Cyber-evolution: How computer science is harnessing the power of Darwinian transformation

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Stephanie Forrest directs the Biodesign Center for Biocomputing, Security and Society at Arizona State University. Credit: The Biodesign Institute at ASU

From a pair of simple principles of evolution—chance mutation and natural selection—nature has constructed an almost unfathomable richness of life around us. Despite our scientific sophistication, human design and engineering have struggled to emulate nature's techniques and her inexhaustible inventiveness. But that may be changing.

In a new perspective article, Stephanie Forrest and Risto Miikkulainen explore a domain known as evolutionary computation (EC), in which aspects of Darwinian evolution are simulated in computer systems.

The study highlights the progress our machines have made in replicating evolutionary processes and what this could mean for engineering design, software refinement, gaming strategy, robotics and even medicine, while fostering a deeper insight into foundational issues in biological evolution.

"With the vast computing resources available today, evolutionary computation is poised to provide the next generation of advances in AI," says Forrest.

Forrest directs of the Biodesign Center for Biocomputing, Security and Society, at Arizona State University. Miikkulainen is from the University of Texas, Austin.

Their research findings appear in the current issue of the journal *Nature Machine Intelligence*.

The paper focuses on six hallmarks of Darwinian evolution and examines how well digital systems have managed to duplicate these features in order to find solutions to complex problems and generate novel outcomes. These are: openendness, major transitions in organizational structure, neutrality and random drift, multi-objectivity, complex

genotype-to-phenotype mappings, and co-evolution.

Nature as guide

Darwin's remarkable insight reveals how a random iterative process can act on an initial set of conditions to continually improve an organism's fitness—its ability to flourish and reproduce. By implementing these mechanisms, known as evolutionary computation, computer scientists attempt to evolve solutions to various problems over time, through similar processes of mutation and selection, rather than by designing such solutions by hand.

The use of evolutionary computation involves creating an initial population of individuals on a computer, then evolving the population over time, using principles of variation, selection, and inheritance. While the basic idea is simple, the subtleties involved can become dizzyingly complex. Evolutionary computational approaches are also highly versatile, allowing researchers to model biological systems that change with time, such as ecologies or cancer, as well as social systems, including economies or political dynamics.

In principle, virtually any system or technique has the potential for some degree of computer automation, including the design, development and debugging of computer programs, a longstanding goal in computer science.

Calculated creativity

One reason researchers are so excited about borrowing a page from nature's playbook is that the use of evolutionary principles can lead to wildly original solutions that cannot be predicted in advance, allowing computers to make better guesses than their flesh and blood counterparts.

The exciting developments in evolutionary computation are being driven by ever-more-sophisticated algorithms as well as enormous advances computing power, which has increased millions of times over the past 20 years. This has enabled the careful modeling of a broad range of real-world processes, including the simulation and design of new formulas for agricultural growth, smart treatments for injuries and disease and the fine-tuned control of robots and autonomous machines.

Computer-age blueprint

Of the six evolutionary hallmarks highlighted in the study, researchers have made significant inroads in applying several of them. One startling feature of evolution is its openendedness, or ability to advance transformational processes indefinitely, without an established final state. The study cites several examples of artificial life programs that have achieved a measure of openendedness.

Multi-objectivity alludes to the complexity of biological fitness, which results as a consequence of various trade-offs, for example, between resources expended to find food as opposed to attracting mates, producing sufficient offspring and protecting young. Many such features must balance one another to achieve maximum reproductive success. Researchers have recently made progress mimicking multi-objectivity in programs using EC.

Another critical feature of Darwinian evolution that has been modeled in EC systems is co-evolution—the phenomenon of multiple species interacting over the course of evolutionary time, through complex networks of cooperation and competition. Such dynamics have found their way into EC applications including game playing, robot navigation and multi-agent problem solving.

Challenges ahead

Nevertheless, nature keeps some evolutionary cards close to her vest. Certain Darwinian processes have proven more difficult than others to co-opt for problem-solving computer programs. Further, while techniques of evolutionary computation can often mimic processes found in nature, there are also significant differences. Unlike Darwinian evolution among living species, EC tends to operate by applying strong selection pressure to small populations, where more neutral processes such as genetic drift are suppressed.

Further, in nature, the genetic template from which the final organismic form or phenotype will emerge is much more flexible and subject to embryological and epigenetic modifications, allowing for more creative and unpredictable outcomes. Researchers would like to improve this genotype-to-phenotype mapping, incorporating rich environmental interactions to better approximate nature's profound ability to generate novelty.

Finally, evolution's most impressive feat remains too poorly understood to be replicated by computer, namely the ability to achieve major organizational transitions. Here, Darwinian processes can act over time to yield convulsive and unforeseen alterations in structure, for example, the progression from self-replicating molecules to membrane-bound cells, multicellular organisms, advanced social structures and societies with language and culture. Much more work is needed to ferret out the details of nature's organizational transitions.

Nevertheless, the startling advances in evolutionary computation are likely to play a guiding role in the development of machine creativity, drive innovations in engineering and hopefully, elucidate some of the many mysteries still remaining in the study of evolution.

More information: Risto Miikkulainen et al, A biological perspective on evolutionary computation, *Nature Machine Intelligence* (2021). DOI:

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