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Editorials

History of life on Earth

Geoffrey North

All of you will be familiar with those educational graphics that put into stark perspective how tiny is our place in the Universe, how on a clock that began ticking with the origin of life, humans evolved less than a minute before midnight. And the time since *Current Biology* began, 25 years ago, would be the merest fraction of a second. Yet, with our distorted perspective, we have felt this anniversary worth noting, as we did back in January with a special issue on 'The Biology of Fun' [1]. We took the opportunity then to note the fun we have in producing the journal and to demonstrate, through the collected articles, the importance of 'fun' as a biological concept. For our second special issue of this anniversary year, we thought we should take a broader view, and consider the history of life on Earth.

The articles in this issue provide an eclectic look at that history, from ideas about the origin of life, through key developments such as the 'great oxygenation event' and mass extinctions, to the evolutionary history of particular phylogenetic groups. Those familiar with *Current Biology* will know that we have a long-running interest in the diversity of life on Earth and further directly relevant articles from our archive are collected on a special webpage (www.cell.com/current-biology/history-of-life-on-earth).

Much of the focus of modern biology is on delving in ever greater detail into the mechanisms by which living things work, with insights derived primarily from studies on a handful of 'model species'. The general idea is that what is true of *E. coli* is true of an elephant, a unity demonstrated perhaps most strikingly by the highly conserved genetic code relating nucleotide and protein sequences in all cells [2]. But biology has a second dimension, with phylogenetic variety that has its own scientific value and fascination. That variety raises its own questions and sheds light on all biological issues, for example by highlighting the contingencies and constraints of evolution.

Taking the broadest view of the evolution of life on Earth, it is clear that, from the formation of the earliest cells, considering life as a whole there has been elaboration, an increase in complexity. Yet it is also clear that evolution is not driven by 'progress' — with the exception of the artificial selection we have used in the domestication of animals and plants for our own purposes, evolution is a blind watchmaker, and can lead to loss and simplification as well as gain and an increase in complexity.

That evolution can involve loss is well illustrated by blind cave fish: as explained in a dispatch in this issue [3], eyes contribute a significant proportion of the energy demands of an organism, and when they are not useful — as in the darkness of a cave —there is a strong pressure to save energy by losing them. There are many lineages of animals where there seem to have been significant decreases in complexity, for example in the evolution of the parasite lifestyle, something which complicates attempts to understand evolutionary history of traits such as complex, centralized nervous systems.

As living things have evolved and diversified, first in the oceans and then on earth, they have dramatically changed the environment they inhabit [4], something which in turn has created new opportunities for further evolution. Such changes have perhaps never occurred so rapidly as at present, due to the environmental depradations of humans — quite unique in our combination of individual size, population number and level of consumption. What this means for the future of life on Earth, on a long timescale, remains to be seen; somewhat less portentously and on a much shorter timescale, we look forward to the next 25 years of *Current Biology*.

A big thank you to all the authors who have contributed articles to this special issue, and again (see [1], end) to my excellent colleagues at *Current Biology* and Cell Press generally — in particular to Florian Maderspacher, who played the biggest part in conceiving and implementing this issue.

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Geoffrey North is Editor of *Current Biology*.

