive if close intermarriage among blood relatives is prohibited or avoided and marriage cycles are long. Their detection in terms of network patterns is a problem of some subtlety (relational functions and attributional cognitions are also inter-dependent in terms of how such groups operate).

3 b. Self-bounded bicomponent groups are common in complex societies and their graph-theoretic boundaries are often functionally interdependent with caste, class, and ethnicity (which are often radially cohesive).

3 c. Specifically, multiple connectivity of marriage links between families provides a boundary condition for potentially cohesive social classes. This generalized and potentially large-scale networked basis for cohesive social integration also provides – if our hypotheses continue to be confirmed – a new basis for explaining the network evolution of different systems of social class. This is consistent with one of the dominant hypotheses in the theory of social class as put forward, for example, by Schumpeter (1927, translated from the French):

> "one can, without making appeal to a theory of classes, and by means of an easily identifiable criterion, define social class by the simple sociological fact that ... intermarriages are there predominant."

This possibility suggested to the PI (White 1996), elaborating Schumpeter's idea, that marital relinking among families might be a basis for studying some of the boundary conditions for the formation of social classes. What is needed for a giant subset of intermarrying families to possess multiple connectivity is for a sufficient number of marriages to be distributed in a way that, within some kind of spatial or social boundary condition, is both relatively dispersed or random and, when combined with parent/child links, of sufficient density to surpass the criticality condition for multiple connectivity. The particular type of social class system is not thereby constrained, and may depend on the agency of the actors, their local interactions and the nature of their networked access to resources. Significantly, we do not have to presuppose a classification of actors to differentiate a multiply connected subset of actors which we hypothesize might correspond to a social class: The relinked or nonrelinked network relations of the actors make the group boundaries self-defining and dependent upon the social actions of relinking or not relinking into larger groups.

3 d. One of the interesting hypotheses for contemporary societies is that as kinship relations weaken in their locally cohesive intensity, to become radially cohesive, they acquire – as weaker ties – greater potential for diffuse integration, in terms of social class, ethnicity, the emergence of patterns of generalized exchange, or, in conditions such as in the Florentine case study, of market exchange.

3 e. The importance of radial cohesion in complex societies is by no means limited to recognition of the importance of kinship and marriage networks. Such networks may be diffuse but radially cohesive in ways that, in channeling pathways for succession to office for the transmission of ownership, are fundamental to the political, economic and social structure of large-scale social systems. Equally if not more important, however, are other networked relationships that operate in occupations and institutional structures, cross-cutting kinship and marriage ties, that may also have hitherto unrecognized structures and functions that operate through radial cohesion.

Tests of Social Class and Radial Cohesion Hypotheses. In the Feistritz and Tlaxcala studies, we apply our theory of a generalized and potentially large-scale networked basis for cohesive social integration to explain certain aspects of the network evolution of different systems of social class. Elaborating one of the dominant hypotheses in the theory of social class, we argue and demonstrate that multiple connectivity of links between families defines a boundary condition for cohesive social classes. The correlation of social network structures to belief systems in our different cases provides construct validation for this application of the theory, where each case may have different local principles and processes that interact with global structures

In Tlaxcala, we apply our theory of cohesion to the differential structures and functions of different social relations that are fundamental to social organization of different cases, examining how multiple connectivity operates for networks composed of single types of relations and the combined network of all relations. One of the fascinating findings for Tlaxcala is that the only dense local clusters of *compadrazgo* ties are those of men who have served together in the civil or religious town councils. All the other ties are radially cohesive, meaning that they radiate outward so as to avoid local clustering, but connect into bicomponents with "small world" distances such that every pair of couples is connected by multiple independent paths of length six or less. This instance is important because this is the only case where the centralized indigenous political authority of a population has been suppressed by a colonial regime, and the integrative network structure provides a large-scale decentralized alternative to regional sociopolitical integration. [WSBN 1999b]

Methodology and Hypotheses 4: Local Interactions and Global Structure – 2 Proximal Mechanisms and Segmentary Structures. Because the criticalities that give rise to emergent structures are interactive with potentially quite different small-scale processes, similar structural forms observed at the large scale might lead to radically different outcomes. This poses research problems of some subtlety. In each of the different research populations of this project, we will be looking for ways that large-scale properties of social networks – those properties that might lead to social cohesion – interact with more localized interactions in social networks, to give rise to what complexity theorists would call emergent phenomena: ones that give rise to at least temporarily stable properties or "predictions" that hold for a given configuration of actors, resources and connecting processes. For example,

Hypothesis 4 a. Bicomponents structures that have segmentary or clustered subsets are more likely to break up into cohesive subgroups.

