Networks. Network studies are an important adjunct to further development of cognitive anthropology and theory. When reliable means of identifying relational properties of behavior, cognition, and cultural structures or systems are available they help overcome limitations of other types of descriptive studies, descriptive statistics, or ad hoc inferences about how mind, culture and social behavior interact. Roles and groups are core concepts formalized by network analysis to provide tests of social theory. As for core problems of cognitive anthropology, contributions here include explanation of emergent cultural consensus, network bases of schema theory, causality, and theory-testing.

Roles form key network and institutional structures that can be understood in relation to social processes. Network ethnography can also operate in this way to further understanding (White and Johansen 2006, chapter 1). Network studies enhance our understandings of cause and effects of emergent roles and their dynamical patterns of shifting stability, including hierarchy. Finding hierarchy and its network embeddings, for example, often depends on global as well as local information on how local patterns fit within global ones. Both the understanding of global network structure and analysis of micro-macro linkages are additional advantages. If we wanted to find the leaders in a large urban community (see Freeman et al., 1960), for example, we could start from a sample of potential leaders, ask them who the leaders are, and iteratively construct a snowball sample of higher order leaders until finally a leader subnetwork or evidence of a single leader emerges.

Cohesive Groups have patterned interactions that are self-reinforcing and self-stabilizing in certain spatiotemporal frames. Study of these interactions can also account for individual choices, the emergence of cohesive units as socially and cognitively recognizable entities and the consequences of these units and their changes through time for coordinated group behaviors. This kind of information may differ significantly from interview or observational accounts of individuals acting independently. The network concept of structurally cohesive subnetworks of varying intensity, as defined by the least number of disjoint redundant links between each pair of
their nodes, provides ways to study to what extend social groups, affected by their patterns of cohesion, come to be self-reinforcing and consequential in their effects.

**Cognition.** Formally defined core concepts from network science help capture how cultural consensus forms and changes around emergent roles and cohesive groups, given that humans are cognizant of role and group structure. Such concepts provide the bases needed for explanatory theory about sharing and differentiation in societies and cultures. Both cognitive and brain networks include various types of hierarchical organization. The human eye and visual perception *per se* do not allow us to truly “see” reality but rather to extract patterns of perception at successively higher levels.¹ There are no inherently “true objects” or “natural attributes” of objects corresponding to our perceptual world(s), but rather complex patterns of relations that identify objects cognitively with varying coherence and descriptive categories involving variable salience. As with other species, our views of the world have evolved adaptively as per our Gibsonian affordances – i.e., the means by which we relate to our environment. The organism-environment system is a relevant network for study.

**Deeper problems: Mind, Logics, and World.** The frequent disconnect between social behavior and cognition is a useful problem for study in the context of social networks, cognition, and culture. D’Andrade’s (1974) “behaviorscope” experiment showed that the categories subjects list in conveying their immediate judgments of others’ behaviors differ greatly from those they later report from long-term memory of the same events. The experiment also showed that the similarity structure of categories used in memory-based judgments is closer to those of the linguistic categories involved in expressing recovered memory and uncorrelated with those used in immediate judgments of these events. No wonder, then, that the studies of Bernard, Killworth and Sailer (1977, 1980, 1982; BKS and Kronenfeld 1984) showed that there is roughly only 50% agreement between the network links that people form and their mental recall of these links. Romney and Freeman (1987) showed that the "best" informants on behaviors in groups, according to consensus, “can be used to reveal long-range stable patterns of events,” while average nonconsensual judgments of the worst informants can be more useful “to reveal the details of a particular event of special interest” (the accident-bystander phenomenon, for averaging perceptions of completely independent observers). These findings connect with the

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¹ Because these patterns are constructed in the mind by interactions of neural networks, our mind has a perception of durability and continuity in our experiences, chunks of which will persist in various aspects of memory and mental schemata even as our attention is intermittently shifting from one experience to another.
Theories proposed by Gibsonian psychological studies reviewed herein: namely, that experience and memory is stored in continuous perceptions, feelings and “narrative-like” constructions about ongoing interactions: in episodes rather than in bits of time or cognitive categorization.

Network science is not simply a “method” of data collection and analysis but theory-driven in ways that begin from decisions about coding or structuring data so as to focus the analysis on theoretical questions. Results are heavily dependent on mathematical theorems about graphs, networks and relational algebra that capture “necessary connections” (see White 1974, White and Reitz 1983, White and Harary 2001, Moody and White 2003) for results that are not prima facie visible to the observer, either as ethnographer, preceptor of a network graphic or network participant. Local choices and subsequent behavior in networks, for example, have necessary implications for global features of networks, and vice versa. Some of these properties are best examined through formal definitions and theorems. Through proper tuning and validation of how to code networks (e.g., “experientially”)², network modeling can contribute to ethnography and to cognitive anthropology, and vice versa.

The sciences today are undergoing major transformations, rethinking and re-synthesis. They in turn are affected by transformations in physics, biology and ecological psychology in dealing with complex systems and, in particular, the dynamics of complex systems. I address here how these new syntheses affect anthropology and those social sciences concerned with human cognition, culture, and networks. Cognitive anthropology is caught in a position of having to reconcile individual cognition in the human brain with the existence of cultural patterns in terms of shared and meaningful symbols.

