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WHY MODEL?

S. E. VAN DER LEEUW

Department of Anthropology,
Arizona State University,
Tempe, AZ, USA

I discuss the utility of modeling in the social sciences, with emphasis on the long-term study of the coevolution between society and nature. I emphasize the need for such models to develop dynamical theories concerning processes about which we are only informed through their consequences and results.

INTRODUCTION

I am often asked, "If and when you are able to observe human behavior all around you, why would you want to model such behavior? And if you do, what can you hope to achieve?" In the second part of this paper, I will try to answer these questions, and some others, from the narrow perspective of one of anthropology's subdisciplines, environmental archaeology; but that requires that I first outline the particularities of that discipline with which most of the readers of this journal are not familiar.

Archaeologists and historians have been called "prophet[s] turned backwards." They deal with a distant past about which they often know as little as about the future. Their objective is to explain the remains of the past, both in terms of processes that may be presumed to have been valid in the past as they are in the present and in terms of the special circumstances that distinguish the past from the present. In doing so, they have to

Address correspondence to S. E. van der Leeuw, Department of Anthropology, Arizona State University, P.O. Box 872402, Tempe, AZ 85287-2402, USA. E-mail: vanderle@asu.edu

deal with a particular conjunction of problems that do not apply to any other discipline. Four of these are particularly relevant in this context. First, archaeologists cannot assume that their sense of the relationships between people and their artefacts is the same as that of the people they study. Second, archaeology bases its interpretations on few and meager clues about the past. Its theories are therefore generally underdetermined by observations; its data, moreover, are static. They reflect the results of dynamics between people and materials, landscapes, monuments, and so forth, but they do not reflect these dynamics themselves. The discipline therefore has difficulty linking cause and effect in the past. Third, in contrast to most other disciplines, archaeology does not aim to reduce a wealth of data to a few essentials. It does the reverse, putting flesh and clothing on "bare bones." Its logic is therefore very different from the logic of the natural sciences, but also from that of the social sciences. Finally, archaeology is fundamentally pluridisciplinary. It uses both information derived from widely different kinds of data and interpretations that attempt to combine the natural and life sciences with the social sciences and humanities.

PARTICULARITIES OF ARCHAEOLOGY AS A DISCIPLINE

First, to archaeologists, "the past is a foreign country." They do not speak its language or know the customs of its inhabitants. Hence, they cannot assume that their sense of the relationships between cause and effect, or between people and their artefacts, is the same as that of the people they study. An ethnographic example from Papua New Guinea beautifully illustrates the difficulties this causes. In the western highlands, many populations have a different perspective on the relation between past and future than we do in Western societies. Whereas we feel the past is behind us, and we are looking toward the future, the highland tribes argue that, as they can see things in the past, they must be turned with their back toward the future. Hence, the general tendency among many tribes is to idealize a stable past, and to view any kind of change as "degradation." The tribes "keep on course" by comparing the present to the past, much like a person in a rowboat sets course by aligning the boat's present position and direction with a fixed point in the direction from which it came. If the present deviates too much from the past, the highland tribe will try and correct the course it is on by (ceremonially) going back to the point in time where the root of the problem lies and sorting it out. In the case of the Huli, which we know very well through the recent work of Ballard (1995), we can follow the development of environmental degradation through time and glimpse the history of a population that slowly moved from the dry hillsides into the swamps that predominate in the valley below. A population initially concerned with having water flow over their fields became one concerned with draining it out of those fields.

How could that have come about? From a Western perspective, where the past is past and the future is what counts, one would probably argue that the population made the move deliberately—that living in the valley had an economic or other advantage. But Ballard's detailed field research presents a very different picture. Observing some degradation, the society felt the need for a ceremony in order to correct things that went wrong in the past, so as to reestablish the equilibrium between people and nature. Such a ceremony would require feasting, notably the killing of large numbers of pigs to be sacrificed and eaten by the participants. Raising the necessary pigs required cutting down the forest to expand the area devoted to horticultural activities. The pigs, moreover, ravaged the vegetation around the gardens. As soon as the destruction of the vegetation exceeded a certain threshold surface, erosion followed rapidly under the tropical rains. Rather than moving down the slope deliberately, a positive feedback loop between its perception of time, of the environment, and of the means to improve it destroyed the population's means of subsistence and forced it to move down the slope against its design. The inhabitants' concern to keep the environment as it was in the past ultimately transformed that environment and landed the people in the marsh formed by the soil that washed down the slope!

