Complexity in Action: “The Emergence of Agro-pastoral Societies”

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Abstract

This paper presents a simulation in which a fictitious society of hunter-gatherers evolves into a society based on farming. The purpose of this simulation is to show that even a simple system of rules can produce complex behaviour over time, providing a model of change with non-deterministic aspects. The model is very simple, based on agents with a small set of rules. The experiment does not try to reproduce a realistic transition to agro-pastoral societies but instead proposes to illustrate certain theoretical issues of the understanding of such a transition.

Key words: simulation, agents, emergence, hunter-gatherers, agriculture, complexity

1. Introduction

We propose a minimal model for the transition from a hunter-gatherer society to an agro-pastoral one. The application of such of a model to archaeology is relatively recent, and so far only a few examples are available.

David Thomas (1972) used this technique for his study of the Great Basin prehistory and at the same time Linda Cordell used a computer simulation to study the settlement changes within the Southwest borders of the Mesa Verde region (1972). Later, in 1978, the School of American Research hosted a seminar on archaeological simulations, later published by Sabloff (1981). In the eighties we saw important works on the American Southwest by Dove (1984) and Kohler et al. (1986), and on Mesoamérica, by Reynolds (1986).

These latter works adopted a new perspective in relation to the previous studies. The main deficiency of the previous simulations, as pointed out by George J. Gumerman and Timothy A. Kohler (1995) has to do with the main perspective used in the construction of the model. Early works modelled top to down, that is to say, first they built a global or systemic model and from there deduced the individual level.

Epistemological development in sciences such as anthropology brought forth a new point of view. The individual was enhanced. Authors like Bourdieu, Sahlins and Giddens, have focused on concrete human actions, which should be understood as the mediation of social relationships and cultural meanings. Jim Doran (1993, 1994) follows this approach and intends to provide (with a simulation) a theoretical model for the evolution of human societies.

The understanding of how these human individual practices shape tradition turns into the primary objective of an investigation.

The models based on agents are built on a bottom up perspective. The emphasis is placed on the agent as the origin of global behaviour. It is through the agents’ interaction that the structure is built (Gumerman and Kohler 1995:6).

This theoretical trend was reinforced by new ideas introduced by the concept of complex adaptive systems (CAS). In complex adaptive systems agents interact and evolve by reacting to the environment and to each other. Even sets of agents animated by simple rules can interact in complex patterns that tend to get more elaborate over time. Complexity arises from simplicity.

This approach centres the analysis on the mechanisms operating at the individual level, avoiding the traditional ecological determinist approach. Global changes at the system level do not require global changes in the environment. The complex patterns that arise from individual interaction can change due to small scale fluctuations and give rise to new global arrangements.

In our simulation we intend to demonstrate this last principle. We begin by modelling bottom to up, starting with a simple model of agent interaction. We tried to keep our agents as simple as possible, in order not to globally pre-define the behaviour of the system.

Our model tests a simple hypothesis: can the change from a hunter-gatherer society to an agricultural one occur by chance, without postulating any dramatic change in external or internal conditions? In other words: can we build a model of a society based on a system of relations with the environment, and watch that system change suddenly after a long period, without any external change, only its own internal processes?

What we have constructed is completely theoretical. It does not emulate any known situation neither does it try to incorporate any type of empirical data. The model is centred on the demonstration of the evolution characteristics of a system that includes two competing potential equilibrium states, by showing that the shift from

