ARTIFICIAL LIFE AND HUMAN SOCIETIES

Parisi D.
Institute of Cognitive Science and Technology, National Research Council, Italy

Keywords: Artificial Life, neural networks, genetic algorithms, human societies, biological evolution, cultural evolution, social survival strategies

Contents

Summary

Artificial Life is the study of all phenomena of the living world through their simulation in a computer. The phenomena of the living world include individual human behavior and its products, that is, human societies, cultures, and technologies. Artificial Life simulations of human behavior and societies do not ignore their biological underpinnings but do not try to reduce these phenomena to biology. The chapter briefly describes the basic tools used in the simulations (neural networks, genetic algorithms, learning procedures, models of the environment, cellular automata) and presents simulations of biological and cultural/ technological evolution, types of survival strategies adopted by human societies, and historical versus abstract human societies.

1. Artificial Life

Artificial Life is the study of all aspects and phenomena of the living world by means of their reproduction in artificial systems. To reproduce a phenomenon in an artificial system generally means to simulate the phenomenon in a computer. However, in some cases, for example if one is interested in studying the behavior of an organism in the environment, it may be appropriate to construct computer controlled physical systems such as biomorphic robots that reproduce the behavior and the physical interactions of the organism with the environment. Simulations are a new modality of expression of theoretical models in science. Traditionally, scientific theories and models are expressed in some symbolic medium which may include some more or less formalized portions of everyday language, logical expressions, and the quantitative symbols of mathematics. Simulations are theoretical models that are expressed as computer programs. As computer programs that can run on a computer, simulations are “active” theories or models. The researcher can run the simulation and observe if the results of the simulation replicate the phenomena which the theory/ program was intended to explain. If a theory is expressed as a computer program, this guarantees that the theory is consistent, complete, and free from vague terms and unexpressed assumptions, since otherwise the program could not run in the computer or it would not produce the expected results. This may represent a critical advantage of simulations as theoretical tools for the social sciences since, often, theories in the social sciences are not demonstrably consistent and complete, are expressed with insufficient precision, and may contain implicit and dubious assumptions. Artificial Life has a particular perspective on the phenomena it studies: it tends to view the phenomena of the living world as complex systems. A complex system is a large set of elements that interact locally and through their interactions give rise to global properties of the entire system that cannot be deduced or predicted either from a knowledge of the elements, or from the rules that govern their local interactions. Complex systems exhibit a number of properties that are different from those of simple systems. First, complex systems are very sensitive to initial conditions. Very small differences in initial conditions between two systems can result in large and unpredictable diverging paths in the further evolution of the two systems. Second, complex systems tend to react unpredictably to external perturbations. Large external perturbations can be absorbed without visible consequences while small perturbations can cause catastrophic consequences. Third, complex systems tend to change in unpredictable ways, for example with long periods of stasis followed by sudden large changes. Finally, complex systems are often organized in a hierarchy of levels, with one system at one level of the hierarchy being an element of another system at the next higher level and complex two-way interactions between levels. Because of these properties of complex systems, Artificial Life is nonreductionist. The phenomena of the living world are deterministic but this does not imply that they are predictable. Furthermore, even if knowledge of the elements of a system and of the rules that govern their local interactions is extremely useful for understanding the system, knowledge of a system cannot be reduced to knowledge of its elements.

Simulations are crucial tools for the study of complex systems. Complex systems are not easily analyzed using the traditional tools of science, that is, traditional mathematical tools (e.g., equations) and laboratory experiments. Because of the large number of elements and the high nonlinearity of their interactions, equations that describe how aspects of the system change as a function of other aspects quickly become too unwieldy. Traditional laboratory experiments are appropriate for simple systems in which the researcher can manipulate a single cause or a few causes and be confident that these manipulations will have systematic and predictable effects but they are in general not very useful if one is interested in complex systems. On the other hand, although the properties of complex systems cannot be deduced or predicted from a knowledge of their elements, a simulation model of a complex system, that is, a model of its elements and of their rules of interaction, can be run in a computer and one can literally see what global properties emerge from the interactions among the elements.

Furthermore, simulations represent not only a new “language” with which scientific theories can be expressed but also new tools for the detailed empirical investigation of complex systems. Simulations function as virtual experimental laboratories in which the researcher can control and manipulate a large number of variables and observe the consequences of these operations in systems that are no longer in existence, or are too big, too temporally extended, or too complex to be brought into the real experimental laboratory. Given the limitations in the possibility of doing real experiments in the social sciences, the use of simulations as virtual experimental laboratories may constitute another critical advantage of simulations for the social sciences.

