Creating Alternative Cultural Histories in the Prehistoric Southwest: Agent-Based Modeling in Archaeology

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CREATING ALTERNATIVE CULTURAL HISTORIES IN THE PREHISTORIC SOUTHWEST: AGENT-BASED MODELING IN ARCHAEOLOGY (A PROGRESS REPORT)

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INTRODUCTION

The object of the workshop was to discuss and demonstrate the modeling of artificial societies and to suggest its potential for extending our knowledge about the prehistoric Southwest. Our efforts are part of the much larger questions anthropologists have asked for generations concerning how culture and cultures evolve. Traditional study of human social change and cultural evolution has resulted in many useful generalizations concerning the trajectory of change through prehistory and classifications of types of organization. It is increasingly clear, however, that four fundamental problems have hindered the development of a powerful, unified theory for understanding change in human social norms, behaviors, and institutions over long periods of time.

The first of these is the use of whole societies as the unit of analysis, as if the individuals within a group were unimportant, or had somehow agreed to put their own best interests behind those of their group. However, such group-level effects, if they exist, must themselves be explained. Sustained cooperative behavior with people beyond close kin is achieved in most human societies, and increasingly hierarchical political structures do emerge through time in many cases. Successful explanation and the possibility of developing fundamental theory for understanding these processes depend on understanding behavior at much more disaggregated levels, for example, at the level of the individual or the family (DeVore 1988; Elster 1989). Among the advantages of such an approach is that it allows for specific modeling of peoples' norms and their rules and strategies for behavior (or schemata) as they evolve through time.

Secondly, traditional analysis is aggregated not only over individuals, but also over space. Current research, however, indicates that stable strategies for interpersonal interactions in a heterogeneous, spatially- extended population may be very different than in a homogeneous or "well-mixed" population in which space is ignored (e.g., Lindgren and Nordahl 1994). Most social interactions and relationships in human societies before the recent advent of rapid transportation and communication were very local in nature. It is necessary to preserve space as conditioning the density and type of interactions among these local agents.

Third, cultures have been considered homogeneous systems generally in equilibrium with their environments, tending towards maximization of fitness for their members. Little consideration was given was given to historical processes in shaping evolutionary trajectories, or to "non-adaptive" aspects of cultural practice.

Finally, most discussions of cultural evolution have failed to take into account the fundamental mechanisms of cultural inheritance (how culture is transmitted) and the effects of changes in modes of transmission through time (Boyd and Richerson 1985; Cavalli-Sforza and Feldman 1981). Understanding culture as an inheritance system is fundamental to understanding culture change through time.

Researchers associated with the Santa Fe Institute (SFI) are attempting to address the difficulties in earlier approaches by working in multi-disciplinary teams and with computer simulation, specifically agent-based modeling (Gumerman and Gell-Mann 1994). Since its inception in the mid-1980s, SFI has been devoted to the study of complex adaptive systems (CAS), Such systems evolve or learn through modification of compressed internal schema, are composed of many interacting parts, and range in scale from prebiotic to the global economy (Gell-Mann 1992). Much of the archaeological research at SFI has to date emphasized the prehistory of southwestern North America, and more recently the use of computer simulations to understand the evolutionary process. Working with such messy and computationally large problems as cultural evolution in spatially extended systems would not have been possible until recently. In the interdisciplinary spirit that distinguishes other SFI activities in the physical, biological, and computational sciences, the cultural evolution program brings together for sustained collaboration experts in many fundamental areas of inquiry interested in new approaches in agent-based computer modeling.

AGENT-BASED SIMULATION IN ARCHAEOLOGY: HISTORICAL CONTEXT

Simulation in archaeology has a relatively long but sporadic history. David Thomas (1972) years ago simulated some aspects of Great Basin prehistory. In the same year and within the boundaries of the Southwest Linda Cordell (1972) used a computer simulation to study settlement changes at Mesa Verde. In 1978 the School of American Research hosted an advanced seminar in simulations in archaeology that was edited for publication by Jerry Sabloff (1981). After the first flurry of interest in the uses of simulation for archaeological research simulation efforts remained almost dormant until recently, with a few exceptions including, in the Southwest, Dove (1984) and Kohler et al. (1986); and in Mesoamerica, Reynolds (1986)—whose work on modeling changes in subsistence in Oaxaca represented a very important departure from traditional approaches.

Part of the reason for the unsustained interest in simulation, we think, was the "top down" approach to modeling they typically employed, in which all rules for interaction between social and environmental and cultural elements had to be built explicitly into the model (as opposed to constructing more generalized agents potentially capable of many sorts of interactions). This proved to be an enormous task, and as a result, models were over-simplified and did not adequately reflect any actual cultural situation.