The three-world problem. In some fields it is beneficial for social scientists to consider philosophical problems that affect research. For networks and cognition, Popper’s (1959) critique of logical positivism is a good place to start. Popper argued “that positive evidence (‘confirmation’) and the inductive method (the search for rules that lead from limited observations to the establishment of valid generalizations) are not at the heart of science” (Schweizer 1998:44). Loosely stated, science is not defined by method, and that "appropriate methods" do not guarantee results. “Rather, negative evidence (‘falsification’) and deduction are

² Because their collaborations contribute value to reputation, for example, biotech organizations (Powell et al. 2005) self-report their new collaborative contracts annually in their trade journal; Aydn nomads proudly report their marriages and ancestors to ethnographers (White and Johansen 2006); network surveys may constrain and limit responses but also ask respondents to report on personal experience as well as experiential observations. Dyadic self-other reporting may provide estimates of the reliability of such reports.
at the core…. In the spirit of critical rationalism, when choosing between rival hypotheses, we should always select the one that has higher information content by being more general and thus more challenging due to its wider range of application. And we should [tentatively] keep the one that has survived serious attempts at falsification and therefore has proven less false than its rival.”

The three-world problem, as debated by Popper and Eccles (1977), is one that also confronts cognitive anthropology:

World 1: The physical world (and human brain and behavior in that world).
World 2: Mental activity and human consciousness.
World 3: Objective culture, "which is the creation of World 2 but takes on its own distinct and permanent existence."

My goal for Fig. 1, in proposing a complex heuristic model – of physical brain, behavior, and material culture in relation to immaterial mind and culture –, is to open up new problems in cognitive anthropology, bringing to the study of culture and cognition potentially new theories and approaches from the field of social networks.

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Fig. 1. The three-world problem at two levels: **Columns**: Individual and Social, Thought and Relations. **Upper ovals**: Cognition and mental expression; vs. Networks and behavioral expression. **Lower ovals**: Brain and organismic behavior relative to the environment; vs. Culture, group and role. **Arrows**: suggest cycles such as B↔C (reciprocal) and A→B→C→D→A (directed). Further discussion is provided in Appendix 1 (White 2010a).

My concern in drawing Fig. 1 is with how these three worlds are related. How is it possible for “Objective” culture to take on a distinct and durable existence? Arguments between scientists
such as neurophysiologist Damasio (2007) and philosophers like Gluck (2007) are seemingly irreconcilable. Their critiques of one another fail to resolve the problems of Popper and Eccles. My proposal is that we may come to better understand human behavior, cognition, and culture if we separate elements such as action, thought and culture into material components and immaterial patterns, using different aspects of networks of relations, such as relational pattern, abstraction from material to immaterial (patterns of thought, patterns of culture), and material causation.

Fig. 1 is a heuristic model that expresses how the three-worlds might be related. Key features are that: unlike the brain, immaterial A=mind is not directly causal to observable C=social behavior; and, material B=brain is not causally connected to immaterial D=Culture. Direct causalities do reciprocate between observable C=social behavior and material B=brain. The upper ovals in the figure involve what individuals “do” in terms of thinking (internally) vs. behaving (externally) as persons embedded in social networks. The lower ovals involve B=brain (with its organism-environment interactions) vs. the nonmaterial elements of D=culture. The columns suggest that elements A and B play out at the individual level (mind and brain) while C and D do so at the social level (networks, culture). The main driver of human thought and behavior, in this model, is the A→B→C→D→A cycle among material (B,C) and nonmaterial (A...D) elements that include mind and culture. The network oval C evokes the idea that episodic behaviors are internally (experientially) and externally perceptual and can be represented as network flows with an episodically temporal ordering in behavior that draws on restructured and weakly encoded memory of episodic experience. Solid and dashed ovals encircle material and immaterial elements, respectively, with causality between material items, pattern projections between thought and culture, and abstractions between material/immaterial counterparts: “mind studies brain, behavior models culture.”

Among the heuristically useful features of this framework is that it recalls that habitual pattern behaviors may be coordinated directly by the brain, as opposed to conscious mind-brain mediation of behavior. In my ethnographic examples below, Pul Eliyan sidedness behavior is usually habitual, sometimes strategic, and occasionally requires a conscious computation when encountering strangers from the local area. Chuukese residential choice is a conscious decision, as are Karate Club members’ decisions in their dilemma of choosing alternate subgroup membership. Heuristically, it is useful to observe that – just as A=mind expresses itself through
language – external C=social behavior expresses itself through gesture, movement, facial expression, and action (White and Johansen 2006). These constructs depend on what ego and alter observe to be the motivators of social behavior: what is assumed social actors' perceptions, memories, and the contexts of interaction. Like material culture, items of C=social behavior have meaning in a network of meanings; external behavior is constructed as social relations. This conception views how we construct intended or observed relations as elements of social networks.

Relational thought. For humans, the assumption that mind operates largely through categories fails to be convincing because humans also think relationally, as has been demonstrated experimentally (Hummel and Holyoak 2005, Penn, Holyoak, and Povinelli 2008). One problem with 1960s cognitive anthropology was that meaning was seen as defined by categories, an element in first upper circle of Figure 1, without the element of relational cognition.


Time-series of episodic events as experiences thus lend themselves perceptually to network coding and analysis. Such studies may be done at many different time scales. In our studies of kinship networks for example (see White and Johansen 2006 for an ethnographic example) there are intergenerational events such as marriage, childbirth, death, migration, and proximal interactions within the culturally recognized and individually perceived event boundaries and time-scales of event sequences. The network links among events and actors exhibit structural and dynamical patterns, including recurrences for which tools exist for studying complex dynamics (see Carollo and Moreno 2005 for methods), fractalities (White and Johansen 2006:136-137), and structural cohesion as a predictive network variable relating to shared-culture formation.

