Emergence, transformation and decay in pastoral nomad socio-natural systems

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Chapter 9
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Abstract
A network approach to economic organization, kinship systems and complexity dynamics is used to explore some of the laws governing socio-natural systems for the case of nomadic pastoralism. No pretense is made of the accuracy of this provisional formulation. Nomadism is a case where regularities are particularly evident, however. Some of the regularities apply to other types of societies or subsistence modes, so some care will be taken as to the level of generality of some of the principles formulated. To engage in this level of theorizing about empirical cases, graph theoretic concepts of network segregation and cohesion provide measures that are usefully related to issues of the emergence, transformation and decay of social and economic networks and their sustainability and resilience in relation to the environment and the organization of energy, material, social, and informational flows. *Segregation* tells us, for example, how elements of a network divide into parts and *cohesion* is a more complicated concept that helps us understand generically how parts of a network pull together into emergent blocks that have higher degrees of resilience and internalized processes.

OUTLINE

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- Patrisibs: a basic organizational unit of nomadic pastoralists
- Dual market in brides and bride payment
- Social networks as flow structures in socio-natural systems
- The spreading of wealth and dispersion of pasture
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- Concomitance of scale in pastoral economies
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  - small units/small animals (sheep, goats)
  - The problem of the desert (camels)
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  - The invention of fbd marriage:
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4. Analyzing kinship structure and dynamics by dynamic graph structure modeling
5. 'How to' and examples of the approach, including applications to pastoral nomads
6. Aydĭnlĭ: Case study of small-unit small-animal pastoralists
   - Fractal marriage: inclusion and exclusion
7. Pastoral politics and complex system dynamics
   - Equality and inequality
   - Decision-making
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8. Conclusion: implications for other systems and questions raised
9. References

Units as entities AND as open systems

Don't make FBD unique to Islam/Arab
Small animal-small scale: fractal
Camel- fractal
Cattle-exogamy

Give examples:
Problem of pastoralism
Problem of the desert
3-gen plineage segments
exemplify uncertainty

Glossary (might be removed if explained in text)

Format

Most of the right margin boxes call attention to repeated principles, but some are still notes remaining from conversations with Sander on things to think about to relate to other chapters: those may eventually disappear, but some might be turned into cross references to other chapters. The GLOSSARY at the end (copied out of my current book manuscript – will get permission to "reprint" if it is useful) is marked by a differed word document "section" so that endnotes will appear at the end of the main section, and endnotes for the glossary will appear separately. I will need to decide whether the glossary is useful or something to delete.

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1. Introduction

A purely pastoralist society, as Kazanov (1984) aptly demonstrated, does not exist: each is interdependent with the larger world, and migration between nomad groups, as well as from town to country, is often the norm. Shifting of location, however, involves a high degree of openness to exploration and adaptation to innovation with respect to organization and technological skills useful to the lifeway and maintenance of a group's political boundaries. Spencer (1998) surveyed the spate of new and high quality studies of pastoralism in recent decades along complex continua of variability, such as degree of insertion in the market sector, egalitarianism vs. hierarchy, or conformity to competition. Pastoral nomads often operate in socio-natural niches that are sufficiently remote from centralized political authority so as to minimize taxation and conscription and sufficiently marginal to intensive land use that pasture is available either freely or at low rent. The specialized eco-economic niche of pastoralism requires adaptation through complex practices and distributed practical knowledge specialties. These in turn require modes of integration for self-maintenance: The task and knowledge structures of pastoralism require a high degree of networked integration, not only internally but externally as well (see for example Barth 1972).

What are the precise structures of information-management and resource flow that maintain the resilience as socio-natural systems of nomadic pastoralists, and how do they work? To open and address such questions, the argument developed here is based on six initial premises. As used below, and numbered **P1-P7**, these help explain the principles governing emergence, transformation and decay in the dynamics of nomadic pastoralists.

P1 As human activities repeat themselves they are bundled for minimization of effort (time and energy) by a process of "soft assembly" of interacting elements whereby routines that perform a variety of tasks more effectively displace many of the previously uncoordinated activities. **P1 corollary** Cooperative tasks are bundled along with the network cohesion that enables them. Cohesion is a crucial network variable because it identifies the fundamental groups such as communities and ethnicities that constitute a society.[1] **P1 corollary** New networks build out of differentiations and debundlings of old networks.

P2 Response to uncertainty that threatens survival involves long-term commitments to exchange relationships as a means of reducing risk.

P3 Wealth-holding groups are necessarily coexistant with exchange relationships (such as marriage alliance), the tradeoff being that agents work on behalf of the group in return for rights in the wealth held by the group.

P4 The organizational profile for interactive response to scaling-up for survival crises (P2) involves the cascade phenomena of complex systems that are network driven. **P4 corollary** Pastoral nomads with small production units are at an "edge of chaos" governed by segmentary fractals. **P4 corollary** Scaling up or down is often fractal.

P5 The capacity of any system, R, to represent the diversity of another system, S, cannot exceed the *flexibility* of R as a coding system. This is Ashby's principle of *requisite diversity in representation* rephrased by Wilden (1987:192).

P6 Emergent outcomes of complex interactions are often mediated by network effects. Understanding the network effects of complex interactions requires a means of flexible and variegated representation such as a graph theoretic analysis for the study of cohesion.

P7 Cognition does not consist of internal representations and operations: it is necessarily and predominantly *scaffolded* by patterned elements in the behavioral environment.

These propositions link explanations that sit on the intersections of diverse domains best approached through a comparative analysis of human activity systems and ethnography (exemplified by premise **P1**) combined with a network approach to economic organization (**P2**) and to the study of kinship and social organization (**P3**), while drawing on complexity theory (**P4**), informational coding (**P5**), graph theory (**P6**), and cognition (**P7**). Conceptual terms from each domain are found in the glossary, and introduced along with basic definitions. Special attention is given here to the importance of combining a network and a complexity approach, implemented through the use of graph theoretic analyses. Some of the implications of this approach are also explored for hunter-gatherer, sedentary, urban and other systems discussed in other chapters.

2. Multi-Task Bundling, Uncertainty, Exchange and Scaffolding

Before examining the structures and informational-cum-resource flows of nomadic pastoralist societies, as noted above, it is useful to consider six premises chosen to help explain similarities and differences among such societies. To begin with **P1**, variability in the pastoralist mode of life is partly organized around a number of common structural constraints that result from the bundling of activities according to minimization of effort (Goodenough 1963, Ch, 10; Roehmer and Syme 2002:22-24). For example, male activities in pastoralism bundle together such that fraternal groups are formed out of the combination of male herding and co-resident males engaged in defense of herds and tasks attendant to their care. Structured variants of these groups include fraternally extended families and patrilineages, come to predominate at different levels of social organization. [2]

P1 bundling of activities by minimization of effort

The structured variants of these bundled units, in competing and cooperating with one another to form an economy, must respond to uncertainty that threatens survival in their environment (**P2**). *Uncertainty*, in Knight's (1921;

H. White 2002a) usage,[3] differs from risk, which involves known probabilities that can be compensated by mixed economic strategies, whereas uncertainty involves unknown probabilities, a source of instability that cannot be controlled at the level of the individual unit, say by portfolio risk management through diversification. Those uncertainties that can be devastating to survival of the groups whose bundled activities make them the basic units of production necessitate the organization of economic, social and political networks that create offsets that cannot be achieved autonomously and require mechanisms of interdependence.

P2 response to uncertainty that threatens survival involves certain long-term commitments to exchange relationships

Most nomadic pastoralists and most segmentary societies, for example, are bundled into units that are multi-purpose, but adjusted to meet different scales of uncertainty: thus the extended family or minimal lineage deals with local problems, the lineage deals with problems in a larger area, the maximal lineage deals with larger problems, and clans or tribes with regional issues.

P7 cognition does not consist of internal representations and operations: it is necessarily and predominantly *scaffolded* by patterned elements in the behavioral environment

How the relationships between these different units are constituted in terms of the exchanges by which producers provision themselves from suppliers or act as suppliers to consumers, middlemen, or other producers, are of crucial importance. Individual producers or production units must find commitments to multi-purpose bundles of long-term relationships that are effective as a coordinated response through exchange to the problem of collective survival. The principle at work here (**P2**) is that the survival uncertainties of a group with "common fate" in a lifeway are the strongest influence on their particular organizational foci and impetus to that portion of their social and network organization that is dedicated to long-term commitments. Not all exchange relationships are bundled in this way, and many are of a more casual nature, but pastoral nomads are affected in a particular way by survival uncertainties. Hypothesis 1a states a general proposition adapted from H. White (2002a) and 1b argues for its applicability to nomadic pastoralists.[4]

Hypothesis 1a (Survival Uncertainty). Orientation to uncertainty on the upstream or supply side implies that a producer will invest in the strategic construction of long-term relationships with certain specific suppliers. The favored supplier relationship is an implicit social contract to continue delivery in time of need. The problem of guaranteeing the long-term endowment of productive labor or capital will be met through quality of reputation and long term exchange commitments.

Hypothesis 1b (Nomadic Orientation to Uncertainty). Nomadic pastoralists almost universally, in their traditional ecological contexts, face their principal survival-threatening uncertainties on the upstream supply side and, by hypothesis 1a, engage in strong-tie network-building in terms of relationships oriented towards supply rather than distribution of animals, and concomitantly, for reasons adduced below, towards supply rather than distribution of brides. How they dispose of animals, whether as consumption goods or via exchange, is the easy problem. Insuring that a family can replenish its herds in emergency situations is the hard problem of survival.

These first two principles, **P1** and **P2**, are incomplete without a third that would explain how it is that local productive units such as co-residential frater-

nal groups can use marriage ties, in which their members exit their local group, as a means of alliance to build exchange networks. This is not self-evident. The term marriage alliance is used in anthropology in a way that implies that the groups involved are corporations that are not merely localized groups whose members may enter through birth and exit by migration, but groups that grant lifelong rights to the wealth of the local group engaged in wealth production. A third principle, namely of agent-based mediation, is needed to define and explain the link between marriage alliance as a phenomenon commensurate with the existence of corporate group: When members migrate out of the spatial location of a productive group, they can be induced to act as an agent on behalf of that group if they are given rights that belong to them by birth,[5] or allocated by other principles, such as purchase of rights in ownership (**P3**). Groups based on birth or common descent are the human prototype of corporation, the goal of which is the preservation of wealth. This principle is articulated by Bell (2002:16-17) in his definition of a wealth-asset, which must (a) possess a capacity to grow in value, number or size, (b) generate a flow of consumption benefits for those holding the rights to the wealth-asset, (c) be scarce in the sense that marginal increases in its growth must have a positive valuation (i.e., not constitute a surplus for which there is motivation for disposal), and (d) "be exploitable over an indefinite time horizon by a multi-generation group, linked by inheritance rules, that holds rights to its accumulation over that horizon," or, he notes, by functional equivalents such as corporate shareholding.

P3 wealthholding groups are necessarily coexistant with exchange relationships (such as marriage alliance), the tradeoff being that agents work on behalf of the group in return for rights in the wealth held by the group

Nonmarket wealth is the basis for corporate lineage formation: fraternally extended families, for example, will preserve an organizational memory and corporate structure over generations as a patrilineage. As it applies to an ethnographic context, wealth-assets typically circulate in different spheres of exchange than nonwealth items (e.g., consumables).[6] The concepts of wealth and agency [7] provide the link between marriage alliances, lineages, wealth, rights of inheritance, and the transfer or exchange of wealth between corporations through such means as bride payments, where wealth is transferred from one corporation to another (groom's to bride's) in exchange for rights such as retention of the offspring of the marriage as permanent members of the husband's group. [8] These are all mechanisms commensurate with patterns of structured variability that recurrently co-evolve—governed by principles 1 and 2—in relation to common problems of the lifeway. It also follows from these three principles that, given the mobility of pastoralists, the corporate lineage will be nonlocalized (called in anthropological parlance a sib and more specifically in this case a patrisib) although its primary production segments are localized.

P4 The organizational profile for interactive response to scaling-up for survival crises involves the cascade phenomena of complex systems that are network driven.

Two more principles follow from the first three. The fourth (**P4**) begins with a specific corollary of the second, the coordinate multi-purpose bundling of long-term exchange relationships to face environmental and survival uncertainties. The corollary, for the nomadic pastoral lifeway, is that this is achieved by the ability to divide and regroup in flexible ways such that the hierarchy of groupings is also a means of local or increasingly collective response to problems that occur (and can escalate) at different spatial levels. This organizational profile is analogous to the market profile of firms in H. White's (2002) theory

of the network dynamics of the modern economy,[9] but in the present context takes different hierarchical forms. The most elaborated of these, in our context, is the organizational principle of segmentary lineages that extend as well to clans, tribes and larger regional units. The segmentary principle is a network cascade of hierarchical branches, and it corresponds dynamically to a potential for small events such as disputes to escalate to higher and higher levels of opposing segments.

More generally, the interactive dynamics of the pastoralist mode of life are 'complex systems dynamics' with self-organizing properties. For example, they produce structures of integration, namely, network cascades of hierarchically nested units. A cascade is a succession of stages, operations, processes, or units that build off one another. Segmentary systems such as found among nomadic pastoralists involve all of these at once. Units segment at the different generational levels of fraternal or marriage ties that bond patrilineages and sublineages that are more closely bonded. These units compete and cooperate in spatial and temporal scales that are fractal in being self-similar variations of units and their activities, scaled up or down; they exhibit a *power-law* potential for runaway feedback in terms of the mathematical function that governs the cascade of processes in conflict escalation. There is a duality in scaling as between the power law provision of an *operational* ability to scale-up quickly when responses to large-scale problems are needed, even if rarely, and the *organizational* concomitant of a fractal construction of hierarchically nested network segments. The power law scaling relationship is one in which, for example, conflicts that escalate from small to large at some power multiple (like doubling in numbers) escalate as well in the intensity of violence, spatial scales of mobilization, or length of the conflict by some other power multiples (see Johnson 1982 on North African nomad conflict rates and decision-making). The cascade effect is emergent from co-evolution between a network form capable of segmentation along an array of hierarchically nested levels and behavioral capabilities of the segments in opposition to one another or united against the outside groups.

