

Evolution & Behavior

The sudden sprints of evolution

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This Break was edited by -----, xxxxxxxx - TheScienceBreaker

ABSTRACT

The diversity of form in life on Earth is striking; we share the planet with animals as different as sea slugs and giraffes. However, we still know very little about how evolutionary forces operated on long timescales to shape biodiversity.



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As evolutionary scientists, we see a paradox when we compare short-term (“ecological”) and long-term (“geological”) observations of evolutionary rates. When we look at adaptation to contemporary changes in environment, rapid evolutionary responses seem to be the norm. However, when examining body evolution in the fossil record, organisms seem to have basically the same form for a very long time, known as evolutionary stasis.

Many evolutionary biologists interpret this result to indicate that fundamentally different processes occur on ecological and geological timescales. Most famously, [Niles Eldredge](#) and [Stephen Jay Gould](#) proposed the theory of punctuated equilibrium. Under punctuated equilibrium, a species is more-or-

less defined by stasis. Then, in response to environmental change, genetic revolutions, or other rare events, rapid change occurs and leads to new species. It’s very important to understand that in Gould and Eldredge’s view, speciation and change in form are coupled. Thus, the kinds of adaptation we see on ecological timescales must be insufficient to explain the adaptation seen on longer, geological timescales.

Nonetheless, many biologists disagreed with Eldredge and Gould. Instead, they argued that well-understood processes that operate on ecological timescales simply cascade up to produce the patterns seen in the fossil record and across the tree of life. Under these models, the creation of new

species is not coupled to changes in body size and shape. Work by several influential theoretical biologists, including [Russell Lande](#) and Mark Kirkpatrick, showed that these processes can result in rare, but rapid pulses of changes in morphology, and suggested they may explain the discrepancy between ecological and geological data.

Inspired by this debate, my colleague Michael Landis and I have been working on modeling the paradox of stasis for several years now. Our key idea, which we originally proposed in 2013, was to introduce a new kind of mathematical model into the debate. These models, called [Lévy processes](#), can capture the three main modes of evolutionary change proposed in the literature: stasis, rapid pulses, and incremental changes. Note that these models differ from those of Eldredge and Gould because they do not couple speciation to changes in body size and shape. Interestingly, Lévy processes have a long history of successful application to modeling stock prices, because they can capture the general wandering of stock prices as well as the large jumps that occur when major business news comes out.

Our initial explorations of these models showed that they provide a good explanation of how primate body and brain size evolve, but left a lot of open questions. Thus, we decided to undertake a new, large-scale study of the importance of rapid pulses of evolution in shaping body sizes across vertebrates. To do so, we developed a new mathematical framework for doing calculations efficiently and accurately with Lévy processes and then tested our model using 66 groups of vertebrates, including almost 10,000 species.

Our results were striking: in approximately 1/3 of the groups we looked at, models that including rapid pulses explained the data the best. Moreover, we found the pattern dispersed through the vertebrates, equally supported in birds, mammals, lizards, and fishes. Thus, we inferred that bursts of rapid evolution are common across the vertebrate tree and play a major role in shaping modern biodiversity.

We were also able to estimate the rate at which pulses occur and the magnitude of the change when they do occur. In line with several previous papers, we found that jumps occur on the order of once every 10 million years. By comparing this inference to theoretical predictions from Lande and Kirkpatrick, we argued that our results are broadly compatible with their models of how stasis and rapid evolution can be explained without invoking new processes that do not occur on ecological timescales.

There are several directions that Michael and I will be pursuing in future research. In particular, our model is phenomenological: it doesn't directly address the underlying genetic and environmental causes of rapid evolution. We are currently working to address this by using population genetics theory to ground our modeling in parameters that can be measured in modern organisms, including mutation rates and population sizes. More broadly, we hope that our work will be an important step toward understanding the forces that shape the "endless forms most beautiful" that Darwin spoke of over 150 years ago.