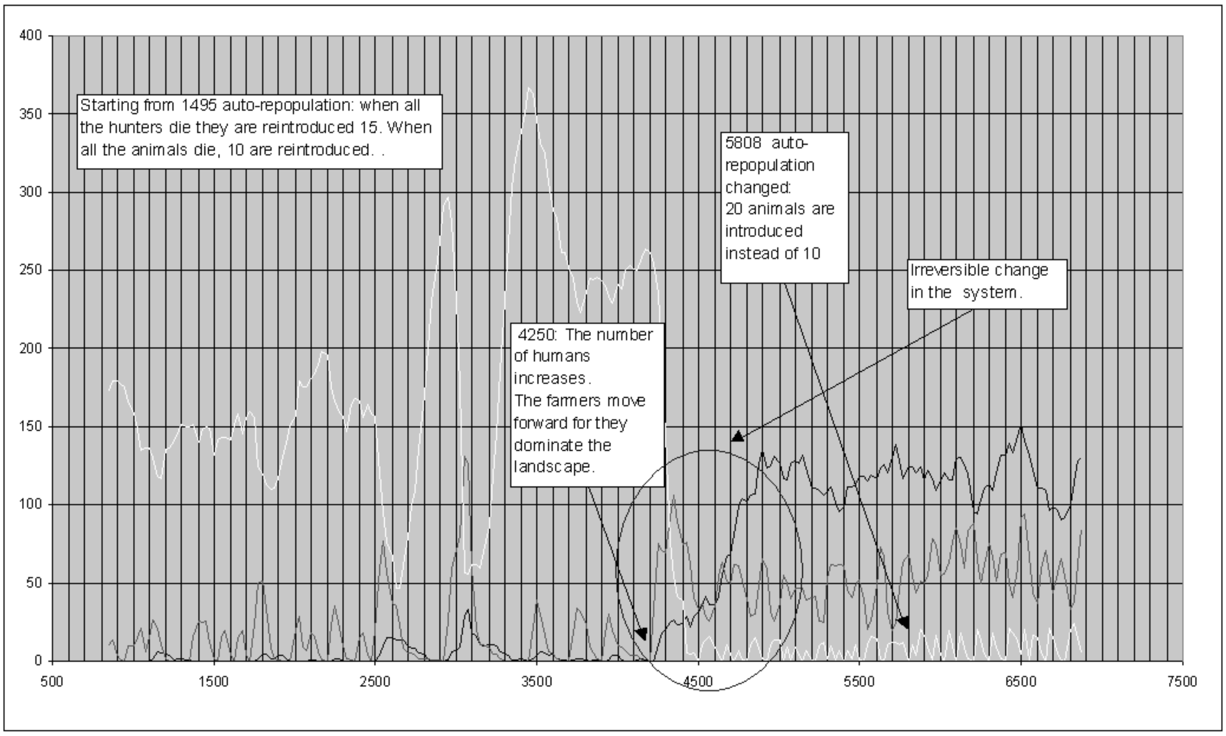

Figure 1: A long simulation: a total of 7000 cycles for a life-span of 50 cycles. Around cycle 4500 the systems shifts from predominantly hunting to farming, although no new causality was introduced.

one state to the other can be the result of very small causes. In our view, this raises the question of searching for global causes to global phenomena.

2. Overview of the Model

The model is composed of a landscape and three type of agents: cattle, hunters and farmers. The tool used for the implementation was AgentSheets (http://www.agentsheets.com).

Our aim is to create a system where all agents compete for natural resources, in our case represented by plants. The success of each type of agent is determined not only by the direct availability of the natural resources but also by the capability of other agents to gather those resources for themselves.

The landscape consists of a grid, where each square corresponds to either a water cell or a soil cell. Using AgentSheets drawing tools a specific landscape can be drawn as needed, by "painting" water and soil. There are no different types of soil, nor any representation of the relief.

The vicinity of water determines the evolution of landscape, in particular the growth of plants, which in turn determines how cattle, hunters and farmers behave. So the most determinant parameter that influences a specific run of the model is the actual drawing of lakes and rivers in the landscape. The availability of plants determines the behaviour of cattle. The behaviour of cattle in turn determines how the hunters move around. And farmers try to get close to the water to build their farms.