More explanation needed?

The segmentary principle is not the only form characteristic of the social organization of pastoral nomads, but it is one that emerges in historical circumstances in which its operational capacity for expansion are especially advantageous. White and Johansen (2003) argue for its historical emergence in the context of small lineage based units of production and exchange operating within long-distance maritime and camel trade networks in which significant relations of trust and intergenerational preservation of wealth, and the skill and knowledge to produce wealth and add value through exchange, takes plac within the lineage. Korotayev (2000) shows that the segmentary system spe cific to Arabia diffused throughout the Arabized world through the conquest of the Caliphates in the 7th and 8th centuries.

P5 The capacity of any system, R, to represent the diversity of another system, S, cannot exceed the *flexibility* of R as a coding system. This is the principle of *requisite diversity in representation* rephrased by Wilden (1987: 192).

Behavioral networks are always more complex than the cognitive and lin guistic map of social relations. Understanding precisely the network effects o complex interactions, e.g., for modeling organizational structure and dynamics

requires graph theoretic analysis. The premise here is Ashby's law of requisite variety of coding systems (**P5**).

When we use graphs as flexible representations to see how actual empirical networks map onto different cognitive or symbolic "R" representations of "S" behaviors, the corollary of Ashby's law is often exemplified: many representations are vastly oversimplified compared to the complexity they are taken to represent. If R, the representational system, is that of graphs and graph theoretic models, it is eminently flexible. A later section will show how to observe temporal and spatial properties such as fractality and emergent groupings by measuring the properties of segmentary structures and the cohesive links between segments that form additional emergent units, mapped onto a network representation and spatial topology.[10]

P6 understanding the network effects of complex interactions requires graph theoretic analysis.

A seventh premise (**P7**) is that cognition does not consist of internal representations and operations: it is necessarily and predominantly *scaffolded* by patterned elements in the behavioral environment (Hutchins 1995, Clark 1997, North 1997). In cognition, as in action (P1), new ideas and behaviors emerge from "soft assembly," out of local, unorchestrated interaction of heterogeneous elements.[11]

Combining premises 1-7— focusing on links between production mode, cognitive and social responses to survival uncertainties that affect the construction of networks, and the scaffolding by which cognition builds on external networks, institutions and embodied knowledge— can be especially useful in finding the "causal" social-constructionist links between economy and social organization. These links are key to how information-processing and resource flows contribute to the emergence, maintenance and resilience, or decline, of socio-natural systems.[12] A basic theory for these processes would show how cognition and organizational structures are scaffolded in terms of (1) sets of actors who overlap not only in what they produce but in their upstream supply and downstream demand networks (2) sharing similar uncertainties as to risks of survival (3) and consequently focusing their cognitive and network-building investments on forms of bundling and activities that will minimize risks of loss under uncertain threats to survival.

Sedentism's reliance on spatially fixed settlements leads to bundlings of different activities such that many of the contents of social relations map onto multi-purpose and loosely correlated sets that are cross-cutting. In nomadic societies, as people interact with differing spatial constraints over a range of spatial locations in migratory domains, activities shift or move along with the sets of individuals who perform them. Since people can move together, they can maintain their multi-purpose links with others in tight, embedded clusters. They have an extra dimension for conflict resolution through spatial flexibility, but conflict must be handled in and through embedded clusters. This leads to the following prediction.

P1 new networks build out of differentiations and debundlings of old networks.

Hypothesis 2 (Settled/Nomadic). Settled societies tend to have more differentiated and cross-cutting networks of different types as a mode of integration. Nomadic societies tend to have more hierarchical bundling of embedded aspects of multi-purpose networks.[13] From the individual viewpoint, and in the

organization of communities, their hierarchical embeddings tend to have the form of a core-periphery structure. Close kinship relationships (however defined locally) will tend to replicate this core-periphery structure.[14] This will not be true for sedentary societies, where cohesive groups in kinship networks will tend to cross-cut other kinds of groups and organizations.

For nomadic pastoralists the cognitive scripts, roles, and expectations for the "network-building" supplier side orientation in the exchange network (P2) will constitute the more structured core of the core-periphery social organization suggested by Hypothesis 2. Cognitions and scripts of relations on the consumer side will be more diverse, less formalized, and less constrained to specific persons or institutions, with it being "taken for granted" for example, that one will have consumers, with no elaborate search and lock-in of commitment necessary. Further, given the multipurpose quality of core relationships and the orientation to reducing uncertainty (e.g., through building strong reciprocal relationships), the emphasis in core relationships (correlated with the stronger kinship ties) will be on relationships of trust, albeit ones that have some flexibility for being refashioned from time to time.

3. Parameters of Scale: Pastoral Nomadism & Kinship Networks

The rhythms of production modes may include variants on hunters chasing animals, gatherers chasing seasonally distributed harvests, cattle nomads chasing pastures coterminous with water, camel nomads defending water rights and chasing value in exchange while raiding for more camels, and so on. Numbers of persons at the level of the single productive unit and numbers of the animals they are dependent upon scale up or down depending on the mode, the animal, the environment and other factors. Concomitance in scales includes the following hypothesis, demonstrated by White (1969) for AmerIndian societies:

P4 scaling up or down is often fractal

Hypothesis 3 (Commensurate Scaling). The scales of interpersonal cooperation of production modes in subsistence economies covary strongly with the spatial scales of network cohesion.

Hypothesis 3 is the theme or hypothesis of this section. To see why *fractals* are involved (see glossary) some relatively simple models may suffice, for example, comparing a hypothetical society consisting of production units of goat herders, with one consisting of production units of cattle nomads. The goat herding production unit might be based on an extended family occupying a mobile tent, ca. 10 people, and 3 times their biomass in animals (let's say, 250 goats). A production unit of cattle nomads might have 40 people in a production unit and say, again, 3 times their biomass in animals (say: 30 cattle). Say that first unit occupies say 120 square units T of territory (120T) for 40 units B of biomass (120T:40B), and the second has 120B units of biomass: What is the required scaling-up of territory? The scaling cannot be a constant ratio (say 3x120B=360T) because biomass is a volume measure but territory is an area measure. Studies of interspecific scaling of median dispersal distance D and mean adult body mass M are allometrically related by the 0.75 power, so instead there may be a scaling power instead of a ratio. There's our first power

law: for example, if territory $X=kD^2=k(M^{3/4})^2=kM^{1.5}$ and mass triples, territory goes up by five.[15] The territory occupied by our cattle nomad production unit will be 5x120B=600T by the power law relationship, not 360T. Figure 1 shows the power-law scaling between increase in biomass and increase in the average roaming distance of domesticated animals per day and pasturage territory.

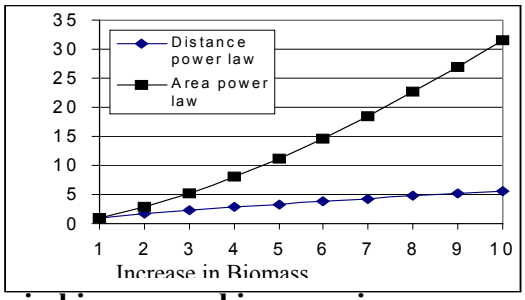

Figure 1. Increase in biomass and increase in average pasturage territory and roaming distance per day

A model for up-scaling the networks of our goat and cattle nomads can be set up, recalling that pastoralist production units, as per hypothesis 1, require interdependence by exchange with others for survival. Say that the goat herding production unit needs a society with 50 similar units, and assume for simplicity that the cattle nomads need the same number of other units. The territories of the two societies will be of sizes 6,000T and 30,000T respectively. Further, the 10^1 people in each goat herding production unit have to link up to the 49 other such units (typically families) in a population of 500 and on a smaller territorial scale than that of the $10^{1.6}$=40 people in the cattle nomad production unit, who have to link up with nearly 2000 people in their 49 other units, who are in a territory not 3 but 5 times larger given our simple power law between biomass and territory. To model the social networks that link these groups requires that we consider the nature of the linkages, and the demographics of how the links are built given a nomadic pastoralist social structure that consists of groups of agnatically related males as the primary and residential unit of production, and intermarriages between these units as a means of setting up the linkages between fraternal groups that can be used for purposes of exchange.

One might think that the pastoralists with larger production units, because they have more women in their groups, will have an easier chance to link up with other units, if the total number of units is the same. The demography of the goat herding production units, say with an average of three adult males and three adult females in each, with three females coming in as wives and three sisters going out as wives of men elsewhere places this society on the borderline of not having enough links to create the cohesion needed for an exchange economy. It cannot be taken for granted *a priori* that the six adults born into the group are bonded lifelong. Unless there is a strong sense of lineage, when the three sisters "move out" and join husbands, they may be lost to the group, with no "gain" from the marriage link elsewhere. And without a strong sense of lineage, its men have only three links through their wives, to other groups, i.e., three sets of brothers-in-laws (WB) in other groups.

We know from graph theory that if you want to link N (e.g., 50) groups you need at least N-1 ties (e.g., 50 as well), or an average degree of 2. What are needed for cohesion are lots of redundant cycles, for which you need, at minimum, an average degree of 3. Small unit pastoralists are on the verge of their society "falling apart," the edge of chaos. But without a strong lineage principle it is even worse, because even if you have a claim on your brother's wife, mediated by your wife who has become a member of your group, your wife's brother may not much care about his sister after she has married and moved in with you. The issue here is that the brother-in-law relationship, if it is not a *reciprocal* relationship, isn't much to count on.

P4 pastoral nomads with small production units are at an "edge of chaos" governed by segmentary fractals

The remedy for this potential verge-of-chaos situation is for members of production units to reinforce a corporate principle involving lifelong membership in the lineage. This will double the average outdegree of the productive unit, consisting of living members of the corporation, but will also gain the unit additional relationships reckoned through the nonliving lineage ancestors, especially the more recent ones. The oldest living heads of two separate families, for example, might be "linked" if their deceased fathers were brothers (they are FaBrSo to one another). This is exactly what many pastoralists do: they construct a segmentary lineage system in which (1) lineage ties are stronger the closer the common agnatic ancestor and (2) ties between segments, including larger ones beyond the lineage, reinforced by marriage, intensify rather than diminish with segmentary distance. The segmentary principles are fractal and power law governed, in ways to be discussed in a case study example.

What about the larger production units of cattle nomads, intermarried over huge territories, but with, say 12 incoming and outgoing women to form links. They also need to reinforce the lineage principle at least enough to make the brother-in-law relationship reciprocally meaningful. That gives them a surfeit of potential for linkage. But they need to spread a significant number of these linkages over larger distances and much vaster territories, and lest the sister and brother-in-law relationships be forgotten because of distance, less frequent visiting and the vastly diminished likelihood of all coming together at one time, they also need to reinforce their links, over and over again, with other units. They often use their surfeit of linkages, in spite of the vaster distances, to link and reinforce the ties of a given local unit with every other lineage (a larger unit) in the society, and to do this, they usually use the principle of *lineage exogamy*. One might think that with all those extra potentials for linkage, they would have no qualms about marriage within their own lineage, but no: that is precisely what they forbid.

Selection of a Sample of Pastoralists for Testing Generalizations

To measure the extent to which nomadic pastoralists develop nonlocalized lineages (sibs), bridewealth, and other features, and differ amongst themselves on lineage endogamy versus exogamy and other features, we turn to Murdock's Ethnographic Atlas data on 1170 societies (White 1986, ed., expanded

from the 862 societies in Murdock 1967). Data on the 72 societies that are nomadic and depend more than 45% on pastoralism are used to test statistical generalizations. Table 1 cross-tabulates the two variables used in sample selection. The sample for pastoral nomads does not include the eight societies in the second row in Table 1 (nor the 1190 societies with 45% or less dependence on animal husbandry that are excluded). Note that all those 55% or more dependent on animal husbandry are nomadic (p<.0001).

		V4 Animal Husbandry					
		5 46-55% Dependence	6 56-65% Dependence	7 66-75% Dependence	8 76-85% Dependence	9 86-100% Dependence	Total
	1 Nomads	24	10	11	15	12	72
	2 Sedentary	8					8
Total		32	10	11	15	12	80

Table 1: Selection Criteria (Excluding Sedentary) for Constructing a Sample of Nomadic Pastoralists[16]

Patrisibs: A Basic Organizational Unit of Nomadic Pastoralists

Cooperative requirements of nomadic pastoral peoples differ in scale but are organizationally similar in the cases of large versus small animals, such as cattle versus goats and sheep. Large animals make paramount the defense of herds, and typically implicate larger corporate organizations of related males, such as patrisibs (defined as extended patrilineages that span multiple communities), in production and defense. Although nuclear or extended family units operating in concert through cooperative networks might be sufficient to manage herds of small animals, patrisibs organized across communities are also predominant in kinship organization. (FN: For large-animal pastoral nomads, French researchers Chaventré (1983), Cazes (1993) and Barry (1996) carried out population studies with computerized genealogical datasets, and Barry (1998) has done extensive kinship analysis on genealogical networks and empirical marriage patterns.)

Table 2, for the nomad sample, shows 80% have unilineal descent groups in the form of patrisibs (categories 4,5), 10% have other forms of patrilineal groups (categories 3,6), and only 10% lack patrilineal groups. Differences in percentages of forms of patrilineal organization compared by type of pastoralism are non-significant (p=. 42).

		V40 Predominant Type of Animal Husbandry				
		3 sheep and/ or goats without larger domestic animals	6 camels, alpacas, or llamas	7 bovine animals	8 equine animals	Total
V17 Largest Patrilineal Kin Group	1 None		4	4		8
	3 Lineages in single community			4		4
	4 Sibs, i.e., lineages in multiple communities	2	13	32		47
	5 Phratries, i.e., three or more maxmimally extended sibs	1	5	7	1	14
	6 Moieties			3		3
Total		3	22	50	1	76

Table 2: Predominance of Patrilineal Sibs in the Sample of Nomad Pastoralists (no statistically significant differences for V17 by V40)

Reciprocal Markets in Brides and Bride payment

In production systems involving either large or small animals, there are also commonalities in terms of how networks of the social units of production and exchange are organized. The primary problem of production is how to obtain and maintain productive capital in the form of herds. The orientation of producers in terms of dealing with this primary source of uncertainty is towards the suppliers of herding capital, and these suppliers are primarily the other productive units of herders. As many ethnographers have noted, the production constraints and orientations of pastoralism operate to establish a moral economy in which the reputation of families or sibs is the basis for establishing the trust and social bonds with other producer units who can resupply breeding animals at key points in the productive cycle. One such point is when a man marries: his nuclear family requires endowment with breeding capital in animals. The upstream orientation of pastoral producers towards suppliers (rather than downstream consumers, who are already assured) is consistent with White's formulation of how network orientations co-evolve with different market structures.