4 b. The higher the level (k-) of connectivity, the higher the correlations expected between the subgroup boundaries of the k-connectedness and other empirical measures of social cohesion or solidarity. (This will also validate labeling our measures of connectivity as measures of potential cohesion).

4 c. Successive levels of k-connectivity will have segmentary or clustered subsets which we predict will be more likely to break up into weakly versus strongly cohesive subgroups.

Connections within a bicomponent need not be homogeneous: Local interactions or k-components of higher order within bicomponents may give rise to further emergent global or subgroup properties. The effects of relinked redundancies are mediated by local interactions and the nature of local connections. If each dyadic link is itself cohesive rather than divisive or conflictual then the network of connections is far more likely to be cohesive. Fault-lines of divisiveness, conflict, or differentiation are likely to restructure and to localize the clusters of cohesiveness. If, within a redundantly relinked group, there are a number of dyadic links that are either conflictual, or even, to the contrary, particularly strong or cohesion relative to other links, then the local distributions of ties may effect the breakup of a potentially cohesive network into subgroups or factions. Or, if different kinds of relations are differentially distributed among sets of actors, then there may emerge a series of differentiated social positions or social roles. The detection of such substructures is the province of what are known as blockmodels in social network analysis.

4 d. Kinship societies, for example, typically have lines of cleavage or segmentation that divide up multiply connected groups into solidary subgroups with various kinds of oppositions between them. Segmentation may also occur hierarchically, as the splitting off components at more and more localized levels.

4 e. Marriage preferences (derived from a network statistical decomposition of departures of actual marriage patterns from expectations for random marriage under demographic constraints -- see methodology in case 6 of hypothesis section 2) interact with demographic constraints to generate rules and structures with a wide variety of different implications for forms of social cohesion.

4 f. Augustins (1998) argues, for European inheritance and succession allocations, that the dominance of different grouping principles of kindreds, domestic groups, and lineages is associated with different equity framings – egalitarian (division of property/titles), privileged/unique (unity of estate, titles), sex selective – which lead to different characteristic coalitions (formalized within a game theoretic for sharing) that associate to different network structures (which we hypothesize to link with different forms of social cohesion as identified under hypothesis (4 e).

Tests of Divisive versus Cross-Cutting Structure, Segmentation, and Marriage Structure Hypotheses

Tlaxcala versus Feistritz: The local inheritance regimes – partition of wealth among children versus impartible inheritance by a single main heir – correlate with bicomponent integration into a single rural social class (with partible inheritance) versus bicomponent segregation into two rural social classes (with impartible inheritance and non-heirs going into non-farming occupations).

Dukah versus Pul Eliya (in Schweizer and White 1998). Those cases examined with this methodology exhibit complex marriages rules whose structural implications can only be determined precisely from network analysis. In the Dukah case different social strata are found to be similar in lacking marriage preferences for blood kin and in preferring endogamy with status-equivalent families. Under the demographic constraint of the smaller numbers of status-equivalent elites, identical preference behavior leads to radically different outcomes, as the elites are closely relinked with higher marriages densities, including many blood kin marriages, while commoners are relinked with very low densities, and virtually no blood kin marriages. The Pul Eliya case shows patterns expected under hypothesis 4 f: an egalitarian ethos associated with direct marriage exchange between ambilineal kinship groups whose internal structure and dual organization of marriages is detectable only in a network analysis of oppositional clusterings within a bicomponent structure.

Methodology and Hypotheses, 5: Networked Production Groups, Cohesive Solidarity and the Framing of Ties and Outcomes. The present project will provide a collaborative "laboratory" of comparative ethnographic studies in which we envision a theoretical synthesis with small-group or experimental studies of human behavior. Lindenberg (1998, in Doreian and Fararo), for example, has elaborated a theory of social solidarity that we will use to test the construct validity of our measures of large scale cohesion in social networks. He argues that, in groups that share goals and resources for producing common goods, five necessarily operative criteria define the presence of solidarity: *cooperative behavior* with respect to the common good, *sharing*, *responses to need*, *avoidance of damage* to others, and explanations or *repairs for failure to comply* with solidarity norms. These are the behaviors that evidence and enforce cooperative behavior over self interest. Strong solidarity is theorized to result from such a buildup of overlap of sharing groups that risk comes to be cognized as shared, and, in the way that interaction between group members is cognitively framed, individual gain does not alternate with solidarity. Further, with strong solidarity, Lindenberg predicts that group boundaries will be strictly delimited, and that equality rather than equity (fairness but not necessarily equality) will be a governing norm of interaction.

