Colloquium

A multitrajectory, competition model of emergent complexity in human social organization

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The repeated pattern of emergent human organization at a societal level going from small-scale, egalitarian decentralized societies to complex, stratified, and centralized societies is well-documented in the archaeological record of past societies. In this paper, I outline a multitrajectory model that relates to the broad features of this sequence of societal change. Competition is shown to play a critical role in the way interaction—among decision making, demographic parameters, and social units that organize resource ownership and procurement—either promotes or inhibits change in social organization. Multiagent simulation is discussed as a way to link culturally embedded decision making to emergent properties in the multitrajectory model.

The repeated pattern of emergent human organization at a societal level going from small-scale, egalitarian, and decentralized societies to complex, stratified and centralized societies is well documented in the archaeological record of past societies. Less evident are the factors that determine the degree and extent to which some societies have gone through this sequence. Early macrolevel evolutionary theories (1, 2) about the development of complex societies saw either a unilineal or a multilineal progression from simpler to more complex societies based on more-or-less homogeneous classes of societies: hunting/gathering societies giving way to tribal-level societies that in turn give rise to chieftain-level societies that then become state-level societies. This focus on the transition from one level to another, with the individual society taken as a unit, downplayed the importance of internal changes within a society as a precursor to these transitions.

More recent theories consider change in the internal organization of a society to be a crucial aspect of the process by which complexity arises. Drawing upon arguments developed in general systems theory, the unit of the unilineal and multilineal arguments has become a structural complex, subject to change in its internal organization (3–5). This trend of deconstructing the societal unit of unilineal and multilineal evolution has now arrived at the agent, be it an individual or a group of individuals with a common interest (6–8). Change, as Blanton (9) has argued, does not simply happen, but arises out of the designs and plans of agents and out of competition and conflict among interest groups. Stein emphasizes the structuring role of heterogeneity and interaction of groups within societies rather than focusing on the resulting organizational structure: "The organizational forms of Mesopotamian complex societies emerged through the dynamic interaction of partly competing, partly cooperating groups or institutional spheres and different levels of social inclusiveness" (10). This perspective has led to a shift in current arguments toward exploration of the role of agents and their interaction within societies, hence to the potential of agent-based simulation as a way to "move beyond culture-specific patterns of change to focus on cross-cultural patterns and transformational changes in the evolution of complex cultural systems" (8). Transformation is a key aspect because the

changes that have taken place in the complexity of social organization are ones of kind and not just of degree.

The progression from simpler to more complex societies has been characterized by the number of levels of organization involved and whether the hierarchy is "bottom up" or "top down" (11), that is, whether a given level is composed of comparable units from a lower level or not. We can represent the "bottom-up" sequence of societal complexity as a sequence of levels composed of units from the previous level, along with a structure that integrates the units into a coherent whole. The sequence is as follows:

Solitary society: $I = \langle\{\text{single individual}\}\rangle$
Group consisting of several individuals: $G = \langle\{I_i: 1 \leq i \leq m\}, \Sigma_G\rangle$
"Band society"/"community" composed of several groups: $B = \langle\{G_i: 1 \leq i \leq n\}, \Sigma_B\rangle$
"Tribal society"/"simple chiefdoms" composed of several Bs: $T = \langle\{B_i: 1 \leq i \leq p\}, \Sigma_T\rangle$ and
"Complex chieftains" composed of several Ts: $C = \langle\{T_i: 1 \leq i \leq q\}, \Sigma_C\rangle$,

where Σ_x, $x \in \{G, B, T, C\}$, stands for the internal organization of the units making up a society at a particular level in the sequence.

The "top down" concept applies primarily to state level societies. State level societies—often taken to be societies with three or more levels of organization (11)—are more than the next level in the above progression. Even though state societies address more complex organizational issues than those that occur with complex chieftains, distinguishing them are two transformations: first, a transformation into a structure in which higher level, centralized positions also have power and authority over lower level positions and decision making; and, second, a transformation away from homogeneity of units at the same level to specialized units directed from higher levels in the hierarchy (5), that is, a shift to what has been called "control hierarchies" (4). The transformation from a complex chieftain to a state system has been characterized as "a fundamental organizational divide" (12) separating tribes and chieftains from state level systems.

