Chapter 5. Networks and Hierarchies

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Abstract

This and the preceding chapter take us from the slow evolution from humans as mainly governed by biology to humans as social and societal beings, and to urban and contemporary social formations. It continues the focus on urban phenomena initiated in chapter 4. But rather than look at the drivers for the urban dynamics, it looks at the patterning of urban systems, and how such patterning is shaped by the constraints of interaction. It therefore views urban systems as hierarchies of networks. In particular, this chapter explores principles, models, and examples that relate *networks* to *hierarchies* in ways that suggest how interactive social and economic processes generate networks, and in generating partially scalable networks, shape some of the basic properties of network hubs, of cities as network hubs (with not only more connections to other cities but with larger populations), and of city systems. The multi-net theories developed here model how potentiated actions play out in interactive systems as multiplicative effects. Finally, the chapter shows how to represent these effects as well-structured but highly dynamic departures from entropy that invite new generative and scaling models (social-circles process models, *q*-exponential scaling) for the study of emergent but often volatile hierarchical properties in social and urban-networks.

Introduction

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

We attempt to answer such questions in this chapter by showing how two of the recurrent forms of networks, segmentary networks and cross-cutting or cohesive networks, overlay and interconnect dynamically with one another in multi-nets, the multiple networks that bridge the interactions between different classes of entities. In keeping with the ideas presented in the last three chapters, we argue that interaction networks are the vehicles and structures that carry the dynamical processes responsible for the construction of social systems. In the first part of this chapter, we will look more closely at different aspects of the dynamics of such networks, and show that they apply irrespective of the degree of complexity of the systems considered. Indeed, we do not want to imply that evolution is in the direction of greater network complexity. The same concepts apply equally well to pre–urban and urban social forms, and in both cases complex constructions often fall apart into component modules that are considerably simplified. The existence of such modules, however, also entails new possibilities for re–

couplings. In the second part of the chapter, we will deal more specifically with the processes of rise and decay, uncoupling and decoupling, that are revealed by network analysis of urban systems.

Biological and Social Scaling in Networks

As we have seen in Chapter 1, physical and biological phenomena scale according to power laws that hold over many orders of magnitude, linking the metabolism (M) of organisms with a host of other features, including body mass (B), which scales at the sub–linear ¾ power, $M \sim B^{-3/4}$. The meta-organization of somatic components and their constraints—as with circulatory and nerve cell networks, for example, that serve the same regions of the body—*involves the coupling of networks and inclusively organized hierarchical levels*, such as from mitochondria to cells, cells to organs, organs to organisms. The evolution of these levels allows cross-level power-law scaling that entails common design principles for living organisms such as more efficient use of energy with greater size through slower metabolism.

The importance of networks, network components and network theory (and its concepts) in developing new understandings of our human heritage as social beings has also come to be recognized in (network) economics, sociology, anthropology, and the sciences of complexity. But the work done in these disciplines teaches us that there is no uniformly efficient design for social organization of the kind there seems to be for biological organization. Organizational scalings such as we observe in social systems tend to operate on the basis of proportionality or multiplicative effects linked to emergent network structure, and are thus fundamentally different from the cross-level, scale-free power hierarchies we find in biology. The hypothesis advanced here to explain this difference is, that social organizational and other extra–somatic networks are not intrinsically or locally organized by level hierarchies, although the individuals in the extra-somatic networks are provided with materials and energy they require from level hierarchies above them and thus are extrinsically constrained by nested level hierarchies.

To accommodate this fundamental difference between somatic biological networks and extra–somatic social ones, we offer a theory of multi-nets – multiple level networks with several different sets of elements that undergo diachronic changes in their attributes and in the relations between them – as exemplified in studies of civilizations and their cities and industries as dynamical networks. The multi-net theories and models developed in this chapter show how extrinsically potentiated actions play out in interactive social systems as multiplicative effects. Furthermore, we will show how to represent these effects as well-structured but highly dynamic departures from entropy that require new generative and scaling models (social-circles process models, *q*-exponential scaling) for the study of emergent hierarchical properties in social and urban-networks. .

Chapters 3 and 4 have shown how our primate ancestors evolved cooperative behaviors and cognitive approaches with flexible community boundaries that put a premium on learned behavior. Humans further developed a capacity for linking communities; they explored and tinkered with different ways of organizing communities of communities and networks of networks. Their multi-nets complexified to include different kinds of intersecting hierarchies, some that defy any neat analytical attempt to distinguish uniform layers or levels. Bottom-up processes of emergence are seen to continuously push up through network-driven organizational transformations as against top-down efforts at organizational control (H. White 1992).

Human multi-nets do not set us apart as a species, but understanding how they operate – or even learning to represent and analyze them in constructive ways – may well help humanity to cohere and persist in co-evolution with our planetary ecology. What is different about us as humans is not that we operate within a world composed of multi-nets but rather the extent to which we have extended and rescaled these multi-nets extrasomatically in so many diverse and interdependent ways. This will be seen to provide the forms in which the social organization of humans helps to partially escape the entity constraints of biology, but also to impose huge new costs and instabilities that deserve extremely careful and cautious study.

Studying social dynamics in a multi-net approach begins not only with the idea of multiple types of relations among nodes, but also that of multiple types of nodes, and intricate interactions between different levels of sub-sets in the networks concerned. A set of discrete 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. Network realism requires that we be able to specify multiple levels of zooming-in, say, on the occupants of network positions that are identified analytically, some of whom may focus their activities on particular sub-nets, such as family or work, while others may make or attend to connections that open up or regulate flows over longer distances of between polities, as in the (negative) case of international conflicts or (the positive one of) trade. Looking at how certain actions and network structures serve as network regulators allows us to study the dynamic processes whereby changes in the topologies of network links that carry such functionalities operate interactively with the behavior of occupants of multiple network positions.

Networks, Hierarchies, and Stabilities: Concepts and Theory

This section defines core concepts of interaction networks, hierarchies, and stabilities and focuses on how networks generate hierarchies in five different modalities. Interspersed with these principles are a half dozen examples taken from empirical studies of social networks, and four different generative models – random, small-world, scale-free, and social-circle – that provide mathematical and simulation results supporting the connections between micro processes of interaction and the more global structures and properties of networks, which in turn constrain some forms of interaction and facilitate others. The chapter thus aims to explain how networks act in a dual capacity as vehicles and structures that carry dynamical processes constructive of complex systems. The remainder of the chapter then focuses on cities, city networks, polities, their historical dynamics, and the implications of these dynamics for stability, instability, structure, and scaling.

Multi-nets and “Interaction Systems”

Networks are in no way a special form of social organization, something that sets certain types of organization apart, as if there were “hard-wired” or “formal structures” on the one hand and “network organization” on the other. Rather, it is through understanding the generality of interlinked processes as networks that we come to grips with the fundamentals of complex extra–somatic social organization.

“Multi-nets” is a generic scientific concept describing how different networked processes link up, one that embodies strategies aimed at understanding the linkages by which the dynamics of any given “system” may need to be traced through multiple kinds of entities interacting in a variety of ways. Humans are embedded in stacks of networks, some neatly layered, and others overlapping. A “system” in this sense is not so much an entity as a researchable set of questions that frame themselves through largely observable interactions. 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 alongside external perturbations, and one likely outcome will be a set of multi-net representations for these interactions that facilitate the testing of dynamic principles. As an example, I will treat cities here as networked entities that relate to larger entities like polities on the one hand, and to a huge diversity of constituent entities on the other. To get a handle on how cities emerge from both their internal and internal interactions I will be concerned with providing a much more precise way of modeling the network processes that govern the differentiations of their sizes into a hierarchy of sizes that is often simply taken for granted without any clear explanation as a Zipfian size city-law hierarchy.

Our multi-nets approach uses the full range of network analysis methods, some of which have long been standardized (Wasserman and Faust 1994), but it does not restrict itself to the modeling of network structure. Its aim is to develop theoretical principles that capture how complex systems of interaction are nested in networks.

Boundedness

In a dynamical system, entities and interactions affect other entities and interactions through time. Boundedness is therefore a crucial concept that specifies some of the containment properties for the dense internal interactions of an entity, and how they relate to its environment. A major problem in the social sciences has been to find adequate ways to frame empirico-theoretical questions and testable hypotheses about boundedness properties and conditions for extrasomatic multi-nets (see Moody and White 2003). Rather than set out to model such multi-nets as boxes that represent variables, and then define arrows showing influences of each variable on others,[1] our approach begins with a focus on identifying the various interactions that make up a dynamical system and hence approaches the boundedness and boundary conditions for the system and its component entities from the perspective of the observed interactions rather than from the presumed units interacting. Through this process it aims at specifying the concrete bounded entities that exist in space and time, including those in the space-time of cognition, the space-time of individuals, cities, and of other agents such as structurally cohesive groups.

Hierarchy

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[1] Boxes, arrows and causal path analysis based on correlations and partial correlations are too abstract to understand and specify complex nonlinear systems and their emergent properties. Moreover, this approach is dependent on a general linear model, and lacks an explicit theory to handle nonlinear dynamics. This was the statistical approach of the general systems model of the 1960s and 70s, exemplified in the (failed) Forrester models of urban dynamics.

Hierarchy poses similar problems. A general view of hierarchy and network scaling for human societies is that the cohesive units of networks provide the metabolism of social organization. As in any science, entities have cohesion that is measured by (a) resistance to decoupling by external perturbation, (b) internal coupling that potentiates coordinated action, robust communication or synchronization, and (c) characteristic configurational lifetimes or half-lives if entity break-up or decay occurs with exponential decay. From the smallest to the largest scale within each network and domain of human social multi-nets and civilizations, micro levels of agent or group behaviors and macro levels of global networks have the capability of flexible recouplings that reshape cohesive units. The approach proposed here defines the relevant hierarchical levels on the basis of a study of the between-node and between-cohesive-units interactions in the multi-net, rather than pre-define hierarchical levels and then study the interactions between them. It thus avoids some of the blind spots that traditional approaches to hierarchy engender. Allen and Hoekstra (1993), in treating hierarchies in ecology, wrestle with similar problems and define hierarchical levels in much the same way as I intend here.

Cohesion

Cohesive groups defined by their internal relationships may overlap or share constituent members,[2] just as we know from experience that we may and do belong to multiple communities. This is one of the most important of the flexible characteristics of human social organization. Even in pre-state societies, humans were not necessarily bound to a single territory, although from the viewpoint of states, de facto limitations loosen with changes in transportation. And, if cohesive units are free to form as networks, network cohesion theory tells us that hierarchical embedding cannot be taken for granted. A conceptual measure employed in multi-net theory is that of structurally cohesive embeddings, in which patterns of interaction are summarized into nonexclusive sets of elements, each of which has levels of cohesion defined by the multiplicity of their internal linkages and their concomitant resistance to disruptive perturbations. This measure (Moody and White 2003, White and Harary 2001) 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 element sets to overlap at different levels.

