Research Center Shines the "Light of Evolution" across Disciplines

Researchers at one NSF Science and Technology Center seek to illuminate the creative power of evolution and the nature of scientific reasoning itself. This article, the second in a series exploring intersections between diverse fields, looks at the rich possibilities that can occur when experts across disciplines leap the barriers that separate them.

By Meredith Holmes, SWE Contributor

The theory of evolution is one of the most important scientific advances ever made. Earth-shaking when first introduced, it continues to be crucial to our understanding of the natural world. Nevertheless, more than 150 years after Charles Darwin published *The Origin of Species,* evolution remains poorly understood, even rejected.

Darwin would have envied the scientists at the BEACON Center for the Study of Evolution in Action. He had to rely on observation, collection, and analysis of the fossil record to develop and elaborate his theories. While he knew evolution was ongoing, the process was invisible to him because tools to witness it did not exist in the 19th century. In *The Origin of Species*, he laments, " ... natural selection is daily and hourly scrutinizing, throughout the world, the slightest variations; rejecting those that are bad, preserving and adding up all that are good; silently and insensibly working, wherever and whenever the opportunity offers ... We see nothing of these slow changes in progress, until the hand of time has marked the lapse of ages, and then so imperfect is our view into long-past geological ages, that we see only that the forms of life are now different from what they formerly were." Thanks, in part, to advances in computer science and genetics, researchers at the BEACON Center can watch evolution unfold on a daily, even hourly basis.

It is worth noting some differences between the scientific and the colloquial meanings of the words "theory" and "law." In scientific parlance, a theory tells us *why* something happens; a law tells us *what* is happening. Laws flow from theory. Just as evolution is a "theory," so, too, is gravity, referred to formally as the Universal Theory of Gravity.

Through research, theories are thoroughly tested, and are accepted as true on the basis of repeated, observable evidence. However, theories — even Einstein's Theories of General and Special Relativity — continue to be tested. They are modified, enlarged, and qualified. This process is essential to moving our understanding of the natural world forward.

A cross-disciplinary mission

The BEACON Center is a National Science Foundation (NSF) Science and Technology Center founded in 2010. Led by Michigan State University (MSU) in East Lansing, the BEACON Center involves faculty from the university's College of Engineering, College of Natural Science, College of Agriculture and Natural Resources, and Lyman Briggs College, an undergraduate college at MSU established to bridge the gap between the sciences and the humanities. BEACON also partners with four other universities: North Carolina AT&T State University, the University of Idaho, the University of Texas at Austin, and the University of Washington. "BEACON is multidisciplinary to its core," said Erik Goodman, Ph.D., director of the center and MSU professor of electrical and computer engineering, when BEACON was awarded the NSF grant.

The name of the center is both a metaphor for dissemination of knowledge and an acronym for Bio/computational Evolution in Action CONsortium. The logo, a lighthouse inside a double helix with strands representing both computer code and genetic code, illustrates the intersectional purpose of the center: to fuse biological and computational research and teaching. Danielle Whittaker, Ph.D., managing director of the BEACON Center, explained, "We focus on 'Evolution in Action' because our understanding of evolution is greatly facilitated by seeing it happen in real time, as opposed to inferring events from the fossil record, for example. Computational techniques such as digital evolution are powerful ways to observe evolution in action, and can enhance our studies of biological evolution."

Diversity of projects and personnel

Rather than fund a few large, expensive studies, BEACON supports a wide variety of smaller studies that emphasize interdisciplinary and inter-institutional collaborations. As in nature, diversity in human communities is desirable, so diversity of faculty, staff, and students is a top priority at BEACON. "Diversity of personnel is absolutely good science," said Dr. Whittaker. "One of the greatest benefits of ensuring that our participants are diverse with respect to gender and ethnicity is the resulting diversity of thought and different approaches to questions. We all learn from each other in ways we might not initially predict."

Dr. Danielle Whittaker is field biologist and managing director of the BEACON Center.