Cohesive groups in networks. Cohesive blocks (maximum subnetworks in which each pair of nodes are connected by a certain minimum number \(k\) of disjoint paths) are found operationally
in a manner that fits the basic conceptual form for the idea of the cohesion of groups, the way cohesion is perceived for groups, and the way that cohesion ties a group together both internally and by resistance to being dismembered. It also shows the way that networks provide a particular set of the degrees of freedom in how cohesive groups may relate to one another through overlap (e.g., membership in multiple communities) and through core-periphery subgroup hierarchies for levels of cohesion. This opens the way to the following hypothesis:

**The Cohesion and Consensus Hypothesis:**² Levels and variations of cohesion within social networks for society as a whole and within its varying segments, measured within networks for cohesive blocks (subnetworks) with a minimum level \( k \) of disjoint paths between every pair of their nodes, tend to predict levels and variations in cultural consensus, provided that the connections that define the network have some positive perceptual relation to the subject or contents of cultural consensus.

This hypothesis was suggested by Schweizer (1996:116) but without an analytic measure of cohesion. It was reiterated by Ross (2004:124), who took density as a measure of cohesion, which it is not. White and Harary (2001) were the first to both formulate a formal measure of network cohesion that drew from the theory of graphs, and to test the predictiveness of the concept with a simple empirical example. They predicted how a Karate Club studied for two years by Zachary (1977) divided its membership between the club owner and the instructor, and the order of secession of members as the teacher formed a new club. This has a cognitive dimension because to decide with whom to disconnect individuals had to assess (1) their relation to others relative to the themselves, and owner and instructor, and (2) who were their closer or more distant friends in the network and how those allies stood in relation to the two leaders. Defectors moved to the teacher’s side by breaking with those on the owner’s side but did not follow a simple individual-level decision rule; rather, their behavior entailed a perception of group cohesion by breaking ties that were less cohesive with the owner’s side than the ties they kept, and; for ties of the same level of cohesion, breaking the more distant tie from the owner. Attributes of the leaders with respect to those of students were not predictive.

³ There are of course other network predictors of cultural consensus, such as parentage or ancestry, common history, common educational experience or exposure to the same media sources such as specific TV and radio sources. These are “vertical” rather than the “horizontal” influences of structurally cohesive groups. There are also “oblique transmission” influences such as effects of common types of prestigious figures that inspire learned agreement.
Atran et al. (2002) tested friendship and social interaction as predictors of cultural agreement for environmental cognitions for populations but found no correlation (Ross 2004:122). Boster (1986) found kinship as a source of agreement among Peruvian manioc cultivators but, again, had no measure of cohesion and no findings for a cohesion-consensus hypothesis. Interaction alone and network density alone, in these studies, were not predictive of cultural consensus. Altran et al.’s (2002) expertise networks, however, did predict cultural agreements, and might have been more cohesive.

Moody and White (2003) tested the predictiveness of White and Harary’s structural cohesion measure, and showed that: (1) students’ level of structural cohesion in friendship-group ”blocks” strongly predicted their reports of attachment to high school; and (2) cohesive strengths of co-memberships in the cohesive blocks of business alliances predicted similarities in the choices of firms in their political party alliances. In both cases, none of the other network or attribute variables – including density, centralities, and dyadic tie measures as well as student attributes – outperformed the predictiveness of the cohesion measure.

Powell, White, Koput and Owen-Smith (2005), using the Moody-White measurement of structural (block) cohesion, analyzed time-lagged effects from year to year of multiple variables in the choice of partners for strategic collaborations in the biotech industry. They found that diversity of level of cohesion in the cohesive blocks to which potential partners belonged the year before were strong predictors of partner choice. Here, none of the other network or attribute variables outperformed the predictions of cohesion and diversity measures.

Fig. 2 (a)/(b) shows with two different network structures how cohesive blocks are defined and stacked by internal level of network-tie cohesiveness. The differences between (a) and (b) illustrate two slightly different model networks: (a) an “integrated” single-stack of cohesive blocks and (b) a network with multiple cohesive blocks that are segregated but overlapping. In (a) the ties are fully randomized. Random edges always tend to create embedded levels of “socially integrated” $k$-cohesion, like a nest of Russian dolls, i.e., forming a single hierarchy of cohesion. The biotech networks studied by Powell et al (2005), for example, have single-stack cohesion with maximum cohesiveness varying from 4 to 6 from year to year.

Each of the two graphs in Fig. 2 has 20 nodes, but while (a) has 38 all-random edges, (b) has 33 random edges plus 3 strategic ties placed to create the greater complexity of two cohesive but overlapping subgroups. The random graph in Fig. 2 (a), with its 20 nodes and 40 links (each link
adding one degree to each of the two nodes linked) has an average degree per node of 4 edges (some with more and some with less). Those that have degree four or more are circled but no set of the 14 nodes with degree 4 forms a 4-component. Instead, there are 17 nodes that form a 3-component (red nodes). Here the 3-component is a subgraph of the 2-component, which has additional (green) nodes and nests in the largest (1-) component of all the connected nodes. In Fig. 2 (b), however, the red nodes differentiate into two 3-components.

**Fig. 2.** Cohesive blocking in graphs with 20 nodes and different numbers of nodes and random edges, with additional edges added in 3 (b). Colors of k-cores are k=3 in red, k=2 in green, and k=1 in yellow. This differs from sorting by degree, as shown by circled nodes in 3 (a) for nodes with degree ≥4. (a) has a single cohesive hierarchy. (b) has two k-components that are not differentiated by the k-core concept but belong to the same 3-core. If the two 3-blocks in 3 (b) were social groups, the Cohesion and Consensus Hypothesis would predict greater consensus in each of the two 3-components than in their combined k-core (colored red). For social interaction networks, greater consensus might be expected by the cohesion-consensus hypothesis the greater the cohesion of a k-component.

