Introduction to the Special Issue: Advances in Genetic Algorithms — Research Trends and Perspectives

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More than 20 years ago, John Holland published the book *Adaptation in Natural and Artificial Systems* (Holland, 1975) describing a general framework for understanding the mechanisms responsible for adaptive change in a variety of systems over a broad range of timescales. Over the years, as Holland continued to develop his ideas and published other books and papers building on his basic framework, the influence of Holland's ideas has steadily grown. Today, John Holland is regarded in many circles as a visionary whose insights address critical issues relevant to scientific inquiries in fields as diverse as economics, immunology, cognitive science, and ecology (Booker et al., 1999). His research has also provided much of the intellectual foundation for the new science of complexity (Holland 1995, 1998).

Holland's insights have provided the starting point for many computational models of adaptation, including genetic algorithms, classifier systems, genetic programming, and Echo. His ideas have also influenced work in other research paradigms in evolutionary computation and in machine learning. As we approach the 25 year anniversary of the publication of Holland's landmark book, now is an opportune time to assess the impact of Holland's work on our understanding of adaptive systems and evolutionary computation. What are the common themes that have emerged from the diverse research efforts stemming from Holland's ideas? How close are we to a deeper theoretical understanding of the phenomena Holland has characterized so clearly and persuasively? What research remains to be done? The papers in this special issue offer some interesting insights into these questions.

The first paper by John Holland summarizes his perspectives on genetic algorithms and provides new ideas about how to fully exploit their power. The *cohort genetic algorithm* is a robust class of GAs that allows for low reproductive rates so that hitchhiking effects can be minimized and crossover can search effectively for improvements. The *hyperplane-defined functions* provide a new class of test functions explicitly designed to make the search for improvements depend on the discovery of building blocks.

The next paper by Lanzi and Wilson reports on research using classifier systems to solve problems in non-Markovian environments. The authors describe an approach in which the state information needed to solve such tasks is represented by the contents of a memory register, and classifier rules change the value stored in the register. Tests with a

series of simple non-Markovian environments achieved near-optimal levels of performance. While this approach is less ambitious than Holland's original proposal involving an internal list of tagged messages, it is nevertheless an important first step toward one way of realizing Holland's goal of building an adaptive system capable of evolving and using symbols.

The next two papers discuss research related to Holland's ideas about complex adaptive systems. Holland proposed Echo (Holland, 1995) as a canonical, computational model capable of exhibiting the properties of a complex adaptive system (CAS). The paper by Richard Smith and Mark Bedau explores this conjecture about Echo and describes experiments that suggest Echo fails to exemplify key aspects of Holland's theory of CAS. The paper by Steven Hofmeyr and Stephanie Forrest focuses on the immune system, a quintessential example of a natural CAS. This paper presents a framework for an artificial immune system (ARTIS) that generalizes the authors' previous groundbreaking work on mechanisms for computer security. ARTIS is described as a general approach to distributed adaptive systems, and the authors describe how it is both similar to and different from Holland's characterization of classifier systems.

The last paper by Robert Smith, Claudio Bonacina, Paul Kearney, and Walter Merlat is exactly the kind of exploratory paper that Holland alludes to in the following observation he makes at the end of his contribution:

> A final comment: In the early phases of research, selective probes guided by taste and intuition are more likely than data-gathering suites to yield advances. Collection of statistically valid results early on is likely to trap the researcher on a local peak, while probes can suggest more interesting alternatives involving substantial changes in the concept. Journals carry few exploratory papers, sometimes by design, but such papers help other researchers develop a sense of the field. Shades of the genetic algorithm at the meta-level!

The authors speculate about the implications of Holland's view of adaptive systems in the context of general software agents and propose a framework for studying these issues.

We thank the authors and reviewers for their contributions to this special issue. We also thank the authors of all the papers submitted to the special issue that could not be accepted. We hope that this special issue will help "develop a sense of the field" and spur more innovative approaches to evolutionary computation.

References

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