Embeddedness

Some of the ways that structurally cohesive subgroups in networks bear on the issue of hierarchy are shown in the four representations in Figure 1:

Diversified network embeddedness is the most inclusive form that is taken by structural cohesion—with a combination of overlap *and* hierarchy as in Figure 1—but in any particular network such groups may distribute in either of the two alternate forms: strictly hierarchically embedded at one pole, and with or without overlap at the other, independent of hierarchy. Embedded structures affect and sometimes regulate one another, and one way in which this auto-regulative interaction may take place is through

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[2] Network researchers are typically mistaken if they look for cohesive entities in networks as emergent groups or communities that are mutually exclusive, under the modality hypothesis.

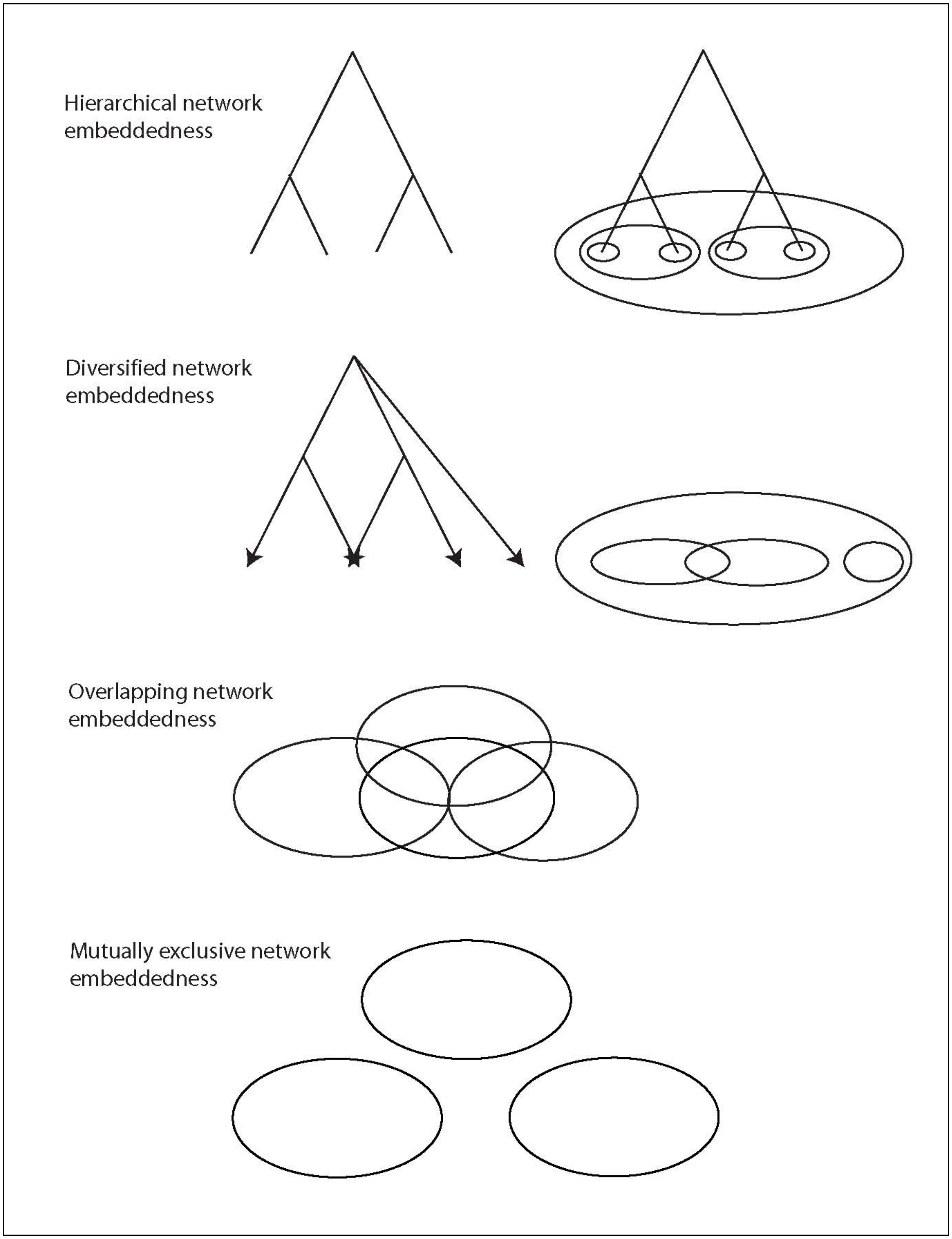


Figure 1: Distinct Types of Network Embeddedness in relation to Hierarchy

cohesive embedding. But that is another story.

In any case, if structural cohesion is taken as the proper measure to identify communities or cohesive subgroups in networks, then the predictive cohesion hypothesis is that these subgroups will be the best predictors of corollary measures associated with generalized cohesive-entity characteristics (a), (b) and (c) above. This prediction matches what is found in this subfield of network cohesion research (Moody and White 2003).

Networks and Causal Chains

The approach summarized here, applied to network and interaction data in empirical research, is to try to conceptualize, measure, and test theories and hypotheses concerning the causal chains for which networks, conceived as structures that change through time, provide the proximal linkages or carriers of effects. Processes or events that occur in networks have effects on localities, and subsequently on larger areas in the network. Convective flows in networks, and radial diffusion or propagation, are key processes generating inhomogeneities and network dynamics. Such effects are not always dissipative: condensations also form around cohesive units, hierarchical structures or flows within the network. These are elements that support a structure of connections and internal processes that can absorb new inputs and configurations and utilize them to capture energies that ultimately organize into coherent spatiotemporal orbits.

Stabilities

The capacity for stability is a fundamental property of complex systems, which depend for their existence on self-sustaining interactions. As Iberall (1972:375) noted, "Stability, in a nonlinear sense, is not necessarily sharply defined." Jen (2005:8-9) defines *stability* in terms of dynamical recoveries from small perturbations that return to an original state, and defines *structural stability* by the ability to return to other dynamics (e.g., by varying external parameters) that are qualitatively similar. Economic systems provide an example. They may be resilient through continual change to return to structural stability, but they are not stable in the strict sense. They are characterized by limit cycles rather than conservative stationarity.

Level Hierarchies

One of the early founders of complexity theory, Arthur Iberall (1972: 338), defined level hierarchies, and hierarchical couplings between them, as connected levels that represent a drastic change in organizational type that still leaves the system related and connected. Functionality at each higher level is more broadly embracing than at the lower levels: for example, protons, neutrons and electrons are connected as atoms, atoms connected as molecules, molecules as cells, cells as organs, and organs as organisms. Yet, even as this system scientist formulated his concept of embedded hierarchies, Iberall could not find a general explanation or justification for hierarchical levels (pp. x-xi) because they depend on dynamics rather than statics. To the extent that level hierarchies exist, behavior at one level is not reducible to laws or regularities from the levels below. Rather, given that the laws of the levels below are not violated, there are new properties at each level, complexity scientists ranging from Lane (2005:35, on Holland) back to Anderson (1972), Holland (1978), and Iberall (1972: x-xi, 369-371) have noted this feature of complex systems. In the case of ecologists such as Allen and Hoekstra (1993), the levels in such hierarchies distinguish themselves by the clock times at which the majority of processes at that level operate.

Searching for laws that connect levels, Iberall (1972: 369-377) argued: "for consistency in describing all system levels, I am concerned with classifying complex systems and their stationary or near-stationary constellations, and attempt to use a purist doctrine that limit cycles can emerge only from non–conservative systems," that is, from observable patterns of materials and energies released from higher (e.g., solar) to lower (e.g., life on earth) hierarchy levels where losses at a higher level operate as the potentials driving gradients at smaller and faster scales at the lower level. "My position is that periodic orbits should invariably emerge in the cosmos, essentially from systems with a non–conservative nature" that counteract the entropic state of decay to rest by driving near-equilibrium processes at lower system levels. In his summary of general principles of systems science, entities are unstable in Jen's narrow sense. in any local domain: "the only potential motional states are a uniform distribution and inhomogeneous condensations. The uniform distribution appears to be less stable [i.e., given "lossy" perturbations from other levels]. Thus motion tends toward the condensations." Life, for example, "evolves, becomes unstable, forms new patterned structure, etc. This appears to be the continuing chain of thought in the science of general systems," concluded Iberall (1972:376). For him, networks as "chains" of causal processes constitute system dynamics, and these often coalesce into limit cycles. Level hierarchies exist, but they are born out of causal processes, their levels have highly dynamical, near-equilibrium, normal life phases, they may change dynamically (e.g., as when planetary atmosphere changes from methane to oxygen in mutually interactive support for life-forms), and even the levels themselves will eventually degrade.

Hierarchy: Cultural and Mathematical Definitions

Level hierarchies, therefore, are not a natural order of things, as promoted by Aristotle and the political hierarchs of urban cultures, and hierarchy is not easily defined outside of mathematics. This is partly because the word becomes so overloaded with cultural significance following the rise of complex societies. *Hieros* (sacred) and *arche* (rule or beginning) combine in the Greek etymology to form the word *hierarch*, (the person from whom emanates the power) one who occupies a position of authority in a religious "order"; or, by extension, occupancy of high position in a hierarchy, such as governmental hierarchs. "A group of people who occupy a position of authority" constitutes a core dictionary definition of hierarchy, with a derived meaning of categories, ranks or grades according to position, ability, or status. The English etymology for authority traces back to originator(s), giver(s) and enforcer(s) of laws associated with cities and state-level polities. These and earlier etymologies point back to hierarchy in the context of belief systems invented in cities and states. Cultural concepts of these sorts could well have been absent in the pre–urban context.

Mathematically, a graph is a set of nodes along with two types of relations between pairs of nodes: edges, which represent undirected links, and arcs, or directed edges. The most generic definition of hierarchy in a graph is one with non–symmetric arcs and no directed cycles, that is, arcs forming directed paths that connect from node to node but never return to an earlier node in the path. This definition – which goes by the name DAG or directed asymmetric graph – allows triplet paths (from *a* to *b* to *c*) to be transitive or intransitive. The transitive closure of a DAG is irreflexive, anti–symmetric and fully transitive. A DAG differs from a downward-branching taxonomic structure in that branches may converge (see Figure 1B). If all elements in a graph are connected in a transitive DAG, the graph forms a complete hierarchical order. Some of the examples that follow illustrate the commonality of DAGs as a type of network. They occur in kinship networks in the relations of ancestry, if only in the ordering of recognized temporal relations exclusive of authority. In recognizing ancestry as a cultural construct humans are cognitively equipped to elaborate other forms of hierarchy and relational structures, as discussed in Chapter 3.

Network Examples of Pure Hierarchy

Examples 1 and 4 (p.8 and 16 respectively) are real-world, mathematically definable hierarchical networks. They are at opposite poles of poverty and wealth within highly competitive socioeconomic fields: (1) rural and urban contexts in the industrializing economy of China, where 1/6th of the population is now involved in seasonal migration and (2) industrial district supply chains in the modern production economy of Tokyo. They emerge through the network construction of hierarchies that offer cooperative and competitive advantages in the context of individuals in the first case and firms in the second. The Chinese migrant laborer discussion group networks illustrate the case of a morality of generalized reciprocity associated with kinship and village networks underpinning a support system for urban wages that are highly competitive in the world economy (China’s industries are now credited with producing 72% of the world’s goods, for example). Similarly, the apex of Tokyo’s most industrialized sector shows organizational forms that are economically competitive because of careful non–market management of buyer/supplier relations. What these two examples have in common is efficiency: there is very little wasted effort in the way that links are mobilized.