What constitutes Σ_x for a given society in the "bottom up" sequence has been a central topic of inquiry in anthropology. The Σ_xs can be highly variable even when comparing societies at the same level. Nonetheless, whereas societies at a given level may have arrived at different Σ_xs, the Σ_xs at a given level have in common the means for providing a solution to the problem of organizing a number of comparable units into a coherent whole.

The change in the Σ_xs as one goes from one level to another is not achieved, though, through a sequence of small modifications of the structural organization at a lower level. Instead, as Haas notes for a village, a village is not merely the aggregation of individuals households into a limited area but entails "new organizational principles and fundamentally new forms of social relations" (8).

The first two levels of the sequence relate primarily to non-human primate societies. The first level is exemplified by primate species in which individuals live solitarily except for purposes of mating. The second level is common to non-human primate species. The group, or troop, is the locus of day-to-day interaction of individuals, yet internal organization of a troop varies widely from one primate species to another. Individuals become full-fledged members of the troop through biological birth and rearing. The organization of the troop into a coherent whole depends on a variety of experientially activated relations among troop members, such as grooming and dominance hierarchies.

The third level characterizes (simple) hunting and gathering societies. These societies are composed of several residential groups (the structural analogue of the primate troop), each of which may act as a corporate group with regard to resource ownership and access. Typically, there is no political structure or institutionalized position of power and authority. The fourth level adds an organizational structure that links several "bands" or communities together. Groups within the collectivity may have political positions or other inherited and ascribed positions of power and authority, but, for the collectivity as a whole, there need not be a single, centralized position of power or authority. When there is a centralized position of power, the term "simple chieftain" is sometimes used. Both a centralized authority and an additional level of organization characterize the next level, "complex chiefdoms" (11).

Common to all of these levels beyond the first is a hierarchical, organizational structure built up from units at a lower level, thus making the units at a given level structurally substitutable for each other. Admittedly this characterization is simplistic and leaves unstated what constitutes the internal organization, Σ, that must occur at each level for that level to have internal cohesion and possibly long-term stability as a coherent whole. Nonetheless it suffices as a way to identify a critical aspect of the hierarchical organization of human societies that also relates cooperation to social organization in human societies, namely, the capacity to construct shared systems of meaning that transcend individual experience, that is, culture. This capacity is central to the shift from level 2 (group level) to level 3 ("band society"/"community" level) because the shift depends on an organizational structure not found in non-human primate societies (13).

Contrary to a primate troop, membership in residential groups in a band society is not based on biological reproduction and face-to-face interactions. Instead, residential groups typically have cultural rules regarding group membership. Mating, a biological process of reproduction, becomes marriage, a cultural institution that regulates who may mate with whom for purposes of reproduction and thereby creating the social identity of offspring that are produced. The cultural institution of marriage is central to the formation of linkages among the constituent units. Marriage typically involves individuals outside one's social group, a practice whose basis is encapsulated in E. B. Tylor's comment that humans have the choice between "marrying-out and being killed out." (14). Yet primate troops do not mate out and are not killed out as a consequence, thus underscoring the fact that the difference between the second and third level runs far deeper than is suggested by simply adding an addition level of organization.

Although a society at the third level can be defined formally as being based on a collection of (residential) groups, the shift involves more than just adding organization to the constituent units (14). The transition from the second to the third level is based on a shift—away from a biological/individual experience basis for defining both the social boundary and the social organization of a group—that also establishes an individual's identity as a member of one's society. Unlike primate troops where troop identity and social boundaries arise through reproduction and face-to-face interaction, in hunting and gathering societies, the social boundary, and hence the social identity of the collective as a whole, as well as the location of an individual within that collectivity, depends on a cultural construct we refer to as kinship.

