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# Structure and Agency in Complex Adaptive Systems A review of Dynamics in Human and Primate Societies: Agent-based Modeling of Social and Spatial Processes, edited by Timothy A. Kohler & George J. Gummerman, 2000. (Santa Fe Institute Studies in the Sciences of Complexity.) Oxford & New York (NY): Oxford University Press; ISBN 0-19-513168-1 paperback, £28.99 & US$40; ISBN 0-19-513167-3 hardback, £46.99 & US$65, 412 pp., ills.

Stephen J. Shennan

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## Structure and Agency in Complex Adaptive Systems

*Dynamics in Human and Primate Societies: Agent-based Modeling of Social and Spatial Processes*, edited by Timothy A. Kohler & George J. Gummerman, 2000. (Santa Fe Institute Studies in the Sciences of Complexity.) Oxford & New York (NY): Oxford University Press; ISBN 0-19-513168-1 paperback, £28.99 & US$40; ISBN 0-19-513167-3 hardback, £46.99 & US$65, 412 pp., ills.

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Archaeologists, anthropologists and their social philosopher predecessors have long been interested in the processes by which such structures as states and civilizations emerge from human action. The frameworks within which they have pursued that interest have varied over time. One of the earlier ones, and certainly one of the most influential, was the Marxist view of history as class struggle, involving the emergence of contradictions between the forces and relations of production. More recently, the neo-evolutionary framework which has been such a dominant influence in Anglo-American archaeology over the last 40 years has emphasized the growth of complexity and social hierarchies as a process of group adaptation. Those groups which developed hierarchical social mechanisms for overcoming subsistence instability, or for competing better with rival groups, would be more successful. The adoption of innovations such as agriculture, which made it possible for societies to harness more energy from their environment, provided the basis for supporting increasingly complex social structures.

In the 1970s there were attempts to make explorations of these adaptive processes, and in particular the process of *morphogenesis*, more rigorous and systematic by building computer simulations in which variables were defined and their relations with other variables specified by systems of equations. By and large, these attempts were unsuccessful. If structure was going to emerge, it had to be programmed into the relations between the variables in the first place.

The agent-based approach to the modelling of social processes, of which this book is an excellent example, attempts to overcome the shortcomings of these earlier frameworks. Consequences of postulated processes are rigorously followed-through by means of computer simulation. Structure is not built in to the model from the beginning but emerges from the interaction between 'agents' through a process of self-organization. 'Agents', as Kohler (p. 2) describes in his introduction, are 'processes, however simple, that collect information about their environment, make decisions about actions based on that information, and act'. The outcome of such local actions, based on local knowledge and decision-making criteria, can often be large-scale patterns unintended by the individual agents. A famous early example showed that individual preferences for spatial neighbours of the same type as oneself rapidly led to the emergence of segregated neighbourhoods.

This insight has profound consequences. The human tendency to anthropomorphize the world tends to lead to the view that complex patterns must be the result of complex intentions and mental operations as well as global knowledge. In fact, nothing could be further from the truth, as te Boekhorst and Hemelrijk illustrate in their description of an example from situated robotics. Their robots are small vehicles that move randomly distributed cubes into a central heap and line up the rest against the wall. Far from requiring complex object recognition software and capacities for co-ordinating movement and action to achieve this, they need only minimal sensors and movement control. The pattern emerges from simple local responses to colliding with the cubes and with other robots.

Indeed, this is one of the major themes of the book: what are the minimal requirements for the emergence of structure from action? Are they purely mechanical, so that structure is simply a function of the degree of interconnection between different elements? Is it necessary to assume evolutionary dynamics of selection and adaptation? What is the role of conscious intentions and knowledge? These are issues of great significance for the understanding of both human history and biological evolution.

In addition to their robotics example, te Boekhorst and Hemelrijk cite a simulation of dominance interactions between individuals in which the effects of winning and losing are self-reinforcing. The study showed that patterns of cooperation could arise without any memory mechanism in the individuals, simply as a result of the fact that fleeing from the attack range of one opponent leads an individual into the range of another. The observed series of immediate reciprocal actions of support corresponded to that of the famous Tit-for-Tat strategy in the Prisoner's Dilemma game but without any of the assumptions about the costs and benefits of cooperation versus defection that Prisoner's Dilemma involves.

In a similar vein, Pepper and Smuts use an agent-based model to examine the evolution of cooperation in a simple ecological context. They show that patchiness of food distribution can itself create sufficient population structure to generate between-group selection, leading to the spread of group-beneficial traits, without any need for the operation of kin-selection. One of the traits they modelled was feeding restraint. In freely-mixing populations the individual paying the cost of feeding restraint was only rarely among those reaping the benefits, in contrast to the situation when resource patches were isolated and small. Too much isolation, however, was also problematical. Continuing cooperation depended on groups being able to export their increased productivity to other patches, otherwise between-group selection did not occur. When within-group selection is the only relevant process then cooperators will die out.