The interaction of all the factors can be described as follows:

- *Soil* produces two types of plants: X and Y. X (rendered light gray in our screen shots) requires close proximity to water, and corresponds to what would be grass or cereal. It grows fast and provides food for cattle and humans. Plant Y (gray areas) requires less water, grows slower, and does not provide food for cattle - it corresponds to bushes or trees. As plants are eaten they disappear from the soil (the software uses paler colours to render short plants), and need time to grow again.
- *Cattle* eat type X plants. A cattle agent has the ability to "smell" concentrations of plant X and move in their direction. As the plants are eaten, cattle move to other concentration spots in the landscape. With time the first plants to be eaten grow again and cattle eventually return to the same places. People also eat type X plants and so compete with the cattle for the same food.
- Both *hunters* and *farmers* have the same eating patterns. They can absorb plants X and Y and kill and eat cattle if they can catch them (there is a "killing" rule – if an animal is in a cell with three or more humans around it gets killed and eaten). The difference between hunters and farmers is in their moving rule. Hunters "smell" cattle concentrations, and so follow the herds around the landscape. Farmers follow water concentrations. When they find a spot close to water they "camp", and move no more. Farmers also camp when they find more than two farmers already camped. This tends to generate "villages". Plants X grow faster in the vicinity of a sedentary farmer – this corresponds to our "agriculture" effect. So the farmers' diet consists essentially of plants X, with an occasional cow that walks into the village.
- Cattle and humans reproduce themselves when a certain age/energy combination is achieved. For cattle there is the further constraint that a female and a male have an "encounter" – this allows for the future study of gender biased hunting practices, an aspect that we do not cover in this paper. With regard to humans, this rule means that the rate of reproduction of each type is connected to their ability to

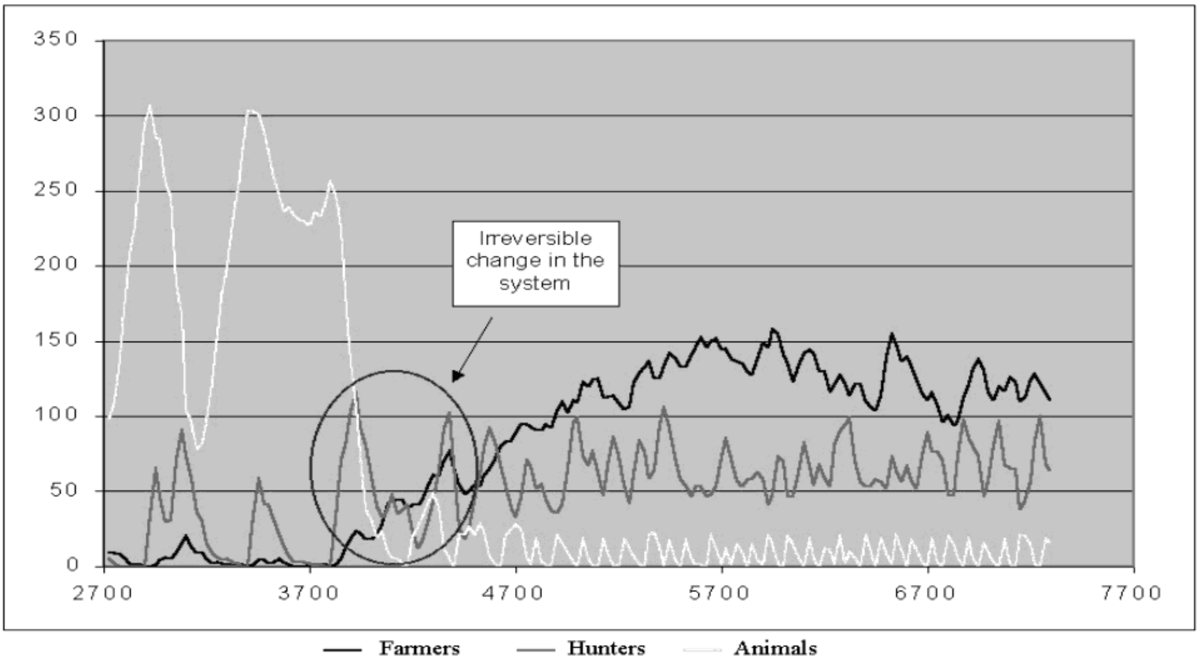

Figure 2: Another look at an irreversible transition. Note that there are no clear macro-level conditions associated to the shift.

gather resources and so obtain the necessary "energy level" for reproduction.

