

Computer simulation in archaeology. Art, science or nightmare?

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Resumen

Se propone ampliar el concepto mismo de Arqueología Virtual a la simulación de sociedades humanas y no sólo la simulación de objetos que existieron en el pasado. La idea es poder disponer de una herramienta para explicar las formas de causalidad social a un nivel tanto micro como macro. El objetivo, por tanto, ya no es el artefacto arqueológico, sino la sociedad en su sentido más amplio, si bien se trata de una sociedad que sólo existe en un mundo "virtual". Esta sociedad artificial, nuevo objetivo del análisis se crea con su propia estructura y conducta simuladas. Con la posibilidad de simular sistemas sociales virtuales, se hace posible una nueva metodología para la investigación científica.

Palabras Clave: ARQUEOLOGÍA VIRTUAL, SOCIEDAD ARTIFICIAL, SIMULACIÓN, MODELO A BASE DE ACTORES

Abstract

By simulating historical processes and not just the archaeological material, I intend to explain social causality at the micro and macro levels. The target is no more an archaeological artifact but a human society at large, although existing only in the virtual world. A new target, the artificial society, is created with its own structure and behavior. With the possibility of simulating virtual social systems, a new methodology of scientific inquiry becomes possible.

Key words: VIRTUAL ARCHAEOLOGY, ARTIFICIAL SOCIETY, SIMULATION, AGENT-BASED MODELLING

1. Computer Simulation as a Time Machine

History only runs once, but inside a computer a virtual model of the historical past would run infinite times. In the computer, we would explore (by altering the variables) the entire *possible* range of outcomes for different past behaviors. The idea is then simulating inside a computer what we know about actions having been performed in the past and experimenting with the effects they may produce in such a virtual world.

In this way, Virtual Archaeology would not be limited to the reproduction of stones, walls, buildings, pottery sherds, animal carcasses, but a chronologically ordered sequence of changes and modifications acting over the consequence of former changes and modifications. That means that, inside a computer, the Past would be seen in the Present as a sequence of finite states of a temporal trajectory. Such a simulation would not "see" the past as it once was but as potentialities for action, that is, explanations that can take place when it encounters a situation of some sort.

An important aspect of this way of understanding historical causality is that it forces the analysis to pay attention to the flux of ongoing activities, to focus on the unfolding of real activity in a real historical setting.

A computer simulation should allow us to understand archaeological observables in terms of a priori *affordances*: relationships between observed properties and the inferred properties/abilities of people having generated those properties.

The affordances of any archaeological evidence become obvious in its use and/or formation process. Both involve establishing and exploiting constraints (between the user/producer and the material evidence of his/her action, the user/producer and the natural environment, and the material evidence and the natural environment).

For this sort of cognitive task to work, the scientist, as programmer, should know what precipitating conditions generate an increase in the probability of occurrence of an effect. Beyond a simple addition of individual random decisions, social activity should be defined in terms of social *dispositions* or *capacities* within a system of subjects, intentions, activities, actions and operations, some of them rational, others clearly indeterminate, impulsive or unconscious. The fact that the performance of some social action **A**, in circumstances **T**, has a probability **P** of causing a change **Y** in some entity **N** (social agent, community of social agents or the nature itself), is a property of the social action **A** (Barceló 2009).

The implementation of such causal affordances or potentialities inside a machine to explain what it "sees, is usually called computer "simulation" of a causal process (Edmonds and Moss 2011, Epstein 2006, Macy and Willer 2002, Sokolowski and Banks 2009, Zacharias et al. 2008).

2. Virtual Societies

Writing a computer program to simulate social activity in prehistory has long seemed an impossible task. There are still many social scientists thinking that we cannot reproduce what humans did and believed inside a computer, because a machine is a bad surrogate for the complexity of human beings. These scholars seem to believe that we do not have access to the knowledge necessary to accurately reflect all of the interweaving and evolving components of social activity through history. Machines are limited to the calculation of input-output pairs, and no social activity would be so simple. This criticism is mostly wrong, especially in modern times when artificial intelligence has shown how the appropriate interconnection of very simple computational mechanisms is able to show extraordinary complex patterns, and when access to GRID technologies of distributed supercomputing becomes easier. Obviously, not everything can be simulated within a computer, because of the many limitations of the approach, notably the non-uniqueness difficulties that arise when describing social mechanisms. Non-uniqueness means in effect that the true input-output mapping cannot be selected from among a large set of possible mappings without further constraints imposed. This undesirable behavior may be due to different factors, among them: noise in the measurements, insufficient number of measurements, but specially, because of the non-linearity of the social activity itself: different actions can produce the same observable archaeological features, or the same action may not produce always the same archaeologically observable features. Fortunately, however, satisfactory computer simulations can sometimes be given for effects resulting from social mechanisms whose operations are too irregular to enable the archaeologist or social scientist to reliably predict their future performance, or to systematically explain why they sometimes fail to produce the effects they produce on other occasions.