Concurrent with the realization of the difficulty of modeling social processes from the "top down" was a change in the theoretical stance of many researchers. After a century of exploring the power of systemic, holistic explanations—a century that in anthropology moves us from Émile Durkheim to Roy Rappaport through a host of functionalists—social scientists in a number of disciplines are now increasingly interested in exploring the power of individual-based approaches to explanation. Evolutionary ecologists and evolutionary psychologists make this move in order to bring explanation down to the level at which selection processes operate most effectively. Cultural transmissionists choose this level of analysis because it is here that individual and social learning takes place. Practice theorists emphasize that human actions must be understood as mediating social relations and cultural meanings; understanding how these individual human practices in turn shape tradition then becomes the major research goal. Some post-processual archaeologists have argued that we must begin with the individual, the culture, and history in order to understand relations between behavior and material culture, cause and effect, and fact and theory (Hodder 1986). Agent-based modeling is "bottom up", i.e., it focuses on the agent (be it a cell, ant, or a corporation) as the generator of behavior, and on the interaction among agents as the source of structure. In the archaeology of the Southwest, agents might be individuals, families, hamlets or villages, depending on the problems addressed.

The new generation of simulation using agents as the focus of analysis is thus very different from earlier "top down" efforts. Furthermore, the nascent theory from which this agent-based modeling springs—that of complex adaptive systems (CAS)—is also very different from the General Systems Theory popular with many archaeologists of the 1970s. CAS are composed of many interacting, often heterogeneous agents, and therefore the emphasis is on the individual and not on the sub-system or system; the dynamic behavior of the individuals and the system is of greatest interest, rather than any equilibrium that might be obtained by the system (Holland 1992). The emphasis on the agent allows exploration of the development of complex behavior from (possibly) simple rules. The agents can have many different characteristics, including motives, resources, alliances, and interests, all of which can change through time. The focus on CAS and the individual appears to avoid many of the legitimate criticisms of the "ecosystem approach" in archaeology (Brumfiel 1992; Trigger 1984).

Much of the work at SFI has been cast in terms of completely artificial societies that involve only simulations that are not tested with historical data. Artificial societies are composed of—

- agents, the "people" of artificial societies

- a spatial environment, i.e., a landscape on which agents interact; and
- rules which define the behavior between agents and between agents and the environment (Epstein and Axtell 1996).

The two projects described below are at the juncture of theory building and experimentation. Actual archaeological and environmental data collected over many years will be tested for fit with simulation using various rules about how households interact with one another and with their natural environment. By systematically altering demographic, social, and environmental conditions, as well as the rules of interaction, we expect that a clearer picture will emerge as to why the Anasazi followed the evolutionary trajectory we recognize from archaeological investigation.

Within archaeology, similar directions have been explored or discussed by Doran et al. (1994), Palmer and Doran (1993), Renfrew (1987), Shennan (1991, 1993), and several contributors to Gumerman and Gell-Mann (1994) and Renfrew et al. (1982). Our proximate goal is to develop agent-based simulations to explore and refine models for settlement behavior in northeastern Arizona (Long House Valley) and southwestern Colorado (the Mesa Verde area) (Figure 1). These simulations are being compared against the local archaeological record. The larger goal, towards which these projects are small steps, is to help close the gap between theory and data in archaeology.

TWO EXAMPLES FROM THE SOUTHWEST: WORKS IN PROGRESS

In both projects, Palmer Drought Severity Indices and other environmental characteristics (Van West 1994) were used to generate annual maize production landscapes. We loose "agents" representing households onto paleoproductivity landscapes and observe their locational solutions to making a living in those landscapes. These solutions are then compared with site records from our study areas. We now briefly describe these two projects, both of which long-term efforts that are in their initial stages.

Long House Valley

Long House Valley is a 400 sq-km, self-contained landform in northeastern Arizona that was home to the Kayenta Anasazi from the time of Christ until about A.D. 1300 when the region was abandoned (Gumerman and Dean 1989). The area has had a 100 percent archaeological survey, and intermittently over the past 25 years, it has been the subject of multidisciplinary teams, reconstructing the past environment in unprecedented detail. Changes in the water table and cycles of erosion and deposition have been coupled with precipitation patterns within zones in the valley to estimate the maize-growing potential for each hectare in the valley for every year from A.D. 400 to 1450.

An agent based computer program developed for “growing” artificial societies (Epstein and Axtell 1996) was modified to accomodate the Long House Valley simulation. The first step was to enter relevant environmental data, and data on site location and size. Simulations run to date using these landscapes vary in a number of ways. The initial population of the agents (households) can be scattered randomly or placed where they actually existed at some initial year. Total population can be held at intervals determined by archaeological estimates or be allowed to increase or decrease based on criteria intrinsic to the simulation. The environmental parameters may be left as they were originally reconstructed or adjusted to enhance or reduce maize production. Finally, and most importantly, the rules by which the agents operate may be changed.

Households must identify both farm and residential land. Movement rules for agents are triggered when a new household is created or when a household can't produce enough maize to maintain itself. Standard demographic tables for subsistence agriculturalists are used to determine population growth and household fissioning.

There are three sufficiency criteria for selection of farmland: 1. the site must be currently unfarmed; 2. the site must be currently uninhabited; and 3. the site must be have a potential maize production of 160 kg of maize per household member. If more than one site qualifies under the sufficiency criteria, the farm site closest to the current residence is selected, following economic maximization criteria.