Theories that develop out of the experimental tradition of group dynamics can be tested directly against a sample of ethnographic studies that are richly elaborated in terms of social network data. In the variety of ethnographic and historical datasets that we are studying, there is much to be learned from heuristic hypotheses concerning interdependencies. Network function, cognition or structure have emergent properties that are interdependent in that they come to frame subsequent functions, cognitions or structurally constrained actions. This often leads to the kinds of path dependent dynamics of institutional development noted by North (1990): The crescence or slow congealing of micro-level interaction into institutions that may lock each other into local optima.

Hypothesis 5 a. Bicomponent groups are often associated with the shared production of some goods. This is hypothesized as a principal social choice factor in relinking behavior (decisions to stay or leave a group in relation to productive activity and marriage-choice categories).

5 b. Whether the associated production groups will be strongly or weakly solidarity will depend on the overlapping of shared productions, relations with other groups, and the cognitive framing of interaction.

5 c. Bicomponents are not necessarily strongly solidarity (our only examples are the Tlaxcalan and Turkish nomad cases); they are usually only weakly solidarity (see Lindenberg for definitions). Weak solidarity, however, is usually more broadly integrative, while strongly solidarity groups often break into competing factions (like the Turkish Nomad case which has local clusters, but not the Tlaxcalan case, which has radial cohesion).

How production groups organize local interaction also affects the way that social ties or outcome events are interpreted or cognitively framed (Lindenberg 1997, 1998).

Bell (1998a in Schweizer and White 1998) begins from recognition of actors as members of production groups; where rights of such groups over persons are distinguished from rights of persons over wealth held by such groups. Three types of wealth transfers or payments are distinguished: those involving *exchange,* between parties with different interests (such as members of different groups), those involving *alliance,* between parties in different groups seeking to align their interests, and those involving *transfers* between parties in the same group, involving a presumed commonality of interests. Bell's concept of wealth-holding groups (1998a,b) and Lindenberg's of production groups are closely aligned. My translation of Bell's central hypothesis (1998a) is:

5 d. Differences arise in cognitive framing between payments in the context of solidarity – dowry as gifts for *alliance* – versus those such as bridewealth that arise in the context of *exchange*. Different types of payments, arising out of production groups, set a context for interpreting structural interdependencies (with predictions that differ depending on whether models of exchange or of alliance are mobilized).

5 e. The cognitive framing of dowry for alliance, for example, sets a basis for structural interdependence among maritally cohesive families (structurally endogamous aggregates) which is weakly solidarity across different groups, even in the presence of a high degree of stratification and division of labor. In contrast, bridewealth as exchange (unless additional alliance elements are present) sets up a competitive gain-maximizing orientation between different groups, and a basis for structural interdependencies through solidarity within groups, expansion of group size, and problems of group segmentation (Bell and Song 1995).

For pre-state societies, one of our best theories of the consequences of different types of production groups, tested cross-culturally, comes out of the comparative work by Paige and Paige (1981). We will be looking for extensions of similar theories that have broader applications, but their hypotheses may apply to some of our ethnographic cases in complex societies, e.g.:

5 f. In pre-state societies, low resource production produces high evaluation of reproduction, leading to female-centered groups; high but unstable resources (like animal husbandry) produces high evaluation of potentially shifting alliances, leading to ritualized segmentation; and high resource production produces high evaluation of in-group social capital, leading to strong fraternal interest groups, emphasis on reproductive surveillance, and bridewealth exchange.

Tests of Cohesive Solidarity and Framing Hypotheses

The Turkish Nomads are one of several nearly perfect examples of the applicability of these hypotheses. Their shared-risk production group predicts relinking behavior and bicomponent integration (5 a) with strong solidarity (5 b). The high-resource husbandry productive base predicts their strong fraternal interest groups, and emphasis on bridewealth in marital exchange (5 f). From hypothesis set 4 concerning local interaction mechanisms, decentralized nomadic decision making predicts informal leadership: Leaders emerge from the densest coalitions involving kinship- or marriage-linked supporters. Close-kin intermarriage reframes bridewealth payments so as to neutralize them within the group, where alliance is the substitution frame (5 d,e). Internal political alignments depend on local densities of relinking. Local clustering of kin ties generates segmentary fission within the group (5 c) and predicts feuding but alliance against outsiders.

