Chapter 4: Networks and Hierarchies

Douglas R. White

Abstract for Lane, West, van der Leeuw, and Pumain, eds.
A New Perspective on Innovation and Social Change.

Individuals and organizations depend for their existence on complex interactions that provide indirect benefits that are channeled (subject to constraints) through circuits of feedback and feedforward in a bewildering array of different levels and time scales. The social pressures to create new organizations and transform or abandon older ones are experienced by human beings as occupants of positions in networks of many different sorts. Occupancies of (multiple) positions place demands on human activity. The ways that activity changes as a result of social pressures—processing multiple demands under existing constraints—within the ensemble of activities in networks of multiple relationships transform social organization interactively. This occurs not just within organizations—where time, energy and personnel are limited and activities can be bundled and rebundled to supply the spatiotemporal efficiencies needed to handle the flow of material, events and information that occur in networks of interactions—but in the management of relationships between individuals and organizations.

This chapter develops a theory of multi-nets—multiple level networks with several different sets of elements undergoing time-series changes in their attributes and the relations between them. A set of multi-nets can always be expanded analytically simply by identifying the interactive links between them. Conversely, an analytic focus within a multi-net may zoom in on interactions within a sub-net. So too with occupants of network positions, some of whom may focus their activities on particular sub-nets, such as family or work, while others opportune as well to make or attend to connections that open up or regulate flows over longer distances. Looking at how certain actions serve as network regulators allows us to study the dynamical processes whereby the topologies of network links that carry functionality change relative to the behavior of occupants of network positions, each affecting and sometimes regulating the other.

Careful analytical representation of multi-net linkages—e.g., attention to which elements are *members* of other elements, such as individuals with memberships in multiple organizations, and to which pairs or sets elements *interact*—sets up hierarchies such as nested embeddings, as for example, persons who belong to families that live in communities that are located in territorial groupings under various polities. Multi-net theory, however, resists reification of levels and hierarchies and treats them instead in terms of how particular elements are either *definitionally* or *interactively* related to other elements along a series of observable dimensions. Multi-net theory then employs conceptual and statistical measures designed to avoid imposing observer, administrative or methodological biases, such as: the assumption that individuals or families belong to single communities (i.e., that a network analysis of community structure will sort individuals into mutually exclusive communities); or that behavioral observations in networks or time-series are statistically independent. One conceptual measure employed in multi-net theory, for example, is that of structurally cohesive embeddings, in which

patterns of interaction are summarized into overlapping sets of elements that share levels of cohesion defined by the multiplicity of their internal linkages. This measure is mathematically robust in doing justice to structurally emergent sets of interacting elements stacked by inclusion according to the levels of cohesion of the sets, while at the same time allowing different stacks of elements to overlap at different levels.

The utility of multi-net theory is illustrated by examples taken from a project (supported by ISCOM) on civilizations on dynamic networks. Here cities are one type of element, territories another, and one in which cities and their hinterlands are located, polities are another type of element that sit on or above cities and territories, and industries constitute a fourth type of element that operate in different cities or territories. Coded attributes, relationships, and other types of elements are added to the multi-net as needed, given the focus of the project, in developing a model of the rise and fall of economic activities in intercity trade networks. The analysis proceeds from a baseline of network economics in which certain properties of the observed trade network, such as route connectivities, are taken to define emergent units—such as structurally cohesive blocks—that have predictable implications for the context of economic behavior, such as network zones with market price potential (by definition: *multi*connected) as opposed to zones connected through single nodes (which make them, by definition, subject to monopolistic trading practices). The network predictions of the theory in this case are consistent with a new literature on network economics, but the multiconnected zones are predicted to allow equilibrium (supply-demand) market pricing that is less subject to inflationary tendencies than are the one-connected zones (i.e., those in which the removal of a single node is sufficient to disconnect the network).

In complex interactive systems, baseline network models are rarely sufficient to account for system dynamics. The motivation for a multi-net approach, in general, is to provide a framework for the coding and analysis of longitudinal datasets in which there is sufficient information to support the development and testing of theories of dynamics. With time-series data on intercity trade and an evolving distribution of industries, for example, discontinuities in the evolutionary trajectory not only become evident but provide clues as to where to look next for sufficient statistics both in terms of parsimony, stripping away unnecessary detail, but also in locating variables needed for robust specification of system dynamics. Looked at episodically, discontinuities in the fit between a baseline model and longitudinal observations appear as shocks or external perturbations. By constructing new variables—which may involve new types of elements and relations—to represent those perturbations that have a more systemic character, it may become evident that there are theoretical and modelable candidates for adding to the baseline model in such a way as to aim as endogenizing an account of system dynamics.

For intercity networks, for example, conflicts involving polities—including internal as well as interpolity sociopolitical conflict—enter as a prime candidate to supplement a baseline network economics model in accounting for economic rise and fall of networked zones and entities.

