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PROSPECTS FOR AGENT-BASED MODELLING IN ARCHAEOLOGY

1. Introduction

Twenty and more years ago there was considerable interest in the possibility that computer simulation could make a major contribution to the practice of archaeology, especially archaeological interpretation, and a variety of exploratory studies were undertaken (see Doran 1970, 1990; Doran, Hodson 1975, chapter 11; Hodder 1977; Sabloff 1981; Moscati 1987, 131-140). But the wave of interest passed, and now relatively few archaeological simulation studies are published annually. The natural interpretation is that here was a tool that was tried by archaeologists and found to be of limited use for their purposes, however valuable it might be for other more "hard science" disciplines.

But in fact the present situation is somewhat paradoxical. Although computer oriented archaeologists, as said, seem to have become disillusioned with computer-based modelling and simulation as a tool, other social sciences are witnessing a significant wave of enthusiasm for it (see, for example, Gilbert, Doran 1994; Conte, Hegselmann, Terna 1997; and the new electronic *Journal of Artificial Societies and Social Simulation*, URL http://www.soc.surrey.ac.uk/JASSS/JASSS.html) particularly in the form of *agent-based modelling*. My aim in this article, therefore, is to reach some understanding of just why this paradoxical situation has arisen, and to consider what will and should happen next as regards agent-based modelling in archaeology.

2. The case for agent-based modelling in archaeology

Agent-based modelling is computer-based simulation (or modelling – I shall not distinguish between the two in this article) in which the models explicitly include *agents*, that is, software entities that have (or, at least, may reasonably be viewed as having) in some sense the ability to perceive their surroundings, to take decisions and to act in the light of their perceptions and decisions. The practical design and implementation of agents is sometimes called "agent technology" (see, for example, Jennings, Wooldridge 1998). Of course, we are here talking about very limited computational forms of perception, decision making and action, which in current practice fall far short of human abilities in most, although not all, respects. It is important to appreciate that the word "agent" is used with a number of different shades of meaning even in this computational context. In particular, an important distinction is often drawn between “reactive” or “reflex” agents, which involve no aspects of high-level cognition, and “deliberative” or “ intelligent” agents which do.

The case for agent-based modelling in archaeology then runs somewhat as follows. Archaeology is a social science or, at least, is dependent upon social understanding. The grounds for this assertion are simple – theories of human behaviour and society, however informal or mere “commonsense” they may be, are clearly needed to interpret the archaeological record. However, current social theory, although deeply insightful, is imprecise and often divided into conflicting schools of thought. It seems plausible, therefore, that computer-based modelling can help advance social theory by providing a more precise formulation and testing of hypotheses, as in the “harder sciences”, and in particular can advance those parts of social theory needed for archaeological interpretation. But human societies involve individuals and therefore their cognition: such mental processes as learning, recognition, planning and induction. Therefore, runs our argument, computer-based models of societies must also grapple with cognition. This in turn means that agent-based modelling is needed. Our models must incorporate aspects of cognition and this is just what “intelligent” agent technology offers.

2.1 *Counter-arguments*

The case just presented for agent-based modelling in archaeology is subject to major challenges. The first and simplest challenge is that computer models are both misconceived in essence and in any case much too simple to address the complexity of human society in any illuminating way. The notion that one can abstract out essential processes of human beings and of human society, and capture them in computational terms, is dismissed and, in effect, it is claimed that the study of human societies cannot be a science. Those who argue this extreme position tend to know relatively little of computers and computer simulation and, for example, to assume that computer model must be numerical in nature. Ironically, these sceptics will often be prepared to accept *mathematical* models of social processes without recognising that computer simulations are often best viewed merely as mathematical models that are not capable of analytical solution.

A more sophisticated challenge to agent-based modelling runs as follows. Whilst it is perfectly possible to use computer-based models to make major advances in understanding human society *without* incorporating cognition into the models, to seek to incorporate cognition is unnecessary, and in practice a “bridge too far”. This challenge is less easily dismissed. Let us leave aside the point that this position is often adopted more from awareness of the very real difficulty of working with explicit cognition in models than from a genuine conviction that cognition is irrelevant to the modelling of human society. Just why is cognition needed in our models?

