Book Review

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Hidden Order: How Adaptation Builds Complexity. John H. Holland. (1995, Helix Books/Addison-Wesley). $24.00, hardcover.

Computer simulations of artificial ecologies typically model the interactions of a population of independently-acting, spatially-situated, resource-restricted, differently-structured, self-reproducing agents. The interactions in such systems are typically highly nonlinear, subject to random perturbation, executed in parallel, and co-evolutionary in the sense that the agents interact with each other as well as their environment.

Examples of artificial ecologies that possess the above characteristics include Skipper's "computer zoo" of migrating flocks of hierarchically invokable fragments of assembly code [9], Shanahan's populations of evolutionary automata [8], Lindgren's co-evolving populations of strategies for playing the iterated prisoner's dilemma game [4], the Turing gas of self-organizing groups of autocatalytic algorithmic fragments of Rasmussen et al. [6], Ray's populations of parasitic and symbiotic self-reproducing assembly code programs [7], the populations of redcode coreworld creatures of Rasmussen et al. [5], Werner and Dyer's populations of males and females that co-evolve communication, and Ackley and Littman's artificial world for testing the Baldwin effect concerning learning and evolution [11].

Each of these complex adaptive systems (and many others like them) succeed in illustrating one or more key features of living systems. However, each of these systems live up to their name in the worst possible way --- they are all exceedingly complex. The emergent behavior and other interesting phenomena are obscured by so much model-specific detail that it is rarely clear whether the observed phenomena represent any important general principles or are merely artifacts of the details. Moreover, all of these existing systems are computationally expensive and deliver little in the way of important emergent phenomena in relation to the amount of computational effort expended. This excessive overhead is not merely a matter of inefficiency or inconvenience; it may actually preclude emergence of important phenomena that can only materialize in the presence of certain minimum amounts of time or matter.

John Holland's new book, *Hidden Order* [3], comes onto this scene of perplexing complexity with the important insight that things really may be simple after all. The theme of this new book is well expressed by the title of Holland's June 1994 Stanislaw M. Ulman Memorial Lectures at the Santa Fe Institute --- "Complexity Made Simple." Holland shows that there is a hidden order underlying the common phenomena that are exhibited by many seemingly different complex adaptive systems.

The ECHO model is the first version of Holland's unification of complex adaptive systems. ECHO explicitly deals with the fact that the agents in the population are independently-acting and self-reproducing. ECHO explicitly recognizes the importance of limited resources, the spatial location of resources, and the spatial location of agents (and changes in their location). In ECHO, fitness is implicit (as it is in nature); it is, at most, an observable quantity. Most importantly, ECHO treats the entire evolutionary process as an inherently co-evolutionary process that involves interactions between agents and other agents as well as between agents and their physical environment.

One narrow way to view ECHO is that it is a massive generalization of Holland's earlier genetic algorithm [1, 3]. However, the importance of ECHO is not what it adds to the genetic algorithm, but what is *subtracts* from almost all current thinking about complex adaptive systems. Holland's new approach captures the essence of complex adaptive systems with a handful of primitive relationships that express the interactions among the agents and between the agents and their environment.

Holland's unifying framework for explaining and understanding complex adaptive systems is based on three primitive mechanisms (tags, building blocks, and internal models) and four properties (aggregation, flows, diversity, and nonlinearity). Tags create distinctions among otherwise indistinguishable agents. In addition, ECHO has trading, combat, and mating as built-in interactions.

In a population of spatially-situated agents, tags induce the formation of the aggregates. The emergence of patterns of aggregation, in turn, leads to a network of non-linear interactions (flows). The mechanism of building blocks provides the ability to deal with the perpetual novelty of the environment. The formation of internal models [2] enables agents to anticipate and evaluate the future effect of potential actions. This later mechanism is not clearly demonstrated by this book; however, this insufficiency is hardly unique in the world of artificial intelligence, machine learning, and artificial life. The trading and combat interactions between agents result in an exchange (voluntary or involuntary) of resources between agents. Mating produces offspring that reflect the traits of their parents. The availability of resources imposes realistic regulation on population size.

Cooperation, symbiosis, parasitism, mimicry, complex offensive and defensive strategies, arms races, the evolution of money, and many other phenomena associated with complex adaptive systems have been reported from computer simulations using ECHO.

The generality of ECHO can be tested by a careful mapping into the ECHO framework of each existing artificial ecology in the field of artificial life --- perhaps starting with the group of eight artificial systems cited above [4-11]. Each of these systems contains (amid a great deal of operational clutter) a few of ECHO's mechanisms and properties (albeit in very different guises). Each has demonstrated one (or a few) of the emergent behaviors attainable by ECHO. The test imposed by such a careful mapping will probably necessitate elucidation of various details that are necessarily missing from this first book (which was intended for a general scientific audience).

The predictive power of ECHO can be tested by determining what additional emergent phenomena can be detected in these existing artificial ecologies (either by looking for previously overlooked occurrences of these phenomena or by enhancing these systems in directions suggested by ECHO so as to produce these additional phenomena). I would specifically nominate Skipper's rarely-cited "computer zoo" involving migrating flocks of fragments of assembly code [9] for special attention among this group of eight artificial systems. Skipper's 1992 work contains more direct analogies to ECHO's mechanisms and properties than the other seven systems; it also demonstrates numerous interesting emergent phenomena. It arguably contains an occurrence of the emergence of hierarchy (metazoans) that is not present in most other artificial ecologies (and has yet to appear in any ECHO simulation of which I am aware).

The book contains five chapters. The first provides the basic elements and describes the three mechanisms and four properties. The second chapter discusses adaptive agents, credit assignment, rule discovery, and internal models in terms reminiscent of the genetic classifier system [2]. The third chapter deals with interactions between the independent agents, such as trading, combat, sexual reproduction, and adhesion. The fourth chapter deals with simulating ECHO. The fifth chapter sets out Holland's approach to testing the usefulness of a new theory.

This book is fundamental reading for anyone seriously interested in understanding complex adaptive systems and artificial life.

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