Artificial Life’s objective in its simulations is to reproduce all kinds of biological entities, from biomolecules to cells, from organs to entire organisms, from populations of organisms to societies and entire ecosystems, and to study all kinds of phenomena that can involve these entities, from the origin of life to evolution, from reproduction to growth and development, from behavior and learning to all kinds of interactions of organisms with their environment. One manifestation of the living world is the behavior and mental life of one particular species of organisms, homo sapiens, and the products of this organism’s behavior and mental life, that is, human societies, more specifically human cultures, technologies, and social structures and institutions. Although the term Artificial Life can suggest that Artificial Life is restricted to the phenomena studied by the biological disciplines (molecular biology, genetics, evolutionary biology, developmental biology, the neurosciences), this is not so. Artificial Life is also interested in simulating the phenomena of behavior and mental life studied by the cognitive sciences (psychology, linguistics) and the social and historical phenomena studied by the social sciences (anthropology, sociology, economics, political science, the historical disciplines). Given what has been said above about complex systems, this does not imply any kind of reductionism of cognitive and socio-historical phenomena to biology. Cognitive phenomena cannot be deduced or predicted from knowledge of biological phenomena, and societal phenomena cannot be deduced or predicted from knowledge of individual cognitive phenomena. However, it is characteristic of the Artificial Life perspective to use the theoretical tools of complex systems and the research methodology of computer simulation to study biological, cognitive, and social phenomena within a unified theoretical and methodological framework. This implies doing simulations in which, hopefully, all three types of phenomena are simultaneously present so that their reciprocal influences and interactions can be examined.

2. Artificial Life and Human Societies

Artificial Life is a recent development and even more recent are attempts at applying the Artificial Life approach to the study of human societies, although “social simulation” is currently flourishing as a new research field. Many social simulations implement some aspects of the Artificial Life approach to human societies but not others. In fact, Artificial Life is a sub-field of a larger field of “agent-based” social modeling. “Agent-based” models incorporate the basic idea of complex systems, that is, a population of elements (agents) from whose interactions the global properties of the system emerge. Agent-based models (or, as they are also known in the biological sciences, individual-based models) contrast with aggregate-variable models, in which a system is described by a number of aggregate state variables and the model is a set of equations specifying the relationship among the variables and how the value of one variable changes as a function of other variables. For example, one of the aggregate state variables describing a wood could be the wood's population size, that is, the number of trees making up the wood, and the model could contain equations specifying how population size varies as a function of variation in other variables such as time or soil and weather conditions. In contrast, an agent-based model of the same wood would simulate each individual tree and would treat population size as an emergent property of local interactions among individual trees and the trees' interactions with the external environment (soil and weather).

Agent-based models of human societies consider individual human beings as elements and try to capture society-level phenomena as an emergent result of the interactions of human beings with other human beings and with the environment. However, agent-based models vary in the extent to which they take biological properties of human beings into explicit consideration. For example, human beings manifest "behavior", that is, they react to external circumstances with appropriate responses (movements, actions, decisions, plans, etc.). This behavior can be modeled as the result of the execution of symbolically formulated rules that ignore the physical (biological) properties of organisms or it can be the product of an artificial neural network directly inspired by the physical structure and way of functioning of an organism's nervous system. Human beings as elements of an agent-based model can all be identical (i.e. their behavior results from an identical set of rules shared by all individuals) or, with more biological realism, no two individuals are identical and inter-individual variability is a critical feature of the system and of how the system changes in time. The behavior of an individual can be hardwired by the researcher and it does not change in time or, again in a biologically more realistic way, it can be the result of a process of change at the population level (evolution) or at the individual level (development).

Artificial Life tends to simulate human societies as the emergent result of the behavior of human beings endowed with biological properties. As all theoretical models in science, Artificial Life simulations simplify with respect to actual reality. However, the artificial human beings that "behave" in an Artificial Life simulation tend to have a nervous system and a physical body, they tend to live in a physical environment, to inherit a genotype from their parents, and to be members of biologically evolving populations.

3. Basic Modeling Tools

In this section we describe some basic modeling tools used by Artificial Life to study the behavior of organisms.