The colors of nodes in Fig. 2 illustrate k-cores. A k-core (for k=1,2,3,…) is a unique subgraph of a graph in which each node has degree k or more. Every k-component is a k-core but not every k-core is a k-component or k-block. In any network these are uniquely defined for the integers k=1,2,3,…, allowing for higher k-cores that are empty. In graph 3 (a) but not 3 (b) the k-cores and k-components are identical for each k. The k-cores of a graph are easily computed, e.g., by Pajek (Batagelj and Mrvar 1998: Menu/Net/Partitions/Core), which deletes all nodes with less than the highest degree k and then recomputes degree, retaining those with k or more links, iteratively. Like the measure of subgraph density, the use of k-cores (defined by Foster and
Seidman, 1989, Seidman and Foster 1978) is often taken in network analysis as a measure of group cohesion, even though this usage is invalid. A $k$-core for any value of $k$ with more than $2k$ nodes may be completely disconnected. Even a subgraph of two cliques (each completely connected) may have 50% density and yet be disconnected. Densities, like $k$-cores, are not measures of cohesion. For small graphs, the combination of spring-embedding and $k$-core coloring usually allows visual identification of $k$-components, just as people with mature skills in relational cognition can often identify the unique $k$-components in their friendship groups. For a more sophisticated use of $k$-cores as fingerprints of network structure, recognizing that cores may be disconnected, see Alvarez-Hamelin et al. (2006).

Fig. 3 shows the results of cohesive blocking applied to Fig. 2 (b) using the algorithm of Moody and White 2003 (in a version implemented by McMahan 2007). Nodes in both 3-components (3-connected) are red, but the splitting diagram to the right shows that there are two 3-connected components. The output vector computed by the McMahan (2007) algorithm tells exactly which nodes are in each of the 3-components, as shown by dotted ovals in 3 (b):

```plaintext
[[3]] [1] "v2" "v3" "v4" "v7" "v15" "v16" "v19"
[[4]] [1] "v3" "v5" "v8" "v12" (N.B.: node "v3" is shared with 3-cohesive block [[3]])
```

Note that “v3” occurs in both 3-components in the separate but overlapping dashed ovals.

Fig. 3: Cohesive blocking of the graph in Fig. 2 (b).  

Armed with this way of measuring the distribution of cohesive groups at different levels of cohesion, it is easy to see how a Cohesion and Consensus Hypothesis could be tested by direct correlation with a pairwise cultural consensus matrix (Romney, Weller, and Batchelder 1986). A single-consensus model would perfect match a network of type 3(a) - integrated cohesive groups, but a divergent-consensus model might match one of type 3(b) - separate even if overlapping
cohesive groups, or one with more or more discrete components of cohesion. Areas in the graph of higher and lower correlation between consensus and cohesion could be mapped and compared.

**Test of Structural Cohesion and Cultural Consensus**

San Juan Sur (SJS) is a peasant community in the Turrialba Canton of Costa Rica studied by Loomis and Powell (1949) in contrast to a nearby hacienda community (Atirro). Their network study is one of the few with data available to directly address issues of networks, cognition, and culture, for which the hypothesis linking structural cohesion to cultural consensus can be tested.

Costa Rica was then seen as the most democratic country in Latin America, “the land of peasant proprietors,” where many of the rising hacendado class arose from peasant communities. The focus of their study was the transition to more stratified society, occurring as

“peasant holdings are being gradually throttled by the large fincas and corporations thus reducing the status of the people from that of peasantry to peonage. Increasingly larger numbers of people are becoming “journaleros” and working for a subsistence wage as peons of the large land owners. What, then, might be expected if the country continues in the present trend toward a peon-patron type of system? For example, is there really a larger lower class on the hacienda than in the peasant community? How do the classes in these two situations compare with those in society at large? Especially important is the influence this transmutation may have upon the possible acceptance of communism by the rural people who have been and are being forced to accept the status of peonage.” (Loomis and Powell 1949: 448).

One focus of this study was on the impact of formal and informal social systems – social networks – on social change. Loomis investigated visiting relations between peasant proprietor families living in the San Juan Sur (SJS) neighborhood and in the nearby hacienda of Atirro. The visiting-network data they collected were published as simple directed graphs, without giving the number of visits but with arcs showing “frequent” visits from one family to other. For SJS 92% of visiting ties were within the community, and kinship ties were most often to the wife and/or husband’s parents. Line values classified the visiting relations: value one for ordinary visits, two for visits to kin, and three for those of ritual kin: god-parents, god-children and compadres. Judges and members of each community were asked to rate one another on a scale of social class

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4 These ties show an extended family structure in SJS with a common – consensual role – pattern in the visiting behaviors for kin. Removing symmetric ties for visiting among kin gives 46 remaining asymmetric visiting ties that form a connected but partially ordered visiting hierarchy differing significantly from random rearrangements of ties (p=0.0000000000003). This is evidence of the salience of a P-graph structure (individual members of couples and their siblings linked to parental couples) for the kinship network (see following section).
from 1-10 (1-100 for the sum of 10 judges). These data allow comparison of structural cohesion with consensual social class ratings in the two communities.