Intuitively, it is the processes of high level cognition that are distinctive in human society – and any theory or model which does not involve them will at best address "low-level" characteristics of human societies which in fact are shared with many other non-human societies (see Mithen 1990; and see also Boone, Smith 1998, for a discussion of this key issue from the perspective of evolutionary theory). But this intuition may be met with the observation that good predictions can often be made about macro-behaviour without addressing cognitive issues – e.g. a popular uprising may be predicted by reference to the properties of society at large. What seems undeniable is that questions which are posed in terms of cognition (e.g. concerning the circumstances in which agents will come to share a particular belief system) simply cannot be addressed, let alone answered, by non-cognitive models.

3. Illustrative projects

To bring these arguments into clearer focus I now describe and discuss some recent and ongoing studies which clarify key issues.

3.1 *Simulating the accumulation of artefacts*

Varien and Potter (1997) have used a computer simulation to study how far the duration of site occupancy can reliably be determined from cooking pot sherd survival in the archaeological record. Their simulation tracks individual cooking pots through time until they break, working with the likelihood of breakage at any particular use. Different simulation variants take into account: the starting ages of the vessels, whether only a single pot from the current assemblage is used until it is broken, or whether each is used in turn, the size of the assemblage of vessels in use, and whether or not broken pots are continuously replaced or only, say, annually. Significantly, they see their simulation primarily as a means to test the reliability of Schiffer's well-known *discard equation*. The simulation is calibrated by reference to an archaeological site (the Duckfoot site in Colorado, USA) which has been studied in detail.

This simulation does *not* address individual human beings or their decisions and there seems no compelling reason why it should.

3.2 *Small-population dynamics*

Gaines and Gaines (1997) have used micro-simulation techniques to explore the demographics (especially survival) of small, prehistoric Southwest Pueblo communities. Each run of their computer simulation tracks the individuals in a small population through birth, marriage and death, making detailed use of available demographic data. They demonstrate the vulnerabilities of small populations to particular internal and external factors.

The authors note (Gaines, Gaines 1997, 686) that they have excluded from their model "cognitive-based corrective actions" by the communities when faced with extinction, but without giving any specific reason why this is so. By contrast, the possibility of interaction between demographic variables and high-level cognition, specifically conceptualization of pseudo-kin relationships, has been considered in detail by Read (1998) who shows and explores how perceived kin relationships can impact marriage patterns and hence group size and locations.

3.3 *Puebloan residential site location in the Mesa Verde Region*

Kohler *et al*. (forthcoming) are using agent-based modelling to explore the relationship between prehistoric Puebloan settlement site location and environmental factors in the Mesa Verde region. A major study and reconstruction of the past natural environment has been made, and of how the patterns of settlement actually developed through time, using all available data. The computer simulation itself (using the Santa Fe Institute software tool-kit SWARM) involves tracking through time household sizes and compositions, agricultural activities and household location decisions, taking into account such factors as the suitability of soil regions for maize production, and availability of water sources.

Note that the agents in this model correspond to households and it is an individual household's *collective* decisions that are emulated using simple rule sets.

Kohler and colleagues' model has many adjustable parameters and a variety of alternative pseudo-histories are being generated. Agreements and disagreements with the real (archaeologically reconstructed) history are being assessed to discover more about the actual location process, and plans to extend the model include such additional factors as reciprocal exchange and predictive planning and household decision making.

3.4 *Hunter-gatherer decision making*

An ongoing project at the University of Essex is directed to the strategic decision making of hunter-gatherer groups and its impact upon the archaeological record (Manologlou, Doran, in preparation). The objective is to integrate Binford's classic study of group hunter-gatherer strategies (Binford 1980) with Mithen's computer simulation study linking individual hunting strategy to faunal deposition (Mithen 1990), and with Renfrew's notion of a "collective mappa" (RENFREW 1987) and so be able to relate a pseudo-archaeological record – ultimately, of course, a real archaeological record – to both micro and macro aspects of group hunting strategy.