Hypothesis 4 (Commensurate Networks-REP). Upstream uncertainty (**P2**) as to how to obtain and maintain productive capital in the form of herds, in White's formulation, expressed in Hypotheses 1a/b, predicts that the problem of endowment will be met through reputation and exchange commitments as the "strong ties" in network-building. I refer to this as the reputational exchange prediction (REP). The liability here is to be pushed down below the survival level in the ability to obtain sufficient animals to continue to develop herds that are viable for the support of the production unit. The production unit looks for an "optimum commitment" of its procurement efforts "from among a menu curve it reads from peers' signals" (White 2002b): that is, it is simultaneously engaged in competing with like units.

The REP rules out, for example, that the groom's family will supply the new couple with animals, because this does not decrease uncertainty that the animals will be available for a groom within his fraternal production group.

That is, transfers from the groom's father to the groom are within the same household production group because residence is patrilocal for 97.5% of all pastoralists. An intra-unit transfer does not address the crucial problem of what a family does to supply its sons with breed animals if or when the family is capital-poor. The ovals enclosing father-son (the triangles) dyads in Figure 2 shows the problem: because the production units are patrilocally extended families where sons remain with the father after their marriages, the endowment of sons with animals by fathers at the time of marriage (a double arrow connecting bride and groom) would not change the overall endowment of the unit at all, so that whether the family herds will be viable at the time of a son's marriage is uncertain, and the risk of failure is augmented by the son's family producing, after marriage, still more children.

The REP prediction shown by the longer arrows in Figure 2 is that a solution to this problem will be sought through exchanges between production units. Optimal timings of such exchanges are predicted to correlate in some way with marriage and the birth of successive children resulting from new marriages. The longer arrows in the figure represent bride payments of animals that move in an exchange structure in a direction opposite to the movement of brides between household production units.

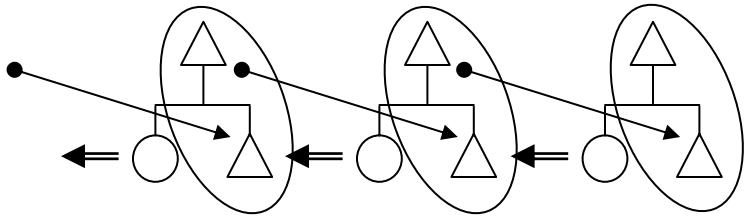

Figure 2: Reduction of Uncertainty by Bride payments of Animals moving against Brides

This is the exchange system connected with marriage that is found among most pastoralist societies, and others as well. The REP prediction (Hypothesis 4) is borne out by the data of the Ethnographic Atlas: payments of bride payment, which under the conditions of pastoralism are often in animals, and that start at the time of marriage, are found in over 90% of pastoral societies. Bride payment exchange systems are very common in the Old World, which had widespread development of large animal domestication, and are very rare in New World societies, which, besides the dog, domesticated the llama, but had no production complexes based on animal husbandry. The husbandry of pigs in Papua New Guinea, however, is often associated with bride payment exchanges, and similar logic might be explored in that context. Bride payment is also common in agricultural societies but is not the near-exclusive form of marriage payments as is the case with pastoralists, and the usual pattern is that those agricultural societies with bride payments are Old World societies that also keep animals. Hence the most likely association of this type of exchange system is with wealth in domesticated animals. Bride payment exchange among societies coded in the Ethnographic Atlas is strongly negatively associated with dependence on hunting and gathering, for example.

The flow of animals associated with marriage among pastoralist nomads (and preindustrial societies with wealth in domesticated animals that enters into marriage payments), as predicted from the hypothesis 1b, is oriented invariably from the groom's family to bride's. That might seem counter-intuitive if we consider a third option, that of dowry, where the bride brings her own wealth, endowed from her family, to the marriage, as in Figure 3. This would seem to solve the problem in a more direction fashion. Now, dowries do occur in some pastoral societies, but always in the presence of bride payments. Why? Consider the reputational part of hypothesis 4: Dependency of the new husband on the bride's family for restocking the supply of herds that will provision his new family unit would lower and not raise the reputation of his patrilocal extended family and create a strong kin-tie inequality because the givers of wives are also the givers of dowry. This is a common pattern for settled, stratified, monogamous agricultural or industrial societies where kinship, by Hypothesis 2, is only one of many cross-cutting ties and kinship inequality can be denied (as in Hinduism) or nullified by a higher industrial occupational status of the husband.

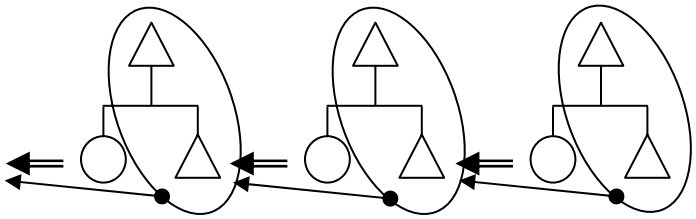

Figure 3: Hypothetical System of Dowry as a System for Transfers of Animals at Marriage

Only by giving bride payment at the time of marriage, as in Figure 2, and not dowry. is the reputation of the extended family unit enhanced by getting bride payment for their daughters and the problem of provisioning the brothers solved through exchange. Further, these exchanges create the basis for future cooperation between units, that is, marital alliances.

Social Networks as Flow Structures in Socio-Natural Systems

Kinship provides the channels for the flow of resources in every human society. Kinship networks link not only people, but are crucial in how people are linked with aspects of the natural world with which they interact. They provide the channels for information, energy and material flows in ways that are crucial for adaptation and resilience of socio-natural systems. Forms of social organization, in how kinship and other social networks are organized, are crucial for understanding the resilience of the socio-natural system. For nomadic pastoralism this is already evident from the recurrent forms of social organization with which it is associated, and their inter-correlated or patterned variability.

Kinship, however, is only one example of the more general importance of social networks and the many kinds of relationships by which they are constituted. Hypotheses 1a,b and 4 as to the effects of survival uncertainties, how-

ever, makes clear that where survival and resilience is at stake, we will find "strong tie" networks of commitments locked in place. Such networks will typically constitute **markets** because the relationships of commitment are directly concerned with supplied/supplier relationships that are of benefit to producers under conditions of uncertainty and potential scarcity. Hence the "strong tie" networks will not be exclusive ties (monopolistic) but with multiple partners, and these partners cannot form exclusive cliques: strong ties may cluster but they must also (1) allow chains of connections between more distant parts of the network, and (2), be distributed in such as way that the average distance in such chains is short, hence constituting a **small world**: one in which ties are both clustered and distances are short. To be useful to exchange, the small world of a network that constitutes a market must also be searchable and **navigable**, which is a function of its topology (White 2002, White and Houseman 2002).

Searchable small worlds with the appropriate topologies to serve as markets seem to come in two forms. One is the **centralized** networks with **hubs** that have many links leading towards different connected sectors of the network, and sometimes to specialized nodes called **authorities** that have knowledge of and access to very specialized resources that are not otherwise easily located. Typically as the number of nodes doubles (power of 2) comparing one set of hubs to another, their frequency decreases by a constant multiple (some other power): thus the frequency distribution of number of edges possessed by nodes (degree distribution) in such a network will have something approximating a **power-law**. Often, in the evolution of such a network, it is the rich-in-ties that get disproportionately richer.

The contrastive small world topology is the **decentralized** community network, so characterized because of its more egalitarian construction: ties tend to be more randomized rather than focusing on central nodes, and each node tends to have multiple short paths to reach any other. The degree to which this is true constitutes a measure of the **cohesion** of a network (White and Harary 2001). When networks are more random, as in the decentralized or community type, the degree distribution is also more egalitarian and does not take a power-law form (log-log linear) but will fit more closely to an exponential (semilog linear) form. Still, a decentralized network, even if created by purely random ties, will have a core-periphery structure with graduated levels of cohesion.[17]

In pastoral nomad societies, the strong-tie networks that can be identified in the kinship network (e.g., those of closer kin ties and of reciprocal marriages between small effective sublineages) tend to be of the latter, more cohesive type. What is examined in the remainder of this chapter is how, both in a concrete case study and abstractly, such networks simultaneously create and link communities, how they define meanings, customs and traditions, and how they facilitate the spread of information and innovation, to paraphrase one of the thematic charters for this volume. To understand the close relationships between social networks and socio-natural linkages is at the heart of understanding what could constitute alternative paths towards sustainable development.

I will not discuss here the types of centralized networks, except to say that many network topologies combine the hub-and-spoke principle with the more cohesive forms of networks. Examples are found in the production markets that evolved in the twentieth century, in which H. White (2000a) notes that the development characteristic of modern production markets is the streamlined hierarchy of producers, each with upstream suppliers and downstream buyers who are differentiated. This kind of market is one with three hierarchically organized roles: suppliers, firms and buyers, with differentiation between sellers and buyers with respect to the firm. The overall topology of this market system is hierarchically centralized but with cohesion within specific markets and in the interfaces between them. Formal organizations and markets as well as state organizations rely heavily on the partitioning of cohesive subgroups and the design of interfaces between them.

The ability of a group to reproduce is one aspect of socio-natural sustainability, but this ability is embedded in complex feedback systems and chains of activity that maintain both the socio-material world and its ecosystem. One of questions addressed here is: What gives a culture associated with pastoral nomadism its sustainability through a concomitant social organization that provides the coordination to accomplish its tasks? It is not that culture is homogeneous but that it in many ways allows variant mixes of homogeneity and heterogeneity, within and between bounded systems, to be coordinated, remixed and transformed in sustainable ways. For small-unit pastoralism, for example, specific types of locally restricted marriage, such as the FaBrDa preference or sister exchange, are highly prized, but they only contribute benefits to the local-unit level, and not to the overall global configuration of the exchange network, which must necessarily be one that is generalized rather than restricted. A prescriptive FaBrDa marriage rule, or even FaFaBrDaDa marriage rule, always leads back to lineage endogamy and cannot connect different lineages, hence such rules cannot stand alone and generate broader social integration, unlike MBD or bilateral cross-cousin marriage, which can of themselves form ideal patterns for generalized kinship systems. Where FaBrDa marriage preferences occur, they can only be one of many heterogeneous types of marriage in play in the creation of distributed network integration, and repeated application of FaBrDa marriage even generates a diversity of other types of blood marriage within the lineage. The marital organization of pastoral society on the small-unit scale is complex in the sense of having heterogeneous statistical distributions of marriage types and partners. The cognitive and preferential gradient for marriages ought to be quite simple: the emphasis on establishing trust ought to place a premium on relatively closer relationships, the enactment of trust out to entail reciprocation, reciprocal ‘strong ties’ between marital allies out to entail more frequent visiting, and sharing of nodes for visiting relations ought to entail the extension or transitivity of marriage ties sufficient for cohesive interconnections between local groups and the formation of a navigable small world that has the potential for broad-based exchange relationships through trusted intermediaries. Fractality, then, will not only be found within

Fractal scaling
State laws

the hierarchy of sublineage units found within an agnatic genealogical charter, but in the nested structure of cohesive groups created by relinking marriages.

The coding rules, such as kinship terminologies, for segmentary lineage systems with FaBrDa marriage might be of interest in light of Ashby's Law of Requisite Variety (**P5**). As might be expected, our pastoral nomad systems of this sort have highly descriptive terminology, capable of indicating precise genealogical relationships and kinship distances. The relationship between the coding system of marriage rules and behavioral realizations of marriage types can be examined in terms of Ashby's Law. Instead of a semantic network and coding system, here we have a social network S and rule system R. A strict practice of MBD marriage, for example, leads to a network characterized in its entirety by repetition of this rule alone, whereas a strict practice of FaBrDa marriage cannot do so.

Marriage exchange as a productive and economic intensification of alliance is crucial to the integration of pastoral societies. The pastoral form of marriage exchange – where the bride's group gives up rights over children, who will be absorbed into and remain with the husband's group even in the case of divorce – is one that necessarily calls for a positive value to alliance relations between groups. Even when the wife is absorbed into the husband's group by disallowing divorce, or divorce is discouraged by the requirement that bride payment be refunded, the door to future exchanges between the groups must not be closed, but neither can it be allowed to settle into restricted exchange, especially in the case of large-unit pastoralism, where exogamy of large patrisibs allows recurrent intermarriage between them. The distinction between small-unit and large-unit pastoralism is recurrent at the level of kinship terminology, which serves as a cultural model guiding marriage choices. Small-unit camel pastoralists, for example, commonly have descriptive terms that open the door to pinpointing of specific families of potential affines. That the difference in distribution of descriptive versus classificatory terms is statistically significant (p=. 002) [18] speaks to the issue of cultural differences between small-unit and large-unit pastoralists in the social constructions of the meaning systems that mediate their smaller- versus larger-scale but nonetheless highly integrative constructions of social networks.