- When a human reproduces there is a pre-set probability that the descendant chooses a different type of life. In other words, a portion of the farmers' sons are hunters and vice-versa. This rule is very important in the understanding of our model because it provides the mechanism by which the society can choose, at any given moment, to shift from hunting to farming or from farming to hunting. There is always a mixture of hunters and farmers present. The more successful a certain type is the quicker they reproduce and become dominant. There is however always a stock of alternative types available in case the conditions of dominance change.
- Human and cattle have a pre-set maximum life-span.

The model is built in a way that concentrates the analysis on the efficacy of the alternative strategies of hunters and farmers, here reduced to different moving patterns. Instead of modelling some disruptive event that would make our society change from a predominant model to some other type, we investigate how a system of interconnected dependencies can change spontaneously, in response to fluctuations in the balance of resources.

3. Observed behaviour

Running the model consists of creating a landscape and introducing initial populations of animals and hunters. Due to the small dimension of the modelling space available the simulations frequently produce short-lived populations. A mechanism of automatic "immigration" was produced, so that when either the cattle or the humans completely disappear, new individuals are introduced. The model can be thought of as representing a portion of a landscape subject to successive migration waves of humans and animals.

The typical evolution of the simulation can be described as follows. The initial group of hunters follows the cattle around killing them whenever possible. The killing rule relates the energy of the animal to the number of humans in the cells around it. So the kills are determined by the patterns of movement of the animals and the hunters (although animals can, by the same rule, be killed if they enter an area densely populated by sedentary farmers). As the animals follow the concentration of plants, and hunters the concentration of animals, the two groups move close together but there is enough fluctuation in the moving patterns to allow for a certain randomness in the hunters' achievements.

When hunters succeed they accumulate energy and reproduce. There is a 10 % chance that a hunter's son will become a farmer. So eventually, if the hunters are successful, farmers will appear and settle down by the rivers and lakes.

The appearance of farmers creates a more complex interaction between the various elements. Without farmers the relationship between cattle and vegetables, and between hunters and cattle, is a predator-prey relationship, with the typical pattern of oscillating populations. Farmers are located in the same spots where cattle look for food. Since the presence of farming makes the plants grow faster, the herds have more food available – farming disturbs the "natural" availability of resources.

Where there is a large cattle population, the farmers have little chance of survival, since the big herds will eat their food. The existence of a group of hunters increases the survival chances of the farmers. If hunters disappear the herds will increase and eventually destroy the farming lands. However if farmers manage to hold and create a sufficiently large population they will be able to hold the cattle away, since cattle entering dense "villages" are killed by surrounding humans. And a big enough population of farmers produces hunters in quantity by the 10 % rule. So the interaction of farming, hunting and grazing is more complex than the simple predator-prey relationship. The increase of complexity has the counter-intuitive consequence of allowing the system to become more stable in demographic terms, as we will see.

The model can run for very long periods of time with the populations of hunters, farmers and cattle oscillating consider-

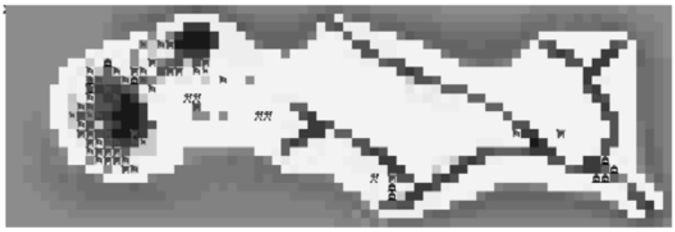

Figure 3: A compact herd, a small group of hunters and a few farmers. In many of these type of situations the humans disappear. The system reintroduces then a fresh small tribe of 15 hunters. Corresponds to cycle 2.707 of figure 1.