SJS and Atirro differ organizationally. The sixty Atirro residents interviewed were finca employees who worked for a small daily wage, lived in a tightly nucleated cluster, were much more mobile than the SJS residents (sixteen had lived there for less than a year) but enjoyed a rent-free “casa” during their employment. An administrator directed the work of the finca and a “mandador” directed the workers and was answerable to the finca owner. Here, structural cohesion would be expected to be fragmented but with some fragments indicating organizational specialization, as for example, in the finca hierarchy. The results of testing the cohesion-consensus hypothesis are positive for SJS but not for Atirro, where social cohesion in visiting is disrupted by turnover and finca organization.

SJS judges agreed on four classes for Atirro and SLS: upper and lower middle (18% of SLS) and upper and lower in a lower class (59% and 24%). The SJS peasant community is described ethnographically as egalitarian with no upper middle. Nine of the ten judges in SJS rated themselves identically to how others rated them (p.149), and a SJS leader rated himself one rank lower than others rated him. Seven of the ten rated each other mutually as middle class. Fig. 4 shows three types of directed ties for the SJS network, distinguished by color: red arrows for kinship visits, blue for religious or ritual kinship, and black arrows for ordinary visiting. Reciprocal arcs are symmetric ties, as opposed to asymmetric directed arcs.

For the cohesion-consensus hypothesis, SJS cohesive blocking shows red nodes for the large structurally integrated 3-component of the network, green nodes that add to the 2-component, and a single blue node that adds to the 1-component. SJS has the community integration structure associated with a single-cohesive hierarchy, as in Fig. 2(a). The correlation between upper-middle class families and levels of structural k-cohesion in ties for visiting kin (red arrows) is more significant (p < .003) than the cohesive 3-component vs. lower cohesion correlation in SJS (p < .04) with middle/upper low-class (76% of the network) vs. lower low-class (24%) ratings by judges. The correlation between k-cohesion and leadership status is equally significant.

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5 Fig. 3 has 54 red nodes and 20 green-blue nodes (one node is obscured) and has nine green-blue nodes with social class ratings below 46 on the scale 0-66 in Figure 2 of Loomis and McKinney (1956: 407).
Fig. 4. SJS network, with directed ties colored red for kinship, blue for ritual kinship, and black for other. Edges without arrows are symmetric, arcs asymmetric. Most of the blue arrows (for ritual kinship) are within the large structurally integrated 3-component of the network (red nodes), in which most of the arrows are red, indicating kinship ties. The green nodes identify the 2-component, and the single blue node connected only adds to the 1-component.

In the Atirro finca there are no correlates of cohesion with class rank or leadership. “In Atirro the two upper classes have associations directed largely outside the community and little interaction orientated to other people in the village” (Loomis and Powell 1949:157). “The top prestige leaders… were not chosen from these two upper groups and there exists a barrier of significant proportion between the two lower groups and the two upper groups” (low and upper middle class). “The lack of informal communication between leaders [of the two lower classes] and the finca and commissary directors in the classes above is noteworthy.” Mutual agreement on class levels does occurs for eight of ten judges but the community was split equally in their ratings of one resident and, for a leader, three judges agreed with his rating while six judged him higher.
Loomis and Powell (1949:157) conclude their article, in light of their concern with community disaffection in the hacienda regions of Central America, where Costa Rica was a bastion of independent farmer. “The middle class philosophy of thrift, hard work, and higher regard for property is not as prevalent in the hacienda community as in the peasant proprietor community.” In Atirro what little cohesion is there is highly fragmented and the largest set of extended family visiting ties are hierarchically connected to the hacienda employment hierarchy.

**Tests of consequences of cohesion in P-graph structure of kinship networks.** P-graphs illustrates how a network representation can be as complex or as simple as you want to make it. It may be intended to represent known sequences of selected or observed events, or to represent a narrative or story (as in the kinship network of the Biblical Canaanites in White and Jorion 1992), a series of linked conversations, or a cultural model. Typically a network representation is a network model, similar to a cultural model in that a selection has been made of elements, connections, and processes through time that have some systematicity or coherence, or that exemplify complex interactions such as cycles, differential stability or instability of elements and interactions, i.e., complex dynamics. Network models of interactions may be simulated, and, conversely, most simulations will have elements and interactions that map out in time and could be represented as an evolving network, or as multiple coevolving networks. Networks are not just made up of behaviors that instantiate cognition (Read 2008) but constitutive of the felt environment by which humans think, individually, and socialize their collaborative cognition.

For kinship networks of an Austrian farming community studied by Brudner and White (1997), more cohesively integrated members predict those who inherit productive property as opposed to those who do not and who tend to leave their natal community. For a Turkish nomad clan, more cohesively integrated members tended predict those who stay with the clan rather than emigrating to cities, inheriting in this case the productive property of pastoralism. Predictions of this sort are reviewed in White (2009). To better study the structure of kinship networks the network units were converted from individuals to couples (P-graphs, as defined by White and Jorion 1992) so that cycles of marriage as well as marriage among consanguineal kin could be detected. These cycles are a special case of structure cohesion or $k$-connective where $k=2$ (bicomponents) are the maximal level of cohesion (two is the maximum number of parents in a P-graph and standard genealogy). This type of biconnectivity excludes cohesion within families and captures kinship units of *structural endogamy* (White 1997) within communities.
Perception and action based on cohesive structure. Case study findings such as those of Moody and White (2003) on school friendship networks and of business alliances in relation to political affiliation, and of Powell et al. (2005) on human biotech collaborations, each imply an ability to act upon perceptions of cohesive network structure even without any linguistic labeling of the cohesive groups or levels of cohesion, and that these perceptions proved to be largely correct. The first is an example of friendships in relatively small networks within single organizations (high schools), while the second and third are medium and large sized networks of firms and other alliances of the firms (in the first to political parties, in the second, to other organizations that serve functions for the biotech firms). A cognitive ability that would allow individuals or firms to act in such a way that their choice behavior for network ties is predicted by structural cohesion presumes recognition of cohesive structure even when names for \( k \)-components are lacking in ordinary discourse.\(^6\)

