CENTER FOR THE STUDY OF EVOLUTION IN ACTION (BEACON)

EVOLUTION IN ACTION

The word "evolution" may conjure up images of dinosaurs and fossils, but in fact evolution is currently happening all around us. A well-known example is the way that bacteria are constantly evolving resistance to antibiotics, but even larger, longer-lived plants and animals are continually responding to changes in their environments. At the BEACON Center for the Study of Evolution in Action, researchers are examining evolution in real time in biological and digital systems, and even applying these ideas to engineering design problems.

Designs under development for a museum exhibit about BEACON research on Evolution in Action.

The process of evolution involves three major components: variation, selection, and inheritance. First, variation exists in a population as a result of mutations at the genetic level. Second, some variants can outcompete others for resources, and these individuals survive and reproduce more successfully. Finally, if the traits are heritable, they are passed on to the offspring of the survivors, making those traits more common in the population. In this way, evolution can occur in every generation.

This process happens not only in biological systems, like animals and plants and bacteria, but in digital "organisms" that "live" inside a computing platform. Evolutionary dynamics can also be applied in engineering, allowing a selection process to find and evolve the best solution to a problem like software security or facial recognition or automotive part geometry.

Researchers at the BEACON Center for the Study of Evolution in Action work across these three fields, focusing on evolution in genes, in behavior, and even in communities of species. The Center is headquartered at Michigan State University, with partners at North Carolina A&T State University, University of Idaho, University of Texas at Austin, and University of Washington,

BEACON research covers a wide range of evolutionary phenomena, but much of it addresses grand challenges in evolutionary studies. Several scientists are focusing on the process of speciation: how organisms evolve from one species to another.

Richard Lenski's Long-Term Evolution Experiment, in which 50,000 generations of E. coli have been evolving in the laboratory, is a rich source of information about the process of evolution. Twelve lines of *E. coli* have been evolving in flasks for nearly 25 years, and every 500 generations, bacteria from each line are frozen so that they can be compared with their later descendants. This project has already produced several important results, most recently demonstrating that over time, long-term adaptability outcompetes short-term advantages, bringing to mind the fable of the tortoise and the hare.

Computational work plays a very important role in these studies, not just in providing the power needed to decode genetic information that can give clues to the evolutionary process, but also in replicating the process in digital organisms.

Many BEACON projects rely on digital evolution software platforms like Avida, developed by Charles Ofria, Chris Adami, and C. Titus Brown. In Avida, a population of self-replicating computer programs is subjected to external pressures, such as mutations and limited resources, and allowed to evolve subject to natural selection. This is not a mere simulation of evolution; digital organisms in Avida evolve to survive in a complex computational environment and will adapt to exhibit entirely new behaviors in ways never expected by the researchers, some of which seem highly creative. This process happens much faster than evolution in biological organisms, so that a million generations can pass by in a matter of weeks. The "genetic code" of these organisms–basically the set of instructions that the Avidians use–can then be explored to understand what genes or instructions were adaptive in this set of conditions.

Another major focus of research is the evolution of complex behavior, such as cooperation, which is observed in species as diverse as bacteria and hyenas. For example, many lethal diseases are caused by biofilms formed by cooperating bacteria. Spotted hyenas cooperate to hunt much larger animals. The evolution of cooperation can be difficult to understand, since it may seem counterintuitive that helping another individual can be beneficial to the helper. BEACON researchers are working in both biological and digital domains to understand this process. For example, biologist Kay Holekamp's long-term study of spotted hyena behavior in Kenya provides important information about behavior and environmental conditions related to cooperation, information that computer scientists like Risto Miikkulainen are using to replicate the evolution of cooperation in digital organisms.

An understanding of how cooperation evolves is also being applied to develop such behavior in robots. Engineers Xiaobo Tan and Philip McKinley are developing robotic fish, which have real-world applications such as monitoring water quality, and are finding ways to "evolve" cooperative behavior in these robotic fish so that they will be able to school together and coordinate their movements on their own. Biologist Jenny Boughman is collaborating with Tan and McKinley and plans to conduct behavioral studies in which the robotic fish interact with live fish in order to test hypotheses about fish behavior.

Evolutionary engineering is another important focus. Evolution is itself an algorithm, in which the best or fittest types are selected from a range of variation, and the process is repeated generation after generation. This algorithm can be applied to solve engineering problems. For example, Gerry Dozier is applying these principles to create better and more efficient facial recognition software. Rather than using an entire photograph of a face, evolutionary principles enable researchers to determine which few aspects of a photograph contain the most information about individual identity, making the process faster and perhaps allowing the use of a wider range of photographs. □

High school students test the performance of toy cars designed with evolutionary computation.

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A CONVERSATION WITH THE DIRECTOR

Erik Goodman

Why does BEACON need team science?

In contrast to much of the traditional study of evolution by examining the fossil record, BEACON is studying evolution in action, meaning things that we can observe as they proceed in the world today. However, even experiments in bacterial evolution can take years to conduct, so we need other ways to explore the subtle mechanisms of evolution. Happily, the invention of digital organisms—essentially self-reproducing computer programs evolving in a computer—allows us to formulate and conduct some relevant experiments in days or weeks, confirming or rejecting hypotheses about mechanisms observed in nature or suggesting carefully structured experiments to conduct in the lab. Thus, BEACON needs researchers with skills in both biology and computer science.

What is the job of the center director?

For team science to work, the director must work to spur scientists from different disciplines to collaborate. This means cross-disciplinary training for our graduate students, as well as all-BEACON meetings focused on research problems requiring multidisciplinary teams and a competition for seed projects that rewards multidisciplinary research. Since I've spent most of my career in collaborations between biologists and engineers, in modeling of evolutionary processes, and in study of multidisciplinary teaming, BEACON has been a great fit.

As we learn more about evolutionary mechanisms, we look for applications of these ideas in areas ranging from medicine, such as control of infection, to engineering, including design and control of robotics, electronics, transportation, and agricultural machinery. The interactions among BEACON researchers help to create a fertile landscape for identifying new problems to address with team science.

Above: Terrrestrial robot swarm.

At right: Students with 3D printer used to produce evolved robotic components.

EDUCATION AND OUTREACH: CRITICAL COMPONENTS OF BEACON'S MISSION

Through K-12 programs, teacher training, online software and computer games, podcasts, and museum exhibits, BEACON educators are demonstrating to the public that evolution is a process that can be observed and applied.

BEACON's artist-in-residence Adam Brown is developing three-dimensional glowing, sensing, and audio-producing robots called biolumes that will be installed in a display in MSU's new Broad Art Museum. The robots will evolve in response to museum visitors as attractive lights and sounds draw people closer, while less attractive patterns may drive them away. This exhibit will function as a living laboratory, showing evolution in action as art.

The center is training a new generation of interdisciplinary researchers. Collaborative courses taught by faculty in the biological and computer sciences are requisites for BEACON graduate students. A program called Avida-ED, an educational version of AVIDA, provides undergraduate students an opportunity to do experiments on evolution. And a one-week residential program launched in July 2011 introduces high school students to inquiry-based field opportunities focused on evolutionary science.

STUDY OF EVOLUTION