Network Example 1: A Hierarchical Network of Generalized Reciprocity

Not all human social hierarchies are based on power, domination, or authority. Survival on the margins of urban society might require, and surely mobilizes, networks of social support that are outside formal economic institutions (Lomnitz 1977). Du, White, Li, Jin and Feldman (n.d.) were surprised to find evidence of network hierarchy in their analysis of networks of assistance in everyday activities and of discussions concerning problems of social support (marriage and family, childbearing and planning, contraceptives, old age) among 200 women migrants in a Chinese industrial city. Some of the women’s reports of their outgoing ties were mirrored symmetrically by others who reported outgoing ties back to them. When symmetric ties were excluded, however, the asymmetric ties in five of the seven relations reported for the network (all but emotional support and social activities) showed a nearly perfect hierarchical structure of the DAG variety (above) in which the tendency is for help and advice to flow down from woman to woman through ordered levels. And even when all five of these relations were combined into one, the resulting symmetries were only between pairs of women in adjacent or nearby levels of hierarchy. Women at the upper levels of these hierarchies of giving were those with higher status, higher income, and more family connections, including marriage. This is generalized exchange, and it exemplifies a social support system that is self-organizing. Reciprocity may take effect in the course of the life cycle but it is neither balanced in the short run nor necessarily even in the long term. The ranking in these hierarchies is one of responsiveness to a morality of obligation. Such hierarchies are not atypical of the moral orders of pre-state, pre-urban, and many village societies, in which leadership is more of a *primus-inter-pares* obligation to help others rather than one of domination. What is remarkable in this case is that when each woman's ranking in each of the five networks is normalized to a scalar measure between 0 and 1, the common variance among the five in a principal components analysis is 78%, and the structure of the variance is single-factor. Here, the morality of obligation transfers very strongly across the hierarchies of giving.

The Scale-up of Human Settlements as City Networks

Prior to the Neolithic revolution, human societies, such as the ones whose social and technological innovations were discussed in chapters 3 and 4, were limited in scale, perhaps on the order of 500 to a thousand people, or broken up into foraging bands. Even through the Neolithic and beyond, initially with villages limited to hundreds or a few thousand inhabitants, the world population growth trend was largely exponential, at a constant tiny rate (e.g., 1.0001 or .01%) of average growth. A tiny percentage growth per annum on your savings account provides a good analogy. A distinct kind of population growth trend began, however, once cities arose as a network, interrelated and interdependent through trade. Urban settlement size hierarchies (Adams 1981) show growth rates proportional to city size. Distributions of city sizes come to be *scalable*, where frequency $f(s)$ of size s varies inversely to size, $f(s) \sim s^{-\alpha}$, that is, governed by a power law. For your savings account the analogy would be that the percent interest rises with the amount of money in the account (the rich get richer faster). The advantages and attractions of cities, in short, came to be multiplicative (Algaze 2005).

The findings of Chapter 1 show that cities have to run to stay in place and to import managers and skilled workers in production in order to maintain their position. If we extrapolate these findings back in time we have an explanation for the peculiar population growth phenomena observed in urban civilizations. Total population N (rural and urban) tends to have trends, within finite historical periods, governed by power-law proportionality of growth to size, expressed as $N_t = CN_0(t_0 - t)^{-\alpha}$, where t is historical time and t_0 is a time in the future, a "singularity" that acts as an absolute historical limit to the trend. Power-law growth, given a constant C and coefficient α, cannot continue past t_0 because N would become infinite. Power-law growth, in short, is unsustainable. It requires readjustment whenever population size precipitates a crisis of energetic and material resources.

If we look in Figure 2 at world population figures from the time of the Neolithic to the present, we see exponential growth giving way to power law growth after the rise of cities in the fourth millennium BCE, but this growth trend is broken circa 500 BCE during the crisis of archaic civilizations. This occurs several thousand years before the singularity that would have occurred if the world population growth power-law of that time had continued without change.

After 500 BCE, there are three phases shown in Figure 2 where world population growth flattens but then begins another power-law rise toward singularity. Flattening occurs at about 1250 CE, then again at about 1650; and again at about 1860. Each time, after the flattening, a new power-law growth resumes, each curve oddly pointing, roughly, to the same t_0 singularity. These growth spurts and halts are due partly to the growth of cities *per se* but also to the new technologies and communications thresholds developed out of urban economies that provide significant breakthroughs, including those in agricultural production that can support more population and organizational forms that can help cities overcome centrifugal tendencies.

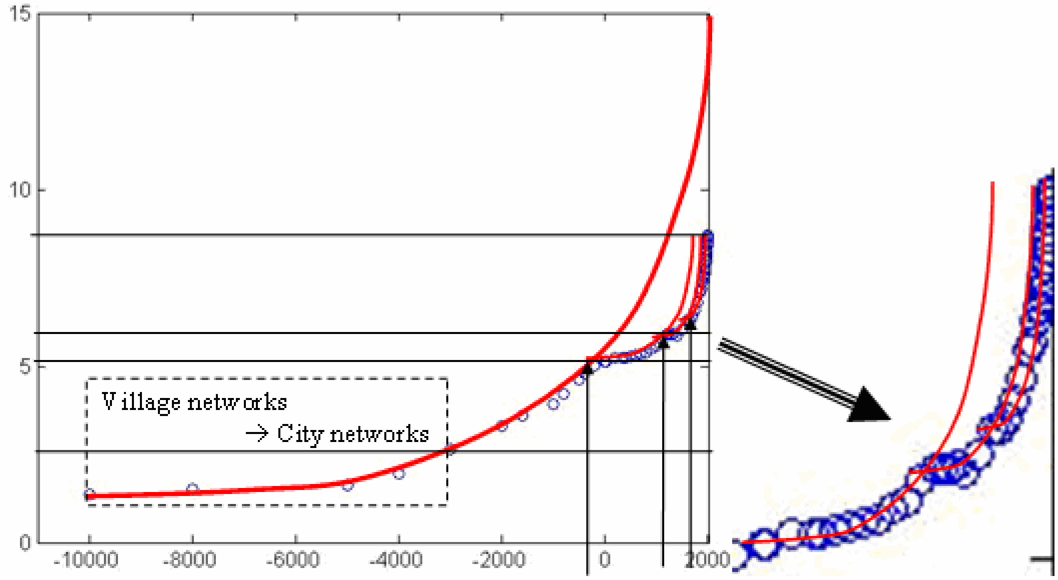


Figure 2: World Population Power-Law Growth Spurts and Flattening

Network Models for Scale-up and City Networks

To relate *networks* to *hierarchies* – hierarchies of network cohesion, hierarchies of network hubs and hierarchies of cities as network hubs not only with more connections to other cities but with larger populations – we must examine models that can show how interactive social and economic processes generate networks that are scalable and in doing so also generate some of the basic properties of city systems. A *scalable network* is one that can be scaled up in interactive population numbers (network nodes) and retain its functionality without having to scale-up costly links. A 5% density of links in a small network, when scaled up, becomes an unbearable cost in number of links per person in a network of a million nodes.

The *structural cohesion* concept (Moody and White 2003), which depends only on the minimum number of independent paths between all pairs of nodes, is consistent with *network scalability* to larger networks without increasing density. On the contrary, minimal density decreases with network size.

Types of Scale-up: Hierarchies of Group Cohesion and Hierarchies of Rank

As city networks grew, and grow today, they develop structurally cohesive relationships such as sets of cities that each have multiple trading routes to reach one another. Structural cohesion of this sort offers obvious competitive advantages in securing the best terms of trade, whether through economic, political or other means. As regional networks form, highly cohesive subsets may begin to differentiate, each having its own cohesion hierarchy as a group. Similarly, as new industries form, they may be dependent on circular patterns of exchange and interdependency. It is not unusual to see cohesive hierarchies of collaborations in new industries that grow out of innovations that are enhanced by the multiplier effects of multi–connectivity, which is another name for structural cohesion. The biotechnology network below, of collaborative inter–industry contracts, illustrates the role of structural cohesion in early stages of a developing industry.

Network Example 2: Organizational Cohesion in the Biotech Industry

Here, networks of innovation emerged out of the potentials provided by changes in the laws governing patents and commercialization that had developed out of innovations in Silicon Valley and the IT industry. These provided the scaffolding for organizations and institutions to build networks of scientific collaborations that expanded the knowledge base and technology for development of new products. Rather than competing with large pharmaceutical companies for improved mass-market products for illness, healing or health-enhancing treatments, specialized niches were sought through collaborative ties. And rather than protecting new privately held knowledge following the pattern of the pharmaceuticals, the industry built through successes as parent firms spawned specialized offspring. Emergent organizational couplings between complementary partner firms resulted in rapid emergence of a single broad structurally cohesive core of organizations linked through collaborative ties in a division of labor, capital, and marketing. In so doing, core organizations in the field benefited from broader diffusion of knowledge, but, through bringing new recruits into a mixing process for new knowledge potentials and skills, also managed to prevent stultification that could result from sharing and homogenization. This involved a dynamic of periods of heavy recruitment of newcomers alternating with periods that focused on integration of knowledge as between new recruits and established practitioners (Powell, White, Koput and Owen-Smith 2005; White, Owen-Smith, Powell and Moody 2004). Balancing broad cohesion with innovation, the success of the industry led to a scaling-up of overall size and dispersion of the industry sufficient to enable internal niche diversity to withstand competition by the pharmaceuticals, the instabilities of the marketplace, and the volatility of R&D funding sources. In the biotech industry study, several hundred variables pitted against those measuring structural cohesion were entered into a time-series database used to test hypotheses about predictors of new contracts between organizations, the biotech firms and partners. McFadden's conditional analysis for each of 11 time-lagged periods showed two major sets of predictors that beat all other competitors in these predictions: structurally cohesive multi–connectivity and associated measures of diversity, including the multi–connectivity of the cohesive set of partners that would result after the tie is completed. What Powell, White, Koput and Owen-Smith (2005) were able to demonstrate statistically for new link formation and repeat links in the biotech industry was a refutation of the Barabási model of proportionality effects for preferential attachment to hubs, and to show proportionality effects for multi–connectivity: the more multi–connectivity the more the attraction for potential collaborators.

Multi–connectivity is not the exclusive preserve of urban or industrial systems, however, but a structural feature of networks generally that is potentially involved in how social groups develop cohesive power. Innumerable historical examples can be given where a growing empire fuelled by a city network meets resistance from groups at their borders that may be initially weak but fuelled by their conceptions of ethnic and cultural differences and able to mobilize opposition through a decentralized enlargement of structural cohesion networks of resistance that can easily emerge victorious (see Turchin 2006). Turchin follows Ibn Khaldun in referring to this phenomenon as the Arabic *asabiya* (cooperation) but the obvious fact here is that cooperation, as structural cohesion in networks, is scalable.