The fallacy that thought depends on language. We know from experimental comparisons between human and other animals show that relational reasoning (Hummel and Holyoak 2005) is critical to humans’ ability to negotiate their extensive skills in social networks. The special relationship between human cognition and the complexity of human social networks includes those of “non-perceptual relational similarity based on logical, functional, and/or structural similarities between relations and systematic correspondences between the abstract roles that elements play in those relations” (Penn, Holyoak, and Povinelli 2008:111).\(^7\)

Dominant anthropological views of the early 1960s, however, assumed that cognition and culture were largely constructed through language and linguistic categories, which in an extreme case can be problematized in a quote from Helen Keller: "Before I had words I had only sensations." Keller, however, was deafblind. It has been shown experimentally that with sight alone humans have enormous complexity in their understanding of social relations. Orangutans and other higher primates also have understanding of complex relations acquired by watching and listening. This hints at where words and language fit in Fig. 1 as opposed to nonlinguistic, e.g., relational cognition.

\(^6\) The cohesive blocks in the biotech industry were unnamed, and it is doubtful that the friendship groups were named because they cut across grade levels and partitioned groups within grade levels.

\(^7\) Cohen (1969, Cohen et al. 1968) showed evidence of modes of reasoning using relational reasoning rather than analytical categories of nonverbal tests but such evidence has been largely ignored.
We can narrativize culture as a phenomenon taking on “its own distinct and [durable] existence,” and as such stories are supported experientially by the duration of network groupings with a high degree of structural cohesion (Moody and White 2003) and where social networks form detectable communities (Estrada and Hatano 2008). The algorithmic science of finding unique “strong boundaries” of cohesive network subgroups, as proven mathematically for cohesive blocking (overlap detection for hybrid communities) is barely in its infancy. Yet White and Harary’s (2005) time-series predictions of karate-club member decisions are replicated in Estrada and Hatano’s model, and serve as an example of precisely matching predictive models for how ties dissolve as a club splits in two during a conflict between leaders. For every population in which there are data on the kinds of elements that constitute a culture or subculture, tests can now be constructed using cohesive blocking models and also Estrada’s community detection algorithm to predict consensus or other patterns of behavior.

**Co-descendant sidedness: South Asia.** Humans can cognize complex role and structural patterns in social networks, only some of which are encoded in language. An illustration of complexity in pattern recognition is explicit in South Asian kinship cognition, express in discourse that is explicitly computational. When two people in a Dravidian language region are uncertain how they are related, for example, it is a computational discussion of whether they have a common close ancestor that allows them to decide whether they are “parallel kin” or marriageable “cross” relatives. This calculation expresses the existence of positions in the kinship network connecting same or opposite sides of two sets of intermarrying male lines (*viri*-sides) so if there is an *even number* of their female links – mothers of male or agnic ancestors linking them to an ancestor – then they are cross and marriageable (Kris Lehman, pers. comm.), as with ♂ZD, ♂FZD, ♂MBD or more remote cross-sided-kin (♂MZS of course is not marriageable either). Otherwise they are same-sided, as with Z, FZ, MB. This shows cognizance of a balance principle of signed graphs that is proven as a theorem by Cartwright and Harary (1956): If we regard the male links as (+) same-side ties and female links as (-) opposite-side in a marriage network, the balance theorem partitions all and only the (+) links into one of two sides, assures that (-) links connect opposite sides, and that all cycles contain only even numbers of (-) links (but any number of (+) links). Descendants with overlapping ancestors need only marry properly-sided consanguines (e.g., ZD, FZD, MBD) to form *viri*-sides (opposing sets of agnatic lines) that intermarry. The *viri*-sided balance principles implicit in Dravidian egocentric kinship
terminology organize coherent sidedness for networks of consanguineal marriages. Caveats for consistency are that sidedness can incorporate totally foreign spouses but cannot apply to distant families related through marriage, this for the practical reason that, (1) there are too many paths to follow, unlike tracing near ancestors, and (2) these may not be among “your” kin who share a common network structure of sidedness. Thus, a network of consanguineal marriages will be sided if everyone follows the local co-descendant viri-sidedness rule (or, in a matrilineal society, a uxori-sided rule wherein an even number of fathers of uterine ascendants will create same-sidedness in a uxori-sided consanguineal marriage network).

The structure of kinship networks is often valuable in understanding how kinship works, even at the terminological level. Leach’s (1961) Pul Eliya contains a complete genealogy of a Sri Lankan community with agnatic compounds and cross/parallel kinship terms with Dravidian “egocentric” sidedness rules. The restudy of these data, analyzed by Houseman and White (1998a) and White (1999), however, shows that 100% of the male links in the kinship network among those kin linked by common ancestors can be divided into viri-sides such that women from one side marry men on the other (White and Houseman 1998b). The egocentric categories of the Dravidian kinship terminology do not explain how this comes to be when named matrimonial moieties are absent. There is a minority of wrong-sided marriages between nonconsanguines. The name for them is dos, “improper” marriages. Pul Eliyans also have a reason not to practice viri-sidedness village-wide or with outsiders because irrigation rights and extended family residences in compounds are normally inherited by sons and allocated to a daughter when she lacks brothers. Thus they lack even lack a rule for membership in agnatic descent groups that is consistent with their close-kin network of male-based sidedness. To inherit and avoid dos marriage, the heiress will marry a man from a distant village whose sidedness can be ignored (some brothers from distant villages are able to marry women on opposite sides). Strategic marriages preserve cognatic inheritance relations without violating the integrity of a cognized but not fully articulated linguistic inscription of network sidedness. Sidedness and its strategic alterations are difficult to perceive in Leach’s (1961: flyleaf) genealogy but rather easy to interpret in the viri-sided P-graph diagrams of Houseman and White (1998b: Figs. 4.3, 4.4, and 4.5). But, community members have an elaborate understanding of network sidedness expressed in their kin terms and, while a minority of non-sided marriages occur for those who do not marry consanguines within the core community, they do retain consistent sidedness among the majority
of the village that are connected through common ancestors. The explanation of this limited network sidedness is their cognizance and use of the balance principle of signed graphs among close kin, wherein the *practice* of keeping balance creates a balanced network *structure*.