Warren County, Tennessee. At level of states and nations, these hypotheses raise similar questions for which similar hypotheses can be developed. For Warren Co., we have data on 3191 couples in a giant connected component of kinship and marriage ties, with census district and occupation coded for each. We can pick out two highly clustered communities, the county seat, and the largest of the farming communities. Other smaller communities tie into these like spokes on a wheel. The bicomponent, however, is found to span all the communities. What kind of families are involved in the relinking across communities? Farming families or those with more urban occupations? Our next step is to create a matrix for each community of the frequency of marriages between families classified by the occupation of the father (farmers are predominant, with other occupations concentrated in the county seat). This will tell us the kind of social stratification, if any, in marriage choices. We will then test whether the bicomponent predicts succession to local political office.

Methodology and Hypotheses, 6: Social and Cultural Capital. This last set of hypotheses is intended to open up new questions about our findings. An alternative to our cohesion hypotheses is that "relinking" is simply an appropriate behavior for members of local groups, and it is membership in local groups that affects many of our outcome variables (although certainly not network criticality or phase transition outcomes). We will test this alternative against our hypothesis that relinking generates a certain kind of social capital in terms of cohesion and a certain kind of cultural capital in terms of greater likelihood that the relinking couple and their offspring are more likely to receive both material (e.g., inheritance) and symbolic capital investments from members of their relinked group (bicomponent). The concepts of social and cultural capital are two principal applications of social theory based on social networks. Different types of cultural and social capital that individuals acquire in the course of their lifetime – differential knowledge, skills, and connections due to the social background or origin of individuals, and the acquisition of occupational, professional, elite or avocational ties, or of wider, cross-cutting, ramifying, bridging, or 'weak ties' (**Granovetter** 1973, 1982, 1985), including the exploitation of structural holes by entrepreneurial strategies (**Burt** 1992) – are constituted via social networks. We will try to address the question of what role different types of cohesiveness, or its lack, play in the formation and dissolution of social groups and institutions and how they affect the acquisition and retention of different types of capital.

VI. Programs and Algorithms for a New Methodology for Studying Cohesion

Much of the precise graph theoretic base for the measurement concepts developed for this project, as well as the software implementation, have evolved in a collaborative co-authorships with graph theoreticians Frank Harary (Harary and White 1999, White and Harary 1999) and Vladimir Batagelj. The methodological work of previous NSF grants and Humboldt Awards (White 1997, Brudner & White 1997, White & Skyhorse 1997, White & Schweizer 1998, White, Schnegg & Brudner 1998, 1999) provides a great variety of programming and statistical tools, as well as the means of computer visualization, for our approach to large-scale social network research. The present project has also been instrumental to the development of Pajek (White, Batagelj and Mrvar 1999) as a large-network data analysis package (Batagelj and Mrvar 1999) that runs efficiently on desktop computers. Such collaborations, between mathematicians or computer scientists and anthropologists (e.g., Hage and Harary 1983, 1991, 1996) or other social scientists, have fueled the rapid development of social networks as a research and theoretical paradigm in the social sciences, as well as recent developments in mathematics.

Bicomponents are identified in large graphs (Hopcroft and Tarjan 1973), with V vertices and E edges in linear time O(max(V,E)). Bicomponent detection is now standard in network analysis packages (UCINET and Pajek). Tricomponents and k-components of higher order are easily computable: tricomponents in linear time O(V+E), and all k-components in low polynomial time O(V**.5 E**2), or near-linear time in parallel computation. We will implement tricomponents (Even and Tarjan 1975) in Pajek as a sparse-network algorithm. A further algorithm (Even 1979) to compute all the k-components of a network will be implemented within the present project in collaboration with James **Moody** (1998) at Ohio State. These algorithms will allow us to detect and subgroup clustering of cohesion for orders of connectivity beyond bicomponents (components with 3 or more independent paths between each pair of nodes) within networks that have several types of ties, including kinship. For kinship networks alone, if we delete the lowermost generation of couples and simply substitute for them a link from wife-giving parents to daughter-in-law-taking parents, we can also examine a hierarchical clustering of network k-components.

The PI will work with **Harary** to generalize our approach to the topic of conditional connectivity (Harary 1983) in graph theory, and to develop the basis for a further set of cohesiveness concepts that we will implement for algorithmic analysis of network data. The PI's work will continue on **P-graph representations** of kinship and marriage networks (**White and Jorion** 1992, 1996; **Houseman and White** 1996, 1998a, 1998b). P-graphs have proven of decisive importance in the detection of emergent large-scale social groups in large populations. A **P-graph** allows us to draw as a multigraph all relevant genealogical trees and to observe their intersections in terms of common ancestors. The multigraph takes couples and unmarried offspring as nodes and has two kinds of edges for parent/child links, depending on whether the offspring is male or female. Thus a couple will have edges connecting to their children, and at most one male-type link to parents (parents of the husband) and one female-type link to parents (parents of the wife). If there is no endogamy the multigraph contains no cycles. Every empirically observed circuit or cycle of parent/child links in a P-graph corresponds to a structurally endogamous marriage: the most recent marriage in the circuit is between individuals who are previously connected by kinship and marriage ties. All of the relinked families within the cycle aggregate into a larger set of families in which every pair of families is multiply connected. For the largest aggregate of all such cycles that are connected by sharing an edge, every pair of families in the aggregate are multiply connected: This statement is congruent with a theorem about bicomponents in general, not just in kinship networks. Hence, the P-graph allows the entire kinship and marriage network of a society to be analyzed for multiply connected components (bicomponents) that are hypothesized to be a basis for large-scale social integration and social class formation.