The tree view of life

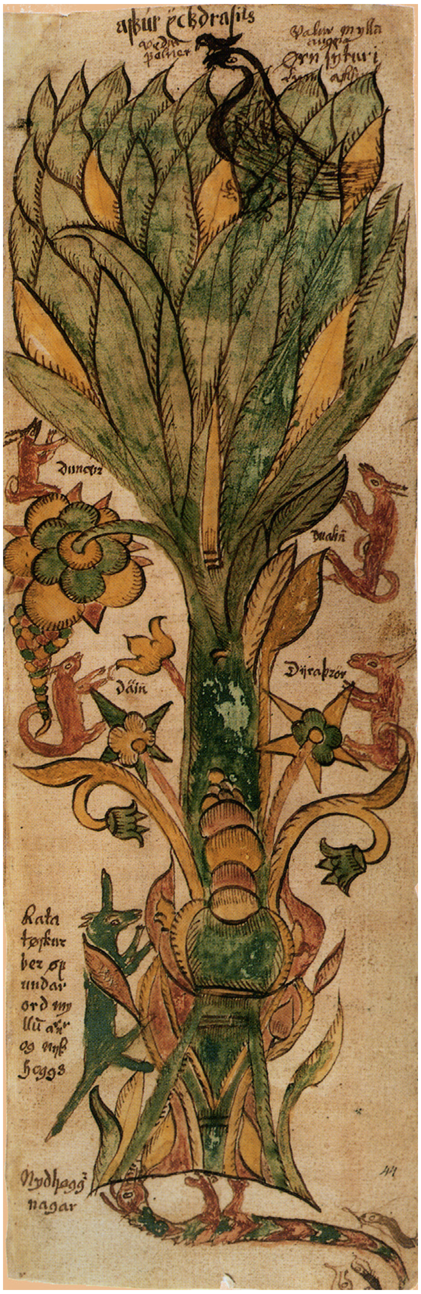
Florian Maderspacher

"Ein Bild hielt uns gefangen"
[A picture held us captive]
Ludwig Wittgenstein

"We're related to the grass", our biology teacher once proclaimed in his South Tyrolean accent that was at the same time unmistakable and highly liable to impersonation. Our 14-year-old, hormone-clouded minds can perhaps be forgiven for not immediately fathoming the profound scientific truth behind this statement, but looking back now, it stuck as poignant way of encapsulating what is perhaps the single most amazing fact biology has taught us.

Whatever we see moving and growing around us is a member of our extended family. The mighty eagle and the ugly slug, the sequoia, the grass and the green slime on the beach — all are our relatives. And also what we don't see — the microbes on our skin and in our guts, the bacteria that can kill us and the fungi that provide antibiotics — it's all in the family. They all run on DNA, RNA and protein. They all share similar genes. They all share a common ancestry billions of years ago. (A word of caution: every living thing — we know of. It is after all possible that there are entire domains of life that are as yet undiscovered. Just consider the Archaea — one of the two or three fundamental domains of life — which were only discovered less than a lifetime ago. And while Archaea are clearly related to the rest of life, other, completely cryptic foreign life forms may exist, or may have existed, forever buried beyond recognition.)

Granted, astute observers of nature had long noted that humans share a number of features with other creatures, like apes or other mammals. They share fewer features with reptiles and fewer still with fish. From these nested similarities, a hierarchy of decreasing relatedness could be delineated that, since Darwin's time, has been taken to reflect the temporal order of divergence during Earth's history. The lineages leading to closely related groups branched later than those leading to more distant relatives. But only in the age of molecular biology have we come to fully appreciate



Yggdrasil: The Old Norse world tree and the animals inhabiting it, from a 17th century Icelandic manuscript. (Image: Wikimedia.)

how profound the relatedness really is: all animals share genetic signatures of their body plans, all eukaryotes share a basic cellular make up, all life forms share a fundamental operational logic. And what's more, molecular comparisons have revealed the very structure of this unity of life, the pattern by which lineages are related to each other. This is a huge accomplishment of biology — to which our special issue on the history of life of Earth pays homage.

It's hard not to feel a sort of mystical shiver when facing this great unity of life, this oneness, this kind of biological Brahman. But while biologists are well acquainted with this feat, one wonders whether it has really gotten the place it deserves in mankind's overall cultural consciousness (if such a thing exists). We don't even seem to have a proper name or an image for this overarching unity and resort to ambiguous terms like 'life' or 'evolution'. How can we fathom it?

Relatedness is an abstract concept — in family matters and in evolution. And while modern biology makes relatedness quantifiable — you share 99% of your DNA with a chimpanzee and around 15% with the average lawn — these numbers remain abstract. The most straightforward way to think about it is to take relatedness as a measure of the time that has elapsed since you and your relative split ways. Thanks to molecular phylogenetics combined with various clever methods of time calibration, biology has come up with a fairly good — though by no means perfect — estimate of when lineages separated from each other. From the lineage of our closest living relatives, the chimpanzees, ours separated about 6 million years ago, from that of the eagle around 320 million years ago, from the slug's around 800 million years ago and from the grass lineage around 1.5 billion years ago.