Kinship is central to the way a collectivity is conceptualized by its members. A hunting and gathering group such as the !Kung San in Botswana distinguish themselves as the *ju/wasi*—the "real people." The "real people" are a collectivity whose identity arises through its members having kin relationships to one another. For the !Kung San, being a dangerous or possibly harmful person, being a stranger, and being a non-kin are synonymous (15). Thus, their society, as is true of other hunting and gathering societies, is made up of those persons who have an identifiable kin relationship to one another. Critical here is the fact that kin relatedness is not an *a priori* based on biological ancestry or putative biological links (although there may, or may not, be a local, native theory about blood relatedness and reproduction), but derives from a cultural construct, namely a kinship terminology. The means for establishing whether or not a kin relationship exists between a pair of persons is through knowing, or determining through a kind of kin term calculus (16, 17), the kin term that identifies the way in which one person (ego) is related to another person (alter).

The kinship terminology, namely, the collection of kin terms one uses in reference to other individuals (such as the kin terms Mother, Father, Aunt, Uncle, etc. in the American/English kinship terminology), is analogous to a language, in that the terminology has a "generative grammar" that determines how the kin terms are related to one another as symbols; hence, the set of kin terms forms a structured set of abstract symbols based on an internal logic (16, 18, 19). But kinship is more than just a set of relations that identify the conceptual linkage between egos and alters. Other aspects of social relations, such as societal rights and obligations and expected behavior, including cooperation, are central to kinship relations.

Evolutionary models for the origin of cooperation between individuals refer to individual characteristics or behavioral strategies (such as tit-for-tat) that presumably arose through the process of natural selection and possibly were reinforced by correlated interactions (20). Although these models may be central for understanding the basis of cooperative behavior among non-human primates and during hominid ancestry, a very different dynamic for cooperative behavior is introduced once the profound shift from an experiential to a cultural basis for framing an individual's behavior took place. This shift is not just one of degree, but introduces a dimension to human behavior that is reducible neither to a genetic model for behavior as used within sociobiology (21), nor to dual inheritance models that consider the phenotype to be the product of both genetic transmission based on biological ancestor/descendant relations and learning/imitation transmission arising through interaction of individuals (22, 23), nor to models of cultural inheritance (24) based on the notion of memes as the cultural analogue of genes. None of these approaches, by itself, is adequate for understanding the nature and forms of social organization that became possible with the advent of culturally constructed systems of meaning, such as culturally defined notions of kinship and kinship obligations, rights, and duties. These constructed systems

provide meaning for individual experience and define collectively understood appropriate ways for individuals to interact.

Kinship in human societies carries with it not only a constructed basis for transforming a group of individuals into a system of interconnected individuals, but also a commonly understood conceptual basis of expected, and expectable, behaviors. In effect, the cultural construct of a kinship terminology shifts the formation of interpersonal relations from an experiential basis to one in which there are expected ranges of behavior by virtue of a common understanding of what kinship relations entail in terms of proper behavior, that is, to a context in which the experiential aspect of interpersonal relations is framed and given meaning through a shared understanding of what constitutes proper behavior according to a cultural construct that transcends individual experience. Individuals may be expected to cooperate with one another simply by virtue of their kin relationship; that is, engaging in cooperative behavior is part of one's understanding of what a particular kinship relation entails, independent of individual experience, traits, or attributes. Further, one also understands that failure to act properly as a kinsman may lead not only to conflict between the persons directly involved, but also to social sanction by others through the common understanding that one has acted in a manner other than is proper for a kinsman.

Meat sharing among hunter and gatherers illustrates the close linkage between cooperation and kinship. Sharing in hunting and gathering societies typically takes place in accordance with cultural rules about what constitutes individual vs. collective ownership. By and large, whatever is culturally deemed to be individually owned is outside of collective interest in whether sharing is done properly and instead depends on expectations of individuals about how close kin should act with one another. In turn, these individual expectations may affect whether or not someone is perceived of as being kin, as noted by A. Strathern (25) for the Melpa of New Guinea. In contrast, whatever is collectively owned also involves a collective interest in whether sharing should take place, what constitutes sharing, and, when sharing is done, whether it has been done properly or not.