We have implemented (within the object-oriented computer programming language C++) a created landscape over which hunters and prey move on a minute by minute basis. Each day the hunters can choose between resting at their base camp, individually and locally following one of several possible hunting strategies, hunting a previously detected herd in a group, or selecting some of their number to form a party to move to a field camp with the intention of hunting from the field camp the following day(s). Following MITHEN (1990), these choices are determined primarily by the individual experience of hunters, and by the information they have collected on the previous day which they "pool" in the evening when they, in effect, form a collective view, a "collective mappa". Using this mappa they then decide what is to happen on the following day. The hunters' collective decision making is determined by 12 heuristic situation-action rules. For example, one rule translated into English from C++ is:

IF at base camp and there is not enough food for three days
THEN organise a hunting trip with only the most skilful hunters taking part

In the creation of this scenario many detailed design decisions have been made and parameters set. These determine, for example, the features of the "landscape" including the difficulty of crossing certain types of terrain, route-finding by the hunters, the heuristic rules which determine collective decision making including the precise criteria for moving to a field camp (selected from a set of possible camps). We have attempted to be realistic in our design choices, but there is no question of this being a specific simulation of a specific hunting group or locality.

Many factors can be varied in particular experiments, for example, the numbers of hunters and prey, the number of days the scenario is to last, the activity level of the hunters, and the probability with which a particular pursuit of a prey will prove successful. Following BINFORD (1980) the numbers of prey are linked to a representation of mean annual temperature. As the scenario is executed, the faunal debris at each camp is recorded and cumulated, and the various decisions made by the hunters logged.

Experimentation is under way, and we are seeking simple but non-trivial relationships between "archaeologically recoverable" patterns of faunal remains and the "unobservable" daily hunting strategies selected by the hunters. Later we hope also to demonstrate some of the special circumstances in which hunter-gatherers can become semi-sedentary.

Notice that explicit within this model are aspects of both individual and collective cognition.

3.5 *The DE-CENT project*

Following the earlier Essex EOS project which focused on spontaneous trajectories to social complexity and centralisation (Doran *et al.* 1994; Doran, Palmer 1995), the recently commenced Essex DE-CENT project aims to study, at an abstract level, processes of de-centralisation in societies, whether these are spontaneous or whether they are explicitly "managed" by the members of the society.

Processes of social de-centralisation are, clearly, related to emergence trajectories (as considered in the EOS project) but with important differences. For example, we may reasonable conjecture that de-centralisation involves the breakdown or overriding of normal mechanisms of stabilisation. For example also, it is possible that throughout a period of de-centralisation the memory and concept of central organisation is retained in the collective memory (in a sense that may be made precise) of the agent community and remains causally significant.

More particularly, the DE-CENT project has the objectives:

– to discover and examine the possible types of trajectory to de-centralisation;

– in this context, to compare models at different levels of abstraction including those which do and do not explicitly include high-level cognition;

– in particular, to examine the role that a network of (de-centralised) local groups can play in sustainable natural resource management and if possible to formulate relevant policy recommendations.

Of direct relevance here is that the DE-CENT project has an important archaeological dimension. One extreme possibility to be investigated is social "collapse", implying de-centralisation to the point of fragmentation, with significant reduction in quality of life, which is to be contrasted with "benign" de-centralisation (whether or not it is managed) in which quality of life is substantially preserved or even enhanced. A number of archaeologists have focused on socio-cultural collapse (e.g. Renfrew 1979) and have discussed the precise processes and causes which determine it.

The DE-CENT project is addressing head-on the issue of just what must go into a model of human society if it is to be informative for a particular purpose. The main model to be implemented will include and focus upon deliberative agents and the interactions between individual and social processes involving them, but without necessarily associating agents with individuals or with particular types of group. Secondary models will put much less emphasis on high-level individual cognition concentrating rather, for example, on social roles and their interaction.

3.6 *Observations*

The order in which I have presented these projects is intended to illustrate an important progression: from relatively simple models in which cognition is not at issue, and seemingly need not be so, to relatively more complex models in which cognition is necessarily the main focus of interest. It should be noted that the locus of cognition in a model is not necessarily in correspondence with a single human being. Very often we use an "intelligent agent" to emulate the cognition of a collective. In these projects (apart perhaps from the DE-CENT project) it is clear that the judgement as to whether cognition *needs* to be explicit in the model has rested largely on the intuitions and assumptions of the models' creators about the important causal processes at work.