There are currently 46 projects underway in three research "thrust groups." Common to all three groups is a focus on biological evolution, digital evolution, and evolutionary applications.

Thrust Group 1, Evolution of Genomes, Networks, and Evolvability, looks at the actual processes of speciation and adaptation, using a combination of techniques, including experimental evolution in biological and digital organisms, mathematical modeling and simulation, and integration of lab and field data.

Thrust Group 2, Evolution of Behavior and Intelligence, focuses on the evolution of behavior — especially cooperation, social coordination, and communication — of individuals. Researchers in this group are also using evolutionary computation to create better, smarter robotic systems and control systems that respond to the environment.

Thrust Group 3, Evolution of Communities and Collective Dynamics, studies evolution, stability, and emergent properties of groups of organisms and explores engineering applications of biological studies.

Nothing is simple; nothing is automatic

There are costs associated with a cross-disciplinary research approach. Research teams — especially distributed teams such as BEACON's — are expensive and require constant, high-quality communication. As Dr. Goodman pointed out, "Every team, every group from its inception, is pulling itself apart." So human resources experts and good leadership are essential to making a center like BEACON effective.

Said Dr. Whittaker, "At BEACON, we believe that the most important job of our management team is to enhance communication among our members so that they can do their jobs together — that is, research and education. Since our members are spread out over five institutions and across several academic fields, this can require substantial technology, such as videoconferencing and online systems, and training." BEACON also brings people together through its annual Congress at MSU, weekly videoconferencing seminars, and travel funds for researchers at different universities.

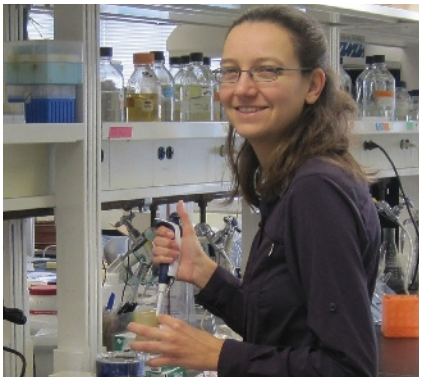
Pursuing the interesting part of the story

Caroline Turner is an MSU Ph.D. student working with Richard Lenski, Ph.D., who, since 1988, has been studying 12 populations (now past the 50,000th generation of evolution) of *E. coli* bacteria, one of which has evolved the ability to consume citrate. Because an identifying characteristic of *E. coli* is its inability to consume citrate in an oxygen-containing environment, some researchers in the lab are looking at whether this lineage of the bacteria qualifies as a new species.

Turner earned her undergraduate degree in biology from Oberlin College. While working on her master's in ecology at Cornell, and looking at how organisms can shape their environment and how the environment affects the organism, she realized she was "missing a really interesting part of the story." Turner said, "The ways an organism changes its environment have an immediate effect on the organism itself, but they also change the evolutionary pressures the organism is experiencing. There's an interesting feedback loop I wanted to know more about."

So Turner began to look at Ph.D. programs where she could study the interaction between ecology and evolution. She chose MSU, and the BEACON Center opened a year after she arrived in East Lansing. "I was very interested in the long-term evolution study and in the Avida system, and in the fact that BEACON promotes these kinds of connections."

Currently, Turner studies how the evolutionary change in the *E. coli* population affects the ecology of the system and how those changes, in turn, affect further evolution. Turner says her research is "very basic," but that the process has implications for biological remediation of industrial chemicals. Turner also works with the Avida software program to track generations of digital organisms. A digital organism is essentially a string of computer instructions with a sequence of instructions that enable it to make copies of itself



Caroline Turner is a Michigan State University BEACON Center graduate student researcher studying ecological and evolutionary interactions in bacteria and digital organisms.

(tens of thousands of copies in a few minutes). Because there will be some error in the copies, instructions may be different in the offspring than in the parent. This is what sets up the possibility for evolution to occur.

Digital organisms offer another system in which to run experiments. Turner said, "Digital organisms are not so much a model of biological evolution, as a separate instance of it — another system in which evolution takes place."