For many hunting and gathering groups the division between individual and collective ownership of a resource once it has been obtained is demarcated by the size, skill, and probability of success of obtaining that kind of resource. Large game animals, by and large, take skill that may not be equally distributed among males, and a hunting expedition has a much greater risk of failure than, say, a foraging expedition for vegetal resources. Not surprisingly, large game animals are typically subject to culturally specified rules about sharing of meat. Among the !Kung San, the distribution of meat is not done by the hunter of the animal—a man in !Kung San society does not "own" the animal by virtue of killing it—but by the owner of the arrow used to kill the animal (who might, but need not, be the hunter; refs. 16 and 27). In effect, the group collectively owns the animal (as is true of all resources before their procurement), and the hunter is acting as an agent for the group. The cultural rule assigns to the owner of the arrow the right to distribute the meat, which has the effect, reinforced by the way in which others will downplay the size of the animal that has been killed, of preventing skilled hunters from translating their success in hunting into a means to gain power through controlling access to a highly desired commodity. The actual meat distribution is in accordance with rules that are expressed in terms of kin relations (save that the hunter(s) always receive a share regardless of their relationship to the owner of the arrow), but the quantity is not specified precisely and can become a source of conflict (15, 26). Other groups have different rules about sharing of meat, but have in common the concept that cooperation in the sharing of meat is not left up to individual choice. Instead, it is part of one's identity as a hunter.
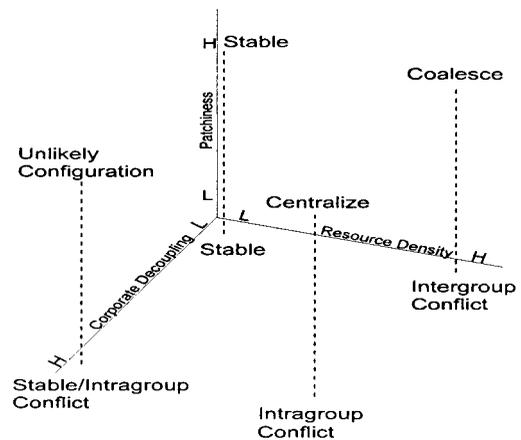

Fig. 1. Outcomes for the multitrajectory model corresponding to eight extreme configurations.

Sharing of meat is critical for equitable access, on the average, to meat by all members of the society; sharing allows the vagaries either of skill or luck in hunting to be averaged out over the persons involved. But cooperation does not occur only because of experience or individual strategy. Rather, it is part of what it means to be a hunter in these societies. One cooperates because it is part of one's identity as a kinsman, a hunter, and a member of one's group. Failure to cooperate—that is, failure to act as a hunter should—can and does lead to social sanctions being imposed on the transgressing individual. But sanctions can be imposed only when there is an already agreed upon understanding of what constitutes proper behavior, and the latter is culturally specified.

From the viewpoint of the individual there may be tension between what one understands to be proper behavior and one's own goals, desires, ambitions, and the like. Acting according to the latter may lead to sanctioning of behavior when there is consensus that the behavior is outside the range of what is considered to be acceptable. The result is that the effect of culture and cultural rules is not one of determining behavior, but of constructing the properties and "laws" of a social universe within which action takes place. These properties and "laws," unlike those of the physical universe, are not deterministic and can be overridden if circumstances warrant doing so, but, in so doing, the potential for sanctions being imposed also arises; i.e., there is self-correction of violations of the properties and "laws" of the social universe.

The social identities taken on by individuals and their associated expected patterns of behavior may suffice as a proximal cause for why a person acts in a particular way, that is, why a !Kung San hunter gives the animal he has hunted to the owner of the arrow for distribution, but it leaves open the problematic issue of how the cultural context within which these identities are embedded arises and is constructed in the first place. It is to this issue that I now turn.