Working again with **Harary**, the PI will complete a fundamental conceptual model (P-systems) for the representation and structural analysis of kinship networks (Harary and White 1998). P-systems will offer a highly useful generalization of the P-graph approach. Further mathematical collaboration with Harary will include our elaboration of a theory of conditional homomorphisms and conditional graph colorings (Harary 1984) that will be of great use in network analysis. The PI will work both with **Harary** and **Batagelj** on the measurement of conditional densities. In White, Batagelj and Mrvar (1999) we define an <u>index of relinking</u> that is a special case of White and Harary's (1998) approach to conditional densities, which defines density functions for graphs that have special constraints on their edges, as do P-graphs. These measures will be of critical importance to the comparison of bicomponent structures across different ethnographic and historical cases.

Crucial to the organization of our project is a series of workshops given by Harary, White and Brudner (longitudinal ethnographer for the first two pilot studies) at the research centers of our various collaborators. These will serve 1) to help direct various working groups on methodological problems, 2) to provide training for researchers who are using our methods, and 3) to provide a forum for researchers to present ideas and findings and to receive feedback on issues of conceptualization, measurement and hypothesis testing.

Seven working groups are planned, three at Irvine, and four three elsewhere; we expect more to develop. These are: 1) genealogical sampling, headed by **Eric Widmer** (**Geneva**) and **Bill Fitzgerald** (UCI), who are developing approaches to uniform sampling techniques for network datasets, 2) new developments in statistical blockmodeling, headed by **Ron Breiger** (**Cornell**; see Breiger 1991, Breiger & Han 1997, Breiger & Roberts 1998), 3) bicomponent casing of historical events, led by **Peter Bearman** (**Columbia**, with input from H.White and C.Tilly on related topics), 4) theory of network criticality and transition, led by **John Padgett** (**Santa Fe Institute** and Chicago), 5) algorithmic development, headed by **David Goggin** (Computer Science, **UCI**) and **Robert Johnson** for quick-and-approximate computation of the centralities of subsets of nodes, measured at different time periods in the evolution of a network, 6) development of rapid longitudinal fieldsite survey techniques, headed by **Lilyan Brudner** (**UCI**), and 7), headed by the PI, approximation formulae for criticality of giant k-components, which have not yet been solved by graph theorists. **Harary** and graph theoreticians and computer science faculty (such as **David Eppstein, John Gennari, Wanda Pratt**) from UCI will provide consultation and interact with researchers at various workshops.

VII. Plan of Research, Timing and Budget

The basic plan is simple: we have 36 datasets for case studies undergoing or ready to undergo analysis (with new fieldwork funded or pending in some cases), and 10 Ph.D. candidates-in-training or post-docs at UCI, plus a number of students, post-docs and faculty researchers at other institutions, each involved in one or more specific projects using common methodology and theoretical concepts. Many of the central training functions and collaborative advising on these projects are done by the PI, who is Graduate Director of the UCI Social Networks Program, chair of three of the students on this project (Fitzgerald, Jester, Skyhorse) and committee member for 5 others. Most of the specific projects are directed by other PIs affiliated with the general project. Each is assumed to have independent initiative and adequate funding, including travel. In six cases PI White is also the PI of a specific project (Tlaxcala, Omaha Indians, Industrial Bourgeoisie of the Nord-Pas-de-Calais region, European Royalties, Drame village/Slovenia, and Pul Eliya). Students will thus either be: collaborating with White (e.g., Schnegg from Cologne; Casasola, Jester, Johnson and Skyhorse from UCI) and/or Bell (Casasola) at UCI; PIs on their own thesis project for which White is advisor or committee member, or collaborating with some other faculty member in the U.S. or elsewhere on a project for which White is an advisor or consultant. Alcántara from UCI for example is working with UNAM professor Jorge Gil (and S.Schmidt, 1997) on a project on Mexican elites for which White is a consultant. In some cases data are from a researcher who is deceased, such as Mead, Leach, Dorsey or V.Turner but whose data are available for analysis. In other cases a living ethnographer such as Colson, Goodenough, Scudder, Fischer (Hamburg) or Chagnon has made field data available for secondary analysis.

