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STEERING COMPLEX ADAPTIVE SYSTEMS

Complex adaptive systems (CAS) – systems such as ecosystems, markets, and the immune system – pose some of the most important problems of the 21st century. Because CAS have no central executive and are made up of diverse agents that learn and adapt as they interact, they are difficult to steer. This difficulty persists even though we have large databases for many CAS.

The key components of CAS are boundaries and signals: Biological cells are bounded by external semi-permeable membranes which pass selected proteins that serve as signals and resources; retail and wholesale firms are defined by departments that determine their buyers and sellers; immune system antibodies decompose invading antigens to signal other agents in the immune system; and so on. In all cases, tags – relatively small parts of the signals such as active sites on enzymes, headers in memoranda, and motifs in DNA – determine how the signals are routed and processed.

The conditional interactions between CAS agents, mediated by signals and boundaries, pose particular difficulties for traditional mathematics. Attempting to analyze CAS using a standard mathematical approach, say statistics, is like trying to learn the rules of chess by analyzing the statistics of tournament games. A less traditional option for examining CAS centers on extracting mechanisms (formally called operators) and the "building blocks" they manipulate (generators). The result is a finitely generated dynamics (FGD), an approach related to mathematical studies of finitely generated groups. An FGD leads to laws, similar to Newton's laws or Euclid's axioms, that help to steer the CAS, much like Newton's laws enable the steering of planetary probes.

Because CAS components are always assembled from copies of a limited variety of elements (generators) – 4 nucleotides for chromosomal DNA, 20 amino acids for proteins, 32-64 chip level instructions for computer programs, 26 letters for English words, and so on – the signals, boundaries, and tags of CAS-relevant FGD can be defined in terms of strings. Furthermore, genetic operators (e.g. mutation and crossover), applied to string-defined tags, determine the progressive co-evolution of signals and boundaries, a sine qua non for understanding and steering CAS.

BIOGRAPHY

John H. Holland is professor of computer science and engineering and professor of psychology at the University of Michigan; he is also external professor and member of the executive committee of the board of trustees at the Santa Fe Institute.

He was made a MacArthur fellow in 1992 and is a fellow of the World Economic Forum. He serves on the Advisory Board on Complexity at the McDonnell Foundation.

Professor Holland has been interested for more than 40 years in what are now called complex adaptive systems (CAS). He formulated genetic algorithms, classifier systems, and the Echo models as tools for studying the dynamics of such systems. His books Hidden Order (1995) and Emergence (1998) summarize many of his thoughts about complex adaptive systems.