**Residential inheritance dependence: The Chuukese puzzle.** Another example important for understanding kinship is how behavior choices are made as part of “shared culture” but in ways that are ascribed by fixed categories such as descent or residential groupings. Relational thinking about where to reside after marriage, for example, is analyzed in a network study by Skyhorse (1998) of the Romanum Chuukese (aka Trukese) genealogies. This is a question that spawned the Fischer-Goodenough residential rules controversy: should residential choice be broken down into categories based on the lineage of the wife or husband, with the wife’s father maternal uncle, or husband’s father, and so forth, and should the categories be “emic” (how people think about these choices) or “etic” (describing choices in the observer’s language). Skyhorse, however, shifted the question to show cultural uniformity in terms of how the context of networks relationships predicted choice. Nearly 100% of the couples she studied with the aid of complete Romanum genealogies went to live with the holder of lineage land whose was “closest” to the husband or the wife in terms of the rules for inheriting land. This is the kind of decision analysis (Fjellman, Geoghegan) reviewed in White (1974), but now contextualized by how people were embedded by meaningful links within the global kinship network of genealogical links.

**Subgroup versus individual centrality.** In the two examples discussed above, and in my Karate club example, network-based cognitions and decisions play out in is the mutualities of how two people regard each other with respect to others: in “sidedness” of mutual ancestral descent, the mutual considerations of alternative inheritances by spouses play a leading part in residential choice, and dyadic considerations about dropping friendships in factional disputes. In sociology these are known as Simmelian effects of the network embedding of dyads within triads, or how network structure and groups influence behavior. While the centrality of individuals has been shown to be an important influence on their behavior (Freeman 1979 distinguishes effects of betweenness versus closeness or simply number of connections, for example), Estrada and Hatano (2008) test a more Simmelian measure of subgroup centrality that characterizes the relative participation of each individual node in all subgraphs in a network. This measure, over a large sample of empirical networks, is almost totally uncorrelated with
betweenness centrality for individual nodes. Estrada and Rodriguez (2009) go a step further to exploit their group-oriented method to define uniquely-determined network communities based on patterns of shared subgroup centrality and the clustering of “communicability” in networks. Measures based on group effects such as these (and structural cohesion) should predict degree of cultural sharing among members of a network, no matter how extended, effects on individual agency, and on the potential agency of groups.

**Diversity and Sharing.** The integration of network approaches into cognitive anthropology reopens significant new problems of sharing and diversity; continuity and discontinuity in culture; and stability, metastability and instability in complex systems (including culture). New approaches can help in new syntheses at the ethnographic level and theoretical level, including comparison and explanation. The concepts of structural cohesion are ones around which communication, social reinforcement and agreement may shape cultural consensus. These group-oriented network measures also identify social boundaries that may overlap and that may change rapidly. Members of a cohesive group may also affiliate elsewhere to create complex network formations.

**Continuity.** Many anthropologists have felt obliged to explain how continuity in culture occurs. Sir Herbert Spencer coined the term “superorganic”, as if society was an organism whose existence required shared culture. Durkheim referred to collective consciousness. Alfred Kroeber and Leslie White continued the use of the superorganism concept as if it were an explanation, and we see the term “distributed cognition” in use today in cognitive anthropology. J. W. Powell in 1880 coined the term “enculturalation” to describe what we see today in evolutionary syntheses of developmental (ontogenetic) processes. For Oyama (2000:71) and many contemporary researchers: “What passes from one generation to the next is an entire developmental system” that is inheritance-dependent but as the outcome of a dynamical process, a view that can benefit from further empirical research testing the modern synthesis in developmental and cognitive psychology supported by new experimental evidence of *direct perception* (Michaels and Carollo 1981:11-13), with network and organism-environment embeddings as part of unexpected solutions to mind-body two world problem.

**Discontinuity.** Dynamical processes, like episodic direct perception, have discontinuities, often cycling among different states. Leach’s (1961) study of the Pul Eliya emphasizes that there is no corporate charter of norms linked to the permanency of descent groups that continue
indefinitely, and all is not harmony: most of the many conflicts he described involved failures of delayed reciprocation in discrelional transfers of property between matrimonial sides. Statistical changes as well as institutional ones (like policies introduced by British colonial authorities) may change frequencies of behavior that change the context in which new expectations and norms are formed around changed network formations of structurally cohesive groups.

**Metastability and instability in complex systems, including culture.** Reexamining of the problems of continuity and discontinuity in culture, sharing and diversity, and stability, metastability and instability in complex systems (including culture) can help in a new synthesis of cognitive and social anthropology. These include problems of theory and method and issues of dualist versus monist social theories as described by Leaf (1979).