Second, the difficulties of relating observations to processes are compounded by the fact that archaeological data are usually very scant. As a consequence, their theories are generally extremely underdetermined by the observations from which they are derived. To explain underdetermination, Atlan (1992) presents a simple but troubling example. Suppose one has five lights, which can shine red, yellow, or green. There are in that case 3^5 possible combinations of the three colors, and 3^{25} (about a thousand billion!) possible combinations of connections between them that could explain the exact configuration of lights observed. It is easy to see that to decide between them on a logical basis would take an inordinate number of observations. If, in this relatively simple case, there are not enough equivalent possibilities to link the observations into a theory that explains them, we must conclude that most theories about more complex phenomena are underdetermined by our observations and overdetermined by the ideas that we bring to bear on them.

This problem does, of course, affect all scientific disciplines. But in the natural sciences it is less acute than in the social sciences and humanities, either because the problems studied are very simple or because the theories formulated to explain complex problems reduce the problems to their simplest (unrealistic) forms, or both. Moreover, both the natural and the social sciences can study processes as they occur. They can thus multiply the number of observations by taking all successive observed instances of a process into account. Archaeological data, however, are essentially static. It is therefore impossible for archaeologists to attain the densities of observation that are commonly achieved in the natural and social sciences.

Another consequence of the static nature of archaeological data is that they do not point to specific relationships between cause and effect. Our data reflect the *results* of interactions between people and materials, landscapes, monuments, and so forth, but they do not reflect these interactions themselves. At best, these interactions can be inferred from circumstantial evidence—for example, if the same artefacts regularly occur together in similar contexts, or if one consistently observes co-variation between human activities and environmental changes.

Altogether, therefore, archaeologists are more open to "reading explanations into the data" than are members of many other disciplines. That danger is all the more real because it is exceedingly difficult in archaeology to contradict a theory. There are two reasons for this. Firstly, notwithstanding theoretically rigorous procedures for the recording of all sections, plans, objects, and contexts by a variety of means, anything that is not identified as information during the excavation will usually not be registered because its significance is not understood. Second, excavations require large amounts of time and money. Hence, it may take a generation or more before a site is excavated that provides the evidence to contradict the conclusions of an earlier excavation. By that time the earlier theory has had a chance to profoundly influence the course of the history of the discipline. In that sense, archaeological theories are a bit like the spectacular press "scoops" that are denied ten days later in fine print on page fifteen of the newspaper that initially announced them in headlines on the first page.

Third, in contrast with most other disciplines, archaeology does not aim to reduce a wealth of data to a few essentials, but to do the reverse. It is the aim of the discipline to put flesh and clothing on bare bones. Whereas for most scientists, explanation is a question of isolating from among a wealth of observations the few that, together, explain all the others, for archaeologists explaining the few bits and pieces they have usually means viewing them as the remains of processes that involved much more. As a result, the structure of archaeological reasoning is very different from that of most other disciplines and, in particular, from the natural, life, and social sciences.

One of the most basic tenets of much of modern science, usually referred to as "Occam's razor,"[1] holds that phenomena are simple unless it can be demonstrated that they are complex. When faced with several alternative explanations, the scientist must therefore choose the simplest—that is, the one that involves the fewest number of assumptions. In archaeology, however, phenomena are assumed to be complex unless their simplicity can be demonstrated. Simplicity or elegance therefore can not be used to decide between theories as is done in mathematics or physics.

The historical nature of the discipline also precludes the use of experiments as a tool to corroborate theories. It is generally held that the phenomena studied are so complex, and involve so many degrees of freedom, that historical phenomena are unique combinations of more generally valid processes. They may be thought of as deriving that uniqueness from their sensitivity to initial conditions. As such, therefore, they do not recur ("history does not repeat itself") and, because they do not, it is not possible to corroborate any theory by means of experiments.

But another aspect of the sensitivity of historical phenomena to initial conditions has even wider implications, although these have not yet been widely discussed. Complex systems theory does not only assert that similar causes can have different effects, but also that different causes can have similar effects. This poses at least two important problems. The first of these is epistemological. One needs to ask whether it is always possible to distinguish different causes from similar ones, or similar effects from different ones. The answer is mainly dependent on the sensitivity of one's measurements and conceptual distinctions. But the second problem is

[1]Named after the medieval British monk William of Occam who first formulated this principle.

ontological and much more difficult to answer: we have to question the validity of the relationship between imputed causes and observed effects, which is one of the cornerstones of the Western scientific and intellectual tradition. For a growing number of archaeologists, these two problems preclude the use of either "verification" or "falsification" as means to decide between theories, except in very rare circumstances.

As a result of these difficulties (and others), archaeologists therefore generally decide between theories on the basis of their internal coherence and the volume of data that appears to corroborate them, as well as on the diversity of the instances that can be explained by invoking a theory. But inevitably, they also are influenced by the extent to which theories coincide with the archaeologist's personal experience, general worldview, and, in particular, current vision of the past. The scenario is often one of accepting the least improbable explanation. Or as one leading archaeologist put it, "my faith in an archaeological explanation is proportional to my faith in the archaeologist that proposed it."