Our aim should be to simulate human beings “living” in a virtual environment that is an abstraction defined by us on the basis of social theory and/or historical data. By implementing social events as computational agents and their mutual influences as interactions, we plan to discover that collective action may be described and explained as non-accidental and non-chaotic.

Seen in the framework of agent-based modeling, the artificial societies we pretend to build are based on a set of simulated social agents having a (virtual) body, and living in and interacting with a (virtual) environment. They are represented as members of an evolving (virtual) population of social procedures (mechanisms), which determine important aspects of the population’s structure and development and therefore of the individual’s behavior. Agents are pieces of software with individual goals and rules of behavior and capable of self-controlled goal directed activity. Virtual social agents “live” in an environment populated by many other agents, so the successful completion of their tasks is subject to the decision and actions of others. On the one hand, agents may interfere with each other due to a mere side effect of their activities. In other words, people having lived in the past do not appear as passive museum objects. Inside the computer simulation, and as well as they did in their real world, they act as influenced by other people having lived at the same time and any other change in the social or physical environment, for instance, climatic change, social transformation, etc. People interact, influence others, reinforce some actions, interfere with others, and even sometimes prevent

the action of other people. People consciously and deliberately generate contexts (activities) in part through their own objectives.

Agents may interact as well with non-agent entities in this environment explicitly represented as some form of “world”-entity. As the real world constrains the structure and behavior of the real agents, the simulated environment plays that role for the simulated agent system. The perceptions of the simulated agents need to have some origin in the environment that has to be represented in the environmental model. These dynamics also can be so complex, e.g. containing production of new entities that one may assign some form of behavior with the simulated environment, programmed as global state variables. Every environmental dynamic that is model-specific can be counted to it. An important consequence of this view is that the agent and the environment constitute a single system, i.e., the two aspects are so intimately connected that a description of each of them in isolation does not make much sense.

Running this computer model of an artificial society simply amounts to instantiate the simulated populations of people, letting the agents interact, and monitoring what emerges. Although embodied agents tend to be computationally simple and to live in computationally simplified environments, if one places many agents together in the same environment interesting collective behaviors tend to emerge from their interactions. What *emerges* from the collective execution of rules packaged in form of agents is a gradual updating of agent’s beliefs and the concomitant modification of their plans, arriving at some form of *social order*. This should be conceived as any form of systemic structuring which is sufficiently stable, to be considered the consequence of social self-organization and self-reproduction through the actions of the agents, or consciously orchestrated by (some of) them.

3. Virtual Prehistories

Archaeologists and historians have begun to convert social theories to computer programs, intending to simulate social processes and historical trajectories of known societies. It implies carrying out “historical experiments” that would otherwise be impossible.

There are increasing numbers of examples in the specialized literature. In the case of testing social theories by means of agent-based simulations we should consider the important studies by Claudio Cioffi-Rivilla (Center for Social Complexity, at George Mason University), Nigel Gilbert (Centre for Research on Simulation in the Social Sciences, at Surrey University), Scott Moss (Centre for Policy Modeling, at Manchester Metropolitan University), Klaus Troitzsch (Institute for IS Research, at Koblenz-Landau University). These authors, among many others, have developed the necessary computer languages and programming environments. John H. Goldthorpe, Peter Hedström, Diego Gambetta and Raymond Boudon have proved the fertility of explanation through social mechanisms, developing for years an analytical approach to social explanation, mainly with research about the interaction between cognitive rationality, axiological/normative rationality, social norms, the aggregate social outcomes, and other topics such as beliefs or values that conforms the individuals/agents motivation (see references in Hedström and Bearman 2009).

There is also an increasing number of simulation studies applied to historical research. Most of them are based on pioneering work by Jim Doran, whose EOS system simulated the emergence of social order at the end of Middle Paleolithic Times (Doran et al. 1994). Doran's approach has been pursued by many other scholars, which have modeled different hypotheses about foraging behavior and social reproduction in small-scale societies. Of related interest are simulations of hominid behavior, using relevant archaeological and paleo-ecological data to test specific hypotheses about the origin of humankind (see references in Kohler and Leeuw 2007, Barceló 2009, Costopoulos and Lake 2010).