We should also notice that these projects differ importantly in objective. Simple, non-cognitive models tend to be related to specific target situations and to be used to gain new insights into those specific situations. They are subject to validation, that is, establishing detailed and reliable correspondence with reality, according to the procedures of standard computer simulation methodology. Complex models involving explicit representations of cognition are more likely *not* to be validated against any specific target system, and to focus rather upon discovering the properties of combinations of abstract processes. Often these are so-called "emergent" properties which arise from the base assumptions of the model in non-obvious ways.

Finally, the non-cognitive models for cooking pot sherd survival and for small-group demography are both easily seen as extensions of mathematical models, unlike the those involving explicit cognition. They illustrate that there is no hard and fast technical distinction between mathematical and computer-based modelling.

4. Problems with agent-based modelling

It is perhaps not just a matter of chance that the studies in the foregoing list that involve more "intelligent" agents are as yet incomplete. Such studies encounter major methodological problems which we should now consider.

The first point to be made is that, rather surprisingly, there is no standardised methodology for agent-based modelling. There is no agreed way to proceed. Studies are exploratory and very little attention is paid even to standard "text-book" computer simulation procedures. In fact, there are two types of practical difficulty that regularly arise. Firstly, as I have indicated above, modelling with non-trivial agents implies great difficulty in detailed validation of the model, that is, in establishing its exact correspondence with reality. Elsewhere (DORAN 1997) I have examined how this difficulty leads to a concentration first upon *broad-brush* (rather than specific) validation and upon attempted *general* conclusions for a whole class of social or organisational contexts of interest. Second, beyond that, comes a natural emphasis on "theory building", that is, the discovery and precise characterisation of significant new properties of social processes, individually or in combination, without any reference to particular target systems in reality (compare EPSTEIN, AXTELL 1996).

The other type of recurring difficulty is that such models are complex and difficult to specify and program. They require expertise in software development and agent technology which is rarely available to archaeologists. Furthermore, they require very substantial computing power to study in any detailed way. This arises because such models invariably have many adjustable assumptions and parameters built into them, although this is not always recognised by experimenters. Exploring the model parameter space and discovering the interesting behaviours within it is therefore difficult and very time-consuming, even when it is feasible at all. Just a single computer run for a particular combination of parameter settings may be difficult to interpret ("what is really going on here?") even if a detailed trace of the events (including agent cognition) within the simulation is obtained. This arises from the sheer amount of information in such a trace, and the obscuring effect of the pseudo-random factors that will normally be incorporated.

5. Does the concept of an "agent" help or hinder?

There is a more subtle difficulty with "agent-based modelling". The term "agent" is variously and usually ambiguously defined in the computer science and artificial intelligence literature. Worse, it is not entirely clear than the concept is always a help rather than a hindrance. Could it be that the very notion of agent-based models is misleading because the natural but anthropocentric distinction we like to draw between agents and non-agents obscures key issues? I suggest that there are two different ways in which this might be so: by obscuring the notion of a *sound simplification* in a model, and by focusing attention on phenomena of *individual cognition* rather than on those of *collective cognition*.

5.1 *Model simplification*

In all modelling work the problem arises of the level of abstraction a particular model should be pitched for a particular purpose, that is, how much detail should be incorporated into a model if it is to serve its purpose. The solution to this problem does not depend upon whether or not the model includes agents or explicit cognition. Rather it is a case of whether particular *model simplifications*, which may or may not involve agents, are *sound*, that is, may be used safely. By a "simplification" I here mean not just one numeric variable that subsumes many, but rather a part of the model which is in some way an abstraction or summary of a more detailed potential model component for which it stands. A simplification in this sense may itself be complex. We may say that simplifications for particular components of a model must satisfy the following requirements to be sound:

(1)

No simplification must remove from the model a variable mentioned in any hypothesis being tested or investigated.