Generative Network Models

To study scalable networks of both the cohesive and ranked types, we need to consider those few basic generative models in the networks literature that show – through simulations – how formative micro-processes relate to the network topologies that are generated by these processes.

Generative Model 1: The *small-world* model of large networks (Watts and Strogatz 1998) was designed to show that even when nodes and links are highly clustered, average distances quickly shrink to those of a fully random network when only a small fraction of links are randomly rewired. Because this model holds for so many clustered networks, it is of use here primarily as a general observation about the ease with which higher levels of structural cohesion are attained. It helps us little in relation to scale-up by differential rank.

The emergence of scalable networks of the second sort, that of *differential rank*, is also an essential topic of this chapter. Two basic kinds of network models, with variants, illustrate the problems involved in the scale-up by differential rank of human social networks generally and of city networks in particular. These are the scale-free network model and the partially scale-free social-circles model. *Scale-free* refers to invariance under multiplication, and a scale-free model refers to a power law, $y(x) \sim x^{-\alpha}$, where the relationship between logged values in the abscissa and the ordinate is linear. A power-law-slope is invariant under multiplication and for any range of x. *Partially* scale-free refers to tendencies such as those for city-size distributions, where power-law regularities show up in the tails of the distributions, for the larger cities, but do not hold for smaller cities. These two kinds of models relate to questions about how network hubs and urban size hierarchies are generated.

Generative Model 2: Scale-Free Networks. Barabási and Albert (1999) define a *scale-free network,* denoting the number of links of a node j in a network as $\deg(j)$, as one where the links are generated with an attraction likelihood $p(j)$, for i to form a link to node j, proportional to j's current degree, that is, $p(j) \sim \deg(j)$. The scale-free model is considered unrealistic because each actor i must have total sensitivity to the differential "popularity" or degree of every other node, regardless of how near or distant they are in the network. While the scale-free generating model has no initial parameters, it generates networks in which the frequency $f_k(j{:}\deg(j)=k)$ of nodes with degree k have variable power law proportionality coefficients α, where $f_k(j) \sim k^{-\alpha}$. As the number of nodes generated goes from small to infinity, the expected α goes from $\alpha>1$ to $\alpha=3$. The mistake of Barabási (2002) was to infer that any network with degree distribution that fits a power-law $f_k(j) \sim k^{-\alpha}$ with $1<\alpha<3$ must be a result of the scale-free generative model. This is undoubtedly the most abused model and set of assumptions about social networks in the literature.

The applicability of Barabási's framework is often critiqued, here and elsewhere, as a model for different types of networks. A good example is the network of the WorldWideWeb (see box). It exhibits a power relationship $f_k(x) \sim k^{-\alpha}$ for web sites that holds over a great range of frequencies for the incoming and outgoing links. The problem with scale-free generative model as an explanation for this finding, however, is that the more visited sites are not inherently more attractive for the formation of new links, but that search engines *use* the number of links to rank sites preferentially.

Network Example 3: Internet and Technological Networks as Prototypes of Scaleablity.

Technological networks such as the internet are found by Barabási and Albert (1999) to have scale-free properties in which the number of links that a web site or router possesses is an attractor for new links. In this model the attraction to a node j is simply governed by a linkage probability $p(j) \sim \deg(j)$, proportional to j's current "popularity." This attraction is defined as if interactions are equally likely at different network or spatial distances. Adamic and Huberman (2000) show that web sites follow a "winner take all" power law. The internet example of scale-free networks, however, fails to characterize social networks or social organization generally. The instantaneity of internet connection does favour scale-free behavior and "universal attraction," unconstrained by locality or distance. But as a social form constructed out of social imagination it is a model of centralization, truly hierarchical, and the opposite of self-organization. It is the activity of the hubs as businesses and advertisers, and not the citizen's everyday 'attraction' to hubs, which constructs the hierarchy. This is not an appropriate model for human social networks generally, nor an egalitarian model for how a democratic society should organize itself. Even the structure of internet blogs has a destabilizing effect on democratic politics (Kline and Burstein, 2005). Barabási (2002) mistakenly asserts that networks in which numbers of links fit power laws can be considered self-organizing.

The unsuitability of power-laws to model hierarchical ranking in social networks makes it imperative that this chapter include a well-studied alternative model better suited to complex systems and to studying the relation of networks to hierarchies. The *social-circles model* (White, Kejžar, Tsallis, Farmer, and White 2006) shows how networks generated by realistic variations in the wiring of social and economic feedback processes conform strictly to one particular function, the q-exponential (see box). Comparisons and analyses of the variety of networks topologies and local properties generated by variations of the α, β, and γ parameters of the social-circles generative network model produce degree and traversal hierarchies in networks and size hierarchies for city populations that translate 1-to-1 to those modeled by the q-exponential.

The *q*-exponential function. Developed by complexity scientist Tsallis (1988) and studied extensively by Borges (2004a,b) and others, the q-exponential function models complex interactive systems in which entropic diffusion distributes in interactive networks that are already potentiated by storage bins of materials and energies. The dynamics of these processes as they undergo alternating build-up and depletion in their limit cycles (ultimately replenishing energy loss by drawing from higher level hierarchies, much as sunlight operates for replenishing earth energy and, indirectly, its materials for life) traverse only a limited part of their potential phase space, as if the phase space itself were a kind of network constraint. How entropic diffusion operates in potentiated systems as represented by the q-exponential is of general interest because q=1 represents the special case of potentials that decrease to zero, in which case the q-function converges to standard entropy, with q-1 measuring departure from standard entropy. Departures occur either in the case where q-1>0, toward multiplicative or power-law self-enhancing interactions or, where $0<q<1$, toward self-limiting effects.

As an alternative that is only partially scale-free, the generative social-circles model is intended to reflect realistic assumptions about intelligent feedback processes. The likelihood L(i) that i will form a new link is proportional to i's degree, L(i)~deg(i) $^{-\alpha}$. Which j is taken as a partner is the result of a partner-search within i's existing network. The search is conducted efficiently and intelligently by sending a token that has its history encoded by successive neighbors as it travels from one to the next, as in a small-world experiment. If each successive neighbor is not the partner sought they are instructed to pass the token along to the next neighbor but never back to a node already visited. The routing likelihood R(j) of the token passing to a next-neighbor j is R(j)~deg*(j)$^{\gamma}$, proportional to j's degree after subtracting nodes already visited. To make this model completely general, the search ends when a limit on traversal cost from i to k is reached with a likelihood T(i,k)~distance(i,k) $^{1-\beta}$. The parameter α affects activity levels of initiators, β affects the cost of traversal as it rises with distance, and γ affects the variation from random to hub-based intelligent search. If the search ends at node k within the network, a new partnership link is formed between i and k, but if it has to stop at a dead-end within the network, because the distance allowed for the search has run out, then a new partner link is formed with a node k that is recruited from outside the network connected to i.

Generative Model 3: The *social-circles network* model is one of a class of generative models that offers alternatives to the scale-free model with its incorrect deductions about power-laws. One of the powerful characteristics of the model is that all the networks generated, for the value ranges (i.e., 0-2) of its parameters, have degree and link-traversal frequency distributions that fit the parameterized q-exponential function (see box above). Some of the networks generated have *partial scale-up properties*, others do not, and some are *scale-free.* The function, somewhere in between power-law and exponential distributions, has the following properties for its parameters, Y0, q, and κ, assuming here that the distribution is cumulative for the populations scaled:

1. Y0 scales as the total population (populations in cities, numbers of cities, nodes in a network), consistent with a pattern in which smaller settlements have a smaller proportion of urban population.

2. For q, when $q>1$, the tail of the distribution asymptotes toward a power law with slope $1/(1-q)$. When $q=1$, the distribution is exponential. When $0<q<1$, the distribution has no tail, but bounded support where the function strictly vanishes above a certain value of the abscissa.

3. For κ, when $q>1$, $\kappa/(q-1)$ on the abscissa reflects the centre of a region of crossover to the asymptote toward a power-law tail and when $0<q<1$, κ reflects how quickly the function strictly vanishes above a certain value of the abscissa.

The q-exponential function for a cumulative population size S is $Y_q(S \geq x) = Y0\ (1-(1-q)x/\kappa)^{1/(1-q)}$, and its derivative is $Y_q'(x)=Y0/\kappa[1-(1-q)x/\kappa]^{(q/(1-q))}$. For cities, $Y_q(S \geq x)$ is the populations in all cities for a size x or greater, and for networks, these are the number of persons with each degree x or greater.

The relation between the input parameters of the social-circles model and the q-exponential parameters of the networks generated by the simulation suggests how interactive social and economic processes generate partially scalable networks ($q>1$ in the q-exponential function) and in doing so, generate some of the basic properties of industrial and city systems. The three properties of $Y_q(S \geq x)$ are extremely useful for modeling some of the known properties of social networks and of city populations, as in the examples of this chapter. Further, as the examples will show, with a network or city population distribution fitted by MLE (Shalizi 2007) for parameters Y0, q, and κ, it is possible to retro–fit the parameters of the social-circles feedback model that might have generated the observed distribution almost perfectly. That is because the Y0, q, and κ parameters tend to be in 1-to-1 correspondence with the parameters of the social-circles model (α, β, γ, and a fourth, δ, which maps to the values of q) for both cities and for social networks.

Further, if M is the size x of the largest city for of the network hub with largest degree x, as predicted by $Y_q(M=x)=M$ in the model, then the slope of the approach to a power law through M, when $q>1$, is given by the derivative $Y_q'(M)=Y0/\kappa[1-(1-q)M/\kappa]^{(q/(1-q))}$. For cumulative degree and city-number distributions this corresponds to the Pareto power–law coefficient. Knowing q along with Y0 and the crossover at $\kappa/(q-1)$ from Y0 translates into an exact structural description of degree distributions and of the demographic description of city size distributions.

Segmentary Networks and Cross-Cutting Integrative Cohesion

Some of the networks generated by the social-circles model are segmentary, meaning more tree-like in structure ($\gamma=0$, $\beta=0$), while others are more cohesive ($\gamma=1$, $\beta\geq2$). Segmentation and cohesion (and its rough equivalent, cross-cutting integration of ties), present one of the major contrasts in human social organization. Segmentary structures segregate, and keep social units apart except as connected through single pathways, such as common ancestors in a unilineal descent group, or unique heads of lines of converging bureaucratic authority. Structural cohesion and cross-cutting memberships in groups integrate. Cohesive structures have a cost of redundant links. Tree-like network structures minimize number of links but the cost of such efficiency is vulnerability to miscommunication, disconnection, and inequalities of access.