Each UCI student will receive a $1,000 stipend (a double stipend in cases of multiple projects) on completion of their part of the main project: analysis of their case study using common methodology, and testing the pool of common hypotheses. Other students are assumed to have or be obtaining their own research funding.

International travel funds for UCI participants, faculty (including Stephan-Norris, White, Brudner, Bell), students (Alcántara, Stern, Jester, Johnson, Fitzgerald, Casasola, Skyhorse; with three slots open for other anthropology students such as Hess or others) and post-docs (Reyes Herero) are sought from NSF International programs for scientific exchanges with France, Germany, Mexico, Guatemala, Slovenia or Austria and Spain. These funds will allow collaboration with an overseas counterpart at another university, travel to the appropriate research site, and travel to workshops or conferences, as detailed in the budget. Faculty (Bearman, Berkowitz, Breiger, Colson, Goodenough, Grannis, Kemper, Lee, Scudder, and possibly Tilly and H. White in the U.S.; Batagelj, Dupriez, H.Fischer, M.Fischer, Gil, Gribaudi, Houseman, Johansen, Lindenberg, Magaud, McCall, Pizarro, Richard, Schweizer, and Sutter-Widmer, Widmer overseas) and researchers outside the U.S. (Colima, Mrvar, Schnegg) or at other U.S. universities (e.g., Clark) are responsible for their own travel expenses through other funding agencies, often through matching awards. Such expenses as are required for further fieldwork are available elsewhere (e.g., Schnegg restudy in Tlaxcala, Alcántara - Mexico, Widmer follow-up fieldwork in Tzintzuntzan).

Project Topics and Structure of the Research Collaboration. The focus of these studies is on complex societies in Eurasia, Africa and the Americas. In 8 cases (see Table 2) the focus is on multiple levels of social cohesion. 13 case involve specialized questions about the social and institutional change in marriage structures, including special cases of Crow-Omaha type societies, considered by Lévi-Strauss to have a particularly interesting network structure which he terms semi-complex (and with mixed elements, in Lévi-Straussian terms, of semi-complex and complex marriage systems). In 9 cases there is a specific focus on different types of elites and on distributive networks that may provide access to power and succession to office. In 6 cases there is a specific focus on questions about the network construction of social class. Most of the datasets include, but are not limited to, a focus on networks of kinship and marriage and/or institutional structure (e.g., corporate interlock) as well as various types of production groups or organizations, and utilize a common methodology for network analysis. The common questions asked by the researchers in the collaborative work on different cases, as well as comparisons between them, are informed the theoretical framework developed in this proposal, as amplified in cited publications and discussions among project participants.

Detailed Research Schedule of White and Harary, and Workshops (Table 4). The PI's annual teaching schedule repeats a cycle of moderate teaching Winter quarter, no teaching in residence Spring, free summers for this project, and heavy teaching in Fall. Other than fall quarters, when there is no time for research work, the PI's research time will be devoted to this series of closely related projects, which includes supervision of Ph.D. students and collaborative work with post-docs as well as assistance to international projects. Table 4 details an approximate work schedule, which for the PI is little different than the schedule pursued during the last three years, with the exception that it will be much easier to carry out this schedule with grant funding. All of the PIs previous research and travel expenses have been paid for the last six years by grants to his international collaborators as listed for projects below (especially Schweizer, but with support from Lille and EHESS/Paris, MSH/Paris and CNRS programs). Workshops during this 2-year period will be 2 days long, the first an introduction to formal concepts and methods by White, Harary and Brudner, together with discussion of specific research problems; the second a computer lab instructional session on project specific data analysis.(see Work Flow Appendix: Table 4: PI Timetables). Academic year workshops will be during break periods; some may be shifted to summer.

Travel Funding and Timetables for Students and Post-doc (Tables 5 and 6). Some funding is requested from the Anthropology program for U.S. travel for students and post-docs. (see Work Flow Appendix: Table 5: Student/Post-doc U.S. Travel Timetables). Travel funding for Harary will provide the means for collaboration with the PI at UCI or at intersecting sites where both will present training workshops (regionally advertised and open to all researchers) or presentation of results and theoretical ideas to other researchers. Travel funding for Brudner will allow her participation in the workshops specifically to address fieldwork methods and ethnographic and historical aspects of research. The funding sought for student and post-doc travel (Table 6) through NSF international programs (France, Germany, Mexico, Guatemala, Slovenia or Austria and Spain) is for airfare and 10 days maximum expenses per visit, not for extended fieldwork expenses, for which funding is obtained separately (see Work Flow Appendix: Table 6: Student/Post-doc Int'l Travel Timetables).