4. Analyzing Kinship Structure and Dynamics by Dynamic Graph Structure Modeling

I now come to the central argument about the role of social organization generally and of kinship networks in the social organization of pastoralists. To the extent to which cooperation is required in a productive division of labor, social cohesion is required in the networks of the society. In settled and state-organized societies much of the structure of cohesion is provided through formal organizations, cross-cut by the primordial interpersonal relations of kinship, friendship and neighboring. Nomadism utilizes the primordial interpersonal relations for constructing cohesion in social networks without the restrictions of religious or state-governed formal organization. Pastoral nomadism

requires cooperative corporate organization and close division of labor among males (patrilocal residence and patrilineal descent groups being salient), so that the cross-cutting ties that build cohesion include those of marriage, which also have long durability. More generally,

> Ethnicity and endogamy provide the prerequisites for intergenerational succession – … not just parallelism of individual experience and social category…., but the continuity of membership that allows comprehensive acculturation into a persisting and adapting culture specifically designed for a [given] life. (Barth 1987: viii)

Stated another way, for a culture to retain some degree of cohesion over generations, especially in relation to an ecologically sustainable lifeway, there must be some degree of cohesion in terms of endogamy. [19] That granted, endogamy is a problematic concept:

> what is strange about the idea of calculating rates of endogamy… is the very notion of the *endogamous group*, and therefore the basis of calculation, which is in question (Bourdieu 1977:33).

a. Dynamical principles: Components and dynamical processes of social interaction

If a kinship network is conceived as a set of marriages connected by parent-child links, and two marriages as directly connected by parent-child links if two persons in one marriage are parents of one of those in the other, then a *structurally endogamous group* is a maximal set of couples in which each pair of couples is connected by two or more independent paths parent-child links. Structural endogamy, as opposed to rate of endogamy in a predefined group, is endogamy defined by its structural boundaries. [20]

Because structural endogamy is defined independently of social categories, its correlations with categories such as ethnicity, locality, or occupation are important descriptors of social organization. The structural boundaries that it defines are generated anew in each generation. Further, it describes a dynamic process – outcomes of marital choice – that generates a changing social morphology. That morphology, both as a design construct and a concrete social network channeling flows of resources, has important feedback for subsequent trajectories of change, on system resilience, and for system decline.

Changes in the morphology of structural endogamy are created by *relinking marriages* – marriages between two persons already related (White 1997, Brudner and White 1998). Marital relinking is equivalent – in terms of formal network definitions – to the manifestation of endogamy in a population. As noted, without endogamy a population does not reproduce itself but is absorbed into other social formations.[21] Relinking creates part of a more global structural endogamy of which it is a local instantiation. If we consider the density of relinking compared to the maximum possible, or consider sibling ties as ones that add cohesion, then measures of cohesion for a structurally endogamous group may be derived from the study of relinking marriages (White and Harary 2001; Alcántara, Casasola and White 2002).

Each relinking marriage in a population bounded by structural endogamy has the potential to equip subsequent children with two parents who – by virtue of their embedding within this boundary – are historically experienced in a way of life associated with this self-reproducing population. The relatives of a relinking couple have been members of the group, and thus provide the next generation of offspring with a variety of role models for cultural socialization. Conversely, while greater kinship cohesion arises out of relinking, the boundaries of structural endogamy created by relinking do not prevent the children of relinking marriages from leaving the group by migration, outmarriage, or not marrying: Such decisions are voluntary but consequential (having decided to relink to a group through marriage, such a person on average is more closely bound to that group than one who does not relink). Marital relinking is not a "structure" predetermined by rigid norms, but is an open-ended possibility for choice of alternative kinds of relinking, or avoidance of different kinds of relinking.

Structural endogamy and cohesion do not operate as a magnet, but merely a measure of one form of integration within a group. They are neutral with respect to inter-group diversification and independent of the rates of outmigration, outmarriage, and nonmarriage. The concept of structural endogamy, however, can be logically connected to (1) the endogamous cohesion needed for reproduction of a cultural system, without requiring that such groups form a closed universe, and (2) simultaneously, to the dynamics by which a social network – and social organization – is reconfigured from generation to generation. The dynamical by-products of relinking, as a social action that takes place in a network context, are to create structure and contribute to creating the context for further dynamically structured action. Further, when coupled to measures of cohesive integration, the use of these measures provides a means of testing hypotheses about the effects of greater or lesser network cohesion, on larger of smaller spatial scales, and so forth.

The simplest relationship through kinship and marriage ties is one through a single path of elementary relationships of marriage and parentage. Two full siblings, for example, have but one elementary relationship to the same parents. If, like the Egyptian Pharaohs, they decide to marry, they have two independent relationships. Similarly for cousins and other blood relatives. Similarly, members of larger families consisting of blood relatives, when linked by a chain of marriages, will have a single path of elementary relationships, but when that path is closed by a cycle of marriages, they will have multiple independent paths of elementary relationships. In graph theoretic terms, a maximal subgraph of nodes in a graph in which every pair of nodes are connected by multiple independent paths are called a *bicomponent*. Bicomponents are traversable from any node to any other by multiple independent paths and thus have traversal cohesion. They also have structural cohesion in that no pair of nodes can be separated into disconnected graphs except by removal of at least two nodes that help to connect them. The equivalence between traversal and structural cohesion is one of the fundamental theorems of graph theory (White and Harary 2001) that lends

bicomponent cohesion its sociological predictive-ness. Predictive cohesion theory holds that multiple connectivity within a kinship-and-marriage bicomponent is essential to large-scale social cohesion, and includes the basis for social formations such as a solidary political group, clan or social class.

Marital relinking is one of the most variable elements of social organization, characterized by the different forms it may take in terms of the dynamic processes and properties of marriage systems. These may be problematized by asking how each individual marriage activates a series of linking relatives to form cohesive sets that are the basis of emergent social groups, leadership support, the organization of social activities and the framing of boundaries of groups and activities. These may affect changes in institutional forms and attendant norms. Marital relinking is involved in many of the fundamental structures and processes of the formation, adaptation and potential dissolution of a society.

5. 'How to' and Examples of the Approach, including Applications to Pastoral Nomads

The approach taken here to the role of information-processing flow structures in maintaining the resilience of a socio-natural system is based on the analysis of network data on multiple generations of human populations, combined with dynamical complex systems theory, comparative ethnographic statics and dynamics, and a graph theoretic approach to network measurement. For any given population, all kinds of data can be incorporated into this longitudinal research framework but the minimal core data for longitudinal network studies should include kinship and marriage networks. Minimum core data requirements are easy to satisfy by the computerization of genealogical data, and programs and procedures for analysis are available (Batagelj and Mrvar 1997) and documented for anthropological use (White, Batagelj and Mrvar 1997). The basic definitions of the network approach to kinship were developed by White and Jorion (1992, 1996), who also discuss the intellectual antecedents of the modeling strategies. The approach was developed further by White (1997), Brudner and White (1997), White and Schweizer (1998), and Houseman and White (1996, 1998a,b, 2002). Brudner and White (1997) used the approach to study class formation among Austrian villagers having impartible farmsteads under inheritance regulations and found that the single-heirs to impartible farmlands-farm houses complex were those who relinked to form the structurally endogamous community that constituted a social class in contradiction to cadet lines that emigrated or formed a local non-farming working class. White and Schweizer (1998) studied Javanese villagers and local elites and found that elites did not differ from commoners in their marriage preferences, but that class endogamy for the smaller circle of elites had the effect of consolidating elite sources of wealth through marital relinking and inheritance. In that case, women inherited according to Muslim law one-half of the allotment of their brothers. Alcántara, Casasola and White (2002) used the approach to study cohesion among colonial Guatemalan elites and found that not only was wealth

in family fortunes reconsolidated through marital relinking, but – given that equal inheritance by sons and daughters and that greater numbers of siblings entailed a division into proportionally smaller individual inheritances – that relinking marriages among elites (bringing in wealth from in-laws) were more likely to occur in proportion to size of sibling sets. In these studies, the boundaries of structural endogamy and degree of cohesion of subgroups within these boundaries are used to test hypotheses about social and economic consequences for wealth consolidation, class, stability of residence versus emigration, and conservational of adaptive behaviors in the context of the local eco-ecological system.

For pastoralists, I argued above for the need to study the processes by which structural endogamy not only reproduces a population but is critically involved in the regenerating the diversity of skills and knowledge-bases of the sociocultural and productive system. This is equally true in other types of societies, from those with the simplest technologies to the most advanced. Kinship and marriage systems operate as distributed and distributive networks in the key regulatory processes involved in sustainability and resilience, the transmission and mobilization of resources, the mobilization of activity and group formation, class formation, ethnic group formation, and the like. A common mistake of classical ethnography was to look to kinship and marriage 'systems' only for sources of permanency and structure, as if the cultural 'rules' were fixed entities, and not to examine the constitutive networks themselves as a basis for studying dynamics. Longitudinal research using a network data as a scaffolding to integrate other types of data provide a more dynamic approach to a variety of socio-natural systems longitudinally, including pastoralism, using a variety of theoretical formulations, such as the network approach to economic organization already discussed.

6. Aydĭnlĭ: Case Study of Small-Unit Small-Animal Pastoralists

For small-scale pastoral nomads, Ulla Johansen and I (2003) completed a network study based on converting her genealogies on 1309 individuals over 8 generations into files for computer analysis linked to data on individuals, political leaders, clans and lineages, and migration. We used these data to trace the history of the nomad group from its formation and emigration from south-central to southeastern Turkey in the 1850s, as part of a movement of nomads of the Antalya region to escape from conscription and taxation by distancing themselves from the central Ottoman government. Still, these sheep and goat pastoralists are entirely dependent on their ability to contract with villagers for access to pasturage in their complex yearly migrations. Bates' (1972,1973,1974) ethnography of a neighboring nomad group of the same regional and ethnic designations (Aydĭnlĭ Yörük) provides useful ethnographic background. Because these are small-animal pastoralists, the study of FaBrDa marriage can be examined closely and in a broader network context. We also look at kinship networks in terms of the cohesion created by marriages that not only connect families but that relink them through multiple connections. This phenomena creates cohesive blocks of maritally relinked families.

What is unique about this study of pastoral nomads, consistent with the themes of this chapter, is that we were able to test hypotheses about network dynamics in relation to ethnogenesis, migration, leadership, transformation, outmigration, and eventual questions of decline. Of special interest are some of the findings are that go beyond the general characteristics of pastoral nomads already discussed, or small-animal nomads in particular. **First**, while the group emigrated out of a prior group of pastoralists, they did not migrate and then cohere, but cohered and then migrated (**P1** law of succession). Strategic marital relinking was a key factor in their ethnogenesis (**P1-2** cohesion and exchange).[22] They emerged out of a set of marriages largely arranged by a founder who married his children cohesively so as to relink with the children of several other founders, and this was the cohesive group that migrated. **Second**, the group retained a large and dense structurally endogamous core throughout its history (**P1-2** cohesion and exchange). **Third**, all of the group's leaders emerged from this core (**P1** bundling). **Fourth**, the emergence of individual leaders in each generation up to but not including the very last followed a similar set of principles: The multiple connections generated by marital relinkings formed large-scale cohesive blocks that cross-cut the seven major lineages, and contending leaders tended to win out over others as predicted by wealth (**P3**), their cohesion-based recruitment of a broadly integrative set of supporters, and the extent to which their segment of the clan has been previously excluded from leadership (**P4-5** emergence). From the network analysis, we described the political structure as a kind of rotating 2-party system based on competition among interpenetrating cohesive groups rather than hereditary principles of succession or formal election. Note that these four findings that relate to societal constitution are consistent with our first five premises.

Another set of findings (fifth through ninth) relates cohesion and other variables to the processes of adaptation, structural adjustments and material/energy balances in socio-natural systems: **Fifth**, as the group expanded in numbers it was also under an increasing squeeze on land resources due to parallel population pressure from the surrounding agriculturalists, and emigration to towns and cities (off-loading conservation) could be predicted as a result of these demographic pressures. **Sixth**, those who emigrated and those who remained could be very reliably predicted by those whose marriage constituted a relinking and those whose marriage did not relink with the structurally endogamous core (**P1** cohesion, and an inclusion/exclusion principle). **Seventh**, the structurally endogamous core of the clan remains a viable population in terms of numbers, even though an increasing proportion (now a majority) of each generation emigrates (**P1**, demographic change). **Eighth**, the effect of such outmigration is to reduce the average size of sibling sets and collateral relatives such as parallel cousins in the same patriline, thereby altering the demographic structure of the population in the structurally endogamous core (structural effects of demography). **Ninth**, this shift in demography has a number of effects on relinking. While FaBrDa remained a preferred marriage, there were many fewer paternal uncle's daughters available as relatives to marry, and 'relatives' were, on average, becoming more any more distantly connected.

Partial compensation such as increasing numbers of FaFaBrSoDa marriage was evident, but the average relinking was now between more distant relatives (**P1** rebundling of relationships).

Tenth, we found evidence of fundamental structural changes evident at several levels in the latest leadership transition in the 1980s. Relinking among sibling groups at the same generational level was now affected by the fact that there were smaller and more numerous sibling groups, hence the density of relinking was reduced. This was associated with a "crisis of cohesion" in which the new leader was not a member of a single cohesive set of intermarried sibling groups in his generation, as in the past, but of only one of two such groups. The support networks through kinship as an integrative mechanism at the level of the clan had weakened. In addition, the new leader was of an altogether new type: no longer a person whose primary life experience was within the clan, but one whose experience and talents related to townspeople, skills, occupation and education that related to institutions outside the clan. Feuding decreased along with the diminution of the sizes of the male-based segmentary blocks of the clan, and motorized vehicles came to be substituted for camels as the means of migratory transportation.

As a closing note on change in a socio-natural system, the clan persists, but its modus operandi is vastly changed in recent decades, partly as a result of internal/external network dynamics. In the earlier period nomads proudly carried their rifles and aggressively cut a camel-based migratory swath through agricultural lands on their way to summer pastures (Johansen and White 2003). Today the guns are largely gone along with the camels, and the passage of herds as well as summer pasture rights must be carefully accommodated with villagers, often by means of payment. One of the features of the earlier period of larger male-based segmentary groups was that relinking marriages were the means for securing cohesion between segments of the same or different lineages, and as the sizes of the cohesive groups changed, so did the meanings and labels attached to them. Marriages still relink, but more diffusely, and today the resources that are linked often include access to town-based educational skills and knowledge. It is not the degree of complexity of nomad life that has changed, however: innumerable bodies of specialized knowledge and skills present in past times made up a vastly complex division of labor, and marriage served to integrate families into a complex exchange and cooperative network. Part, but not all of the operational function of relinking marriages and structural endogamy has been taken over by other institutions such as formal education and different orders of access to certain occupations via these more standardized skills (the transition to an industrial order as in Hypothesis 2). Population density and the cash nexus have broadened the sphere of each nexus of exchange; elements of older technological systems will be lost or reintegrated if still effective in competition with current alternatives, but the complex dynamic of nomad life goes on.