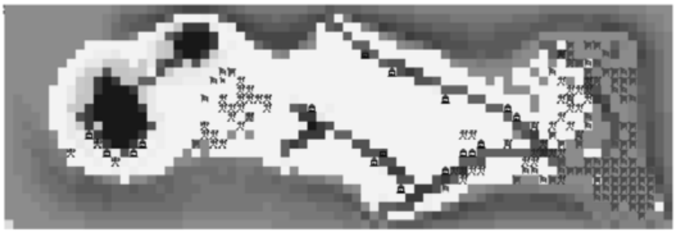

Figure 4: Another view of the first phase. The cattle is split in two herds, each with a group of hunters in persecution. The farming experiments will not survive the movements of the large herd as it latter migrates to the west to graze. By comparing with figure 4 it is possible to see the effect of the herds in the destruction of the farming experiments (lower right corner). This view corresponds to cycle 4.306 of figure 1, with the shift to a farming dominated landscape underway, although no particular aspect of the situation allows us to predict it.

ably, with large amounts of animals, a medium sized group of hunters and a minority of farmers. The farmers sometimes manage to create areas of agriculture, but their survival is closely linked to the oscillating pattern of the cattle population, produced by the predator-prey relation with hunters. In the simulation illustrated in figure 1, this period extends for 4500 cycles, with the maximum life-span of a human set at 50 cycles. So for many generations cattle rules the landscape with a hunter-group following them around, and short-lived but constant farming experiments also take place (see figures 1 and 2 for population graphs and figures 3 and 4 for landscape views of this phase).

If the simulation runs long enough there is a non-quantified chance of a significant mutation occurring in the normal pattern. This happens if farming becomes resistant to the destructive effect of the herds. This, in turn, is due to a combination of the size of the farming population, the episodic decrease of the cattle population and hard-to-quantify aspects of the spatial distribution of agents at a given moment. No simple combination of these factors could be found to be deterministic in the shift (see figure 1 for various “failures” of farming take-off). What should be made clear is this: although the shift occurs normally after a long period of time there is no new factor introduced at that moment, no “evolution” or “adaptation” in the behaviour of agents and no accumulated factor that would have reached a critical point. We believe that the same circumstances that produced long oscillating behaviour also produce the shift to a stable agriculture-based system with the qualification that the latter case has a very low probability of occurrence.

When the shift does take place the farmers become the predominant type of agents in the landscape. Most of the energy accumulated in Plant X growth ends up in the farmers, and not in cattle, as before. Hunters still exist and continue to be produced by the 10 % rule that changes the type of new humans. Cattle population is maintained at low levels by the automatic “immigration” rule and never increases too much because farmers now densely populate the grazing areas and there is always a stock of hunters around to kill the animals. Since most of the energy is gathered locally by farmers, the system becomes much more stable, and the violent population changes of the first phase disappear (check figures 1 and 2 and the landscape views of figures 5 and 6).

4. Relevant aspects of the simulation

The model does not use realistic parameters or rules, and the constraints of the tool used force considerable scale distortions. However, we consider the model relevant as it shows that even a simple interaction system that goes beyond predator-prey relationships can develop complex historical causality.

In our model the shift from a predominantly cattle and hunter system to one dominated by farmers is a macroscopic event of major proportions. The change occurs after long periods of time and consists of a reorganisation of space and the flow of resources, with a corresponding new balance among the populations of the three types of agents present. This major convolution is not, however, caused by any significant change in the causal mechanisms at work in the system, nor by any external factor. It is more appropriate to state that the system contains the possibility of undergoing a major change and that this possibility, having a low probability of happening, occurs only after extended periods of time, or does not occur at all. One interesting consequence of this is that although we have never observed a regression from predominant farming to hunting again, the possibility of that change occurring cannot be completely ruled out. In causal terms nothing really prevents it from happening, except a very low probability that we are not able to quantify.

On close inspection of the process at work in the shift period we feel that the transition is the result of a series of very small scale events occurring in a short period of time. Farmers prevail not only because the relative population of the three types of agent reached some critical proportions but mainly because the spatial distribution of agents was such that a resilient configuration was produced. So the critical factors for the major historical revolution lie in the microscopic details of the movements of agents over a short period of time. In this situation the fact that agent A turned right instead of left at point T in time may have huge consequences later on.

It is this huge difference between the scale of the “effects” and the scale of the “causes” that constitutes the most relevant aspect of the simulation.