The interaction between physical environment and the social agents is now well understood, but we need much more theoretical and methodological work to implement social interaction and the emergence of social contradictions along historical trajectories. Going beyond forager behavior, and moving towards the explanation of the emergence of social complexity, some preliminary work has been published. We can mention the studies about the emergent mechanisms that lead to social institutions in small-scale societies. Artificial societies are also being programmed for studying the origins of agriculture, and pastoral nomad/sedentary peasant interaction can also be analyzed using such methods.

The VIRTUAL ANASAZI project (Gummermann et al. 2003) and the "Village Ecodynamics" project by Tim Kohler and his colleagues (Kohler et al. 2000, 2008, Kohler and Leeuw 2007, Janssen 2009) are "real sized" simulations of historical agricultural societies, designed to investigate where prehistoric people of the American Southwest would have situated their households based on both the natural and social environments in which they lived. Finally, we can mention the investigations by researchers at the University of Chicago and Argonne National Laboratory (Altaweel 2008, Christiansen and Altaweel 2006) who have modeled the trajectories of development and demise of Bronze Age settlement systems for both the rain-fed and irrigated zones of Syria and Iraq. These investigators intend to demonstrate that systems of ancient Near Eastern cities co-evolved in an intimate relationship with their environment, primarily by means of the aggregation through time of smaller fundamental units (e.g., households).

4. Simulating Prehistoric Patagonia

We have built an artificial society based on what we know ethnoarchaeologically from prehistoric Patagonia and the emergence of ethnicity (Barceló et al. 2010). Inside the model, a population of virtual agents moves randomly in search for resources, and organized in households as ancient Patagonians did. There are two kinds of economic activities: gathering, which was an individual task, and hunting, which was only possible when the members of different households culturally similar did cooperate. There are increasing returns to cooperation, i.e. families get more resources working together than individually, modulated by the global parameter **returns-to-cooperation**. Nevertheless, hunting is also affected by *diminishing* marginal returns relative to the number of households cooperating (another model parameter). To find cooperants, households should interact with others within a single local neighborhood – its geographical radius is a model parameter-, within the limits allowed by they perceived cultural similarity.

Households have a distinctive cultural identity, modeled as a q dimensional space with k different cultural traits. This is a surrogate for language and cultural values differences. In this simple model we are not interested in the precise representation of what differentiates "cultures", not only on the intensity of such a difference. Cultural similarity is measured as the relative number of shared cultural dimensions. Consequently, two households consider themselves as belonging to the same "ethnic" group if they are appropriately culturally similar, that is to say, if their cultural similarity is above a critical threshold, also a model parameter.

"Culture" diffuses into population through a local imitation process. With a fixed probability level a household copies some trait of the mode of her group, in such a way that consensus increases and "culturally" homogenous groups tend to emerge. Moreover, "culture" evolves through local mutation, that is to say, the attained levels of "cultural" identity are also submitted to random cultural drift. With a fixed probability level, a household mutates one of her cultural traits which is simultaneously copied by her group (we supposed that geographical proximity ensures that culture of all group members evolves in the same direction).

Our simulation confirms that the degree of cultural differentiation, and hence the emergence of more or less "ethnic" groups seems to depend on:

1. the number F of cultural features that characterize each agent,
2. the number q of traits that each feature can take on,
3. the size A of the territory or, equivalently, on the number of interacting agents.

But the main result of our simplified model is the emergence of ethnicity and the partitioning of social networks even in the case population did not grow. In other words, cultural diversity not only depends on the size of population nor on the extension of territory, but it is socially mediated by many other social feedback processes that affect the way homogenous groups are born, reproduce and die. Ethnic partitioning follows culture differentiation which also follows the intensity and reproduction of labor cooperation. This is a complex social mechanism characterized by the dialectical relationship between the higher payoffs of cooperation, the local carrying capacity, the level of technological development and the risk of increasing social stress when surplus accumulates and wealth became unequally distributed.

Furthermore, in our model, social fusion appear to be less frequent than the fission of former groups, basically by the cost due to *diminishing* marginal returns relative to the number of households cooperating. Only if some individuals within the group increase their own productivity and the absolute volume of their production above a critical threshold, they can invest such a surplus to increase coercion, and hence maintain ever increasing levels of social inequality. Without a dramatic change in technology (i.e. agriculture, pastoralism) we think that this social change is mostly infrequent.

5. Conclusions

By simulating societies that may have existed somewhere and somewhen we can approach the understanding of social

activities in the past in terms of a "pure" system and analyzing then the space of possibilities which are open to the system.

