Biology Can Help Us Tame the Digital Beast

by **Stephanie Forrest** | Santa Fe New Mexican | September 1, 2013

SFI Science Board and External Faculty member Stephanie Forrest explores how biology can help understand complex digital systems.

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We live in a software jungle. Software helps run our cars, manage our money, plan our schedules, provide our entertainment and do our jobs. Software controls the data that is literally streaming through the air around us from countless digital cellphones and wireless networks. These interacting systems have reached a level of complexity far beyond what computer programmers intend when they create a single program to accomplish a particular task. Software systems today are so complex and changing so rapidly, they remind me of living things, which has exciting implications.

I don't mean, of course, that computers are actually alive and are about to take over, Terminator style. I do mean that the level of complexity and the challenges our computers and networks face have much in common with those faced by organisms and even ecosystems. Examining the fertile intersection of biology and computer science and searching for the common "secret sauce" that makes both computers and organisms tick is the focus of my research at the Santa Fe Institute and The University of New Mexico.

For instance, when a computer system or a social media network is attacked by cybercriminals or cyberterrorists, it's not unlike when a human body becomes infected with a virus or bacteria. Computerized defense systems kick in, attempting to eliminate the threat before it does harm. The "threat" is usually a small but destructive bit of software code that can replicate similarly to the way a living pathogen multiplies. But there are differences. So far our computer defenses are rudimentary compared to an organism's defenses, as the latter have been honed by thousands of years of evolution. Studying the ways organisms control threats is leading us to new techniques for cybersecurity inspired by what we know about immune systems.

Even the grandest biological theories can serve computer science. Take Darwin's theory of evolution, for example. We are currently applying principles of Darwinian evolution to software engineering and creating evolving software that can automatically repair bugs in other programs. This is part of an even more ambitious quest to use insights from biology to understand, detect and control malicious behavior on the Internet — one of the largest and most complex human artifacts ever created.

Naturally, these biological insights haven't always been an easy sell to computer scientists, who don't design systems to act like living things and typically don't have degrees in biology. It's easier for someone like me to make these connections because of my liberal arts background from St. John's College here in Santa Fe (Bachelor of Arts, 1977). St. John's doesn't offer courses in computer science or engineering, but it was there that I learned how to make connections and look for commonalities among seemingly different fields of inquiry, such as complex machines and living things. This training has been invaluable in my career as a research scientist, and it happens to align very well with the transdisciplinary thinking going on at the Institute.

It was also at St John's, incidentally, that I discovered my passion for ideas that are more testable than those from philosophy, and where I placed my career bet on quantitative methods. That decision, plus my education in philosophy, led me to study mathematical logic, which brought me to computer science when the field was still young. I was fortunate in my choice of the University of Michigan, where I earned a doctorate in computer science, because UMich had a diverse computer science department with a unique view of computation. My professors included philosophers, engineers, linguists and cognitive scientists. My adviser, John Holland, would later become one of SFI's founders and a pioneer of complex systems research.

Decades later, we are living in this software jungle that was unimaginable when I started graduate school, and we need new ways to understand its growing complexity. On a microscopic scale, we can borrow principles from biology and adapt them to understanding communication on computer chips. At the software scale, we can employ ideas from evolution to help manage the complexity. Moving up yet another step, SFI-style modeling can help us to begin to understand, predict and improve Internet-level behaviors. And at the largest scale, we can study how social, economic and political forces are intersecting with technology and shaping the future of the Internet and our societies.

I'll be discussing these ideas in more detail in Santa Fe as part of this year's three-part Santa Fe Institute Stanislaw Ulam Memorial Lecture Series. In my first talk, on Sept. 10, I will explain what software is and show how we can automatically repair software bugs using a form of Darwinian evolution. In my second talk, on Sept. 11, I will focus on cybersecurity threats and how they can be mitigated using concepts from immunology. In my final talk, on Sept. 12, I will explain how complex systems models can be applied to computers and the Internet. I hope to see you there.

Stephanie Forrest is a leading researcher at the intersection of computer science and biology. She is distinguished professor of computer science at The University of New Mexico in Albuquerque; a Jefferson science fellow now on assignment to the U.S. State Department in Washington, D.C.; and an external professor and member of the Science Board of the Santa Fe Institute. For more information about SFI's 2013 Stanislaw Ulam Memorial Lecture Series, visit www.santafe.edu.

Science in a Complex World: About the Series

The Santa Fe Institute is a private, not-for-profit, independent research and education center founded in 1984 where top researchers from around the world gather to study and understand the theoretical foundations and patterns underlying the complex systems that are most critical to human society — economies, ecosystems, conflict, disease, human social institutions, and the global condition. This column is part of a series written by researchers at the Santa Fe Institute and published in *The Santa Fe New Mexican*.