The argument will be in two parts. First, I outline a multitrajectory model that focuses on relating change in social organization and social complexity to a culturally framed decision model regarding spacing of offspring. The model is based on four interrelated dimensions: (*i*) fertility rates for reproducing females, (*ii*) resource density, (*iii*) the geographic scale over which resources are patchily and seasonally distributed, and (*iv*) the cultural construction of the resource procurement unit in which individuals are embedded. A key aspect of the model is the role played by competition (which need not take the form of conflict) and cooperation (coalitions and coalescence). This model helps identify conditions that may lead to the introduction of new

organizational and structural forms (see Fig. 1).

Next, we consider agent-based simulation as a way to incorporate cultural knowledge into the modeling. Last, we identify issues that are not easily addressed with formal, mathematical models but are amenable to agent-based simulation, such as identifying conditions that may give rise to the production and introduction of cultural constructs, the symbolic systems used to make manageable the potential complexity of individual interactions, and the like.

The multitrajectory model will only be sketched out here because it has been discussed elsewhere in more detail (27–29). We begin with the implications of population growth and increase in population density, both of which relate to (mainly) female decision making with regard to spacing of offspring.

All populations are ultimately limited in density by a region's carrying capacity, K, that is, by the total amount of food resources that can be procured from a region or series of regions. The standard logistic equation, $dP/dt = r_0 P(1 - P/K)$, models a population growing asymptotically to its carrying capacity, where r_0 is the population's intrinsic net growth rate and can be decomposed into $r_0 = f_0 - m_0$, with f_0 the intrinsic fertility rate and m_0 the intrinsic mortality rate. For human populations, f_0 has been estimated to be around 15+ live births per reproducing female over her reproductive period, a value substantially higher than the reported fertility rates of so-called natural fertility populations, which vary from around $f = 4.3$ for the Gainj of New Guinea to $f = 6.4$ for the Amish (30). The difference between the two sets of values lies in the fact that all human populations engage in behaviors that either directly affect the net growth rate (e.g., age of marriage and direct fertility control) or mediate the duration of a biological mechanism, lactational infecundability—a highly effective method of fertility control (30). Even if we allow for around a 50% mortality rate between birth and adulthood and an intrinsic fertility rate as low as $f_0 = 8$, an initial population of 1,000 persons would increase to over 8 billion persons in less than a thousand years. Evidently, hunting and gathering populations have either engaged regularly in behaviors that substantially reduce the intrinsic fertility rate, f_0, or have experienced periods of high rates of mortality, or both.

Whereas the standard logistic model correctly couples the net growth rate to population density, it neither identifies the process by which the growth rate is modified nor allows for heterogeneity in behavior. An alternative is to model directly the culturally framed decision process underlying birth spacing by women in hunting and gathering societies. Briefly, the decision model is based on statements by women saying they want as many children as possible but only in the context of the well-being of her family (15), itself a culturally constructed concept. The model decomposes her average daily expenditure of energy/ time, or total cost (TC), into three components: (i) resource procurement and preparation—a component whose magnitude relates to the current population density, (ii) parenting cost—a cost that relates to the structure of her family (number and age of offspring) and is largely independent of population density, and (iii) other demands on her time/energy—these are largely unrelated to either population density or to family structure. Thus $TC = aT_P + bT_F + cT_O$, where T_P is the cost of parenting, T_F the cost of foraging, and food preparation, and T_O are the other costs. The parameters a, b, and c are weights that convert the three kinds of costs into comparable units because the concern here is with perceived costs, not external measures of time and energy expenditures. Of these three components, the second one is the most substantial one over which a woman has control because she can control the spacing of births. The decision rule used in the agent-based simulation (to be discussed below) states: For a given female agent, if her value of $TC < T_{max}$ for the current unit of time, then do not modify the intrinsic, age-specific fertility rate, else if $TC \geq T_{max}$, then set her current
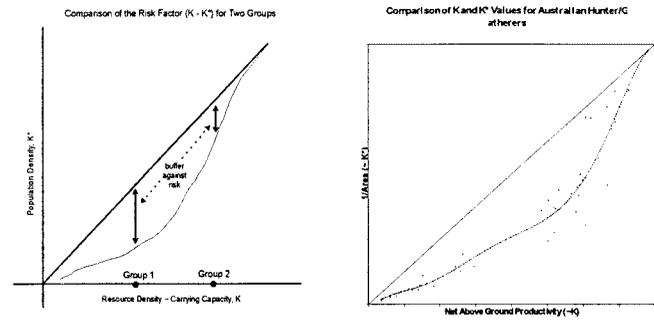