White and Johansen (2006) provide a longitudinal network study that exemplifies metastability by documenting the ethnogenesis, growth, and decline of ten lineages linked through structurally endogamous marriages in a nomad clan and the formation of new groups as clan members emigrate or resettle in urban areas. It focuses on how the initial formation of a structurally endogamous group through strategic intermarriage provides the cohesion for a leader of a long-range migration to form a new clan and move to occupy new territory. It then focuses on how equalitarian rotating leadership creates a period of reciprocal inter-lineage alliances that holds the growing population together for many generations. Intense competition for resources favor large sibling sets with many siblings-in-law while population pressure shunts less competitive smaller families off to resettle in towns and cities. The growing numbers of interlinked nomads and ex-nomads eventually support the movement of wealthier lineage leaders and their families to the city, and ties among the lineages gradually thin out to the point where the clan ceases to be cohesive, as new occupational forms are taken up.

**Conclusion.** The study of networks in the context of cognitive anthropology opens new problems and reorientations. The study of human cognition in the context of networks has many options and possibilities. Humans have the capacity to perceive complex relational structures in networks of behavior with or without a dependence on named concepts or categories. Human behaviors can be organized on the basis of varieties of such perceptions. It follows that schema theory in cognitive anthropology can draw on data on networks of interactions for further clarification and need not rely solely on verbal statements about a subject. The study of network
structure and dynamics provides additional key components, adding to those of symbols, language, narratives and cognitive testing, for understanding human behavior, mind, and culture.

Two of the most basic concepts relevant to social sciences have been those of group and role. Rather than treating these elements simply as part of a socially embedded lexicon, analysis of network data can move the status of these concepts to a level of measurement in network interactions where more formal and thus measurable theoretical concepts can be tested at a causal level. Predictions about the emergence of cultural consensus, for example, can be tested against levels of cohesive groups emergent out of network interaction. Hypotheses of predictive consequences of levels of structural cohesion in groups and in role structures may prove to have explanatory power.

Key to the current study of the relationships between behavior and cognition, then, is how cultural consensus and network connectivity interact. I provided here some of the first tests, using data from the San Juan Sur and Atirro studies in Costa Rican, of hypotheses about how aspects of cultural consensus are predicted by measures of subgroup cohesion. Based on formal graph-theoretic concepts such as structural cohesion in social networks, aka multiple (k-) connectivity, these kinds of hypotheses also extend to sharing in social roles where the role occupants interact cohesively with overlapping role-alters. The latter hypothesis has been extensively tested in sociology using the formal measure of structural equivalence and by Reichardt and White (2007) in their overlapping role-equivalence models of complex networks.

In addition, cohesion in overlapping role-equivalence and the cohesiveness of groups provide theoretical bases for the emergence of cohesion-based institutional structures as an aspect of cultural organization. Further, models demonstrating the presence of cohesive groups and role-overlap structures, as formal measurement concepts, may predict that cohesion-based aspects of

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8 For SJS the predictions from one variable (cohesion) to many independent variables (multiple aspects of consensus, among judges of middle class position, for upper to middle vs. lower-middle and lower class ranking of individuals, and for leadership roles, etc.) is more likely causal than the multiple regression prediction (many predictors, one dependent variable).

9 The concept of role models with overlaps of alters is that every occupant of a role X interacting with role Y has some overlap with co-occupants and common alters and thus a partially shared perceptual environment. Reichardt and White (2007) give an example of a role-overlap model for the 2000 global economy. A dynamical model of overlapping roles computes changes in role-overlap structure in successive time periods.

10 It may make more sense for the study of culture to ground the notion of systemic cohesion not by “Institutions” but by concepts for more concretely cohesive entities such as “Organizations.” This specifies more concrete linkages, objectives, and adaptive redesign (Leaf 2008). Then in the domain of adaptive cognition (Posner 2001) and language there are two concrete adaptive levels for conceptual networks with concrete linkages that are either tighter through logical construction or looser through Ashby’s principle of adaptive variability, where collaborative cognition occurs through the natural and constructed environment, artifacts and observables (Hutchins 1991).
cultural patterns are likely to be shared among individuals because of the common group or role-overlap in environmental perceptions. Studies that integrate networks, cognition, and cultural frameworks may be far more effective in explanatory models of behavior than studies that divorce these topics from one another in the study of culture.

Traditional anthropology was long obsessed with “collective subjectivity.” This emphasis has been slowly problematized in newer approaches to cognitive anthropology. Network studies allow us, when combined with the study of culture and cognition, to make a more radical break with the past and to focus on the more modern problems of struggle between within groups, the better to understand the varied potential effects of the modern world history and the global economy that can be gauged by effects of changes in network structure.

Equally important are the dimensions of time and space. Because groups and roles in complex interactive structures tend toward instabilities or metastabilities it is useful to code and analyze network interactions through time and across group-spaces to understand interaction systems and structural dynamics. Newer models and measures of cohesive groups and interactions facilitate the study of space and time in culture and cognition. Such study tends to clarify assumptions about how individuals and groups coordinate behavior and cognition. Such approaches also shed light on the use of language and communications, and on the development of cultural models within bounded social units. Extension of cohesion-based models of roles can help to understand how role-interactions over time in organizational settings can become institutional or not. Contemporary network studies (Powell et al. 2005, Vedres and Stark 2008) are uncovering the benefits of research on such topics as internal group cohesion versus extra-group structural holes in networks role structure (Burt 2001) that reflect a congruence between anthropological ideas about benefits to groups in shared culture and roles in broader organizational structure. They can also problematize our assumptions in measureable ways.
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http://intersci.ss.uci.edu/wiki/index.php/ Appendices_to_Social_Networks,_Cognition_and_Culture

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