(2)

A simplification must exactly mirror the behaviour of the model component which it replaces. In particular, it must omit no "side" effects e.g. input or output.

Notice that this requirement can be tested locally in the model. Consider, for example, a planning procedure within an agent. If it is the case that *in all circumstances* this procedure may be replaced by a simple rule set, then that simplification is sound.

(3) Alternatively to (2)

A simplification is sound when any inadequacies it may have do not propagate to any of the output measures in which we are interested.

Unfortunately requirement (3) is rarely testable in advance of the model's use, which is why simplification decisions in practice are so often a matter of guesswork. For a detailed discussion of the different types of models and of transformations upon them and their applicability see ZEIGLER 1990.

5.2 *Collective cognitive phenomena*

It is often the case in modelling human society that the significant components of the model seem necessarily pitched at the cognitive level, but are collective rather than a matter of individual cognition. Examples are patterns of co-operation, multi-party negotiations, collective beliefs systems and ideologies, so-called "memes", and language structures. Placing the emphasis upon agents and their individual properties can obscure the role played by these collective phenomena and be seriously misleading. Yet habits of thought imported from artificial intelligence science, with its emphasis on the design and construction of specific pseudo-intelligent machines, are liable to do just that. What is needed is a willingness and ability to structure models in terms of whatever phenomena are significant whether these are collective or individual, cognitive or noncognitive.

6. Conclusions

Archaeologists have a long and honourable tradition of trying out new mathematical and computer based techniques (witness the present interest in *Geographical Information Systems*) partly, no doubt, because of the early and dramatic successes of physical science techniques such as radiocarbon dating and magnetic prospecting. Much of the computer simulation activity of the seventies and early eighties took place directly or indirectly in the context of the so-called "New Archaeology" which predisposed many towards attempting to use numerical and computer-based techniques. And, as noted above, some of the studies were of a type that would now be called agent-based.

We can now suggest why these first attempts to use computer simulation and agent-based modelling in archaeology were not more influential. The major problem factors seem to have been:

– that the technical expertise and computer power needed for substantial and convincing experimentation were not available;

– that the complexity of the models attempted, and the consequent difficulty of model validation, almost invariably meant that the results of a study carried little weight, especially for the more complex intelligent-agent based models;

– the notion of theory building by modelling, as an alternative to strict model validation, existed but was ahead of its time and not widely accepted.

6.1 *Prospects for the future*

The current wave of interest in and enthusiasm for agents in the computer science and artificial intelligence research community has spread widely, and in particular has spread into archaeology. Thus there is a sense in which archaeology has been "infected" by agent-based modelling for a second time, this time along with other social sciences. Will there now be more success? Well, there is much more expertise available to archaeologists than before and greatly increased accessible computing power. And we can predict standardised software developments which will help modelling. And the very fact that other social sciences are involved must help archaeologists. But the methodological problems noted earlier surely still remain. It is hard to foresee the substantial and persuasive experimental studies being undertaken that could make a real and, I judge, necessary difference to the way in which most archaeologists and anthropologists *view* agent-based modelling. Arguably there has to come about a shift from seeing modelling merely as a tool which can illuminate and add substance to *preconceived* ideas, to seeing it as an actual means of *theory building*. Until this quite major change in the general view of agent-based modelling is achieved, it will always be liable to be dismissed as over-complex and impossible to validate.

In the foreseeable future, therefore, it seems that only the simplest agent based models will win much general recognition in archaeology, except possibly in circumstances where it is not at all clear what *is* the interesting behaviour of the model or in what *circumstances* that behaviour will arise. But, in the longer term the prospect remains that agent-based modelling can indeed provide deep insights into human social processes and that this will come to be recognised. This prospect must and will surely be pursued, with archaeologists able to make a distinctive contribution.

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ABSTRACT

Although computer oriented archaeologists seem to have become somewhat disillusioned with computer simulation as a tool, other social sciences are witnessing a significant wave of enthusiasm for it, particularly in the form of agent-based modelling. My aim in this article is to reach some understanding of just why this paradoxical situation has arisen, and to consider what will and should happen next as regards agent-based modelling in archaeology.