



## A Surprise for Evolution in Giant Tree of Life

Researchers build the world's largest evolutionary tree and conclude that species arise because of chance mutations — not natural selection.

By Emily Singer



Honeycreepers, small birds inhabiting the Hawaiian Islands, have a rich assortment of beak shapes. Some species have long, thin beaks suited to plucking insects from leaves. Others possess thick beaks good for cracking open tough seeds. According to the classic view of evolution, natural selection drove the development of these different species. Each variant adapted to suit a different ecological niche. But [Blair Hedges](#), a biologist at Temple University in Philadelphia, has proposed a provocative alternative: Adaptation had little to do with it. It was simply a matter of chance and time.

This controversial proposal stems from efforts by Hedges and collaborators to build the world's most comprehensive tree of life — a chart plotting the connections among 50,000 species of Earth's vast menagerie. Their analysis suggests that speciation is essentially random. No matter what the life form — plant or animal, insect or mammal — it takes about 2 million years for a new species to form. Random genetic events, not natural selection, play the main role in speciation.

Evolutionary biologists find the research effort intriguing, particularly in its size and scope, but they are also somewhat skeptical of the provocative ideas that have emerged. "It's a huge tour de force,"

said [Arne Mooers](#), a biologist at Simon Fraser University in British Columbia. “There are lots of interesting claims — the devil will be in the details.”



Blair Hedges, a biologist at Temple University in Philadelphia, challenges the idea natural selection drives the development of new species.

To build the tree, Hedges, his Temple colleague [Sudhir Kumar](#), and their collaborators compiled data from nearly 2,300 published studies, gleaning from each the time when two species diverged from a common ancestor. They used those data to construct a map of relationships among different species, known as a “timetree.” To form a branch, the researchers started with the two species within a closely related taxonomic group that have the most recent common ancestor. Then they added the next closest species, and so on. (In a family tree, that’s akin to starting with siblings, then adding in first cousins and second cousins.) Bringing all those branches together results in a comprehensive timetree of life.

“It’s an astonishingly large exercise they’ve done,” said [Michael Benton](#), a paleontologist at the University of Bristol in England. “Many people in the field would be unable to do that.”

It will take some time for scientists to sort through the technical details of the paper, which was [published](#) in April in the journal *Molecular Biology and Evolution*. And while some scientists have been complimentary, others immediately challenged the results, questioning both the accuracy of the tree and the conclusions that Hedges has drawn. “I am very skeptical about inferring patterns of speciation from such a broad overview of the tree of life,” said [Chris Jiggins](#), a biologist at the University of Cambridge in England.

## Species Enigma

One reason scientists are skeptical is that Hedges’ clocklike pattern conflicts with the traditional picture of how evolution unfolds. “The classic view of evolution is that it happens in fits and starts,” Benton said. A change in the environment, such as a rise in temperatures after an ice age, might spark a burst of speciation as organisms adapt to their new surroundings. Alternatively, a single remarkable adaptation such as flight in the ancestors of birds or hair in mammals might trigger a massive expansion of animals with those characteristics.

Hedges argues that while such bursts do occur, the vast majority of speciation is more prosaic and evenly timed. To start, two populations become separated, driven apart by geography or other

factors. New species emerge every 2 million years, on average, in a metronomic rhythm tapped out by the random nature of genetic mutations. He likens the process to radioactive decay. It's impossible to predict when an individual radioactive nucleus will decay, but a clump of many atoms will decay at a highly predictable rate known as the material's half-life. Similarly, mutations strike the genome randomly, but over a long enough time the accumulation of mutations follows a pattern. "There is a kind of speciation clock ticking along," Hedges said.

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*[Emily Fuhrman](#) for Quanta Magazine*

In this interactive infographic, three lines trace how frequently organisms speciate over time. Across the natural world — in vertebrates, arthropods and plants — new species most often arise after a little more than 2 million years. This consistency suggests to some researchers that random genetic mutations rather than natural selection drive the development of new species.

Consider Hawaii's honeycreepers. The speciation clock started once the birds migrated to a new island and began to accumulate random mutations. The vast majority of these mutations were neutral, having no effect on the birds' appearance or behavior. Occasionally a beneficial mutation appeared, such as one that made the beak longer and its bearer a more efficient hunter. According to the traditional model of speciation, the adaptations eventually made the two populations too different to interbreed even if they were to come back into contact. In this scenario, adaptations drive the creation of a new species.