Network Example 4: Fairness in a Cost-Effective Industrial District Network Hierarchy

An example of network hierarchy in the modern industrial production system is provided by Nakano and White's (2006 a,b,c,d) network study of supplier/prime buyer relations in a Tokyo industrial district. This network has no symmetric ties and no directed cycles, thus, it is a perfect DAG hierarchical structure, just the kind posited by economic sociologists such as Harrison White (2003a,b) and by economists such as Weisbuch and Battison (2005) to provide the basis of the modern industrial production system. The DAG structures of industrial markets are late forms in the evolution of industrial districts and processing networks. Production chains often take the form of directed sequences, but in many contexts the buyers at the end of a production chain are families or organizations within a community network in which products are exchanged in a cycle of transactions. Specialty craft industrial districts that depend on manual work often lack the hierarchical DAG structure typical of modern industrial production where global displacements cut the redundancy of ties between producers from consumers. The results of the study distinguish the economic structures of fair and unfair exchange structures within a modern industrial production network, where there is a massive potential to exploit unfair network market structure to maximize profits. Nakano and White (2006 b,c,d) show, in fact, that it is the elite suppliers to the OEMs that actually do the hierarchical organizing of their lower-tier suppliers. They do so through a power differential, and that they so is greatly to their own advantage and that of their OEM end-buyers.

The findings of the Tokyo study reflect back on the emerging field of network economics, where Kranton and Minehart (2001) have laid out formal proofs for the effects of network position on pricing advantages. Having studied some of the asymmetries that appear between buyers and sellers moving up the hierarchy toward the elite end-producers for the world market such as Toshiba, NEC, Hitachi, Sony, Canon, Nikkon, and Nissan, Nakano and White (2006d) examined relationships with single-buyer monopsony and single-supplier monopoly within the network. They defined a strictly fair buyer/seller network component as a maximal sub–network in which every supplier has the opportunity to sell to multiple buyers and every buyer the opportunity to buy from multiple suppliers. They then *removed* from the empirically observed industrial network all of the *fair market arcs*, meaning all those links that occur within one or more strictly fair buyer/seller network components. What remain with these removals are all of the original nodes, along with remaining arcs that involve *unfair market advantages* in the sense that they connect to monopolistic buyers with arcs from two or more suppliers who are disadvantaged by not having other buyers, or to monopsistic suppliers with arcs to two or more buyers that did not have other suppliers. Nakano and White are thus able to count the actual number of pure monopsony and pure monopoly triads that exist within the industrial district network and examine their distribution within the levels of the DAG hierarchy.

Segmentation and Cross-Cutting Integration in Network Design and Planning

Urban arteries and freeways are usually considered not as divisive but as connective: when roads are classified as tertiary, secondary and primary, the higher the level the more efficiently they connect places along the route. Network interpretation, design, and planning, however, must consider the opposite: the higher the classificatory level of road transport, the greater the disconnect between communities divided or segregated by the roads, the more they segregate residential populations (as is particularly evident for freeways), destroy social cohesion, and raise the level of fear in residential neighborhoods. The ways in which our urban networks evolve and are redesigned have massive effects on racial and ethnic discrimination, inequality, and political attitudes. Segmented urban, suburban and transport development has become more dominant as an unconscious bias in Europe (and the U.S.) since the 1960s.

Network Example 5: Urban transport networks

Grannis (1998) studied the major cities in the U.S. from a perspective that asked whether, if arteries and freeways are considered as geographic *barriers between neighborhoods*, as they are often perceived by urban and especially ghetto residents, do they actually have consequences for greater racial, ethnic, income, and educational segregation? He compared segregation indices computed on census tracts with identical indices computed from identifying the boundaries of undisrupted communities. What he found was startling: indices for racial, ethnic, income, and educational segregation rise by more than 300% when computed for areas of contiguous residential streets rather than census tracts. Second, he found that these indices were much higher for cities of the gated variety such as Los Angeles. Yet, it is an "improved" LA model that Southern California is famous for in its export of a new model for suburban planning and development. The Irvine Corporation model is one of segmented suburbs, with major freeways never slowed by stoplights or traffic circles and that never allow the traveler a glimpse of life in someone else's neighborhood. Only the industrial parks and downtowns, if any, have the crosshatch pattern of open grid cities.

In California, for example, the contrast between roads that divide and roads that connect is nowhere more evident than that between the classic open city of San Francisco and the gated city of Los Angeles. The goal of road and public planning in LA was to segregate the minority communities and deny them access to the Hollywood/Beverly Hills centers of civic culture. The worst crime in Beverly Hills judging from rates of arrest, is "driving while Black." Behind the joke is no joke. LA, Irvine, and many other Southern California cities are gated cities for the rich, but also for the poor: not only do the freeways disconnect, segregate, and stratify different neighborhoods, but once you move away from the fairly small crosshatch of streets in the "downtown" of each community, residential streets are segmented so that there is only one entrance to a rich neighborhood (often gated, and with a guard) and only one street entrance to a ghetto.

Gated cities create a climate of fear and segmented inequality (Low, 2003). In San Francisco, driving from Marin to city center, the main arteries wind through ethnically diverse neighborhoods, and public culture and interethnic accommodation are learned even while driving. Students of how transport systems shape public culture have classified cities into the segmented LA type and the crosshatch type of San Francisco and find the socio–political correlates of the Gated City, LA type, to be: lack of support for funding public education and civic culture but high support for police protection, strict enforcement, and severe sentencing for crimes against the person but not for white-collar crime.

The themes of segmentary versus cross-cutting organization have relevance to contemporary politics and international conflict. The context of fear and violence is one that spawns defensive and segmentary organization and vice versa. This context can be seen in the central region of the decolonized post-imperial Roman period where conflict was part and parcel of certain forms of segmentary organization that were incorporated into Islam and the segmentary Arab social organization of the Caliphates. Segmentary structures have much longer histories in the Middle East and its historically recurrent ecologies of fear. One of the by-products of today's conflicts with what is labelled terrorism is that the U.S. and Europe are increasingly becoming "Arabized" in a structural sense of social and political organization around an axis of defensive segmentation.

Organization, Innovation, Structural Cohesion, and Cohesive Scalability

Individuals and organizations depend for their existence on complex interactions that provide indirect benefits that are channeled, subject to – often unforeseen – constraints and costs, through circuits of feedback and feed–forward 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. Activity changes as a result of social pressures – processing multiple demands under existing constraints within the ensemble of activities in networks of multiple relationships – and such activity transforms social organization interactively. This occurs not just within organizations – where time, energy and personnel are limited and activities can be bundled and re–bundled to supply the spatiotemporal efficiencies needed to handle the flow of material, events and information that occur in networks of interactions – but also in the management of relationships between individuals and organizations (Goodenough 1963). One of the fundamental ways to efficiently bundle and re–bundle loosely networked – rather than hard-wired – organizations is through structural cohesion.

Urban systems as multi-nets

A Key Failure in the Study of Urban Places: Co-Evolution of Cities and Urban Networks

The concept of power-law tails of urban population distributions of leading cities has long predominated in urban studies and gives a false impression of cities as self-organizing systems (Bak 1996) with universal rank-size scaling (Batty 2006). City sizes are not scale-free and city-size distributions do not conform to invariant or even fully scale-free power laws. There is no commonly accepted explanation for this discrepancy in the urban studies literature, from Zipf to Sassen, nor for the Zipf "law" itself (Krugman, 1996).

For a test of whether city size distributions are stable over time or have characteristic oscillatory limit cycles, data are available from Chandler's (1987) inventory of sizes for the world's largest cities. Figure 3 is highly schematic but tells the story using q-exponential fitting for each of 25 historical time periods (White, Kejžar, Tsallis and Rozenblat 2005). The dark line in the figure shows variations in q for the largest cities in China, and the light line does so for the largest cities in the world in each period. Both sets of q values, those for Chinese cities and for world cities, show statistically significant runs of values that remain significantly above or below the mean for long historical periods, implying long periods of oscillation. This points towards the existence of limit cycles.

Between 900 and 2000 CE there are three periods of high q values alternating with three of low q values for the world, but with shorter periods for China. The q values, while relatively stable for long periods, change massively between different major historical periods. The changes are between high-q periods with thicker power-law tails and greater heterogeneity and low-q periods that are more exponential in the shape of the distribution and egalitarian in terms of city size differences, but also represent more “collapsed” city systems.

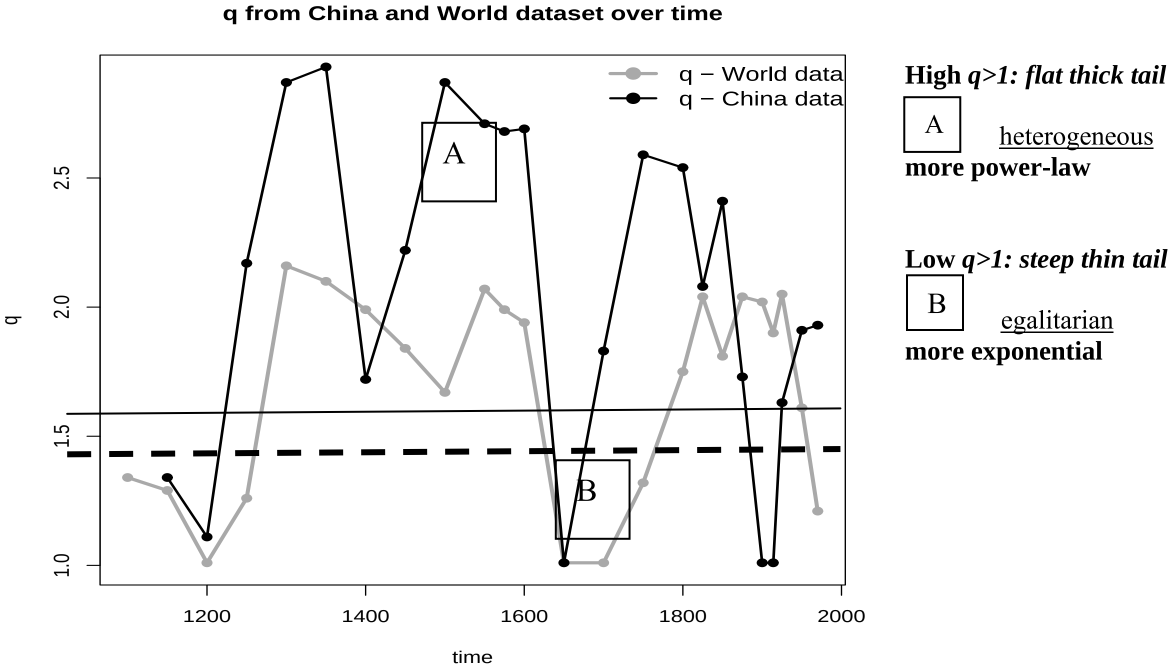
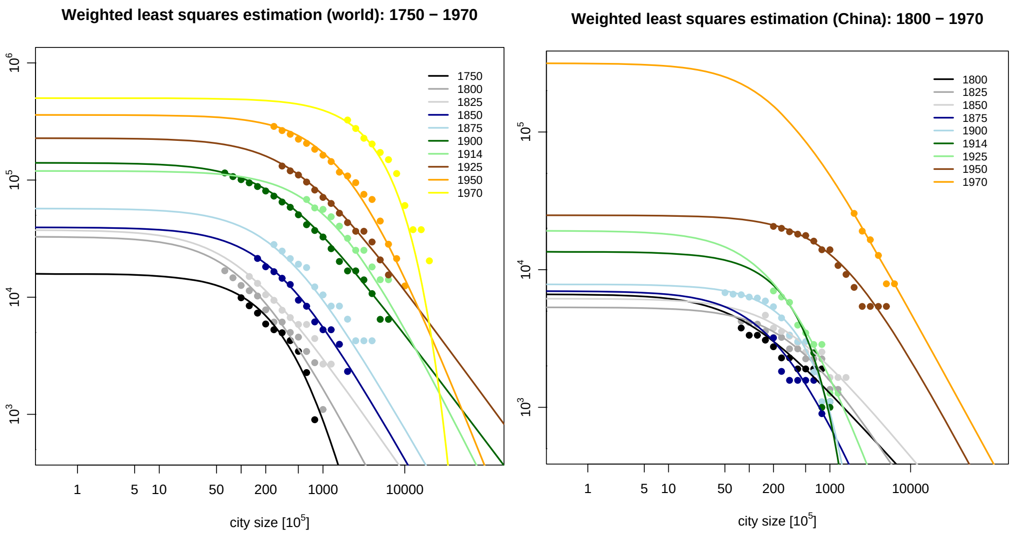