The Avida software enables Turner to test questions about how ecology and evolution interact and look for commonalities in the *E. coli* study. She pointed out, "We're looking for the broad principles of evolution; they should hold true in biological systems and in this computational system." In addition, researchers can accomplish things with digital organisms they can't with biological ones. "Our *E. coli* go through six to seven generations a day, but the Avidians can go through hundreds of thousands of generations a day," she said.

"I have only basic programming skills," said Turner, "so I collaborate with a computer science grad student. When I need a computer science perspective, I go to her, and she comes to me with biology questions."

The BEACON Center provides both formal and informal opportunities for researchers to learn from one another and to collaborate. Turner said, "There is a strong infrastructure at BEACON for bringing people together and for helping us understand each other's work." Grad students attend monthly meetings, listen to presentations, and tour one another's labs. BEACON also offers classes that teach biologists computer skills and computer scientists about evolutionary biology. "The big emphasis in those classes," said Turner, "is how to think in the other discipline."

Describing the central office area where many grad students have their desks, she said, "It's fun to go down there with my questions; I'll start talking to one person, and then someone else joins the conversation, and we'll brainstorm. There's so much energy; it's a great environment for sharing ideas."

Where biology and computer science intersect

If you're going to switch fields — say, from microbiology to computer science — the BEACON Center is the place to be. Michelle Vogel was an MSU microbiology major in her senior year when she took an introductory computer science class in Python® programming and had a conversion experience. "I just fell in love with the thinking process," she said. Vogel also relished the fact that she could get results in a matter of hours. "In my microbiology research, I'd have to wait months for results and months to find out if I'd made a mistake, which drove me crazy."

Michelle Vogel, a computer science engineering graduate student, made the leap from microbiology to computer science and now works with Charles Ofria, director of Beacon's Digital Evolution Laboratory.

What really sold Vogel on computer science and finalized her decision to switch to a seemingly disparate field was an undergrad honor class project. "We used a genetic algorithm to evolve a controller, and I realized how much this work shared with evolutionary biology," she recalled. "This is an intersection most people don't think about." After a year of intensive catch-up taking computer science classes and working on research projects with Heather Goldsby, Ph.D.; Aaron Wagner, Ph.D.; and Charles Ofria, Ph.D., Vogel is now a graduate student in MSU's computer science engineering program. She landed a summer internship with Microsoft. Her contributions there garnered a job offer, and she plans to return to Microsoft when she completes her academic program.

Vogel has worked in three different research labs in the past seven years. She describes BEACON as an "incredibly rich environment" where collaboration is actively encouraged. Vogel finds the regular Friday presentations especially stimulating. "People come together from every discipline on campus, and you'll hear everything under the sun about evolution — ecology, evolutionary biology, philosophy, and computing." In addition, Vogel was able to set up a meeting with a professor who presented at a Friday meeting and helped her with some questions about the application of a particular algorithm. "If not for those Friday meetings," she said, "I would never have known about him, and I wouldn't have known that he was working on something related to what I wanted to do."

Centers like BEACON, engaged in cross-disciplinary research on evolution in action, are relatively new and few, but this approach, especially biocomputational studies, is a growing field. It is also an increasingly necessary one. The explosion of data now available in biological research threatens to overwhelm scientists' ability to analyze it.

As Vogel pointed out, "It used to take years to get a single genome of a yeast or bacteria, so there was plenty of time to process the data. Now a researcher can get that same genome in a week or two, and have access to gigabytes — even hundreds of gigabytes — of data every day."

The biologists don't have the computer knowledge to process all of it. The computer scientists don't fully understand what the biologists want. The biologists know what they want, but not how to get it. Breaking down the barriers between biology and computer science might just be the solution to this dilemma. ■

NOTE: See the opening article of this series, "Innovation Happens at the Intersection," in the Conference 2012 issue, p. 30. http://www.nxtbook.com/nxtbooks/swe/conference12/index.php?startid=30