But Hedges contends that speciation and adaptation are two distinct processes, each proceeding along its own path. (A team led by [Mark Pagel](#), an evolutionary biologist at the University of Reading in England, has made a [similar proposal](#), though for different reasons.) According to Hedges' model, after about 2 million years the two groups of birds accrued so many random genetic differences that they became incompatible. It wasn't adaptive mutations that made it impossible for the birds to intermingle, but rather the accumulation of enough mutations overall, most of them neutral ones. Geographic isolation provided the necessary spark for speciation, but simple time drove the process to its conclusion.

## Tangled Trees

The seed for Hedges' tree sprouted 17 years ago, when he and Kumar began assembling a [database](#) of species divergence — the time when two species split from a common ancestor. But it wasn't until recently that the researchers developed a method capable of synthesizing the collection of data into one grand tree of life.

Hedges convened a small conference on biological diversity at Temple last month, where he and others presented their work. Many in the audience were eager to apply techniques that Hedges and his team had developed, particularly an [efficient method](#) for identifying dates on trees. "It became a running joke that we had all spent years of computer time building our own dated trees when we could have done it a million times faster using their approach," Mooers said.

Only so many people can safely fit on an airplane — once the seats are filled, there's no more room. Is this also the case for the planet? Can Earth's ecological niches be filled to capacity? A number of studies published over the past few years suggest that the answer is yes. They found that the rate at which new species are forming is slowing down, implying that there has not been room for new variants to expand and take root. But Hedges' team saw no evidence for this. "We found that overall, the rate has been constant for almost the whole history of life," Hedges said. In addition, past patterns may not have much bearing on the future. In recent years, extinction rates have skyrocketed to [1,000 to 10,000](#) times the natural level, far surpassing the rate at which new species evolve. Even if the world is full, human activity may be opening new niches.

But there was an undercurrent of doubt beneath the excitement. Building phylogenetic trees, let alone giant ones, is a process fraught with disagreement. While scientists have been constructing them for two decades, it's only in the last five years that they have been able to build large trees with more than a thousand species. The structure of a tree can vary depending on the data that go into it and the methods used to assemble it. To construct a comprehensive tree based on thousands of individual studies, Hedges' team had to figure out how to deal with trees built using very different methods. "Any little biases in the studies going in can percolate up and be amplified," Mooers said — a problem for any study encompassing thousands of species.

What's more, many of the dates in these trees are uncertain or conflicting. Estimates for when two species split might range from 3 million to 8 million years ago, and the scientists have to decide which figure to use. "A lot of objective decisions have to be made," Hedges said. "You have to reconcile differences and somehow put them together in one single consensus."

Hedges' tree also excludes groups for which no genetic data are available, a category that includes many organisms that have gone extinct. Paleobiologists say this choice can skew the outcome. For example, excluding extinct species from the analysis can make it look as though the number of species is increasing even when it's not, said [Charles Marshall](#), a paleobiologist at the University of California, Berkeley.

"The deep patterns will require a lot of technical evaluation," Mooers said. "You can disagree with one-half of the paper and still find a lot to discuss and agree with." Already, some researchers are questioning the basic results. Many of the geological ages of the nodes don't match what scientists have gleaned from the fossil record or from smaller trees, Marshall said.

In addition, some scientists disagree with one of the main conclusions of the analysis — that a wide variety of species seem to evolve on a time scale of roughly 2 million years. Even Hedges was surprised by the finding, given the enormous differences between, say, a wasp and a whale. One hundred generations of insects might pass in the lifetime of a mammal, so one might expect the former to develop new species more quickly. Hedges concluded that they don't. "There are huge biological and ecological differences in these groups," he said. "And yet speciation time is very similar."

This finding contradicts previous studies, which showed large differences in how quickly new species develop. "Our work shows that rates of speciation are indeed constant within groups of organisms, such as within bumblebees, thistles or dogs," said Pagel, "but that speciation rates can vary among groups."

Hedges maintains that constant speciation times are driven by the relatively constant pace of genetic mutations across the natural world. But it's possible that Hedges' consistent speciation rates result from averaging different rates across a range of organisms, Benton said. "To suggest a kind of regular pattern is one people will find quite challenging," he said. "I see where they get it from, but I

think there are other possible explanations.”

While researchers debate their findings, Hedges’ group is already working on an even bigger tree — one with perhaps half a million of the roughly 1.5 million known species. “That will give us a more accurate picture of the evolution of life and how biodiversity will change in the future from human activities,” Hedges said.

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