Finally, the discipline is fundamentally pluridisciplinary. Archaeology studies all aspects of human behavior, anywhere on Earth, during the whole of the time span covered by human existence on the planet. It thus uses information that is derived from widely different kinds of data, analytical techniques from most scientific disciplines, and interpretations that combine the natural and life sciences with the social sciences and humanities, and so on. That pluridisciplinarity requires archaeologists to formulate their theories in ways that are compatible with the languages used in different disciplines. They are required to search for formalisms that explain, for example, the interaction between societies (as described by sociologists and economists) and their natural environment (as described by biologists, ecologists, geologists, and others). Anyone who has done any pluridisciplinary research knows that this in effect entails redefining the objectives to be attained, the questions to be asked, and the methods and techniques to answer them, in interaction with representatives of the disciplines involved.

VALUE OF MODELING

Why then model? One advantage of models is that they enable researchers to economically describe a wide range of *relationships* with a *degree of precision* usually not attained by the only other tools we have to describe them: natural languages. This is extremely relevant to pluridisciplinary research. Each discipline has its own vocabulary and approach, and one of the major difficulties in pluridisciplinary research is to find ways to express oneself that are acceptable to all the disciplines involved and that are free from the connotation of any or all of them. It is thus a major asset of models in that they can be used to express phenomena and ideas in ways that can be understood in the same rigorous manner by practitioners of different disciplines. This is particularly relevant in a discipline such as environmental archaeology, which is based on differentiating between the natural and the life sciences on the one hand, and the social sciences and humanities on the other.

But this aspect of modeling is also relevant at a time at which internationalization of research is the order of the day. One of the fundamental problems of the social sciences and humanities is the fact that, because they study social phenomena, their descriptions are closely linked to specific natural languages. The fact that in the United States one speaks of *cultural anthropology*, for example, but in the United Kingdom one speaks of *social anthropology* reflects fundamentally different ways of looking at human behavior. In origin, the differences may be related to the fact that, whereas in North America understanding cultural differences was the more important challenge, in the United Kingdom understanding social differences headed the list of priorities. Nevertheless, these differences in initial circumstances have led to fundamentally different approaches, toolkits, and theories about social dynamics. Such differences have often hampered international collaboration on social science topics. As a matter of fact, the only discipline that has broken through such fragmentation along national lines is economics, and this is in no small part due to the fact that it does have a formal mathematical language.

Another important advantage of formal models is that the *domain of application of formal models is unlimited.* It therefore includes all aspects of anthropology or any other discipline. Thus, models may include, for example, kinship, ritual, choice, behavior, and so forth alongside aspects of the dynamics between society and the natural environment upon which it is predicated.

Moreover, I find formal models particularly useful in a pluridisciplinary context because they are sufficiently abstract not to be confounded with reality, and sufficiently detailed, rigorous, and (in the case of some computer models) ‘‘realistic’’ to force people with different backgrounds to focus on the same relational and behavioral issues. In various research situations, models have therefore allowed me to dissolve blockages that were due to the fact that some participants did not understand or accept parts of someone else's theory or assumptions. Showing that such assumptions improved the match between the phenomena to be "predicted" after running the model and the actual observed phenomena provided a neutral and unemotional test, and the discussions that were held on the way clarified many insights to all concerned.

No less important in a social science context is the fact that formal models are *not formulated in the same language as describes the phenomena to be modeled*. This has several advantages, of which the most important is possibly that it allows us to abstract—to highlight features that are in our opinion relevant. It is a common assumption, for example, that one may not compare apples and oranges. Yet if one wishes to *explain* why oranges are better at rolling in a straight line than apples, one invokes an abstract dimension (roundness) and compares both kinds of fruits in terms of that dimension. The applicability of any particular model to a set of phenomena does not follow "naturally" from the nature of the phenomena but is defined by the person who applies the model. Models can therefore, at least in theory, be useful in solving problems in which it is important to infer relationships between the observed behavior of certain phenomena and characteristics of these phenomena that have as yet not been identified.

Moreover, certain kinds of formal models are able to describe the *changes* occurring in complex sets of relationships with such precision and economy of space. Due to these properties, modeling is very suitable to formalize dynamic theories about certain phenomena, which can then be compared with our observations. This makes such dynamic models particularly useful for the archaeologist who has mostly static data at his or her disposal. It facilitates their "putting flesh and clothes" on the bare bones of sequential static data sets by helping them to link dynamic processes to their static outcomes. It should be noted, however, that this implies a somewhat different use and status of the models involved than is common in certain other disciplines. Rather than modeling the real world, archaeologists model theories in order to test them against observed data that are supposedly the result of the processes modeled. Other classes of models (multiagent models) allow us to combine such rigorous descriptions of changes over time with an equally rigorous analysis of the role of spatial dynamics in constituting patterning. This is a very important property when one wishes to understand the evolution of landscapes, for example.