Figure 3: *q* values for city distributions

Figure 4 shows some of the distributions of cumulative population by city size for China (4a) and world cities (4b). The curves in the log-log plots for the bodies of these distributions bend toward the horizontal as they approach the y-axis, consistent with the *q*-exponential. These fitted curves show dramatically how the city population curves differ from power-laws (which are straight lines in log-log; but this departure in more evident when the number of cities is cumulated), and how much the distributions differ from one time period to another. On the y axis, in logged units of 1,000, are the cumulative city populations of the logged city-size bins in the x axis. One can see large differences in the shapes of the curves between 1800, 1875, 1914 and 1950 for China, for example, and in the case of the cities of the world, one is struck by how 1700 differs by degree from 1850 and 1900. All of the distributions asymptote at the tail to a power law with slope β measured by $1/(q-1)$ if $q>1$, although the slope of the *q*-exponential as it intersects the largest city M is shallower, as it is set by the derivative $Y_q'(M)$.

Many of the actual data points in the tails, however, differ from the slope expected from fitted *q* (here fittings were weighted by the cumulative number of cities in each bin, and since these weights increase from right to left they give weighting priority to the body of the distribution). A key feature of these distributions is that of systematic exaggeration of the sizes of the very largest city as compared to what is expected from the rest of the distribution. This occurs up to 1950 for China, and to 1850 for the largest world cities. These exceptional sizes of historical cities disappear with globalization. Thus the exceptional primacies of capital cities in the historical periods may reflect their integration into cross-regional trading networks – trading connections to the hubs of other regions –, an integration that is not shared by smaller cities until the economy becomes fully globalized.


Weighted least squares estimation (world): 1750 – 1970

Weighted least squares estimation (China): 1800 – 1970

(a) World Cities

(b) Chinese Cities

Figure 4: Fitted q-exponential curves for World and Chinese city distributions

Strong evidence of long-distance correlations between city sizes in East Asia and westerly Eurasia is given by Chinese variations in q (such as in Figure 3) that tend to lead those elsewhere in the world by about 50 years.[3] This would be expected for a dominant region in the world economy. This also supports the hypothesis that the carriers of positive long-distance correlations in city sizes are the intercity networks, operating primarily through trade relationships. These correlated oscillations, when lagged by 50 years, begin in Eurasia after the Song invention of national markets and credit mechanisms in the 900s.

Mobile states such as the Mongols play significant roles both in establishing and furthering long-distance trade and in its disruption (Chase-Dunn et al. 2006). World-system wars that lead to disruptions of trade networks have a negative effect on city population distributions. I call these degenerative periods *city-quakes* as opposed to the city-rise periods. Trade, diffusion of information and innovations (or materials that can be used for innovations), and warfare play significant roles in city-rises and city-quakes at the population distribution level.

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[3] This figure was made before locating convergent estimation procedures for q and other parameters, using SPSS and Excel Solver for nonlinear regression, and the finding that fitted q values converge and replicate below 1. The pattern in the figure is illustrative but the q values are not as accurate as later scaling. What is important to the present results is that the time-lagged correlations between changes in q values of city systems in China and those in the remaining world cities, the Mid Eastern region, and Europe were replicated in each successive rescaling of q with different estimation methods. The most accurate of our scaling estimates using maximal likelihood estimations (MLE) methods has now been developed in collaboration with Shalizi (2006).

Innovation in Cities: Dynamic Co-Evolution of Markets and States

For cities to produce, to exchange, to consume, and to produce again requires novel, extra–somatic and networked technology. If import substitutions that lower costs proceed without other forms of competitive novelty, the nodes in trade networks become more homogeneous, and advantages to trade begin to flatten (Algaze 2005). Markets induce behavior to realize returns to competitive novelty, and to leading economic sectors and regions of innovation (Modelski and Thompson 1996). Less competitive cities sink in place as their products come to be less in demand; they become less productive, with diminishing resources, and less attractive. Cities therefore have to run-in-place to pay the increasing costs of inefficiencies by producing more innovation relative to their scale. Part of the scale-related cost that must be paid is the increase in the number of cities' inhabitants and the socio–technical networks within the city that support them. Another part of the cost is in the scale of the networks that support cities and their populations externally through trade, communication, and war. Cities must also pay, competitively, for the specialist populations that help to grow and support both the internal and external networks and that generate the innovations needed for the city to maintain its position in a hierarchy of competition among market sectors and states.

Civilizations as dynamic networks based on urban economies and exchange, then, are not "ordinary" social networks, but ones with dynamic properties that are heavily affected by material, energetic, technological, and innovation processes. In contrast, networks built out of cultural imagination can be constructed out of idealized structural principles (like the kinship networks of Greek gods)[4]. Interpersonal "social" networks, however, should show large effects of local structure and high cultural tension between ideal socio–centric templates and practical or operational constraints. The highly unstable and oscillatory behavior observed in economic networks, from stock markets to trading networks and processes of innovation, may be due to the huge constraints and feedbacks of processes resulting in massive material and energy flows and costs. When the magnitudes of these flows increase significantly, they are necessarily transformative of the organizations that carry and channel them (see the organizational transformations section below).

Dynamics and Time Lag Complexity

The slowness of the oscillating limit cycles for the bodies of fitted q values shown in Figure 4 places them at the top of a cascade of processes that link market instabilities to dynamics. Why these instabilities? Trade and markets are a double edged sword: trade is competitive and its terms are beneficial only if quality and innovation relative to price provide market niches that offer a viable profile for exchange partners in the construction of the market (H. White 1989, 2002a,b, 2003). Cities, like shares in the stock market, go up and down in population according to their competitiveness in economic innovation and political leadership (cf. Guérin-Pace 1993). Competitiveness, market share, and ability to exchange at favorable rates all affect urban wages, attractiveness to migrants, and incentives offered to attract innovative and productive firms and individuals. The "market position" of cities in a trade network, then, is an extra–somatic network aspect

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[4] In an ISCOM network study by White (2004) it was noted that the only kinship network of 200+ cases studied that had power-law coefficients as high as 3.0 was that of kinship among Greek Gods.

with proportionality effects not only on the life of individuals in the city but on the city itself as an entity.

The temporal comparisons between the length of limit cycles for q and those of other processes such as the century long or “secular” cycles of rise and fall in regional polity populations (Turchin 2003, 2005), international political leadership (Modelski 1966), and competitive innovation in leading economic sectors (Kondratieff 1994) are detailed in White, Kejžar, and Tambayong (2006). The time periods involved in these various limit cycles tend to be 2:1 multiples of one another, as do, roughly, the concomitant spatial scales:

Oscillations	**Periods**	**Type**	**Spatial scale & References**[5]
440 years	220 years	City q-networks	(1) World
220	110	Secular cycles	(2) Regional (e.g., China)
110	55	Political Leadership	(3) National
55:2 generations	22: 1 generation	Leading Econ.Sectors	(4) Local regional
22:1 generation	11: 1 leadership turnover		(5) Local
11:1 leadership turnover			

Recurrent network processes, including those driven partially by markets, almost always fail to operate at equilibrium but rather tend to establish limit cycles that operate near-equilibrium in keeping processes running by oscillations among states that replenish and expend their resources and energies. These limit cycles are not random but typically conditional on the mechanisms that allow replenishment on the one hand and require expenditure on the other. To identify dynamics in these limit cycles, which resemble but are not as simple as Lotka-Volterra predator and prey cycles, it is useful to look for time-lagged causation of both ups and downs and of phase-specific consequences.

The time-lag in limit cycle repetitions and the possible cascade of processes that comprise their lagged causations can be compared to the time-lags of the component units of these processes, such as the life-times of individuals, or the time between generations. The various ratios between these longer limit-cycle and shorter unit-cycle lags are a direct measure of the complexity of interactions. These are not linear systems that return to equilibrium after a perturbation. The time–lags are a function of the complex time-delays *internal* to the interacting entities. Examples at the generational level are gestation periods to reproduce a generation ($g = 1$ for reproduction in one generation), imprinted memory periods like avoidance of the errors of the parental generation ($g \geq 2$ for repetition), or dynastic periods for the generational unraveling of the transmission of successful leadership ($g \geq 3$).

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[5] (1) White, Kejžar & Tambayong (2005) (2) Turchin and Nefedov (2006), (3) Modelski and Thompson (1996) (4) Kondratieff (1984), (5) Wilkinson and Iberall (1986). Recent results show that when fitting q values at the regional level, e.g., Chinese cities, the temporal oscillations more closely match those of secular cycles.

The ratios between the lag at which an external causal signal is received and the time-delayed cascades of response that are elicited can thus be taken as a proxy of internal nonlinear complexity within interactive entities (Iberall and Soodak 1978). For civil and failed wars, for example, a generational time–lag operates in the avoidance of repeated civil or failed wars in the next adjacent generation (Turchin 2006:9-10,243-244).[6]

White, Kejžar, and Tambayong (2006) explain the doublings in the average lengths of these stacked oscillations (but not the relation to spatial scales) from the fact that the instabilities in all these processes arise from competition, so that conflict phenomena help to define the temporal boundaries at which discrete changes occur between phases. Maintenance of competitive conflicts requires energy and materials for their sustenance. As a result, in a longer limit cycle the phase changes can be coded so that the first transition involves the creation of disruptive conflict and the second involves a crisis in the next shorter limit cycle that dissolves the sustainability of the higher-level conflict.

For comparability with biological scaling, we need scalings of city sizes by functional processes comparable to metabolism. This is done in Chapter 1, where different processes are found to scale with size not only sub–linearly, i.e., with greater efficiency by size, but also linearly and super–linearly. In the latter case, efficiency decreases with size.

Organizational Transformations

As in the examples of historical limit cycles linked in the last millennium to the market economy, organizations are subject to rises and falls at many different time scales that may exceed their capacities. Organizations quickly find ways to build in adjustments to seasonal cycles, but challenges may occur at the level of turnover in local leadership, ups and downs in the business cycle (ca. 12 years), a generational scale, the scale for Kondratieff turnovers of leading economic sectors (2 generations, peak to peak), the longer Modelski turnovers of world political leadership (ca. 110 years peak to peak), and on up to the secular cycles of Structural Demography (Turchin 2003, Goldstone 1991, 2003) and the city size q-distribution and network oscillations.