5. Conclusions of the system analysis

Our model is consistent with the theories close to the concepts of complexity, chaos and emergence.

George J. Gumerman and Timothy A. Kohler (1995) studied the application of intelligent agents in archaeology. For these authors, society should be seen as a unit of analysis - family or/and indi-

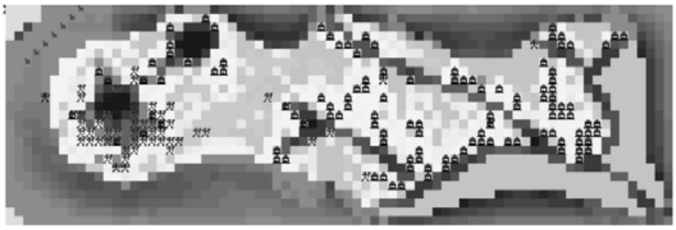

Figure 5: Farmers dominate the landscape, and the cattle has disappeared. The model reintroduces more animals (upper left). Corresponds to cycle 5.808 of figure 1.

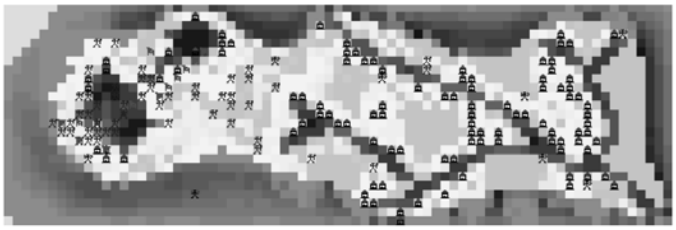

Figure 6: The new system is in place. Farms are created and disappear by the death of the farmer. A small population of animals and hunters co-exist. Corresponds to cycle 6.328 of figure 1.

vidual and space as a condition of the type of the agents' interaction and its density.

Thus culture should not be seen as homogenous and in balance with the environment aiming at a maximisation of adaptation of its members, presuppositions suggested by the processualist approach, but rather as an inherited system, a fundamental element for the understanding of the change through time.

The central aspect of our simulation is that a major global change depends on causes like a certain agent changing direction at a point in time. This is a characteristic of "chaotic" systems – the so called "butterfly effect". The "causes" can be of a very different scale in comparision to the consequences. When causes are so small that they remain undetected we call them "chance".

We can find this vision in a text by Henri Poincaré from the beginning of the 20th century:

> "A very small cause that fails to attract our attention provokes a considerable effect that we can observe, and we say then that the effect is owed to chance. If we knew exactly the laws of nature and the situation of the universe at the initial moment, we could foresee exactly what would be the situation of that same universe at a later date. But even if the natural laws held no secrets from us, we could, even then, know the future situation only approximately. If this would let us predict the next situation with the same proximity, that is all we would need, we would say that the phenomenon was predicted, that is, controlled by known laws. But that doesn't always occur: It can happen that small differences in the initial conditions cause very different final phenomena. A small error in the past will provoke an enormous error in the future. Prediction becomes impossible..." (Poincaré 1914).

These theories break the image of Nature as an unalterable order and expressed by laws that generate an eternal regularity, where time is a reversible variable.

Change can come from an agreement of non-classic factors, not explained in their totality by Marxists or Processual models. The only way to understand change is to observe the emergence of new actions and dig deep in the dirt to find as much data as possible to understand the overall picture

To find a "cause" we will have to look at a scale much smaller than that of the phenomena that we intend to explain. There is not a specific factor for change. The explanations for change lie in a multiplicity of factors, some of them microscopic. So it is necessary to have a total knowledge of the global structure at a given point in time. But we cannot grasp the whole structure, only a part of it. That is why modelling is so important. Geographers have to build maps in order to understand reality, because they cannot work with space itself in its totality, and we also have to build models to understand changes in the past.

This does not mean that the same causes do not have the same effects. What we want to point out is that the causes can be of microscopic scale, and interfere significantly with the macro scale. The possibility of reproduction of the same causes is small, because the probability of the same conjugation of tiny factors occurring is very remote. This is why a non-linear system can become unpredictable. The same effects do not always have the same causes, this happens only when we look at causes and effects at the same scale level.