Fig. 2. (*Left*) Predicted relationship between K and K^*. (*Right*) Data from Australian hunting and gathering groups.

fertility rate to 0, where TC is her total cost over a unit of time and T_{max} is her perceived maximum value for TC consistent with ensuring the well-being of her family.

The decision rule has two main consequences. First, the self-interested, noncooperative decision making expressed in the decision rule can lead to a group level phenomenon that benefits the group as a whole by stabilizing the population size at a value $K^* < K$, thereby removing Malthusian parameters as the limiting basis for population size. And second, the value of K^* varies inversely with the value of the parameter a, thereby showing a link between internal, cultural meaning and external, group properties.

The value of $K - K^*$ is related to the resource density in the region exploited by a hunting and gathering group. Foraging costs in regions with lower resource density increase by an amount greater than implied simply by the difference in resource density when compared with a region with high resource density. Consequently, keeping fixed the parameters of the decision model, when one compares a region with high density of resources to a region with a lower density of resources, the same spacing of offspring for women in the two regions will occur at a relatively lower population density in the region with a lower density of resources in comparison to the region with a higher density of resources. Hence, the magnitude of $K - K^*$ will be greater in the region with a lower density of resources. As one goes to regions with a very low density of resources, the magnitude of $K - K^*$ will begin to increase because both K and K^* converge to 0 as the resource density goes to 0. However, the value of $(K - K^*)/K^*$, namely the unutilized resources per person, will continue to increase. The model predictions are matched by data (31) from Australia on aboriginal hunting and gathering groups (see Fig. 2). Because both $K - K^*$ and $(K - K^*)/K^*$ are measures of the buffering individuals have against stochastic fluctuation in resource density in a region, the model implies that hunting and gathering groups in low resource density regions are less likely to experience population control via Malthusian parameters than hunting and gathering groups in higher resource density regions.

If we now take into account the fact that each group is surrounded by other hunting and gathering groups, these results imply that a globally stable configuration (that is, a stable configuration taking into account possible interaction among the groups) is more likely in a low resource density region, in comparison to a high resource density region, because an alternative to being subjected to the effects of Malthusian parameters is raiding of the resources of neighboring groups. This observation brings us to inter-group competition, where by competition I mean the use by one group of resources potentially exploitable by a second group.

Following Lotka (32), I model competition via the following pair of differential equations:

$$dP_1/dt = P_1(a_1 - b_{11}P_1 - b_{12}P_2) \qquad [1]$$

$$dP_2/dt = P_2(a_2 - b_{21}P_1 - b_{22}P_2), \qquad [2]$$

where $P_i(t)$ is the population size of population P_i at time t, a_i is the intrinsic growth rate for population P_i, and b_{ij} measures the inhibitory effect of population P_j on population P_i, $1 \le i, j \le 2$. For a population in isolation, $K_i^* = 1/b_{ii}$, $i = 1,2$.

If we assume the same inherent growth rate, a_i, $i = 1,2$, for both groups, the system described by Eqs. **1** and **2** has a stable equilibrium when $b_{21} < b_{11}$ and $b_{12} < b_{22}$. The parameters b_{ij}, $i \ne j$, relate to the degree of overlap between the catchment regions for obtaining resources used by each group. Whereas a stable configuration is theoretically possible even with complete overlap of catchment areas, the fact that one or the other of the two groups can modify a parameter value (e.g., change b_{ij}, $i \ne j$, through territorial exclusion) implies that the theoretically stable configuration is unrealistic in practice. Hence, we assume that the baseline configuration for a region consisting of several neighboring groups is one with little to no overlap of the respective catchment areas (25).