Briefly put, there are processes (and phases in those processes) that augment flows and those that diminish them. Organizations process material, energetic, and information flows, and have certain capacities to do so. Flows may rise and fall without transforming the organization so long as the organization can scale up or down, e.g., by adding or subtracting employees, access to modes of transport or information, etcetera, without changing the organization per se. In the case of an economy that places rising demands on the organization, for example, a threshold may be reached where the organization has to deal with flows that are beyond its capacities. If the organization fails to meet the challenge, given competition, its offers may dry up, its business falter, and its size shrink. Depending on how it handles new demands, whether the means are planned or not, it transforms its organizational form, handling more input, moving at faster speeds, producing more output, improving quality control, trying out alternative techniques or strategies, etc. Often, these changes occur in unforeseen ways, or by copying on a larger

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[6] One might go on to examine the embedding of oscillations in q for cities within the millennial downward jumps identified in Taagepera (1997) in the effective mean for number of world polities and oscillations within these periods. Do polities that provide protection to city networks fluctuate more rapidly than the cities they protect, which might have a more stable persistence due to their production and exchange?

scale and in a more repetitive way, what has been seen to be successful previously. The unforeseen consequences may be enormous. But unlike biological scaling-up, these changes do not all follow a single template and are not all subject to the same hierarchical constraints.

H. White (1992:281) calls the recurrent exposure of organizations to capacity challenges a process of annealing—selection and strengthening through survival through crisis. Organizations may survive because they are tough, sleek, fast, meek, large or slow. But whatever may be the case, the organizations that survive are constituted of networks and exist in an environment of networks.

The Organizational Transformation to Capitalism and Oscillations in Forms of Capital

While conflicts rage about early modern capitalism in Eurasia, it is clear that the innovations in markets, banking, monetary credit and financial accounting developed in Song China in the 9th and 10th century, once coupled to Eurasian trade networks (in which Muslims and Mongols were crucial intermediaries), led to an overall rise in city populations in the centuries following the reversion to a rural and non–monetary economy in Europe at the end of the Roman empire. While (in the same periods of crisis as occurred in the Roman empire), the Han empire put down peasant rebellions in ways that led to the carving up of greater China into constituent states and dynasties, the great cities remained and the great empire was reconstituted in the Sui and Tang periods just prior to the Song. The late medieval transformation of Europe is especially interesting because of the transformation from a non–urban non–monetary economy to a market economy.

Organizational transformation is one of the main themes that recur over and again in Peter Spufford's (2002) analysis of patterns of industry and trade in Medieval Europe. He traces the flows of bullion, currencies and trade goods in the Medieval city networks and their surroundings, and embeds his description of the rise and fall of a merchant economy as it displaces a feudal nobility in the same conceptual understanding of historical dynamics and treatment of secular cycles that we see in Turchin's (2003, 2006) accounts of rise and fall of populations, economies, and crises in states and other polities.

What Spufford describes are oscillatory cycles, in which increasing population in a successful economy outruns resources per capita, creating scarcity and inflationary pressure. This creates tensions in the population because the value of fixed assets of property owners increases as workers' wages decline. In the Medieval crises, landowners of rural estates traded on rising land values by renting out parcels, preferring to receive the rents not in kind but in convertible currencies, and using those currencies to hire managers … all the while evicting those with customary claims on land use. Currency incomes were then used to build or rent houses in cities, spending income or assets on new consumption goods that augmented status in the prestigious and remunerative political and religious hierarchies of the times. The details are specific, but the process is one that is recurrent in secular oscillations. As it deepens, crises—in politics as well in the collection of revenues from, and the management of, an increasingly impoverished general population (Goldstone 1991)—beget social conflicts between the rich and the poor, the powerful and the powerless, and accelerate a population decline that has also been affected by parents' declining sense of the desirability of having more children.

The growth phase of a secular cycle promotes organizational transformations as the volumes of trade, transactions, information, material throughputs, and energy required for work, and a myriad other factors place demands on existing organizations that surpass their capacities. On the way down there are organizational transformations on the side of defense, protection, and recovery.

Summary

The different ways that networks generate hierarchy can be grouped into five classes, drawing on generative models of network formation, including the fully random ER network (see box).

***Generative Model* 4**. An ER *random network* is one where E edge links among N nodes are equi–probable. Solomonoff and Rapoport (1951) proved for large N, given a link density c=E/N per node, that the expected size λ of nodes reachable from an arbitrary node approximates $1-e^{-c\lambda}$. The ER in this model stands for Erdös and Renyi (1960) who proved a series of stronger results, as for example that the size of the largest (connected) component of a random network approximates logN for $c < \frac{1}{2}$, $N^{2/3}$ for $c \sim \frac{1}{2}$, and N for $c > \frac{1}{2}$. That is, a rapid transition to a large component encompassing the whole network begins when the E reaches ½N.

Each of the five classes has different implications for the innovation and urban dynamics:

1. Spontaneous formation of structurally cohesive hierarchies.

Here, only the ability for pair–wise bonding to form chains and cycles is presupposed. Like the threshold at ½N edges where a giant component begins to form in a ER network, at a higher density threshold, there forms a giant *bi–component* within which each node is connected by two or more independent paths. The *ranking of nodes by structural cohesion* (here, from 0 to 2; 2 for the bi–component) forms a *cohesive hierarchy*. The small-world model has within it the special case of the random network generating model. As the density of random links increases, giant 3- and 4- (and higher) cohesive components will emerge. If there are clustering biases in the network, the combination of random link formation and clustering will produce a variety of cohesive groups, the extent of randomness in the generating process generating cross–cutting groups. This is the form of cohesion that occurs spontaneously in the form of resistance at the boundaries of empires, and often overtakes empires because it is a decentralized form of social hierarchy and appears (as it is not centrally organized) as if it were spontaneous. As Moody (2006) shows for recruitment of opponents in guerrilla and insurrectionary warfare, every friend or relative of an innocent civilian killed or wounded by an occupying military power is a potential recruit to the opposition. These are also the processes we see in the ubiquitous cross-cultural phenomena of freely forming friendship links, for example, that have both a random component and a clustering bias. The same is true of marriage networks, where the clustering bias by ethnicity seems to be higher, but as marriages interconnect sets of families, subsets of families form that are structurally endogamous. Conversely, to the extent that children's marriages enlarge the structurally endogamous group of their parents, structural cohesion creates the boundaries of ethnicity. The growth curve for spontaneous formation of structurally cohesive hierarchies of these sorts is an *S*-curve with a crossover in number of links required for structural cohesion at level k. Every bi–component of n nodes, for example, will contain a cycle of n edges, which ER (1960:34) show the probability of a network containing such a cycle is $1\text{-}e\text{-}(1/2n)(2c)^{n}$.

Spontaneous growth in structural cohesion also forms around innovation, as shown in the biotech example. It is involved in the start-up of cities as networks because of the cohesive network cycles that form certain structural cohesion hierarchies of trade. Once a group of villages begin to trade specialized products, and the trade links form a cycle, the cycles of exchange have multiplicative effects and potential benefits for all the participants. As cycles densify so that every seller has two links to buyers and every buyer two links to sellers, the advantages of potential pricing equilibria begin to kick in to all participants, even when the trade is politically rather than market governed. Because innovation depends by definition on spread (in contrast to invention), innovation as diffusion is enhanced by structural cohesion. So is the rise and attraction of larger cities, and the basic nonlinear dynamics of population growth through growing city hierarchies (as in Figure 2) is fueled by structurally cohesive networks. Tree-like routes of trade do not lead to the same growth rates as cohesive networks because they entail monopolies and monopsonies that penalize partners in exchange.

2. Segmentary (tree-like) and directed acyclic graph (DAG) hierarchies.

ER random graphs are expected to be tree-like when average link densities per node are less than one. At higher link densities they are produced by some kind of structural bias. Selection for efficiency given a high cost-per-link might occur, as in the DAG example of the Chinese migrant women's discussion networks, which might roughly represent directed altruism of better-off and more experienced women helping others in partially-ordered directed sequences of need. They also occur by design, as in the Tokyo example of industrial production chains, to minimize cost through sharing suppliers or to accrue the advantages of buyer monopsonies over suppliers in DAG industrial production chains, where buyers have the advantage of being closer to end-product profits.

3. Scale-free (SF) and power-law hierarchies.

The Barabási and Albert (1999) generative model of scale-free networks must be distinguished from networks with a power-law distribution of degree frequencies that may be also generated by other processes. In each case there is a power-law hierarchy of hubs. Tendencies for links to form among hubs at levels above or below expectations from the scale-free generative model (that is, assortative or dis–assortative connection biases) may be measured in an empirical network or added to the SF generative model biases.

What are often taken to be SF or power-law hierarchies, however, often mask what are actually only partially SF hierarchies of the type 5, unless they are part of the generating processes of level hierarchies of type 4, which are the subject of Chapter 1.

4. Level Hierarchies.

These are treated for biological systems in Chapter 1, as results of typically long and slow evolutionary selection (although not without certain transition thresholds and systemic crashes) for sustainable, self-renewing and stable material and energetic platforms, from galaxies to planetary systems to life forms. Within these there are systems that are unstable in the strict sense of Jen (2006) but that have the recuperative capability of structural stability, such as ecosystem networks and food webs. An example of a transition threshold is that between atmospheric methane and oxygen that coevolved with living plant communities. An example of a systemic crash is the great extinction of the Mesozoic. The view of this chapter, not inconsistent with Chapter 1, is that city systems do not constitute level hierarchies or structurally stable platforms for human life when we look at their scaling properties and their dynamics.

5. Social-circles (SC) with *q-exponential partially SF hierarchies*.

These are the unique focus of this chapter. Of the four generative network models I have examined (ER random network models, small world clustered-and-partly randomized network models, SF power-law models, and SC models), these are one of the three consistent with social networks generally, and the one required for an understanding of the limit-cycles of city systems, unsustainable growth of the human population, and the crises of urban civilizations past and present. There is no assurance here of sustainable dynamics, although the industrial revolution, like the agricultural revolution to fixity-in-place, the urban revolution, the crises of archaic civilizations, and other transitions, represent attempts to surmount the problems of structural instability.

Dynamics

Some of the network principles improving our understanding of the emergence of the fifth form of hierarchy in human society have been explored in this chapter. Cities arose as networks of interdependencies that depended from the start on multiplier effects reflected in rank-size hierarchies and instabilities that demanded recruitment into cities and rises in the total populations of regions with city networks. Volatility of rise and fall of cities occurred not only at the level of individual cities, as is well documented, but, based on current research, also in entire city systems. .

Batty (2006:592) states the case of this chapter, building on the work reviewed here: “It is now clear that the evident macro-stability in such distributions [as urban rank-size hierarchies] at different times can mask a volatile and often turbulent micro-dynamics, in which objects can change their position or rank-order rapidly while their aggregate distribution appears quite stable…. Our results destroy any notion that rank-size scaling is universal… [they] show cities and civilizations rising and falling in size at many times and on many scales.”