We find an example of this in our system: if a certain animal changes its direction, this can allow two hunters to reach it and consequently kill it, which results in the higher probability to reproduce themselves, creating a possibility of growth in their population, which in turn can provoke a disruption in the animal population, which in turns creates the conditions for agriculture to flourish if other tiny factors related to the farmers' distribution contribute positively.

The processualist nomothetic paradigm of the search for rules for a system and determinism in human history is, according to these results, subject to revision.

Starting from one moment in which there are several alternatives of similar effectiveness from the social point of view, it is sufficient that a small scale factor privileges one of them so that it becomes dominant, and constitutes the preferential option making the other ones no longer viable. Carvalho J. Ramos (1999), showed a model where the individually created structures perpetuate in time in spite of the disappearance of the individuals that have created them. He concludes that structures appear in time, and condition subsequent individual actions and consequently perpetuate themselves.

Human behaviour is more complex than our agents'. However the conclusions that we took from the study of our "individuals" can be relevant for the understanding of certain phenomena.

Our model is not perfect, it lacks specific case data or application to a more realistic situation. We will try to work in this direction in further studies.

References

CARVALHO, J.R., 1999. O social emergente – sistemas adaptáveis complexos e interpretação histórica. *Revista Teoria das Ideias*, N° 20.

CORDELL, L., 1972. *Settlement pattern changes at Wetherill Mesa, Colorado: A test case for computer simulations in archaeology*. Ph.D. Dissertation, University of California, Santa Barbara. University Microfilms International. Ann Arbor.

DORAN, J., 1993. Simulating Prehistoric Societies: Why and How? In *Aplicaciones Informáticas en Arqueologia: Teorias y Sistemas*. Bilbao. Denboraren Argia.

DORAN, J., PALMER, M., GILBERT, G. and MELLARS, P., 1994. The EOS Project: Modelling upper Palaeolithic Social Changes. In Gilbert, N. and Doran, J. (ed.), *Simulating Societies*. London. University College of London Press.

DOVE, D.E., 1984. Prehistoric Subsistence and population change along the Lower Agua Fria River, Arizona: A model simulation. *Anthropological Research Papers* 32, Arizona State University, Tempe.

GUMERMAN, G.J. and KOLLER, T.Q., 1995. Creating Alternative Cultural Histories in the Prehistoric Southwest: Agent-based Modelling in Archaeology. *Durango Conference on Southwest Archaeology in Durago,* Colorado.

KOHLER, T.A., ORCUTT, J.D., PETERSEN, K.L. and BLINMAN, E., 1986. Anasazi Spreadsheets: The Cost of Doing Agricultural Business in Prehistoric Dolores. In *Dolores Archaeological Program: Final Synthetic Report*, compiled by D.A. Breternitz, C.K. Robinson and G.T. Gross, 525-538. Bureau of Reclamation Engineering and Research Center, Denver.

KUHN, T., 1970. *The Structure of Scientific Revolutions*. 2nd Edition. University of Chicago Press, Chicago.

POINCARÉ, H., 1914. *Science et Méthode*. Flammarion. Paris.

REYNOLDS, R.G., 1986. An adaptive computer model for the evolution of plant collecting and early agriculture in the eastern Valley of Oaxaca. In Flannery, K.V. (ed.), *Guila Naquitz: Archaic Foraging and Early Agriculture in the Oaxaca*, Mexico: 439-500. Academic Press, New York.

RUELLE, D., 1994. *O Acaso e o Caos*. Relógio d' Água Editores. Tradução de Manuel Alberto. Lisboa.

SABLOFF, J.A., 1981. *Simulations in Archaeology*. A school of American Research Book, University of New Mexico Press, Albuquerque.

THOMAS, D.H., 1972. A computer simulation model of great basin shoshonean settlement patterns. In Clarke, D. (ed.), *Models in Archaeology*: 79-102. Methuen, London.