We identify three competition scenarios. First, we consider recurring conflict between neighboring groups with comparable parameter values in a high resource density region. No single group outcompetes a neighboring group, and, as discussed above, each group is likely to be subjected to the effects of Malthusian parameters. Second, we consider coalescence of groups, with the coalesced group outcompeting smaller, neighboring groups because of the substantially increased population size of the new group. A response by a neighboring group could be to coalesce with another group, thereby resetting the competition parameters to their initial values. In other words, the competition model implies that a globally stable configuration should consist of groups at the same level in the "bottom up" sequence described above, with little or no overlap in their respective catchment regions. Although this might be a stable configuration from the perspective of the system as a whole, it may still be unstable from the perspective of each group.

The third scenario considers the possibility of forming coalitions for the purpose of aggressive takeover of the regions of neighboring groups. If groups G_1 and G_2 cooperate in a coalition for the purpose of aggressive takeover of a third group, G_3, whether the coalition will be maintained beyond elimination of group G_3 depends on being able to maintain the coalition despite internal fissioning forces. Any social system has organizing costs, internal stress and conflict that can lead to fissioning when subgroups perceive it to be in their interest to fission (which may be due to unresolved stress that arises with rapid population increase (33, 34) and they are viable as groups after fissioning. The latter relates to the population density that arises through coalition/coalescence of groups G_1 and G_2. If the resource density over the expanded region used by G_{1+2} is essentially the same as in each group's region before the coalition, fissioning into viable subgroups is possible. On the other hand, if the population density increases as a consequence of the coalescence/coalition, then fissioning into subgroups entails population loss and possible starvation because the subgroups now have a population density that they cannot sustain as separate groups. The cost of fissioning under these conditions may serve as a mechanism to maintain the larger group, G_{1+2}, intact.

The possibility of an increase in population density after coalescence depends, in part, on the scale for spatial and seasonal heterogeneity in resource density. When there is spatial and seasonal variation in resource density on a geographical scale larger than the regions in question, population density increase can occur if resource abundance, averaged over the new, larger region, is greater than resource abundance over the
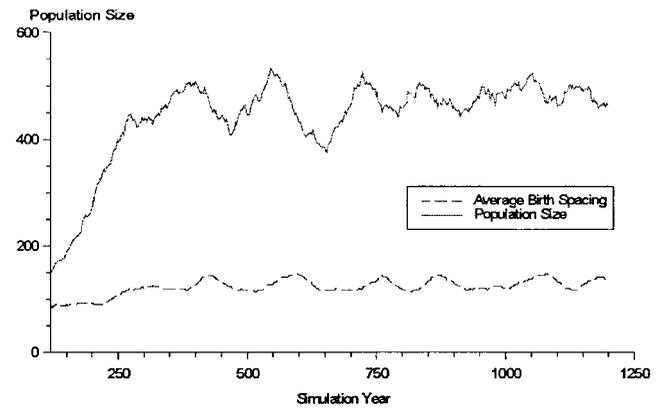

Fig. 3. Simulated population based on decision rule for spacing of births (no scale for birth spacing).

original, smaller regions. Thus the model also needs to take into account spatial and temporal variation in resource density.

Based on the dimensions identified so far, the model implies, for regions spatially homogeneous and temporally similar with regard to resource density on a size scale comparable to the size of the region for a group, a cyclical pattern of neighboring groups forming coalitions aimed at taking over or eliminating neighboring groups in response to stochastically induced resource shortages. The pattern of endemic warfare found in parts of New Guinea (35, 36) exemplifies this cyclical pattern. Strathern (35) comments that local groups in the Mt. Hagan area of New Guinea may expand their territorial base through warfare, but in time fissioning takes place and new local groups are formed.