Examples of recent investigations of civilization–level dynamics, based on *q*-exponential scaling of city size distributions, show limit cycles of city-rise and city-quake operating at temporal scale twice as long as the polity-population limit cycles first identified by Goldstone (1991; Structural Demographic Theory). These latter “secular” (century-scale) limit cycles were investigated further by Turchin (2003, 2005) and Turchin and Nefedov (2006). How cycles of innovation connect to phases of secular cycles is shown by Nefedov (2003) and Korotayev (2006). We find close dynamical connections to interactions in those fields that are “below” those of continent-level network of cities: not only regional secular cycles, but below them, cycles linked to world political leadership of a dominant regional polity, for example.

Rises and falls in city systems are generally connected to conflict in certain phases and to innovation in others. Within regions, these oscillations seem also to be keyed to cycles of population growth, inducing scarcities and socio-political violence, and population declines and recoveries.

Networks and Hierarchy, Revisited

In the design of the ISCOM project, Lane (2005) was grappling with issues of hierarchy in which the concept of level hierarchies as applied in the social sciences seemed to lead to “tangles” in the ways that different entities and processes impinge on one another. This led, for him, to a tension between metonymic historical and concrete network methods in which stories are salient (as is the case with the network theories of H. White 1992) in ways that utilize symbolic interactions that can easily represent “tangles” between “hierarchical” levels and the concerns of complexity theorists to represent phenomena that emerge out of one level but seem to create new entities and processes at another. This led Lane (2005:117) to postulate, as one of the axioms of the ISCOM project, in which research has been directed at information as well as material and energetic processes, notions of “sandwiched emergence” and “triadic hierarchies.”

As regards networks, the important conceptual innovation here was a social ontology that posits “interacting agents, who constitute the micro-level of the triadic hierarchy.” Networks, coded as binary presence of interactions, then constitute a meso-level of the “history of interactions among sets of agents” which also “provides the pathway whereby agents move into the future” and “can endow agency upon recurring patterns of interactions, thereby inducing the emergence of new agents and even new intermediate levels of agents”. But the meso-level is important for another reason as well: it is the locus of process functionality which links to the intentionality and agency, the notions that agents carry as to “achievements,” their recodings of their retrospective histories, and how patterns of behavior are reinforced by values. “Social organizations – sometimes agents, sometimes configurations of interactions among agents and artifacts – emerge to carry out this functionality-preserving functionality. Lane and Maxfield (2005) call such organisations scaffolding structures; they constitute the macro-level of the triadic hierarchy.”

The approach in this chapter has been to take these apparently disparate levels – which leave networks hanging in a kind of limbo between micro and macro – and extend the concept of network to that of multi-nets, which include the actors or agents at some level (for Lane: micro, but there may be many more than three kinds of entities involved), and which also include the emergent phenomena such as organizational “scaffolding” structures as part of the network. Multilayer codings and specifications as to cohesive entities that are composed of other networked entities, including the symbolic and historical interactions then make it possible to see the multi-net as a multi–layer multi–entity multi–relational site where these interactions and codings take place but also a means of seeing how emergence occurs and creates new entities within the multi-net itself, as more global network levels of structuration and process.

What the multi-net approach facilitates is the coding of structural changes over time as an objective correlative of dynamical processes in which interaction goes on at multiple levels and in which models of dynamical interaction can be tested. Insights and correlatives from the "stories" running on these networks viewed both from the actor/agent and the observer level need not be lost in the process. It is to this end that one of the modeling concerns that has driven our interest in city networks (as reviewed in this chapter), has been to see cities as actors in systems "higher up" (such as polities) and as embedding actors "lower down", in short as agents with layers of interaction at different levels. Studies of networks of different sorts then come to exemplify different processes taking place in a larger network of networks and multiple types of entities.

The concept of readily discernible structurally cohesive units – and an understanding of their consequences in different contexts and types of interactions – allows us to navigate emergence of actors and agents from level to level. But the levels are not those of "level hierarchies," which I have tried to define quite carefully and to differentiate from those of metonymic polysemy. Rather, they are dynamical constructions, and the study of their oscillatory behaviors – rises and falls – gives the clues to how they are constructed, wherein lie the possibilities of their instabilities and their structural instabilities, and their possibilities for structural stabilities.

Some of what has emerged from this chapter are clearer views of the inability of over–generalized models such as those for "scale-free" networks to posit facile principles by which the complex systems that we are studying in ISCOM and other projects are assumed to be self-organizing just because the linkage degree or size distributions of the actors – whether individuals, cities, or other kinds of entities – exhibit power-law tails, or deceptive statements of universal scaling laws such as Zipfian city size distributions for what are really dynamically oscillating interactive structures with patterned interactions among readily identifiable moving parts. Secondly, the perspectives of historical and multilevel dynamics can provide more accurate glimpses of the contexts in which innovations are more likely and of what are likely to be their effects given the particular dynamical contexts in which they occur. Thirdly, I have tried to illustrate from a policy view how we should try to be very careful in evaluating proposals for altering networks and network structures, because our ways of understanding the variety of networks and contexts in which they are the conduits of interaction are still highly biased and we will lead us not to understand the unintended effects of our policy tinkering and designs for the future.

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Deleted: Conclusion: Soft–wired Superposition of Networks and Fields

The ways that networks generate hierarchy are discussed in the comparative summary. From a more general perspective, the exploration through network analysis of human social organizations, stability and structural stability, survival, and innovation, subject to theoretical incisiveness, pays rich dividends. There are very general principles of network theory applicable to modeling issues, but hierarchy in human social organization is one of the most difficult issues and not a problem to be taken for granted by preconceived ideas. Wright (2004), for example, notes that the passage from chiefdoms, marked by a single leader who does not delegate authority, to a state with a delegated division of labor for authority, is not an easy or stage–wise process, with states marking an emergent process, perhaps connected to city networks, that takes place outside of and opposed to the realms of chiefs. To pursue this example, which is important to differentiating types of hierarchy, if we look into Wright's (2006) *Atlas* to see exactly what he means, the primary and secondary states have multiple (3+) levels of mobilization of resources upwards through officials designated in an hierarchy of divided offices, and stately offices outlive and recruit their occupants. Chiefs and paramount chiefs, in contrast, may govern subdivided territories with local leaders and ritual specialists but there are at most two levels of chiefly resource mobilization conducting directly to the chief and all political decisions are integrated into the chiefly persona, with succession a matter of competition by personal exertion of power and rank rather than recruitment to office in a division of official political labor.

The transition between chiefdoms and states, where it occurs, involves a major structural shift, analogous to a shift from my type 2 – segmentary – to my type 5 network, where it is the city or the office that pull possible incumbents (merchants, leaders) up into higher levels of the hierarchy given that the city, office, or role continues to be capable of recruiting resources. Cohesive entities, like cities and states, which are based on social circle network generators, however, are not necessarily structurally stable, but depend on a volatile and potentially alienable power-law asymptote that supports resource mobilization and recruitment. What we learned from our q-exponential scaling of city systems is that the scaling of the entire hierarchy may fall to $q<1$, that is, lose the hierarchical power-law tail that supports the dynamism of the system. Two out of ten known historical civilizations, for example, have gone entirely out of business, one being the Mississippian urban culture (Refs.). Neither cities nor states have reached the evolutionary plateau of level hierarchies and are probably very far from that achievement.

Can we characterize emergent hierarchies in social organization in terms of the superposition of networks and fields? Interaction fields can be thought of as networks of interaction for mostly autonomous entities at a commensurate interaction level (e.g., city networks, networks of states) sandwiched between next-higher-level interactive entities (e.g., state polities in the case of city networks, regional blocks in the case of polities) and next-lower-level entities (e.g., urban basins and their constituents for cities, cities and their constituents for states). Rather like chiefdoms, cities and states may have territorial units and levels, but these are not level hierarchies (no matter what states and empires pretend). States and empires will fall apart, and so will cities and city systems (Batty 2006). Emergent units of sets of nodes in interaction fields, such as aggregates of urban basins that often form a structurally cohesive unit, may form the single nodes at some the next-higher-level of entities (e.g., that of polities or other entities *per se* in terms of cohesive networks, and not just their territorial signatures), but these entities have only my type-1 kind of entity, that of structural cohesion, and such entities can also pull apart.

Given that interaction fields may be stacked through emergent cohesive units rather than through fixed hierarchical aggregation or level hierarchies, the importance of the specific feedback and feed–forward loops that govern system dynamics cannot be underestimated. The behavior of state polities affects units and fields loosely above and below, including their city networks and urban basins "below," and other polities and units residing "above," such as cohesive political-economic regions, international market or political organizations, or whatever are the operative rules that govern military, political or economic interactions in higher-level fields. More generally, every "behavior" or action of a cohesive entity has the potential to act as a perturbation on the dynamics at higher and lower levels. If we take the urban field (networks of cities) and look at the effects of perturbations, the perturbations may happen loosely "above" as with polities or cascades of effects from higher levels, or they may happen "below" as with the productive economies of their rural hinterlands or urban basin interdependencies.

With loosely coupled inter-level effects and dynamics, it is axiomatic that for stable or structurally stable fields to continue to exist, a large part of their dynamics must be "autonomous," that is, describable in terms of characteristic and perturbatory network interactions at that level, and that there should be some kind of commensurate stacking of time scales. Given that many of the higher-level field atomisms are emergent ensembles of lower-order entitles that have coordinated or synchronized their activities, most of the higher-level field atomisms (entities, clusters) will be larger so that interaction perturbations may have large effects on a lower level field of interaction, but perturbations that percolate upward may have local effects in a higher-level field that will reverberate diffusively or synchronously in that field. Innovations, which also spread by horizontal interaction, may likewise be stabilizing or destabilizing, depending on their couplings. If the dynamical interactions of the higher-order fields operate at a slower/larger scale, many of the up-percolating perturbations will appear as noise, smoothed with time, enhancing up-field stability. Unit perturbations at the up-field level will have local effects on lower-level entities associated with that higher aggregate unit, and if the network dynamics at that level allow for smoothing effects on local failures in a network (others taking the place of failed localities or regions), lower-level stabilities may be enhanced given the potential for top-down cascades of failure.

Given loose couplings, the dynamical potentials for cascade phenomena need to be evaluated both horizontally as network field properties and vertically for inter-level perturbations. To describe interactions and interaction dynamics in terms of networks, horizontally and vertically, systems analyses must begin to test hypotheses about replicable interaction dynamics on the one hand, and examine through scaling whether some of the same dynamics are operative at different levels of aggregation, either among entities of different size within a field, or among entities at different field levels. To look at interaction dynamics horizontally in terms of networks entails "holding constant" the behavioral presence of higher and lower-level embeddings by taking them in a normal or averaged state or in a series of characteristic positions in their slow-moving dynamic trajectory from above. To look at network interaction dynamics vertically might mean looking at the effects on the field of characteristic positions in their slow-moving dynamic trajectory from above, or the effects of unusually large perturbations from above or below.