The Fractal Model: An Example of Spatio-Temporal (Scaling) Competition and Fractality; Fractality Defined and Tested

Principles of Exclusion and Inclusion

We have alluded several times to the "fractality" of marriage practices related to FaBrDa without giving an explicit definition of fractality. Fractality is a pattern of self-similarity, one that replicates at various scales. In the pattern of competition between units in segmentary patrilineages there is a fractal mechanism at work: competition occurs at all levels, and occurs most frequently at the lower levels, scaling upwards to larger units between which overt conflicts are less frequent but more severe. These larger units also spill over outside the lineage proper, to the level of clans or localities, tribes, and regions. The diversity of marriages associated with FaBrDa marriage, we have argued, works with and against the fractal gradient of segmentation ("I against my brother, my brother and I against my cousin, my cousin and I…"). On the competitive side, as we have seen in the previous chapter, there is selection-at-a-distance against "those-with-whom-one neglects to intermarry," the reverse side of which is that those groups that do intermarry are potentially increasing the cooperativity and exchange relations on which they depend for survival. We have seen several of the lineages in our genealogies fail to intermarry within the clan at a certain point, and outmigrate to villages. On the cooperative side, we have seen that intermarriage scales with a topological distance in which cohesive clusters are continually expanding through the transitivity of intermediated relations (an ally of an ally becoming known, then familiar, and possibly then a new ally). One of the characteristics of fractal growth and scaling patterns of this sort, which operate simultaneously across levels, is that they are often associated with distributions that have the "scale-free" pattern of the Zipfian or power-law sort, as in the example of segmentary conflict, with the events of greater severity being the higher level conflicts that are more rare the larger their scale.

Our argument about marriages associated with FaBrDa preferences is that they do not constitute a single marriage rule, or a preference for a particular type of marriage, but a gradient of preferences and aversions across a great diversity of marriage types. That is, if we compute the frequencies of every type of consanguineal marriage, and plot these frequencies in a graph, ordering them from the types with high frequencies (such as FaBrDa) to those to the lowest frequencies, we should see a gradient that has the characteristic fractal or scale-free distribution: neither flat nor linear, nor exponential decay, but a power-law distribution that is linear in a log-log graph of the two variables, frequency and the associated number at that frequency. This distribution, which is the one we actually observe in the Aydĭnlĭ marriage data, is one which expresses a scale-free organization of diversity of marriage types, consistent with questions in Chapter 3 about whether FaBrDa marriage might be associated with strategies for diversifying types of marriage practices. For example, a variety of types of marriages are practiced by the Aydĭnlĭ, but the closer marriages, on whatever scale of distance or closeness one chooses, are the more frequent, following a constant gradient of dispersal.

Hypothesis 5 (Marriage Power Law). The diversity of types of consanguineal marriage among the Aydĭnlĭ is a power-law (fractal) pattern.

Figure 4 shows the outcome of an experiment in graphing the frequencies of all types of consanguineal marriages up to seventh cousins (234 types) ordered by frequencies on the x axis and number of types of relatives for this frequency on the y axis. The distribution of raw frequencies is linear in the log-log graph and thus a power law distribution, fitting our overall observation (and Hypothesis 5) about a fractal marriage pattern.

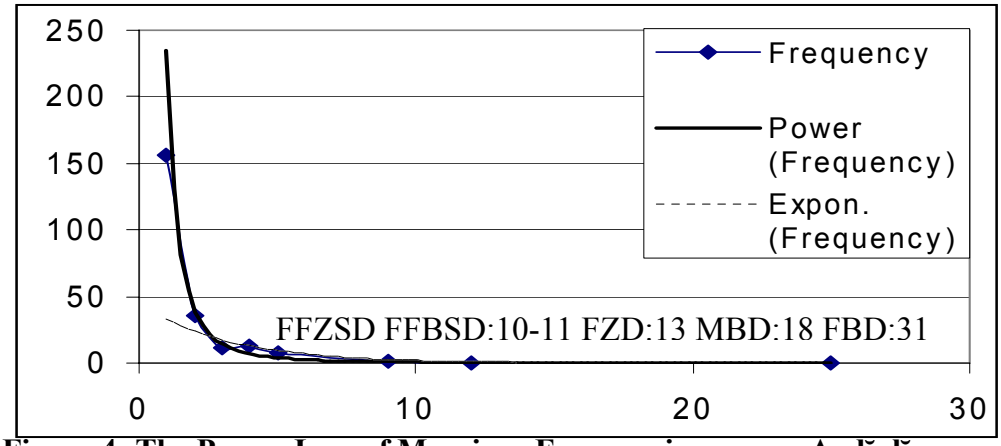

Figure 4: The Power-Law of Marriage Frequencies among Aydĭnlĭ

"Fractal marriage patterns" function rather like Granovetter's (1973) strong and weak ties, which have complementary strengths at complementary distances. The stronger and more frequent ties (but of many fewer types) work at closer distances, in this case concentrically oriented towards close and patrilineal relatives, while the weaker ties of each type are individually less frequent but as an ensemble functional in a distributed manner over longer distances. The fractal distribution of a strong/weak tie pattern of this sort, however, is continuously scaled rather than a simple dichotomy of types of ties.

When other types of distributions are graphed the curve for frequencies of types of possible spouses (all those available in a given category) shows an exponential decay distribution (here FaBrDa is the most frequently available type of relative, MBD the next) as does the curve for percentage married of each type of those available (again FaBrDa is the highest percentage, MBD the next). Only the raw frequencies fit the power law distribution that is characteristic of fractality. The implication is presumably that the underlying mechanisms that produce the power law is not a cognitive preference that maps as a declining preference over kinship distance (this would predict a power law on the percentages of each type married, which does not occur), but shaped by a combination of network and spatial interaction frequencies, such as those governing visiting patterns, operating as satisficing constraints given cognitive preferences (Simon 1957).

7. Pastoralist Politics and Complex System Dynamics

Information Flow and Decision-Making

Generic network models of connectivity and information flow may be useful for understanding the part played by pastoralism, taking a broad perspective on the evolution of human societies. Van der Leeuw's chapter in this book provides some broad guidelines in terms of a percolation model of the evolution of networks from low connectivity (μ, the average number of links of nodes) and low interactivity (measured by the ratio of an activation energy for nodes in the network to the relaxation time in which its diffusion cases) as a proxy for volume of information flow, which I will designate as τ. Connectivity and information flow in band society might correspond to $\mu << 1$ and low τ where small groups are fluid and mobile and interaction localized (vdL's state 1). An increase in τ might correspond to greater variance in information flow and individuals distinguished hierarchically on this basis for transitory periods (vdL's 2a, with temporal structuring and temporal flux in decision making). Small increases in $\mu < 1$ with larger increases in τ might correspond to larger groups with longer temporal and spatial stabilities and with hierarchies, such as chiefdoms and segmentary lineages that are generally growing sedentary (vdL's 2b). As $\mu \rightarrow 1$ fluctuations in stability and size of locally interacting clusters grows very large, and once $\mu > 1$ connectivity in almost the entire network becomes continuous (vdL's state 3). In state 2b in this model, however, pastoralism introduces spatial flexibility, exchanging flexible time of spatial occupancy for sedentary use of space. In so doing it increases the rate of network diffusion by augmenting longer-range spatial interactions between groups. The flexible capability for hierarchical organization, as in organizing not just raids but wars and conquests of settlements, emerges in roughly the same temporal framework as the rise of towns, trade, and cities. The concurrence of specific forms of pastoralism (herdable camels, sheep and goats) associated with segmentary lineages with fractal marriage structures seen to be part of a distinctive hardening and particularly conflictual relationships between pastoralists and sedentists in the Middle East. This may not be a regional particularity but a result of regular processes network dynamics in socio-natural systems, where pastoral mobility and self-organizing hierarchization played a regulatory role in regional patterns of sedentism, both in terms of conflicts and symbiosis. Constraints on nomad populations combined with high fertility are frequently seen to contribute many failed (and a few highly successful) nomad families to the underclass population of towns and cities, while investment in pastoralism and its safety-net of spreading rise might provide hedging against the crashes experienced in agricultural and urban economic cycles.

In Van der Leeuw's perspective, single-channel communication dampens conflict. In contrast, in a network of multipurpose ties, one persons' signal is more likely to be another's noise, and a source of conflict. The very marital relinking that increases social cohesion, for example, introduces multiple channels (multiconnectivities) and ambiguities. While the cross-cutting organization of a sedentary society (Hypothesis 2) diminishes the importance of these ambiguities (and kinship generally), the multi-purpose networks of pastoralist

societies that are commensurate or embedded in kinship relationships and a problematic of trust raise these ambiguities to a continuing source of conflict. In small groups, multichannel messages may be resolved by contextual gesturing. In larger groups, however, multichannel messages may be not clear and more likely to generate conflict. Settled populations may resolve these problems with spatial or temporal distances a means of segregation, producing differentiation in pockets of segregated meanings and changing language. Sedentists and pastoralists in the Middle East, for example, solve their problems of conflict in very different ways. Writing, for example, is a means of reducing the potential ambiguities in trade to a single channel. It solves one of the problems of the transition from small groups to long-distance relationships.

Decentralization, Emergent Hierarchy and Convergence

The central problematic of nomadic pastoralism, is a recurrent process of bundling commensurate activities within the soup of multiple networks and the turnover of dynamically emergent groups. While diverse forms and shifting processes are generated in this dynamic of seeming heterarchy, the emergence of groups and bundling of activities oscillate between cohesive integrative and emergent boundaries of opposition or disintegration. Continually shifting social boundaries and the reframing of activities within them play out in a dynamical balancing of integrative and disintegrative tendencies. Heterarchy is operative in the contending and shifting levels at which multiple networks assert themselves differentially over time. Pastoral nomadism is a complex social organization in which a congeries of dissipative, integrative, cohesive, and solidary forms emerge and decay, none becoming so strong as to contravene or permanently suppress the others.

It may be the case that this complex dynamic is produced by but a few simple rules. The emergence of the rules themselves may follow from adaptive tinkering with flexible recombinatory principles that both generate diversity and create multiple crosscutting groups and relations to integrate this diversity. But why are pastoral societies so homogeneous around certain central axes of variability, as shown by some of the cross-tabulations presented above, and the analysis of Spencer (1998)? Why is there not a much broader variety of emergent rule systems in pastoralist societies? Perhaps the key to answering this question about social organization is not a reduction to some kind of principle of structural permanency that entails a hierarchical system of dependencies, but to understand the dynamics of pastoralism as constituent processes carried out as projects by variable groups and members. [23] If it were simply a matter of norms at the group level that are transmitted as individuals are socialized within them, there would certainly be much more variability among pastoralists than we see in actuality.

Hierarchical societies organized from the top down, such as emerge in chiefdoms, cities and states, have a tendency to diversify and follow highly path-dependent outcomes, while the very decentralitization and distributed decision-making of pastoral societies operating under a similar set of socio-

natural system constraints may allow greater leeway for tinkering to find more globally optimal solutions to common problems. Similarities in the local perspectives of pastoralists may structure tinkering towards more convergent global outcomes.

Relevant operational aspects of the pastoral nomad production system include the fact that with herds able to move freely over a grazing territory, decisions must be made about how to coordinate the dispersal of herds, and, jointly, how to defend herds and settlements as well as how to deal with untoward natural or economic events such as droughts, disruption of transport, blockage from pasturage, etc. Decision-making cannot be totally independent, yet the independence of producers and the value placed on an egalitarian reputational moral economy precludes the emergence of a central decision-making authority. Under these circumstances, the predictable outcome is a combination of the distributed decision-making associated with mobility and, for problems of coordination, decision-making by consensus of representatives of the independent family or extended lineage units.

In a more dynamical view, however, personal identities, decision rules, and choices may shift depending on how the individual is embedded in alternative networks and how these networks are embedded in terms of salience vis-à-vis one another. The concept of heterarchy is one of several concepts in network analysis in conceiving dynamically of how shifting network embeddings, a gradual process, may lead to tipping points leading to different processes, outcomes and configurations in historical social trajectories (H. White 2000; Padgett 2001; Stark 2002; see also Schweizer and White 1998). In a heterarchic system, interactions in multiple networks can generate changes in institutional forms dynamically without centralized decision-making (Padgett 2001). Heterarchy provides one means of conceptualizing how outcomes depend critically on specific historical trajectories (path dependency). Path dependency, however, conjures up a set of highly diverse outcomes of initially or superficially similar processes. With pastoral societies, we seem to have the opposite, a variety of situationally diverse configurations of variables that lead to convergent outcomes, organized around a few central axes of variation. In the mathematical metaphor of determinate chaos, very slight differences in initial conditions can lead to very different outcomes, and an abstract processual space of pastoral nomadism would seem to have a very narrow band of stable attractors.

Equality and Inequality

There is a potential for inequalities in pastoral nomad systems of exchange if bride-givers are viewed as superior in status to bride-takers, or if givers of bride payment are superior to takers. Movement of brides as against bride payments, as in Figure 2, has the potential for balancing or neutralizing such differences. Due to intense competition between families, however, there are some pastoral societies in which there are extremes of difference in wealth and

size between different families or sibs. Many pastoral societies, however, are fiercely or strongly egalitarian.

A common outcome and ecological impact of pastoralist social structure is a relatively even distribution of herds among network interdependent but productively independent families or sibs. When wealth in herds is spread among families, the spatial dispersal of herds may, under optimal conditions (regulating herd density), have the effect of reducing the possibility of overgrazing. This kind of dispersal of animals may occur in some cases even when there is massive inequality in wealth in terms of ownership of animals, but in such cases (e.g., the nomadic Somali; Lewis 1962, 1969) marital alliance with distant affines may be used to establish grazing rights, and the animals of one group may be widely dispersed without losing ownership.