At a higher organizational level, a similar process may account for what has been called "chiefly recycling." Chiefly recycling (37–39) refers to cycling between simple chiefdoms (level 3 in the above "bottom up" sequence) and complex chiefdoms (level 4). As noted by Flannery, "Chiefdoms grow complex by taking over their neighbours. . . . After a period of expansion, most complex chiefdoms break into simple chiefdoms, or collapse altogether" (6). A similar process has been noted in multiagent simulation of modern states (40).

The last dimension considered in the model relates to organizational properties that affect feedback between population density and individual decision making regarding spacing of offspring. When the resource procurement unit is subject to the effects of population increase, a feedback mechanism at the level of individuals is possible. In hunting and gathering societies, a woman has daily feedback on the time and energy cost of foraging, a cost directly related to the number of women foraging in a region, hence to the population density. However, with the shift to domesticated resources, the matter becomes more complex because of culturally constructed rules for ownership of land. Depending on how a land owning unit is defined, individual women may or may not have direct feedback from changes in population density. If the land owning unit is, say, a nuclear or extended family, or if the land owning unit can fission with population increase (as may occur with lineages in tribal systems), overall population growth is reflected not in the population size of each land owning unit but in the number of units. Growth in the number of units may lead to conflict between units over resources within the same society.

Under these circumstances, a shift toward more centralized power (e.g., from tribal/simple chiefdom to complex chiefdom forms of organization) might be expected as a way to resolve intra-societal conflict. Or, if centralized power already exists, the shift may be to a centralized, top level position in the organizational hierarchy that has power and authority over the con-

stituent units as a means to establish control over internal conflict (6). The latter relates to the conditions under which there is transformation from a "bottom-up" organizational hierarchy to a "top-down" organizational hierarchy, that is, conditions for the emergence of state systems.

These scenarios are speculative, in part because the underlying model can only be incompletely formalized using classical mathematical modeling because the latter assumes populations made up of identical agents (as in Eqs. 1 and 2 above) and do not account for structural changes. To get around these limitations, some archaeologists have begun to use agent-based simulation methods (41). These initial forays into using agent-based simulations have focused on simulations that are the analogues of cultural material theories (1) that consider culture as an outcome, not a causative factor, in the evolution of complex systems.

These simulations have had only partial success, leading to the realization that the cultural context in which agents are embedded must be taken into account (T. A. Kohler, personal communication). The means for so doing depends on formal modeling of the logic underlying a cultural construct such as a kinship terminology. The formal model may then be incorporated into the "knowledge" that an agent can draw upon in the simulation. This incorporation, coupled with an agent-based demographic simulation in which fertility values arise through agent decision making, provides a powerful means for exploring the properties that arise through agents acting in accordance with cultural constructs in the context of a demographically changing popu-

lation. For example, Read (28) has implemented the above decision rule in an agent-based demographic simulation based on an inherent fertility rate of $f_0 = 15$ births over a woman's reproductive period. The simulated population of agents quickly reaches an equilibrium population (see Fig. 3) in which the frequency distribution of birth spacing in the simulated population is in close agreement with empirical data from the !Kung San (28). Further, by implementing the kinship terminology, rules for marriage, and rules for camp membership in the simulation, it has been possible to demonstrate that there will be de facto camp exogamy in terms of marriage, in agreement with the ethnographic observation that the !Kung San do not marry within the same camp even though there is no rule against doing so.

The feasibility of incorporating cultural knowledge into an agent-based demographic simulation has been demonstrated (28). The next step involves exploring the conditions, as outlined in the multitrajectory model, under which stresses or other indications of organizational failure arise and over what time and geographic scale. Lastly, and even more challenging, will be agent-based simulations that address the origin and implementation of the cultural constructs through which organizational structures are formulated [see M. D. Fischer and D. W. Read (2000) http://real.anthropology.ac.uk] in response to stress and organizational failure.

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