There are also three sufficiency criteria for selecting residential sites: 1. The site must be within 2 km of the farm land; 2. The site must be unfarmed (although it may be inhabited so that population aggregation may occur); and 3. The site must be less productive than the farmland site identified in the steps for selecting farmland. If more than one site meets the sufficiency criteria, the site is selected that has the closest access to a domestic water source.

How closely the simulations mimic the historical data provides the most obvious test of model adequacy. We must ask: Do these exceedingly simple rules for household behavior, when subjected to the parallel computation of other agents and reacting to a dynamic environment, produce the complex behavior that actually did evolve, or are more complex rules necessary? When it is free to vary, does the population trajectory follow the reconstructed historical curve, and does the population aggregate into villages when we know it did? Does the simulated population crash at A.D. 1300? Do the three-tier site hierarchies known for this area emerge through time under these simple decision rules?

Mesa Verde Region

The Mesa Verde Region simulation differs from the Long House Valley project in having a lower spatial resolution (spatial data are represented within square cells 200-km on a side, or 4 ha in area) and in covering a shorter period of time (from A.D. 900 to A.D. 1300). The target area, however, is several times larger, at about 1,470 sq km. Because it is bigger, it is less completely known than Long House Valley, although we have 100 percent survey coverage within significant subsets of the area. This portion of the Southwest, considered by some to be the "breadbasket" of the Anasazi, is also more dominated by productive mesa-top expanses at higher elevations than is the Long House Valley study area.

Our plan is to use a phased approach to study increasingly complicated sets of household-level decision rules. We are beginning by studying the effects of locational rules for fields and residences that attempt to minimize subsistence effort within the dynamic environment. These baseline environmental rules essentially ignore the activities of other agents except insofar as other households withdraw land from the available pool through their activities. These rules are similar to those outlined above for Long House Valley, above. Coding effort for this model began late Summer 1995 using the Swarm simulation platform being developed by the Santa Fe Institute, which at that time was in a very preliminary form.

We shall then proceed to examine a model for village formation proposed by Kohler and Van West (1996) which adds more explicitly social interactions to household behavior. In brief, this model argues that the intermittent spatial aggregation of households seen in the local record can be explained as the result of household-level decisions as to whether or not to share agricultural production with neighbors. Sharing is most advantageous, we have proposed, in periods of high average local production, especially when these are also characterized by high variability through time and across space. More details concerning the status of this effort and our future directions were reported by Kohler et al. (1996).

CONCLUDING COMMENTS

It is appropriate to examine our efforts in agent-based modeling in light of the stated goals of the conference. One of the calls for the conference was to offer alternative explanations to the systems/ecological paradigm that has reigned so long in Americanist archaeology. It seems to us that many researchers have recognized the limitations of that theory and have abandoned or modified their positions accordingly. Our use of the concept of CAS is a case in point.

Another major theme of the conference was to consider more seriously the role of historical events and processes in the prehistoric southwest. One of the problems of the historical sciences, it is often said, is that it is not possible to rewind and replay the tape of history; slight changes in initial or early conditions may produce vastly different results. While it may be true that it is impossible to predict the exact form of any entity by rewinding the tape, it is possible to replay the tape in a general way to observe different results. Agent-based modeling permits changes in population density, the addition or deletion of clans, seasonal rainfall patterns, and the adoption of a different belief system for all or a portion of the society. The tape of history can be played over and over under different cultural, historical, and environmental conditions and compared with observed archaeological data.

Finally, the conference was heralded as representing new and under-represented views. The two projects described here are new in the sense that we are using agent-based modeling and CAS to increase our understanding of the population dynamics of Long House Valley and the Mesa Verde area. While our tools are new, much of the data and the research questions go back to the 1960s as developed by the archaeological cooperative known as SARG (Gumerman 1971). The major question to be addressed was "Why do populations aggregate where they do?" Ancillary themes were "Why do population aggregations differ in size?, why do locations differ through time, and why do aggregates grow or decrease through time?" The Long House Valley Project is a direct lineal descendent of SARG-induced efforts over 30 years ago (Dean, Lindsay, and Robinson 1978). We phrase our research questions in a more sophisticated fashion today. We recognize many of the problems with the systems/ecological paradigm. We appreciate the role of the individual and of historical accident. And we have the enormous power of at our fingertips of machines that perform prodigious calculations in seconds. To the extent that the approaches we outline here represent a paradigm distinct from that of the New Archaeology, we suspect it represents a case of orderly paradigm "growth" of the sort that Binford and Sabloff (1982) outlined, rather than a true Kuhnian revolution. For that reason, none of us wants to make unrealistic claims for our work. Like every other approach in archaeology, agent-based modeling will not give us definitive answers, but we hope that it will provide new insights and a way to study aspects of the past—such as the effects of changing patterns of exchange or social norms—that have heretofore been out of reach.

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Figure 1. The study areas.