Stratification and competition

Camel nomads and sheep or goat pastoralists, in this general scenario, can operate on a smaller scale than cattle nomads in terms of production units and the geographic scale of networks that link them. The biomass of viable cattle herds places a much greater demand on pasturage, water, and defense. Consistent with this difference in scale, leadership by consensus is more common in small-animal pastoralism (p=. 01) and, as shown in Table 5, so is the flattening of social stratification (p=. 006). In this table, of the societies with simple wealth stratification, 44% are small-animal or camel nomads, and neither of the two small-animal pastoralists in the sample have a level of stratification beyond wealth distinctions. Of the societies with hereditary elite stratification, 71% are camel nomads (often traders). Of the aristocratic and complex stratification among pastoralists, 92% are cattle or equine nomads. The differences in frequency are statistically significant (p=. 006). There is then a predictable correlation between the herd biomass and geographic scale of pastoralism and the elaboration of social hierarchy. Politically, however, most pastoralist nomads are minorities within state systems, with cattle nomads marginally more likely to sustain an independent existence (p=. 05). Further variations in political structure and egalitarianism versus stratification are further surveyed by Spencer (1998).

		V40 Predominant Type of Animal Husbandry				
		3 sheep and/ or goats without larger domestic animals	6 camels, alpacas, or llamas	7 bovine animals	8 equine animals	Total
V66 Class Stratification	1 absence among freemen		1	12		13
	2 wealth distinctions	2	6	10		18
	3 elite		10	4		14
	4 dual			10	1	11
	5 complex		1	1		2
Total		2	18	37	1	58

Elites= based on control of resources; Dual= Elites based on hereditary aristocracy

Table 5: Social Stratification and Type of Animal Husbandry (solid lines grouping elements for correlation, p=. 006)

Degree of explicit hierarchical stratification, then, is one of the explicit axes of variation of pastoral nomadic societies. At the other extreme is the lack of central authority, or dependence on consensus in decision-making. Both entail the problem of how to deal with untoward social events, such as individual or group-level conflicts. Competition, conflict and factionalism are endemic to pastoral societies, yet they are also structured by tacit rules that emerge from the consensual hammering out of a common framework for viewing conflicts. The framing for viewing conflicts tends to emerge from that provided by the framing of social networks. What both extremes of the political stratification spectrum have in common is intense competition within a limited ecological carrying capacity, and a very strong inclusion/exclusion principle (related also to issues of reputation and defense) that sloughs off excess population to settlements.

Because pastoral societies are based on localized groups of fraternal relatives that must be cooperative in terms of herding, their specific vulnerability in terms of conflict lies in endemic or potential factionalism (there is a large amount of cross-cultural evidence of the strong correlation between fraternal interest groups and patrilocal residence with heightened levels of feuding and interpersonal violence). In the pastoral context – of patrisibs distributed across multiple communities and dispersed marital ties crosscutting the sibs – the system of vengeance feuding is structurally forgiving, in two senses. First, the closer the relatives the more care is taken to avoid feuding and the fewer the supporters closely related to the principals who will join the conflict, hence avoiding escalation. Conversely, the more distant the relation, with the threat of greater numbers of supporters on each side, the more initial conflicts are avoided because of the threat of all-out war. Second, the more rigid and polarized the rule of factions, where an enemy's enemy is a friend, for example, the more flexible and forgiving the allowance for switching sides, either now (defectors welcome) or in future disputes. The boundaries separating contestants, that is, are shifting and flexible rather than rigid. Feuds, then, are the primary means of conflict resolution, and are limited in time (though of variable duration) rather than permanent.

Conflict, then, tends to occur at time scales that very in lesser frequency with higher levels of segmentary oppositions. Patrilineal-patrilocal groups are inherently segmentary, which entails that they have a tree-like structure that can be segmented or disconnected into opposing units at any level. The structure of marriage ties and those of unilineal descent, however, are overdetermined and part of a single multi-purpose core-periphery type of emergent hierarchical structure. Even when wives are absorbed into the husband's group, the marital link between groups leaves not just a memory trace, but a link that is equally if not more important for defusing conflicts than patrilineal links. (Unlike some types of societies, pastoralists tend not to fight with those with whom they marry.) In computing connectedness, female links are equally important of not more so than those of agnatically related males, because it is the marriages that interconnect and lend cohesion to agnatically distinct groups

and segments.[24] This also creates the problem of the salience of sources of ambiguity and potential conflict due to multiconnectivity.

For a pastoral nomad kinship network to distribute marriage ties to meet the twin demands of generalized exchange (both maritally and, in tandem, economically through bride payment flows and other transactions) and dampening of the potential for conflict, the optimal structure of marriage, given the possibility for tinkering under given marriage constraints with different kinds and distances of marriage partners, is fractal, and reproduces a core-periphery social structure that is simultaneously one of a self-organizing potential for emergent hierarchy out of segmentary organization. The core-periphery or conical structure of this kind of segmentary system resolves the problem of ambiguity and potential conflicts more or less by a simple multiplication of core-periphery network zones, contexts and mediations that are an operational analog to the segmentation of types of network ties. Both systems are complex. Rather than segmented networks, however, we have in pastoral societies one network of multipurpose for all, but internally structured into zonal and concentric segments that are consistent as well with the strong emphasis on an inclusion/exclusion dynamic.

If fractality here is defined as distributing ties so that no two oppositions between social segments are either more or less likely to be multiply connected than any other, then the potential for segmentary conflict is, if not minimized, then at least equalized such that conflicts will not recur across endemic fault lines. This does not require that feuds will not intensify across a fault line, but that feuds have the potential for healing through the intervention of mediating or cross-cutting ties, that the next feud is likely to occur across another fault line, and, in all likelihood, that the distribution of feud intensities is fractal, and governed by a power law. This also entails that the larger issues of the outbreak of intergroup warfare is part of general phenomena of feuding. It also follows from the fractal distribution of marriage connectivity that the more distant the relation between the parties, the more the feuding will increase in severity and the larger the group mobilized, which is a common property of endemic feuding (Boehm 1987). Feuding, then, could well be studied as a self-organizing system with fractal properties, with conflict emergent from a complex systems dynamics that can generate hierarchy flexibly and on call, so to speak, rather than from a centrally controlled or fixed hierarchically system of decision-making.

Thus, the common attractors of tinkering in social organization for many pastoral nomad societies are one whose properties are constructed out of the structure of the social network itself, in this case the network of kinship and marriage relations. I have tried to detail how this works using H. White's (2002a) conceptualization of a network theory of markets, which posits a concept of the edges in market relations at which uncertainty lies (as opposed to stable probabilities of risk) in the activity of production and the consequent orientation of producers towards reducing uncertainty. This uncertainty for pastoral activities exists among suppliers of animals for herds, which are subject to rapid decimation under adverse circumstances of theft, drought or dis-

ease. The consumers or buyers are more readily available and less subject to uncertainties.

Given the overdetermination of the economic interdependence in an upstream-oriented market of pastoral producers and the fractality of matrimonial exchange and alliance, the shape of the kinship networks of pastoralists will vary from a relatively few societies of large-unit cattle breeders (highly segmentary if they have de-emphasized the integrative potentials of cross-linkages through female relatives) to the many small-unit pastoralists who must necessarily emphasize such cross-linkages. In the latter case, among the less socially stratified pastoralists of the smaller-scale, this pattern is reinforced by multiple causation of decentralized decision-making and the lack of alternative means of conflict avoidance other than distributed alliances.

8. Conclusion: Implications for other Systems and Questions Raised

Almost all of the theoretical framework presented here as a backdrop for the study of pastoral nomads, with appropriate modifications for context, applies to the other types of socio-natural systems studied in this book (hunter-gatherer, sedentary and urban), including a network approach to economic organization, and links between production systems, kinship and marriage as a network channeling the distribution and reproduction of resources and resocialization of human actants in socio-natural systems, the application of complexity dynamics to networked processes, and the utility of graph theory in providing measures of outcomes and structures emergent from network processes, which affect subsequent processes in the path-dependent modality of human institutional histories.

Whereas social networks were once considered to be at the margins of social science, a useful toolkit to study face-to-face processes and fluid situations, such as urban environments, an auxiliary to institutional analysis, the network approach has now become one of the major theoretical paradigms in the social sciences. The ability to apply this approach to human populations in relation to their ecosystems has been slower to develop, however. Still, the assembly of genealogical network data co-extensive with a large population over a long time period is not as formidable a task as it might seem. [25] For Tzintzuntzan, capital of the ancient Tarascan empire, Robert van Kemper, Eric Widmer and I (2001) succeeded in integrating archival and ethnographic census data on the entire population over a century, with relatively complete archival data going back to 1780. John Padgett and I completed the task for a population of 90,000 individuals, mostly elites, over three centuries, from data culled from the Florentine archives.[26] Other datasets on which researchers have provided large-scale network data include colonial Guatemala, 20th C elites in Mexico, colonial America, and scores of smaller populations.

Where, in summary, is the link between the socio- and the natural- in the approach taken here to the role information-processing flow structures in maintaining the resilience of a socio-natural system? Certainly, there many different ways that network approaches can contribute to understanding socio-natural

system linkages, but to me, one of the interesting hypotheses is raised by the theory of H. White (2002a), which I used at the outset to find the orienting connections between social organization and kinship networks, production systems, and sources of uncertainty that arise in socio-natural systems. Perhaps human information flows and social networks are oriented, more generally, towards resolving the problems of uncertainty that are also potential sources of system collapse, the opposite of resiliency. If so, then human social organization might exhibit fairly predictable responses to environmental linkages, ones that are optimal for reducing uncertainty and thus sustainability at least in the short run, but whether they are sustainable in the long run is another question. That "other question" ought to be related to energy transfers: energy utilization in terms of the environment, and energy investments of the human population.

A consequence of the theory of human behavior underlying H. White's (2002a) models of networks and markets is that a majority of human energy will be tied up with reducing uncertainty (and of course human energy expenditures will seek as "least effort" bundling in accomplishing multiple tasks). The social consequences of how uncertainty is managed are likely to be a salient factor in whether an energy utilizing socio-natural system is sustainable over longer time periods. Pastoral society has both a physical land utilization structure and a social network construction – broadly integrative and based on reputational exchange (Hypothesis 4-REP) – that is analogous to the problem of the commons. The REP hypothesis minimizes the likelihood of free-riding and the exchange system is balanced in such a way as to maximize social and wealth equality by reproducing herds against reproducing families linked by bride payment exchanges at marriage. Conversely, it minimizes differentiation in scale of exploitative strategies while not minimizing diversity among producers. This in itself is probably the best predictor of long-term sustainability, which accounts as well for the evolutionary survivability of nomadic pastoralism and foraging even in the face of global densification of population. Systems such as nomadic pastoralism and foraging, in this model, would tend to have inbuilt network mechanisms for preventing inequalities of scale among producers, something that industrial societies do not.

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Glossary

The vocabularies used derive from anthropology (kinship, social roles), sociology (social networks, norms), graph theory (graphs, networks), complexity theory (fractals, power laws) and hybrids (network concepts for kinship). We place the glossary here because it will be easier for the reader to absorb the article after reading the glossary. References are provided to sources where methods and computer software are discussed, such as Pajek (Batagelj and Mrvar 1998) and UCINET (Borgatti, Everett, and Freeman 1992). Additional terms that require illustration and conceptual understanding are given where needed in the text.

Ethnographic and Sociological Vocabulary:

Behavior. An observed regularity in a person's actions, or a pattern of similar actions of members of a group.

Constraint (on behavior). One or more external circumstances that together limit the scope of an action or behavior.

Preference. A regularity in behavior that favors one alternative significantly above chance levels within a set of unconstrained alternatives and attributable to a valued choice rather than to constraints on behavior. Care must be taken in attributing preferences, and they are not necessarily stable.

Norm. An regularity in a people's actions, as members of a group, either in practice or stated as an ideal.

Statistical Norm. A rule of behavior that applies to members of a group, usually including a hierarchy of exceptional subrules.

Ideal Norm. A cognized and culturally shared statement of how people should behave, not necessarily corresponding to how people do behave.

Prescription. An ideal norm that purports to allow no deviation in terms of actual behavior.

Role Relations. Observed social behaviors associated with norms stated by members of a group. The following are examples in the kinship domain that are relatively self-explanatory and widely used in ethnographies, presumably because there are either easily observed or comprehensibly verbalized or both:

Avoidance.
Authority.
Respect.
Informality.
Joking.

Graphs: de Nooy, Mrvar and Batagelj (2002) provide a manual that students can consult for the software for graphical representation and network analysis used in this book. We mostly follow their terminology. As a qualitative or relational branch of mathematics (Harary 1969), formal definitions build on earlier definitions or primitives, here marked in gray.

Node. The elements of a graph that are represented as points, and connected by lines (see below). Synonym: **vertices**.

Line. A relation between a pair of nodes. Its two defining **endpoints** are **incident** with the line. A line may be directed or undirected. An undirected line is an **edge** and an undirected line an **arc**. A **loop** is a special kind of a line that connects a node to itself. Lines may be **multiple** between the same pair of nodes.

Graph. A set of nodes and a set of lines between distinct pairs of nodes.[27] A **multigraph** has multiple lines between nodes. A **digraph** has arcs but no edges, although arcs may be bi-directed and thus represented as edges.[28] A graph may have arcs or edges or both, but a **simple** graph has only edges.[29] A (directed) **path** in a graph is an alternating sequence of nodes and (directed) edges that connects two nodes without any repeated nodes or edges. A (directed) **cycle** is the same as a path except that the endpoints are the same.

Relation. A graph with the addition of loops.[30] See **tie**. A **multiple relation** has multiple lines between nodes. A **directed relation** has arcs but no edges (although edges may be bi-directed and thus represented as edges). A relation may have both arcs and edges, but a **simple** relation has only edges. Graphs and relations may be equivalently represented by a **matrix** in which columns represent nodes, arcs, edges or loops are represented by ones, and their absence is represented by zeros. Operations on the matrix will have corresponding operations defined on the graph or relation.

Networks Vocabulary:

Network. A graph or relation with additional information on its nodes or lines: e.g., a **social network** implies a correspondence between a graph that represents individuals as nodes and social relations as lines.[31] A **subnetwork** is a subset of the elements (nodes, e.g., representing individuals) in a network together with all the information pertaining to the nodes and the lines between them.[32] A object with a mathematical property is **maximal** with respect to this property in a given context, such as a subnetwork or graph, when there is no larger object within the context that contains it that has that property.