In an intriguing way, dynamic models may also allow the archaeologist to some extent to experiment with different scenarios to explain particular sequences of cause and effect. One may, for example, use epidemiological models to study the spread of a disease (Zubrow 1997) or use modeling to relate different environmental and social parameters to the evolution of early sedentary populations in the southwestern United States (Kohler and Gumerman 2000). By running each scenario many times over, one may moreover assess the probability of certain outcomes given a particular set of initial conditions and one or more theories about the dynamics involved.

And finally, certain classes of models allow us to study how interactions between individual, nonidentical entities at a lower level actually result in patterns at a higher level. This is particularly relevant in the study of many of the collective phenomena that are the subject of the social sciences, where the interactions between individuals create the society, which in turn impacts upon the behavior of the individuals or groups concerned. Because of this property, such models are particularly interesting for those of us who study society from a self-organizing perspective.

WHAT CAN ONE HOPE TO ACHIEVE?

What can one hope to achieve by using formal models? Maybe the best way to answer that is by referring to some of the models we have designed and used in the context of our study of the causes and consequences of desertification, land degradation and land abandonment.[2] A first series of models, of the Palaeolithic dynamics of herbivore and carnivore fauna, attempted to get a sense of the natural dynamics in the Mediterranean environment before the impact of human beings transformed that environment. Studying a model based on extant predator–prey equations, we came to the conclusion that the predicted dynamics did not come anywhere near the real ones. We then built a multiagent model of

[2]The models referred to here were all constructed as part of several research projects that I coordinated between 1992 and 2000. These were financed by the Directorate General for Research of the European Union as part of its "Climate and Natural Hazards" research program. More information can be obtained by sending an email to vanderle@mae.u-paris10.fr

the same situation and, in running it, discovered that the "overkill" hypothesis on which these equations are based does not explain much unless the behavior of the individual animals is spatialized. Coupling a Geographic Information System (GIS)-based map of the main landscape units to the simulation allowed us to predict the dynamics that could be inferred from the data with reasonable accuracy.

Another series of models dealt with rural–urban dynamics. These dynamics concern many different spatiotemporal scales. We combined a multiagent model of the past 2000 years of settlement dynamics for a part of southern France, based mainly on historical and archaeological evidence, with a similar model of the dynamics of individual migration in the area in recent times. The former model concerned the interaction of whole settlements (from small villages to towns). After many runs, we had to conclude that the parameters included in it would not explain the present-day spatial configuration of urban centers in the area (van der Leeuw 2000). These parameters were based on a conceptual model of rural–urban interaction that is valid for the Roman and Medieval periods. By adding a set of self-triggered parameters based on a conceptual model of industrial towns, however, we achieved a model that did replicate the whole of the settlement system reasonably well. These parameters began to kick in after about 1500 (yearly) cycles of the model. Interpreted in historical terms, this exercise pointed out that the dynamics occurring from about 1500 AD on are indeed qualitatively different from those driving earlier developments of the system.

On a different, decadal time-scale, the urban system of southern France is heavily dependent on migration, and the aforementioned model cannot take that into account. We therefore built another multiagent model of the population dynamics in southern France as a function of individuals' lifetime decisions, from conception and birth through education, partner choice, career development, and so on, until death. This model allowed us to gain additional insights in the operation of the settlement system dynamics, which were not to be gleaned from the first (settlement-level) model.

In a third case study, of the agricultural dynamics of a region in southern Greece, we built a whole series of models ranging from relatively abstract, master-equation-based and only roughly spatialized models to detailed, multiagent models of decision making which took local decision-making procedures and criteria into account.

Experimenting with each model in turn taught us the need to view environmental problems as the result of a coevolution and allowed us to assess the adequacy of our ideas by successively adding more and more parameters to an initially relatively simple model. This experiment in model building ended with a full-blown model of spatial decision making under changing environmental and economic circumstances, which took the hydrological dynamics, the suitability of different landscape units, and the existing cognitive aspects of crop decision making into account (Lemon et al. 1999).

In conclusion, in our work the possibility of falsifying a conceptual model by implementing it and testing it against observed data turned out to be one of the two major gains of a modeling approach. But the second major gain was at least as important. We heavily exploited the possibility offered by dynamic modeling to focus the minds of many people from different disciplines and cultural backgrounds on the same set of phenomena. The multiagent models rapidly became the focus of true interdisciplinary collaboration in the project. This seems due to two facts: first, that they act as a kind of mirror that reflects the implications of different conceptual models in a neutral way, and second, that multiagent models are based on a bottom-up principle, which facilitates implementing combinations of conceptual models about individual behavior. It thus reduces the numbers of degrees of freedom to be input without jeopardizing the degrees of freedom inherent in the interaction between people.

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