Skyrms' study of the evolution of signalling systems and inference is also a generic one, demonstrating that evolutionary dynamics provides an account of the spontaneous emergence of signalling systems which does not require pre-existing common knowledge or agreement. Where the individuals concerned have a common interest, almost any sort of adaptive dynamics leads to successful coordination of a signalling system, because such systems are powerful attractors in the dynamics. Which system emerges, however, depends on the vagaries of the initial stages of the evolutionary process (Skyrms p. 84). The evolution of a correct rule of inference in the context of a signalling system 'depends on the repeated occurrence of situations where there is a positive payoff for acting on the right conclusion', in the interest of both senders and receivers of signals (p. 87). Skyrms' example is the correct inference of the type of predator currently presenting a threat, from alarm calls which are differentiated by predator.

The remaining studies in the volume are specific rather than generic. They use multi-agent modelling to explore particular situations, based on large quantities of specific information. Lake describes a project in which multi-agent simulation is linked to GIS to explore the processes involved in making foraging decisions. The agents can learn from their own experience and from others and make decisions in the light of their knowledge and goals. In this case the GIS link enables them to have spatially-referenced knowledge in the form of their own cognitive maps. The system is used to explore the likelihood that foraging for hazelnuts was a major determinant of Mesolithic land-use patterns on the Scottish island of Islay, and Lake concludes that it was not. As he explains, however, the major significance of his project is that he has created a powerful generic modelling tool which can be used relatively straightforwardly by others to model the activities of social agents in a landscape.

The papers by Kohler and colleagues and Dean and colleagues model prehistoric settlement change in southwestern Colorado and northeast Arizona respectively, using multi-agent techniques, and go on to compare the results of their models with the settlement histories actually observed. In both cases this is a very illuminating process. Kohler *et al*. conclude that towards the end of their period, either the importance of dry-farming was decreasing, or farmers were now settling in locations which were inefficient with regard to access to their fields, perhaps because social considerations placed a new importance on community members living in face-to-face circumstances. Their model does not reproduce the population growth that actually occurred towards the end of the period they studied, probably because their agents could not intensify, whereas in fact intensification seems to have been exactly what happened, through the increasing use of water and sediment management techniques. The Long House Valley, whose settlement history was modelled by Dean and colleagues, was abandoned after AD 1300, a process generally seen as the result of drought. The simulation results, however, show that the valley environment after 1300 could have supported a reduced population if people had disaggregated into smaller communities and dispersed into favourable habitats. It appears that the environmental factors only partially account for the abandonment of the area. This contrast between the real world and the simulated one is all the more striking in the light of the remarkable success of the simulation in modelling many other aspects of the valley history, and

adds force to Dean *et al*.'s claim that agent-based models can be seen as laboratories for testing competing explanations.

Reynolds' paper is also a settlement study, exploring the role of conflict in chiefdom and state formation in the Oaxaca valley by means of decision trees. These are used to express changes in the factors predicting raiding and warfare targets over time.

Lansing explores patterns of cooperation among Balinese rice farmers and the mechanisms by which synchronized planting patterns emerge over large areas in response to pest and water availability problems. He shows that there is pairwise synchronization of patterns between upstream and downstream farmers but that individuals also imitate those neighbours who obtain the best results, a process which leads to uniformity in planting times, with high yields, and low variance in yields from one farmer to the next; in other words, a highly satisfactory state of affairs produced by traditional methods, and far better than the results produced by centralized development policies.

In a very different sort of way, Lehner's long and detailed paper on ancient Egypt as a complex adaptive system is equally illuminating, although it does not involve any modelling at all. His main concern is to show that it makes no sense to see centralised control as the key feature of archaic complex societies such as Egypt, not least because the state was very limited in its capacity to intervene. The complex adaptive systems perspective directs us towards a bottom-up view of Egyptian society, looking at the connections between people and households. It is here that complexity lies, for example in the inequality among people in various superordinate and subordinate relationships at different scales, both within and between households: hence the view of Egypt in the paper's title as 'the fractal house of Pharaoh'.

Finally, Small's study uses an agent-based model to explore a classic anthropological issue, the impact of marriage rules on the degree of social stratification in Polynesia. Where rules prescribe marrying non-relations, patterns of stratification are extremely unstable. For stratification to emerge, marriage rules restricting kin have to be replaced by rules permitting endogamy; without this, the trajectories of chiefly lines through time converge on one another. Cross-cousin marriage produces a more stable system where chiefly lines tend to keep their high position, but the most stable and rigid system is achieved by permitting brother-sister marriage, such as occurred in Hawai'i.

In his introduction Kohler is very careful not to over-sell the virtues of multi-agent modelling, very wisely in the light of the history of panaceas which have come and gone in archaeology since the 1960s. Nevertheless, the papers in this book make a strong case for the productiveness of agent-based modelling approaches within a broad complex adaptive systems framework. While predictions are always dangerous, I would venture to suggest that these methods will be one of the main means by which the hierarchically-focused social evolutionary approaches of the last 40 years in archaeology are finally reformulated and superseded.

*Stephen J. Shennan*
*University College London*
*Institute of Archaeology*
*31–34 Gordon Square*
*London*
*WC1H OPY*
*Email: s.shennan@ucl.ac.uk*