Unlike individuals as bounded entities, however, the boundaries of polities change longitudinally. A multi-net coding of such changes needs to represent the underlying processes affecting the entitivity and changes to territories and polities. Compared to modern states with sovereignty over territory, for example, the tangled diversity of states in the Holy Roman Empire, in the civilizations project, posed a representational challenge for coding relationships (a common problem in network research). Because Frankish polities were not constituted as having institutionalized polities with sovereignty over territory but rather as interpersonal sovereigns who held territory as private property, changes in polity boundaries reflected the passing of property by customary and elective inheritance rights. Hence the political entity history in this case was coded more appropriately as isomorphic with ancestral kinship relations, with territories being split by inheritance and consolidated by marriage or conquest, rather than as geographic boundary change to a territorially sovereign entity. In this case, the 'ancestral network' coding of polities in relation to territories corresponded to cultural memories and information storage that carried over centuries and in some cases millennia in the way that people and organizations mobilized their activities in trade and conflict. 'Ancestral' networks in general have emergent and memorable boundaries of cohesion which in this case mobilized coordinated efforts to form trading blocks ('hanse'), crusades, and political splits and alliances. Coding of network data that is appropriate to customary practice and cultural cognition is an important step in any study that aims at identifying operative principles of social dynamics. In this case the operative principle of 'ancestral relations' in politics and cultural memory is one that is commonly found in regions where segmentary opposition and alliances are in play, as opposed to current political concepts of state sovereignty.

When entities can change scale—as with the size of cities changing through the demographics of migration, reproduction and mortality, or the size of polities changing through inheritance, marriage, conquest or defeat—their attributes as entities need to be examined by scaling methods: what are the regularities that govern transformations in scale? Are they discrete, differing level by level, or principles that are partially scale-free? Because multi-net datasets are constructed longitudinally, the scaling coefficients themselves can be measured and analyzed in time series to try to understand how the production of entity sizes interacts dynamically with network variables. Results of this form are exemplified for the civilizations as dynamic networks project as part of ISCOM, and matched against scalings of generalized network simulations. In both cases, our results converge methodologically to suggest that there are scale-free properties of networks and civilizations but these are best described and theorized not by power-law invariance (e.g., of city size hierarchies or extent to which nodes form network hubs) but by two parameters, one that describes the degree of scale-free inequality in the upper bins of a univariate distribution hierarchy (like the power-law, but only as an asymptotic approximation, as is invariably found with urban hierarchies) and the other that describes the overall population scale. These two parameters of some of the macro-levels of human social organization are shown to apply within a very general scaling law (the Tsallis q-exponential that recognized *the dependence of smaller units on smaller network neighborhoods* as a systematic departure from scale-free regularities. Further, applying this scaling approach to urban hierarchies coded for different historical time periods (36 in all), the findings of this approach support the idea that the structural parameter q is not invariant through time but highly periodized historically (runs tests reject the random variation hypothesis with $p < .0001$ in each of multiple tests), and additional tests of organizational hypotheses show that these macro-level changes in the network construction of urban hierarchies are closely interlocked with identifiable changes in the micro-economic behaviors and organizational forms as well as meso-level network properties as to how network position affects these behaviors and their organizational context. In short, this example of a sustained multi-net approach to the analysis of historical phenomena shows extensive evidence for a unified network theory for dynamics that couple changes in observed intercity network interactions with changes in scaling properties of urban size hierarchy.

This chapter thus comes full circle in terms of the principles articulated in the first three chapters: What are the fundamental scaling properties of the entities in social systems? How do the forms of human social organization escape the entity constraints of biology? How do representations (both in cognition and stored information), interaction rules, and behaviors come together to form and transform organizations?

The meta-organization for humans is the extrasomatic multi-net. Our primate ancestors evolved cooperative behaviors and cognitions with flexible community boundaries that put a premium on learned behavior. Humans developed a capacity for linking communities; they explored and tinkered with different ways of organizing communities of communities. Their multi-nets complexified to include multiple kinds of intersecting hierarchies, ones that defy any neat analytical attempt to distinguish uniform layers or levels. Bottom-up processes of emergence continue to push up through network-driven organizational transformations as against top-down efforts at organizational control. The sciences of complexity have come to recognize the importance of the network component and of network concepts and theory in developing new understandings of our human heritage.

It is not that networks are a special form of social organization, something that sets us or certain types of organization apart, as if there were "formal structures" on the one hand and "network organization" on the other. Multi-nets are a generic scientific concept, a way of looking at how different processes link up, and of understanding how the dynamics of any given 'system' (which is not so much an entity as the framing of a researchable question) may need to be traced through multiple kinds of entities interacting in many different ways. Take *any* given scientific problem, or focal question, ask how to define and understand a larger system of feedback and feedforward in which much of the dynamics of the system can be endogenized, and one likely outcome will be a multi-net with various testable dynamic equations. Multi-nets do not set us apart, but understanding how they operate—or even learning to construct and analyze them—may well bring us together. What is different about us, as humans, is not that we operate within a world composed of multi-nets, but the extent to which we have extended and rescaled these multi-nets extrasomatically in so many diverse and interdependent ways.