Tie. A set of relations between nodes in a network (e.g., a social network) that can be represented by lines in the graph of the network and for which there is additional information about the nodes and their relations. A **simple** tie is a single relation; a **multiplex tie** is one with multiple relations.[33] A tie between A and B in a social network is **reciprocal** when there is evidence that A gives to B and B gives to A, without an *a priori* constraint of symmetry. Sets of ties in a subnetwork are **transitive** when, for each triple, A, B and C, a tie from A to B and from B to C is always accompanied by one from A to C (see **triad**).

Methods of Graph and Network Analysis:

Cohesion.[34] The cohesion of a network or subnetwork is measured by **k-connectivity** (White and Harary 2002): the minimum number k of nodes that must be removed to disconnect it. To say that a graph has connectivity k is equivalent to saying that every pair of nodes is connected by k or more completely distinct paths (Harary 1969). This way of conceiving of cohesion a classical one in graph theory, but so time-consuming and complicated to compute that network analysis using this concept only began with Moody and White (2000). A network can be decomposed into **embedded cohesive hierarchies** consisting of **k-components**: maximal subnetworks corresponding to each level of k-connectivity. Elaborations are given in the text. The **embeddedness** of a person in a subnetwork is the connectivity of the most cohesive k-component to which that person belongs.

Hierarchical Clustering.[35] A method for showing hierarchical subsets of elements in a matrix or network in which all pairs of elements in the each subset have a minimum {average, maximum} value.

Automatic drawing.[36] Optimal layouts of graphs that minimize line length, in which cohesive sets of nodes tend to be clustered, and hierarchical clustering of cohesive sets can be easily superimposed. **Energized graphs** drawn in the Pajek program implement these automated procedures:

> **Energy commands** move nodes to locations that minimize the variation in line length. Imagine that the lines are springs which pull vertices together. The energy commands 'pull' vertices to better positions until they are in a state of equilibrium. Therefore, these procedures are known as **spring embedders**.—de Nooy, Mrvar and Batagelj (2003)

Triple.[37] A set of three nodes in a network or three of its subnetworks. A **triad census** of triples is a common means of estimating the degree of reciprocity, transitivity, ranking and other local attributes of a network. A triple is **complete** when each pair of its nodes are an arc or and edge, or, in a social network, a tie.

Curvature. For ties that are reciprocal between social units in a network, the local curvature of each unit A is the ratio of complete triples A, B, C to triples where A-B and A-C have reciprocal ties. Clusters of adjacent nodes with high curvature constitute a **topology** of a network (Eckmann and Moses 2002).

Centrality.[38] A property of a node that depends on its relation to other nodes in a graph: **degree** centrality is the number of lines incident to a node; **closeness** centrality is a function of the number of lines in all the shortest paths needed to reach all the other nodes in a graph; and **betweenness** centrality (Freeman 1977, 1980) is a function of the number of pairs of other nodes in a graph weighted by the propor-

tion of the shortest paths between each pair that pass through a given node. These might be useful to measure, respectively, the **activity** of a node in a network, the potential **influence** of a node over others, or the **control** a node has in mediating connections between others.

Recursive centrality.[39] The extent to which a node is connected to others that are central, **eigen** centrality, is measured by the first eigenvector in a principal components analysis of a network matrix (*eigen*=own, in German, connotes that every matrix has a unique set of principal component vectors whose vector product sums reproduce the matrix).

Centralization.[40] A measure of the extent to which a graph has the greatest possible difference of centrality between the most central node and each the other nodes. For each measure of the centralities of individual nodes, the centralization measure of the graph is standardized between 0 and 1, where 1 is the centralization of the star graph. This allows centralization to be compared across different networks.

Cohesion and Edge Betweenness.[41] Edge betweenness is a centrality measure of the number of pairs of nodes in a graph weighted by the proportion of the shortest paths between each pair that pass through a given edge. Girvan and Newman (2002) show that hierarchical clusters of edges with low betweenness identify **embedded cohesive hierarchies** with a high degree of accuracy.

Kinship Vocabulary: see also the Kinship Glossary compiled by Michael D. Murphy at http://www.as.ua.edu/ant/Faculty/murphy/436/kinship.htm.

Types of Kin – e.g., **MBD, FZD, FB, FBD, MZ, MZD, HZ, BW.**

These compounds are used to stand for particular types of relatives, where the individual letters stand for **mother (M), father (F), sister (Z), brother (B), wife (W), husband (H), daughter (D)** and **son (S)**. FBD, for example, is father's brother's daughter.

***Asset and Marriage Transfers*:**

Wealth-asset. See text. **Inheritance** is a binding transfer of wealth-assets or consumables after or anticipating a death to a customary set of heirs. **Testamentary disposition** is the annulment of inheritance through the substitution of a written will left by the deceased.

Bridewealth. A transfer of wealth-assets from a husband's wealth-holding group to the wife's at and following marriage, in exchange for reproductive rights transferred from the wife's group (e.g., over their daughter's offspring) to the husband's (e.g., children are retained by the man's lineage). Bridewealth is typically in the form of animals such as cattle that qualify as a wealth-asset. **Bride price** is a term that can be used to contrast with bridewealth, when only consumables are transferred at marriage, but is out-of-date because of the association with purchase, which is an inappropriate term. **Bride payment** is synonymous with bridewealth except that either wealth-assets or consumables may be transferred.

Dowry. A transfer of wealth-assets or consumables from the wife's group to the wife in connection with her marriage. Note the aysmmetry with

bridewealth: dowry transfers are typically not to the husband or husband's group.

***Descent Groups*:**

Clan. A descent group or category whose members trace descent from a common putative ancestry, where genealogical links to a single apical ancestor are not known.

Lineage. A corporate group whose members share a common ancestor. An **ambilineage** is a lineage whose members share a common cognatic ancestor and affiliate either through their father or mother but not both. A **sib** is a lineage that is distributed across multiple communities.

***Affinity and Descent*:**

Agnatic. A relation between two descendants of the same ancestor trace exclusively through males. Synonym: **Patrilineal.** A **patrilineage** is a corporate group whose members share agnatic descent.

Uterine. A relation between two descendants of the same ancestor trace exclusively through females. Synonym: **Matrilineal.** A **matrilineage** is a corporate group whose members share uterine descent.

Cognatic. A relation between two descendants of the same ancestor. Synonym: **Bilateral.** A **kindred** is an ego-centered group … whose

Unilineal. An agnatic or uterine descent principle. An **ambilineal** descent principle is operative in an ambilineage. **Bilateral** descent is reckoned by the cognatic principle, i.e., through both males and females.

Consanguineal. Two persons are consanguineals if they have one or more common ancestors.

Affinal. Two persons are affinals if a relation between them can be traced that includes a tie of marriage. **In-laws** are the consanguineals of a spouse or the spouses of consanguineals, but longer chains of relationship such as the spouse of a consanguineal of a spouse of a consanguineal (e.g., **HZHZ**) or a consanguineal of a spouse of a consanguineal (e.g., **BWB**) are affinals in the more extended sense of the term.

***Post-Marital Residence*:**

Patrilocal. A married couple goes to live in the household of the husband's parents. Synonym: **Virilocal**. In Murdock's (1967) variant, **patrilocal** entails residence with the husband's patrilineage.

Matrilocal. A married couple goes to live in the household of the husband's parents. Synonym: **Uxorilocal**. In Murdock's (1967) variant, **matrilocal** entails residence with the wife's matrilineage.

Neolocal. A married couple sets up their own household independent of other set of parents. There are of course many other alternatives that the three given here, each having many possible subtypes (and potential difficulties for classi-

fication of households!).

Complexity Theory: Complex systems have embedded interiors with many interacting parts, networks, and fields. From a mechanical point of view, emergent field processes often lead to 'surprising' results that are not reducible to a mechanical or deterministic account. 'Emergent' behaviors at one level are not determined by the embedded levels that produce them but are the result of complex interactions.

Complexity. Interaction between a system and its changing environment is **complex** when system responses to changes are on longer time scales than the tempos of environmental change. Degree of complexity is a function of the ratios of response time to periodicities of changes in inputs. Complex systems can pack **memory** into their internal states.

Tipping Point. When certain thresholds are passed in a network or field internal to a complex system, such as a critical density or alignment, the global properties of the network or field change qualitatively, and can pass on this 'emergent' or structural change to a more aggregate level in the system of which the network or field is a component.

Fractality. Properties or behaviors that are **fractal** are self-similar at different levels of spatial scale (e.g., the appearance of an 'edge' of a coastline at different resolutions) or temporal scale (e.g., the appearance of variation of stock prices at different time intervals). Complex systems often have fractal properties. Many mechanical rules (e.g., growth of savings in an account with fixed interest) and random processes (e.g., distribution of the number of edges of nodes in a graph in which edges are added to new pairs of nodes that are chosen with a uniform probabilities) have a characteristic **exponential** distribution. Fractal processes that result from interaction of two levels (a complex system), such as earthquakes at one level and the random distribution of frictional stresses along potential fault lines at a lower level that affects the production of the earthquake however, typically have the signature of a log-log **power law** distribution that is fractal or scale invariant over a large range of spatial or temporal resolutions in which the log of magnitude varies linearly with the log of temporal frequency. Power-laws, unlike savings accounts, typically imply that the short-term past is no guide to the long-term future.

Exponential versus power law. Two variables are **exponentially** related if a fixed multiples of changes in one is a different **fixed multiple** of changes in the other (which in a semilog scatterplot of the variables yields a straight line). For changes through time, take a savings account as an example, with a 6% interest rate. The first few years, you won't notice much difference in the size of your savings account. But after 10 years your money has doubled and is increasing at twice the rate of the first year. If you leave it for your grandchildren, 30 years, it is increasing at five times the rate. After a hundred years, it is increasing at 30 times the rate, and you have $32,000 in the account. Things look very different at different time scales. Two variables are related by a **power law** if a power multiple (e.g., doublings) of changes in one are a different **power multiple** of change in the other. For every doubling of the energy of an earthquake, for example, the frequency is four times less. Earthquates are measured on a log scale of powers of 10 of their energy. If you throw homogeneous fragmentable solids against the wall (frozen skinned potatoes, chunks of gypsum or soap, and so

forth), even with variation in the force, fragments double in size are six times less frequent. This ratio is **invariant** within a very wide range of spatial scales at which you might care to observe. The fact that power law relations are **scale invariant** means that you mightn't need a "special theory" to account for large earthquakes as opposed to small ones, large fragments as opposed to small ones in the trowing experiment. A "special branch" of a theory of segmentary lineages might not be needed to account for big segments as opposed to little ones. Likewise, a "special theory" to account for FaBrDa marriage in a segmentary lineage system might not be needed if that sysetm has fractal properties.

Network-Defined Concepts in Kinship:

Structural Endogamy.[42] When a genealogical network contains a maximal subset of families of which each pair is linked through two or more completely distinct ties of affinity or descent, they are structurally endogamous. Derived from the more general concept of cohesion, and hence from the theory of graphs, and in such a way that the boundaries of structurally endogamous groups are emergent from the pattern of relationships in the network.

P-graph.[43] In a genealogical network represented as a p-graph, couples or unmarried individuals are identified with the nodes, and lines are drawn between each node identified as a parent or parents and every other node identified with a corresponding daughter or son. Two types of ones can be distinguished one for daughters and one for sons. When a person has multiple marriages, each marriage will have a line to the same parent. If we consider the underlying graph, structurally endogamous subnetworks corresponding to cohesive sets.

ENDNOTE

[1] Along with Durkheim, one could say that it is the cohesion entailed in the division of labor that constitutes society.

[2] For more detail as to law-like regularities in the division of labor and an explanation for this principle, see White, Burton and Brudner (1977). A *fraternal group* is one that typically includes a couple and their married sons. A *fraternal or patrilocal extended family* is one in which married sons typically co-reside with their father, possibly but not always after the death of the father.

[3] Frank H. Knight, American economist (1885-1972) set forth in *Risk, Uncertainty and Profit* (1921) the distinction between "uncertainty" and "risk" as one between randomness with unknowable and knowable probabilities, and gave the earliest statement of the law of variable proportions in the theory of production. The derivation of hypothesis 1 as to the effects of survival uncertainties derives from a reading of Harrison White's (2002a) theory of economic production, networks and exchange, and generalized to the problem of how lifeways are dependent on the production systems that sustain them. The principles of bundling (P1) as they apply to organizational responses of producers to uncertainty (P2) are beautifully theorized by White in his models of economic sociology of modern firms and of markets as social networks. In considering pastoralism as a system of production, it is useful to draw out the implications of his theory for nonmarket economies. To characterize how producers will orient their behaviors towards other elements in the socio-natural system, a crucial structural parameter for White is the locus of uncertainty in production (recall Knight's distinction between uncertainty and risk). What is especially powerful about White's theory is how adaptive behaviors with respect to production uncertainties couple to network commitments in production markets, whether formal or informal, through links to either recipients (e. g., buyers, consumers, clients) or suppliers. If survival uncertainty is paramount on the supply side, producers will orient their network-adaptive behaviors "upstream" towards suppliers. If uncertainty is paramount on the consumer side, a "downstream" orientation tends to occur in which producers orient their network- adaptive behaviors towards consumers. My contention is that White's Knightian uncertainty network principle applies more broadly, beyond the modern production economy, to the social networks of producers generally, including those of preindustrial societies. Thus, network-adaptive behaviors oriented to reducing uncertainties entail commitment to longer-term roles and relationships. I refer to White's (2002) argument for the upstream orientation, for example, as the reputational exchange prediction (REP): network-building by investment in "strong ties" in Granovetter's (1973) sense of durable relationships of trust and frequent interaction. Note that in the upstream orientation to uncertainty, downstream relations with product consumers or distributors will be more variable and shifting: not all of one type, but of diverse kinds of relations; less consistent and less intense "network-building."