3.1. Neural Networks

If one is interested in simulating the behavior of organisms as the product of the functioning of their nervous system, one can use neural networks. Neural networks are simulation models of the behavior of organisms that are directly inspired by the physical structure and way of functioning of the nervous system. Neural networks are sets of units (neurons) that influence each other through unidirectional connections (synaptic junctions between pairs of neurons). Connections have a "weight" (number of synaptic sites at a synaptic junction) and a "plus" or "minus" sign (excitatory or inhibitory connections). A typical neural network has input units, output units, and internal units. The input units are connected to the internal units and the internal units are connected to the output units.

In any given cycle all the network's units have an activation level. The input units' activation level is determined by the current state of the environment outside the network. The internal units' and output units' activation level is determined by the activation level of the units that send excitations or inhibitions to each internal or output unit, filtered by the sign and weight of the relevant connection. If we call "activation pattern" the set of activation levels of a set of units, the network functions by (a) encoding the state of the outside environment in the activation pattern of its input units, (b) transforming the input units' activation pattern into the activation pattern of its internal units, (c) generating an activation pattern in its output units which has some consequence for the outside environment.

Unlike "classical" neural networks, neural networks in an Artificial Life perspective have a body and live in a physical environment. To have a body means that the activation pattern of a network's input units can encode not only the state of the environment outside the organism's body but also some internal state of the organism's body. Similarly, the activation pattern of the network's output units can encode a physical movement that has consequences for the external environment or for relationship of the organism's body to the external environment, but it can also encode a change of the internal state of the organism's body. Furthermore, the physical properties of an organism's body (shape, size, spatial arrangement of sensory receptors, type and degrees of freedom of motor systems, internal organs and systems) have important consequences for the behavior of the organism.

To live in a physical environment means that it is not the researcher who decides what is the input to a neural network, as in "classical" neural networks, but it is the environment that at any given time determines the input. Furthermore, by moving in the environment or by physically modifying the environment neural networks can influence their own input.

The neural networks of simple organisms tend to be restricted to mapping external input (from the outside environment or from inside the body) into externally directed output (external movements or changes in the body). The neural networks of more complex organisms include many recurrent connections that self-generate input for the network.

Much of the input to which the neural network responds is not coming from outside the network but is self-generated internally by the network itself, and the network's output does not encode external movements or changes in the organism's body but it encodes self-generated input feeding back into the network. Self-generated input underlies mental images, memories, predictions of future states, plans, and inner speech. Hence, more complex organisms such as human beings have a "mental life" and not only a behavior.

-
-
-

Bibliography

Epstein R. and Axtell R. *Growing Artificial Societies*: *Social Science from the Bottom Up*. Washington, Dc: Brookings Institution Press, 1996.[Presentation of Sugarscape, a model of social phenomena as they emerge from the local interactions of many "agents", with various applications]

Gilbert N. and Troitzsch K.G. *Simulation for the Social Scientist*. London, Open University Press, 1999.[An introduction to social simulation and a handbook of social simulation tools]

Holland J.J. *Adaptation in Natural and Artificial Systems*. Cambridge, Mass., MIT Press, 1992.[Originally published in 1975 this book introduces the notion of a genetic algorithm and applies it to biological and economic phenomena]

Langton C.G. *Artificial Life*. Cambridge, Mass., MIT Press, 1995.[A collection of papers on the various facets of Artificial Life by some of the protagonists of this new research area edited by the person who has done more than any other to create the new field]

Parisi D. *Artificial Life and Neural Networks. In Frontiers of Life.* San Diego, Academic Press, in press. [How neural networks in an Artificial Life perspective are different from "classical" neural networks]

Parisi D. What to do with a surplus. In Conte, R., Hegselmann, R. and Terna, P. (eds.) *Simulating Social Phenomena*. New York, Springer, 1997. [Simulations of individual survival strategies and social survival strategies]

Rumelhart D.E., and McClelland, J.L. *Parallel Distributed Processing*. Volume 1. Cambridge, Mass., MIT Press, 1986.[The "bible" of classical neural networks]

Biographical Sketch

Domenico Parisi is director of research at the Institute of Cognitive Science and Technology of the National Research Council in Rome. He teaches general psychology at the LUMSA University in Rome and is editor of the journal Sistemi Intelligenti (Intelligent Systems). His current research interests are in extending Artificial Life models to the study of specifically human behavior and the products of this behavior; that is, human societies, cultures, and technologies. His recent publications include *Rethinking Innateness. A connectionist Perspective on Development* (with J.L. Elman et al., MIT Press, 1996), and *Simulating the Evolution of Language* (co-edited with Angelo Cangelosi, Springer, 2002).