We do not pretend to simulate social action as a free exercise. We intend to create virtual societies according to social theory and available historical data to test the observable consequences of such theory and to be able to create the appropriate measuring instruments and to test the theory in the real world. Therefore the starting point of the analysis of social systems by means of computer simulation is not the simulation of one particular system but the investigation of the logically and statistically possible development of specific classes of model systems (pure systems). As these pure systems usually generate a lot more different paths of development than are known from real human history, we have to limit these possibilities by introducing social constraints which are known from social reality. The sociologically interesting question is then why these constraints appeared in reality. Therefore the introduction of constraints is both a methodical tool to limit the logical possibilities and a way to make the models valid for the mapping of social reality.

Agent-based modeling is a mindset more than a technology. With the possibility of simulating past social systems, a new methodology of social and historical inquiry becomes possible. The target is no more a natural society but an artificial one, created with its own structure and behavior (the simulation itself). The value of creating artificial societies is not to create new entities for their own sake, but observing theoretical models performing on a test-bed. Such a new methodology could be defined as "exploratory simulation". Exploratory research based on social simulation can contribute typically in any of the following ways:

- Implicit but unknown effects can be identified. Computer simulations allow effects analytically derivable from the model but as yet unforeseen to be detected;
- Possible alternatives to a performance observed in nature can be found;
- The functions of given social phenomena can be carefully observed
- "sociality" that is "agenthood" orientated to other agents can be modeled explicitly

The simulation may either provide a test of the models and its underlying theory, if any, or may simply allow the experimenter to observe and record the behavior of the target system. As the emphasis shifts from describing the behavior of a target system in order to understand natural social systems the better to exploit the behavior of a target for its own sake, so the objective of the research changes to the observation and experimentation with *possible social worlds*.

Because of this focus on social actions as *practiced* by human actors in reference to other human actors, a computer simulation of social mechanisms having occurred in the past would allow archaeologists to explain what it happened in the past in terms of human motivation and purposefulness. Inside the computer, social activity performed in the past would appear shaped primarily by an intention held by the intervening agents; in fact, the programmer is able to distinguish one activity from another only by virtue of their differing motivations or intentions in different historical circumstances. That is to say, when explaining the past in terms of a simulated network of actions and agents, social actions are no more understood without a frame of

reference created by the corresponding social motivation or *intention*. Social activity in the past can then be explained as composed of subjects, objects, needs, motivations, goals, actions and operations (or behavior), together with mediating artifacts (signs, tools, rules, community, and division of labor). In this framework, a subject is a person or group engaged in an activity performed by another agent. An object is the consequence of this activity. An intention or motivation is held by the subject and it explains activity. Activities are realized as individual or cooperative *actions*. Chains and networks of such actions are related to each other by the same overall object and motivation. For their part, actions are programmed as chains of operations, which are well defined behaviors used as answers to conditions faced during the performing of an action. Activities are oriented to motivations, that is, the reasons that are impelling by themselves. Each motivation is an object, material or ideal, that satisfies a need. Actions are the processes functionally subordinated to activities; they are directed at specific conscious goals. Actions are realized through operations that are the result of knowledge or skill, and depend on the conditions under which the action is being carried out.

We do not know in the present, what caused human action in the past. But inside a computer simulation, agent motivations or intentions can be implemented not only as mere conditions for developing cognitive activity, but also as real factors influencing agent behavior and productivity and defining the social matrix of agent interaction. Inside the computer model, social activity is characterized by essential variability in the behaviors with which they are executed. The frontier between intentional activity and operational behavior is blurred, and movements are possible in all directions. Agent rational intentions can be transformed in the course of an activity. An activity can lose its motivation and become an action, and an action can become an operation when the goal changes. The motivation of some activity may become the goal of an activity, as a consequence of which the later is transformed into some integral activity. The definition depends on what the subject or object in a particular real situation actually is.

Therefore, any explanatory account of a simulated social world must take into account the manner in which the cognitive core of any agent comes to represent not just the gross features of the physical environment in which it is situated, but also the character of the other cognitive creatures with which it interacts, and the details of the social world in which they act. The goals of the agent must be inherent to the agent, rather than being assigned according to a pragmatic 'stance' by an external programmer. Goals, beliefs, and intentions are then arbitrary interpretations of events that took place within the simulation. They do not exist as explicit sentences. Rather, the programmer should be aware of those things that are playing a prominent role in constraining the global constraint satisfaction settling process within the simulation.

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