[4] Nomadic pastoralism is probably the only major subsistence mode where orientation to survival uncertainty, as between upstream (supply) and downstream (supplied) relationships for producers, might be expected to be fairly uniformly on the upstream side. In market economies governed by price, the majority of orientations of producers (or market sectors) are downstream. At the other extreme, say among Amazonian foragers, there is an oversupply of hunters, for example, and as Sahlins noted, hunter-gatherers are more often "leisure time" and "surplus" societies, where supply uncertainties may occasionally be paramount, but not as a rule.

[5] Used as a perspective on women's rights, membership by right of birth in a patrilineal corporate from which a woman marries out when bridewealth is paid gives the woman two worlds instead of the one she marries into, the status of agent for her natal group, and the role of intermediary and broker, with benefits both for her own status and for that of her children, and interests in the arranging of other marriages within the kinship network that may provide further enhancement of her initially weak status as an outsider in her husband's group. Through time, her status grows, and as it grows in her husband's group, it may grow concomitantly in her natal group.

[6] Note that in this definition, prestige goods do not "grow" physically, like cattle herds, but they might be wealth items if the grow in value.

[7] This terminology can be used to address the question of whether transfers of property at marriage from the husband's to the wife's group should be termed bridewealth (which implies that what is transferred qualifies as wealth) or bride price (which might be used to imply that what is transferred are not wealth-assets but consumption goods). In many cases where these kinds of transfers apply, however, the same item, such as animals, may be scarce and qualify as a wealth-asset at one time period but may be plentiful at another time period and qualify as a consumption good. Hence we prefer to use the term *bride payment*, which may or may not involve wealth-assets.

[8] In some societies, highlighting the exchange basis of this transaction, when a woman returns to her natal group, they must return bridewealth paid for rights involving her or her children.

[9] One of the major contributions of White's sociological and network theorizing of the modern production economy is how array themselves vis-à-vis buyers, for example, to form a "market profile" of concomitance between price and quality, i.e., thus capable of responding to different levels and scales of pressure from buyers. The segmentary lineage type of organization is a similar "ensemble profile" for a whole productive or societal sector, arraying levels of organization against levels of event-driven problems or pressures.

[10] Many of the so-called "prescriptive systems" of kinship are modeled so inflexibly, for example, as not to have the capacity represent as a network of behaviors S. Prescriptive system representations are often thought to reflect societies whose governing behavioral norms are firmly grounded in biological genealogy, but a closer representation of their networks shows they are not (White and Jorion 1996, Denham and White 2002).

[11] "Andy Clark's recent book, *Being There: Putting Brain, Body and World Together Again*, argues that embodied biological brains solve complex problems not on the basis of internal representations and operations but through their embedding in "external sources of order and influence," or "cognitive scaffolding." The notion of cognitive scaffolding and the related idea of "soft assembly" (whereby new phenomena are emergent from the local, unorchestrated interaction of heterogeneous elements) [suggests] that similar mechanisms may underlie flexible and innovative action at different scales and sharply focusing analytic attention on issues of control in the midst of self organizing processes." (David Stark, Aug 2002: Distributed Intelligence and the Organization of Diversity web page:
http://www.sociology.columbia.edu/workshops/seminars/heterarchies/introduction2.html.

Arthur, Dulauf and Lane (1997) expand on this theme in their introduction to *The Economy as an Evolving Complex System II*:

> The idea that "interpretative devices" such as explicit forecasting models and technical-trading rules play a central role in agent cognition fits with a more general set of ideas in cognitive science, summarized in Clark (1996). This work rejects the notion that cognition is all "in the head." Rather, interpretive aids such as autoregressive models, computers, languages or even navigational tools (as in Hutchins, 1995) and institutions provide a "scaffolding," an external structure on which much of task of interpreting the world is off-loaded. Clark (1996) argues that the distinctive hallmark of in-the-head cognition is "fast pattern completion," which bears little relation to the neoclassical economist's deductive rationality. In this volume, North takes up this theme, describing some of the ways in which institutions scaffold interpretations of what constitutes possible and appropriate action for economic agents.

[12] Pastoralists do not exhibit all the features of the **W(y)** markets, which by their structure exclude transactions among producers in the same market and call for tiered differentiation and asymmetries between suppliers, producers and buyers or consumers. Nonetheless the orienting assumptions of White's (2002) models are applicable in modified form.

[13] Multi-purpose relationships also entail greater informational ambiguity which highlights the importance of establishing trust, even in unstable and shorter term circumstances.

[14] The clustering of multi-functional (multi-purpose) relationships for which kinship is one of the idioms biases the observer of nomadic societies towards the view that they are essentially "kinship societies," which is a misnomer. The idioms of kinship are insufficient as models of

multi-functionality. Viewed in the light of Ashby's law, it is more correct to explore complex determinations about how different aspects of social relations map onto one another in empirical network datasets by the use of graph theory, as argued above. This also provides a better way to follow and explain historical change, because new networks in general—by the principle of continuity (P1)—build out of differentiations, debundlings, and rebundlings of old networks and the reweighting of new configurations, although sometimes the configurational shifts are very rapid.

The transformation from nomadism to sedentism involves breaking of some of the symmetries that nomadism both allows and requires in the use of space over time. For example, given that nomads move in both space and time simultaneously, they bring with them their coherent bundles of activities and technology. Their subgroups have the capability of splitting up, and then regrouping in one place, maintaining a flexible unity that settlement does not allow. Settled groups with territorially fixed groups at a location x with a set y of activities at fixed loci requires permanent as well as shifting spatially and temporally differentiated relationships for task performance. Orbits of interaction cannot correspond, because individuals from diverse "home" or "work" locations must be drawn together for different kinds of functions, and with spatially distributed and overlapping basins of attraction for similar activities, the cast of characters from site to site is continually changing, so networks cannot map onto one another: groups and networks will cross-cut (Hypothesis 2).

Hence with sedentism we see differentiation of kin (who move to different home sites), neighbors (who cluster on home sites), workmates (at a third set of sites), coreligionists—the familiar categories of settled populations—and the conceptual impossibility that these could be mapped in a coordinate way onto a single multi-purpose network (the new co-religionist communities of the Christian right may be trying to do so, restoring to their human flocks the benefits of nomadism in self-enclosed shopping malls, workplaces and political agendas. Older co-religionist communities such as the Amish or Hutterites persisted only with heavy loss of membership because of all the things they did not do for many participants).

[15] We also get this kind of result from considering that in a random walk through a plane, the length of the path traveled (roaming path) is the square of the net distance traveled.

[16] It is worth noting because of a widespread misconception, that Murdock's Ethnographic Atlas data have nothing to do with HRAF, the library system for ethnographic monographs that Murdock set up in the 1950s. Murdock recoiled from the HRAF as an institution in the 1960s because of their inattention to pinpointing the sites for comparative analysis in terms of time and specific group or locale. Further, HRAF "codes" data only by generic category, like the Library of Congress classification, and is indifferent to the "codes" such as the Ethnographic Atlas in which Murdock identifies, along variable continua, the characteristics of each society in the comparative sample. The societies in the Ethnographic Atlas are not those in HRAF. An identification between the EA and the HRAF is illusory.

[17] Preliminary studies show that such structures tend to have a power-law distribution on the numbers of members of its hierarchically embedded cohesive subgroups the cooperative analog of power-law for degree distributions of nodes in the more competitive network formation models of popularity biases or preferential attachment.

[18] Large-unit pastoralists, for example, are much more likely to have classificatory kinship terminologies with prohibitions that force kaleidoscopic rearrangements of marriage alliances through time, such as the Crow-Omaha patterns of distributing new marriages by disallowing marriage with any descendant of a person's four grandparents. Societies with Crow (matrilineal) or Omaha (patrilineal) coding rules for kin also merge persons in different generations of certain descent lines, mergers that also define classes of unmarriageable "close" relatives, and hence force new marriages into a more distributed pattern.

[19] It is not that too much recombinant diversity is harmful, but simply that the interdependent specializations that may sustain a lifeway are lost as a viable ensemble. Tacit or practical knowledge may be replaced by formal education or analytical skills, but these skills may not be sufficient to carry the lifeway. Whether ecologically sustainable lifeways can be regenerated as specialties emerging out of the diversities reproduced within mass culture is a proposition to be seriously doubted. It might behoove this discussion to make explicit the implicit an-

thropological axiom that some degree of endogamy, or endogamic cohesion, is necessary for the reproduction of a culture that is adaptively specialized to the transmission of tacit or practical knowledge. Without endogamy, parents come from different populations and the diversity of admixture, while not diverse to biological reproduction, may generate such a diversity of skills and beliefs in offspring that adaptive tacit or practical knowledge that carry the adaptive activity streams of the culture may not be reproduced. While novelties emergent at the cultural level from recombinant diversity can simply be marked down to change, many sustainable lifeways that are ecologically and morally viable may be lost in a particular adaptive niche when swamped by too much diversity. This is, of course, one of the problems of mass culture, which may in turn become relatively homogenized without a sustainable ecological base. Diversity is an element fostered within and inbreeding population, but the novelties generated by biparenting are often recombinants of diversities already adaptive within that niche.

[20] Two structurally endogamous sets of marriages are not necessarily disconnected, but may overlap at most by having a single couple in common, never in having a common pair of related couples; they may be connected by no more that a single path of parent-child links.

[21] What is different about marital relinking as an approach to endogamy is that endogamy is normally approached in terms of social categories (endogamy within an ethnicity, within a locality, or within an occupation, for example) rather than as an emergent grouping in social networks. The difference might seem trivial, but is not. Marital relinking creates a "circle" of families or couples who have two or more independent connections. This creates or adds to the cohesiveness of the families or couples who are contained in the set of such possibly overlapping "circles." The outer boundaries of overlapping social circles, created by marital relinking, define the structural boundary of endogamy.

[22] Note the connection here between predictive cohesion theory and percolation theory.

[23] The normative perspective is common in studies of lineage systems, for example, that take an ancestor-oriented hierarchical structure as an organizational feature of social groups whose permanency far outlives that of the individuals born into them. Studies of bilateral kinship often reverse this emphasis by taking an ego-oriented tree as an organizational feature of kindreds whose hierarchical structure is simply concatenated (father's side + mother's side) and thus considered "invariant" in succeeding generations. Hughes' (1988) method of identifying biological groups by factor analysis of relatedness coefficients has a similar "hierarchical" flavor, although his methods of analysis are sufficiently flexible as to be continuous with ours. Blockmodel analysis of kinship networks to produce an image of "role positions" contains a similar kind of hierarchical assumption about recruitment into "roles," but the concept of the duality of individuals and positions (Breiger 1974, Breiger and Pattison 1986) opens up the possibility of heterarchical role systems.

[24] In most of the ethnographies of pastoralists with which I am familiar, males and females are almost equally likely to be remembered within some number (four plus or minus two) of generations, beyond which only agnatic genealogies are remembered (and are often politically revised to reflect current divisions).

[25] Precursors: An early study in the mid-1970s assembled databases for Mexican villages ranging in size from 2-5,000 persons (White, Schnegg, Brudner and Nutini, 2002), and a pilot study using the approach to study development and demographic change 4 villages in Zambia over an 80 year period resulted in a database on over 10,000 Tonga (Clark, Colson, Lee and Scudder 1995).

[26] Similarly, for Peking, I helped James Lee with the assembly of Qing dynasty genealogical archives on 90,000 people over 3 centuries, and that project then expanded to other regions to cover well over a million people on which such archives are not available (Lee and Feng 1999).

[27] The exclusion of loops in this definition of graph is standard in graph theory (Harary 1969), and makes it easier intuitively to conceptualize some of the main theorems about the traversability of graphs.

[28] Pajek options [Main] Net>Transform>Arcs→Edges>Bidirected only.

[29] Harary's (1969) definition of graph is synonymous with simple graph, which he distinguishes from a digraph (directed graph) with directed edges (arcs).

[30] Network analysis packages (Pajek and UCINET for example) are capable of analyzing relations (containing loops) and not just graphs, and of course, analyzing the attributes of nodes as well.
[31] See the previous footnote (4).
[32] Given a partition on the nodes of a network, or a cluster with selective numbers for a set of nodes, [Main] Operations>Extract from Network>Partition or >Cluster will extract a subnetwork according to the user's specification of the node set.
[33] [Main] Transform includes options to >Remove>Multiple lines in various ways that reduce them to simple lines and to convert >Arcs→Edges or >Edges→Arcs.
[34] [Main] Net>Components>Bicomponents with default size set to 3 or more identifies sets of nodes with connectivity 2 or more. Tricomponents have yet to be implemented in the Pajek and UCINET network packages (but see edge betweenness) but are implemented in the NetMiner package.
[35] UCINET's Network>Cohesion>Maximum Flow or Point Connectivity options automatically perform a hierarchical clustering analysis of a matrix of pairwise cohesion values.
[36] [Main] Draw>Draw Partition, [Draw] Layout>Energy>Fruchterman-Reingold>2D or 3D, and [Draw] Layout>Energy>Kamada-Kawai>2D or 3D.
[37] [Main] Info>Network>Triadic Census.
[38] [Main] Net>Partitions>Degree and Net>Vector>Centrality>Betweenness or >Closeness compute the centrality measures for nodes. Degree are computed by Pajek centralities for up to one million nodes and closeness and betweenness centralities for up to ten thousand nodes.

Flow centrality is another measure (Freeman, Borgatti and White 1991), computed by UCINET. When we assume that each edge in a graph has a transport capacity of one unit, the flow centrality of a node u is the percentage of the total amount of flow between all pairs of nodes that is not reduced when node i is removed from the graph.
[39] Eigen centrality is computed in the UCINET program package.
[40] Automatically computed in both the UCINET and Pajek program packages when centrality scores are calculated.
[41] Edge betweenness is computed in the UCINET program package. Hierarchical clustering of dissimilarity scores may be applied to show cohesive groups.
[42] [Main] Net>Components>Bicomponents with default size set to 3 or more identifies blocks of structurally endogamous marriages for a genealogical database in p-graph.
[43] Pajek's [Main] File>Network>Read uses the p-graph format suitable for network analysis as the standard default for reading databases in *.GED formats used by commercial and freeware genealogical programs and produced as well by Pgraph software.