APPENDIX (More data are found on the case study sites at http://eclectic.ss.uci.edu/~drwhite/cases/table2.htm)

Notes to Table 2: **Table 2a: Detailed listing of the Longitudinal / Historical Sample and the Project Collaborators**

Region	Site Location	Contributors and Collaborators	University Codes
(Au)stria	1		
(Aus)tralia	1	1 McCall	U New South Wates
(C)ameroons	1		
(Ch)ina	1	1 Ruan	(at UCI)
(E)ngland	2	3 M.Fischer, Barnes, Epstein,	Kent, Oxford, Sussex
(Eu)rope	1		
(F)rance	2	4 Houseman, Gribaudi, Cristofoli, Dupriez	EHESS, EPHE, Lille
(Ge)rmany		3 Johanson, Schnegg, H.Fischer	Cologne, Hamburg
(Gh)ana	1		
(Gu)atemala	1	1 Casasola	(At UCI: going to teach at San Carlos)
(In)donesia	1		
(I)taly	1	1 Lévi	Venice
(M)exico	4	3 Gil, Schmidt, Alcántara	UNAM
(Mi)cronesia	1		
(Mid)dle East	1		
(Ne)w Guinea	2		
(N)o.Am. Indian	1		
(P)olynesia	1		
(Sl)ovenia	1	2 Batagelj, Mrvar	Slovenia
(S)pain	1	2 Pizarro, Herero	Madrid Complutense
(Sr)i Lanka	1		
(Sw)itzerland	1	1 Widmer	Geneva
(T)urkey	2		
(U.S.)	3	16 *(SFI)=Santa Fe Institute*	*1 Chicago *4 Berkeley *7 Penn *10 Kent *2 SMU *5 Columbia *8 Oxford *11 UC River- *3 Cal Tech *6 Vermont *9 Cornell side
(V)enezuela	1		
(Z)ambia	3	1 Clark	
Totals	36	25	12 U.S.; 15 other

Table 4: PI Timetables	Summer 1999	Fall	Winter 2000	Spring 2000	Summer 2000	Fall 2000	Winter 2001	Spring 2001
PI sites								
Tlaxcala (2 publications completed)	Supervise installation of *Schnegg* for restudy		Check data collection	Help data code and compute-rization	Assist in analysis; send UCI student to field	→	Assist with thesis	(begin new joint Pubs.)
Nord-Pas-de-Callais	Supervise 30 hours of coding		Run analyses	Visit Lille **Workshop**	Collaborate with Lille colleagues…	Regarding additional …	data and write-up	→
Omaha	Review computer file data quality		Run analyses	Assess theory re: write-up	Begin write-up	Write-up	Finish write-up	Submit
European Royalties	Run preliminary analyses		Run analyses	Assess theory re: write-up	Begin write-up	Write-up	Finish write-up	Submit
Drame	Run preliminary analyses		Run analyses	Assess theory re: write-up	Begin write-up	Write-up	Visit Slovenia	Submit
Pul Eliya	Work with *Robert*	…	*Johnson*					
Methods collaboration								
Harary (3 articles in process)	finish publication on cohesion, density, implement algorithms		Work on conditional blockmodels & connectivities		Finish publication of articles	Begin work on book	Work on book	→
Batagelj and *Mrvar*	(joint article should appear)		Propose algorithms	Implement algorithms	Expand computer capabilities	Make system easy for anthro.	Visit Slovenia	(new articles)
Bearman	Historical casing	Aspects of these topics will be incorporated into the workshops			Each of these topics will result in project publications that come out of the workshops			
Padgett	Criticality							
Breiger	Institutional Str.							
Goggin	Centrality							
Widmer	Sampling							
Workshops: White, Brudner and Harary	**Paris Lille**				**Madrid Barcelona**			**Cologne Hamburg**
Student sites								
Nord-Pas-de-Callais	Work with *Johnson*		Run analyses	Visit Lille	Work on joint article	→	Visit Lille	Completion
Mexican Presidents	Work with *Alcántara*		(her fieldwork	(her fieldwork	(her thesis)	(her thesis)	(her thesis)	Completion
Norfolk	Work with *Fitz*		(data)	(his thesis)	(his thesis)	(his thesis)	(his thesis)	Completion
Bevis Marks	Work with *Fitz*		Write-up	(article)	(article)	Completion		
Guatemala	Work w*Casasola*		(her thesis)	(her thesis)	(her thesis)	Completion		

