New model predicts how temperature affects life from quantum to classical scales

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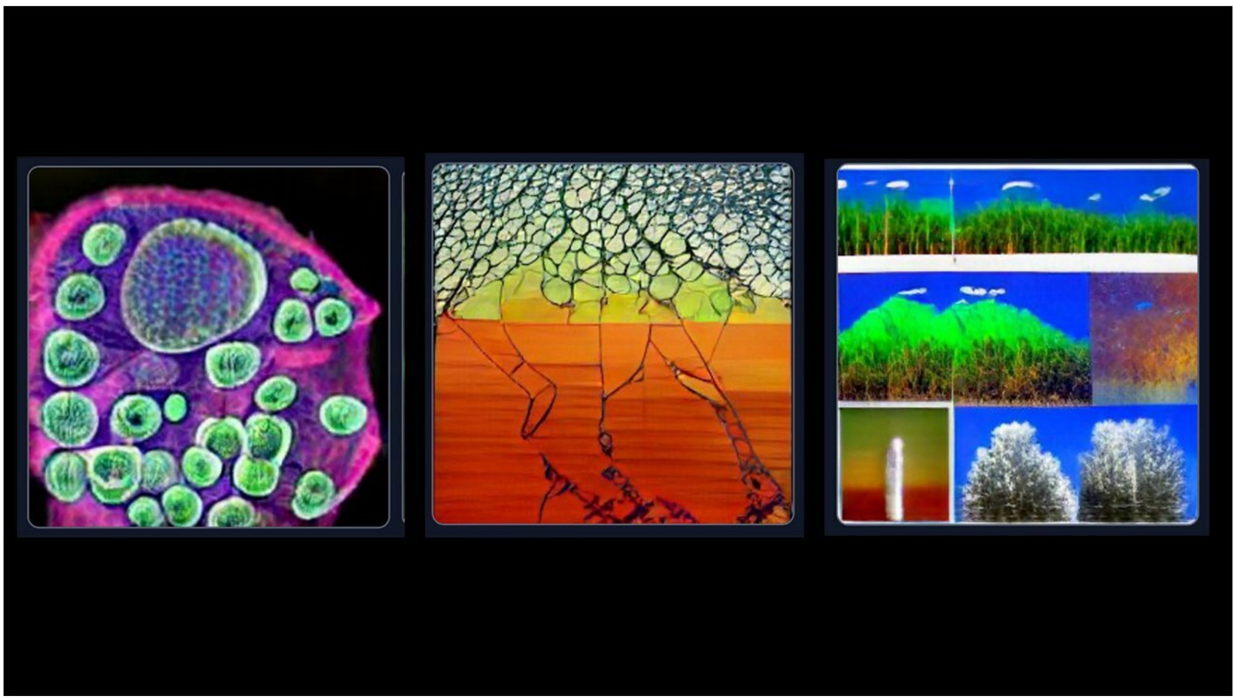

A new general theory for temperature dependence in biology developed by the Santa Fe Institute could help researchers make accurate predictions in a range of areas, including biological responses to climate change, the spread of infectious diseases, and food production. Credit: Dall-E / Katie Mast

Every biological process depends critically on temperature. It's true of the very small, the very large, and every scale in between, from molecules to ecosystems and across every environment.

A general theory describing how life depends on temperature has been lacking—until now. In a paper pubished in the *Proceedings of the National Academy of Sciences,* researchers led by Jose Ignacio Arroyo, a Santa Fe Institute Postdoctoral Fellow, introduce a simple framework that rigorously predicts how temperature affects living things, at all scales.

"It is very fundamental," says SFI External Professor Pablo Marquet, an ecologist at the Pontifica Universidad Catolica de Chile, in Santiago. Marquet, Arroyo's Ph.D. thesis advisor, also worked on the model. "You can apply this to pretty much every process that is affected by temperature. We hope it will be a landmark contribution."

Marquet notes that such a theory could help researchers make accurate predictions in a range of areas, including biological responses to climate change, the spread of infectious diseases, and food production.

Previous attempts to generalize the effects of temperature on biology have lacked the "big picture" implications built into the new model, says Marquet. Biologists and ecologists often use the Arrhenius equation, for example, to describe how temperature affects the rates of chemical reactions. That approach successfully approximates how temperature influences some biological processes, but it can't fully account for many others, including metabolism and growth rate.

Arroyo initially set out to develop a general mathematical model to predict the behavior of any variable in biology. He quickly realized, however, that temperature was a kind of universal predictor and could guide the development of a new model. He started with a theory in chemistry that describes the kinetics of enzymes, but with a few additions and assumptions, he extended the model from the quantum-molecular level to larger, macroscopic scales.

Importantly, the model combines three elements lacking in earlier attempts. First, like its counterpart in chemistry, it's derived from first principles. Second, the heart of the model is a single, simple equation with only a few parameters. (Most existing models require a plethora of assumptions and parameters.) Third, "it's universal in the sense that it can explain patterns and behaviors for any microorganisms or any taxa in any environment," he says. All temperature responses for different processes, taxa, and scales collapse to the same general functional form.

"I think that our ability to systematize temperature response has the potential to reveal novel unification in biological processes in order to resolve a variety of controversies," says SFI Professor Chris Kempes, who along with SFI Professor Geoffrey West, helped the team bridge the quantum-to-classical scales.

The *PNAS* paper describes predictions from the new model that align with empirical observations of diverse phenomena, including the metabolic rate of an insect, the relative germination of alfalfa, the growth rate of a bacterium, and the mortality rate of a fruit fly.

In future publications, Arroyo says, the group plans to derive new predictions from this model—many of which were planned for the first publication. "The paper was just getting too big," he says.

More information: José Ignacio Arroyo et al, A general theory for temperature dependence in biology, *Proceedings of the National Academy of Sciences* (2022). DOI: 10.1073/pnas.2119872119

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