

# The conceptual framework for measuring the emergence of life

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On early Earth, day and night cycles may have jump-started the evolution of prebiotic chemical networks. Credit: Don Dixon/cosmographica.com

The story of life's origin is one of the great unsolved mysteries of science. The puzzle boils down to bridging the gap between two worlds—chemistry and biology. We know how molecules behave, and we know how cells work. But we still don't know how a soup of lifeless

molecules could have given rise to the first living cells.

"It's a really tough problem," says Sara Walker, an astrobiologist at Arizona State University. But she thinks it can be cracked. In fact, she believes there may be a way to measure the transition from non-life to life.

Last month, Dr. Walker presented the inaugural lecture for the NASA Astrobiology NPP seminar series. In a talk titled "Information Hierarchies, Chemical Evolution and the Transition from Non-Living to Living Matter," she described some of the models she developed as a NASA postdoctoral fellow.

These models set up the conceptual framework for measuring the emergence of life, a goal she's now pursuing as an assistant professor at the School of Earth and Space Science and the Beyond Center for Fundamental Concepts in Science at ASU.

She began her talk with a quote from the Harvard chemist George Whitesides, which captured nicely the gap she is trying to bridge: "How remarkable is life?" he asked. "The answer is: very. Those of us who deal in networks of chemical reactions know nothing like it."

If it succeeds, Walker's approach could broaden our view of what life is, and help us figure out whether its emergence on Earth is merely a fluke or the product of some universal laws.

## **Getting to "Almost Life"**

The first step is to jumpstart chemical evolution, and get a pool of lifeless molecules to form a basic chemical network. While at Georgia Tech, Walker and her colleagues developed a new model for chemical evolution based on the environment on early Earth.

"The idea is that the day and night cycles on early Earth may have driven the process," she explains.

The model starts out with monomers—or loose building blocks—and turns them into polymers. Bonds form during the day (during the dry phase) and break at night (during the wet phase). So the system goes over a constant process of building and destroying new chains of molecules.



Living systems are unique in the way they handle information. Genes determine the nature of proteins, but proteins and higher levels of organization also control gene expression. This two-ways flow of information is a hallmark of life. Credit: Jonathan Bailey, NHGRI

Over time, some of the chains may have a useful function. And because they benefit the system, they stay and are replicated by that cycling,

serving as template for the formation of other polymers. Eventually, clusters of polymers begin to grow and interact with each other, until they give rise to a very basic chemical network. Eventually, that network evolves to a state Walker calls "almost life."

## **The Tipping Point**

But how do we bridge the gap between lifeless chemical network and living biological system? "One of the things that's most distinctive about living systems is the way they handle information, and the way it's distributed in the system," Walker says.

According to her, the mystery of life's origins lies in the way these rudimentary chemical networks begin to process information. With that framework in mind, the transition to life becomes a well-defined event: a reversal in information flow.

Life is built upon a hierarchy of systems. At the bottom we have genes. Genes then code for proteins. Proteins direct the working of cells. Cells form tissues, which add up to organs, until we reach the level of the organism.

A hallmark of life is the way information flows between different levels of organization. In non-living systems, information flows from the bottom up—the properties of the individual parts determine the fate of the system.

But with living systems, that flow goes both ways. Not only genes dictate the nature of proteins which in turn affect the functioning of cells, tissues and organisms, but the behavior of proteins, cells, and organisms also control gene expression. This is what Walker calls "top-down control" or "top-down causation."

And to Walker, this transition—from information seeping upward only to information flowing both up and down—is the key to understanding life's origins. Put differently, the blueprint for building an organism isn't stored in its DNA only, but it's distributed in the state of the entire system.

And when it comes to basic chemical networks, Walker thinks, that distribution is something we could potentially measure.

## **Information in Formation**

A potential candidate is a measure called "integrated information." Dr. Giulio Tononi, a neuroscientist at the University of Wisconsin, has shown that it's possible to calculate how much integrated information there is in a network, a quantity he has dubbed 'phi'.

Tononi is working on developing a theory of consciousness based on mathematics and information theory. But to Walker, the origin of life and the origin of consciousness are two related problems.

"The measure should apply equally to understanding the emergence of life from chemistry and to understanding the emergence of consciousness from neural networks," she says. "It's about the way the network is structured, and how it can use information to control its own dynamic."

"A thought you're having in your brain can control all the atoms in your body, and make you get up from a chair and move across the room. In the same way, a bacterial cell can respond to an environmental stimuli and organize all its chemistry accordingly to go after a food source."

The goal is to take these insights and apply them to the puzzle of life's origin. In the end, Walker's approach could broaden our understanding

of what [life](#) is, and of how unique—or common—it might be in the universe.

Provided by Astrobio.net

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