Chuukese	Assist *Skyhorse*		→	(her thesis)	Completion			
Ndembu	find *anth.student*		Analysis	→	(co-author)	→	→	Complete
Wam	find *anth.student*		Analysis	→	(co-author)	→	→	Complete
Pere Manus	*Ruby Salmo*		Analysis	→	(co-author)	→	→	Complete
Old Testament	Assist *Jester*, Grannis		→	→	(their article)			
Collaboration								
Feistritz (cf. Brudner and White 1997)	Reanalyze case with respect to farm sizes		Prepare new graphics	Begin new article with Brudner	Continue publication	Submit article	Visit Carinthia: future work	Plan future work
Tlaxcala V.	Process data		→	→	→	Analysis	→	→
Tzintzuntzan	Assist Widmer		→ consult	w.van Kemper	(co-author)	→	→	Complete
French Public Health	Assist Gribaudi (EHESS funded)		→	Visit Paris Workshop	Write-up and analysis …	… with Gribaudi	→	→
Beti	Assist Houseman		→					
American Presidents	Assist*Granis*&S-Norris: Analysis		Analysis Write-up	→	→	Joint publication		
Geneva Scientists	Assist Widmers and *Fitzgerald*		→	(article)	End			
Turkish Nomads	See book ms to final publication			Make data available	End			
Florence	Analysis		with	Padgett	and D.Watts	Writeup		
Turkish Village	Consult with		M.Fischer	(provide	Training)			
Warren Co.	Web publication	with	A.Turner	*R.Salmo*	(End)			
Corporate I.	Breiger (& Han1997)		*Han*					
Fanti	Advise		Kronenfeld	(provide	Training)			
Groote Eylandt	Data analysis		Write-up	With Peter	Bearman			
Yanomamo	Acquire data		From	Chagnon	Analyze	Writeup		
Consulting								
Spanish Elite	Assist Pizarro, *Reyes-Herrero*		→	Visit Madrid **Workshop**	To be determined			
Qing	Assist Lee to…		archive for	future study	End			
Sawahan	Assist Schweizer		→	(provide student	Guidance)	Visit Cologne:	**Workshop**	
Rapanui	Assist *Colima*		→	→	(her thesis)	→	→	Complete
Gwembe	Assist *Clark*, Scudder, Colson		→	(provide	Training)	To be determined	→	→

Table 5: Student/Post-doc U.S. Travel Timetables	1999-2000 year 1	2000-2001 year 2
Fitzgerald-Norfolk, Bevis Marks, Geneva	To/From consulting with Berkowitz (Bevis Marks), Bearman (Norfolk)	To/From consulting with Berkowitz, Bearman
Skyhorse-Chuukese /Omaha	To/From consulting with Goodenough	To/From Omaha tribal area

Table 6: Student/Post-doc Int'l Travel Timetables	1999-2000 year 1	2000-2001 year 2
Johnson-France, Tlaxcala	To/From France (consultation/fieldwork) To.From Tlaxcala (fieldwork collaboration)	To/From France (consultation/fieldwork) To/From Tlaxcala (fieldwork collaboration)
Alcántara-Mexico	To/From Mexico (fieldwork)	To/From Mexico: Thesis Consultation/Field
Fitzgerald-Norfolk, Bevis Marks, Geneva	To/From Germany for conference presentation/consulting re: Norfolk, Bevis	To/From Geneva for securing new archival collection
Casasola-Guatemala	To/From archival/ interview fieldwork	To/From archival/ interview fieldwork
Anthro student-Ndemdu	None-anthro. department could provide	
Anthro student-Wam	None-anthro. department could provide	
Anthro student-Pere Manus	None-anthro. department could provide	
Jester-European Royalty, Old Testament	To/From Germany for conference presentation/consulting	
Brudner-Feistritz, Drame	To/From Cologne for consultation	To/From Carinthia/Slovenia to renew fieldwork
Widmer- Tzintzuntzan, Mexico	To/From Tzintzuntzan and To/From consultations involving van Kemper at SMU	To/From Tzintzuntzan and To/From consultations involving van Kemper at SMU

A note on Third Year Reduced Funding. Graduate student stipends will end after the second year. Considerable additional write-up time will be needed for the PI and main consultant (Harary) to finish the write-up of technical-mathematical results (new methodology) and for the PI and other collaborators to finish outstanding publications. Few travel funds are required at this time beyond consultations and collaborations for co-authorship. The PI (see White 1990) will put on-line those datasets with release permissions (this excludes Florentine and Omaha data, for example), provide graphic images of analytic results on the web, and make the project methodology and software freely available to other researchers.