Or, consider a walk along Broadway from lower Manhattan all the way to the top of the island, which at a leisurely pace takes about 4.5 hours, nicely matching the 4.5 billion years of Earth history. Walking back in time, you'll be meeting the ancestor you have in common with a chimpanzee after a mere New York minute. You'll encounter the bird lineage near City Hall, and the slug lineage (and that of practically all other animals) South of Union Square. Finally, just a few blocks below Central Park you'll meet the common ancestor shared with that distant relative, the grass. Perhaps, this exercise may give you a feeling for the vast amounts of time that make up the history of life on earth, and for some of its bizarre anomalies: the oldest fossil traces of life, for instance, appear already near the George Washington Bridge, while the first definitive fossils of multicellular creatures emerge only down by Houston Street — what took it so long? But this doesn't really help you fathom the sheer scale and multitude of the unity of life on earth. Another analogy is needed.

The most common metaphor used in this way is of course the 'tree of life'. Trees are a ubiquitous and impressive presence and their lives long transcend the lifespan of a human, yet they continuously grow and renew themselves. So, no wonder they became powerful placeholders across many cultures for all sorts of concepts, from the world tree of the Old Norse to genealogical trees. Those latter trees in particular inspired early naturalists, foremost of course Darwin, who wrote: "The affinities of all the beings of the same class have sometimes been represented by a great tree. I believe this simile largely speaks the truth. The green and budding twigs may represent existing species; and those produced during former years may represent the long succession of extinct species. […] so by generation I believe it has been with the great Tree of Life, which fills with its dead and broken branches the crust of the earth, and covers the surface with its ever branching and beautiful ramifications."

This is powerful stuff. Not only because it is so evocative of this "greatest show on Earth", but also because there is a great deal of apparent truth in it. Trees not only reflect the hierarchies of traits naturalists used to classify the diversity of life. The bifurcations in the tree's branches also echo the bifurcations that are a hallmark of life on all levels of biological organization. Populations split, sometimes leading to separate species, cells divide — so each multicellular organism is its own Bonsai tree of life — and most profoundly the bifurcations of the tree reflect the splitting of the DNA strand during replication. So, the tree is more than a metaphor, it mirrors real biological processes. No wonder then that to this day trees pervade biological thinking. This is probably most evident in the family tree of animals, which fascinates us not only because it's our immediate arboreal neighbourhood, but also because it provides the framework within which we can now begin to try to understand the processes that gave rise to the staggering diversity of animal forms.

But even this tree is far from fully understood, and especially its roots are shrouded in a cloud of unknowingness. For instance, the tree and the splitting times that have been assigned to it (based on fossil calibration and evolutionary rate estimates) tell us that the major lineages of complex animals diverged much earlier — we're talking hundreds of millions of years here, or a dozen or so Manhattan blocks — than we can detect their traces in the fossil record.

The cloud becomes even thicker once we climb out of our animalcentric vantage point and realize that the animal tree of life is really only the tiniest twig on the overall behemoth. Most of the diversity of life on earth sits within the Bacteria, Archaea and single-celled eukaryotes — the stuff that diverged above 59th St, essentially. And here, molecular comparisons have revealed that the tree is not a useful heuristic device at all anymore. This is largely due to the fact that these critters swap around DNA not only with their own kind but promiscuously with everyone and anyone. It's as if you were to constantly swap books and clothes and furniture with your neighbours. You would still live in 8R, but would it really still be the same apartment? In this vast domain of life, the concept of the tree as a reflection of the real unfolding of evolution becomes practically meaningless. You can of course still trace the bifurcations of individual genes and cells, but it doesn't tell you much about the evolutionary history of an organism as a whole.

So, is the tree — as a metaphor and a means of understanding of the unity and diversity of life on Earth — obsolete? Other, less evocative concepts have been proposed, ranging from bushes and shrubs to the inevitably bland 'networks'. And do we really need one image to capture all of evolution's greatness? Maybe not. Maybe it is enough to know that "we're related to the grass". But mankind's inability to fathom much more concrete facts — like climate change — doesn't inspire confidence. Maybe it doesn't matter. Maybe it's just something that makes for geeky conversations. But maybe, if we all had fully internalized that all the creatures that we're exploiting, killing, chopping down and depriving of their livelihood are truly and fundamentally one with us, we would indeed start to treat them differently.

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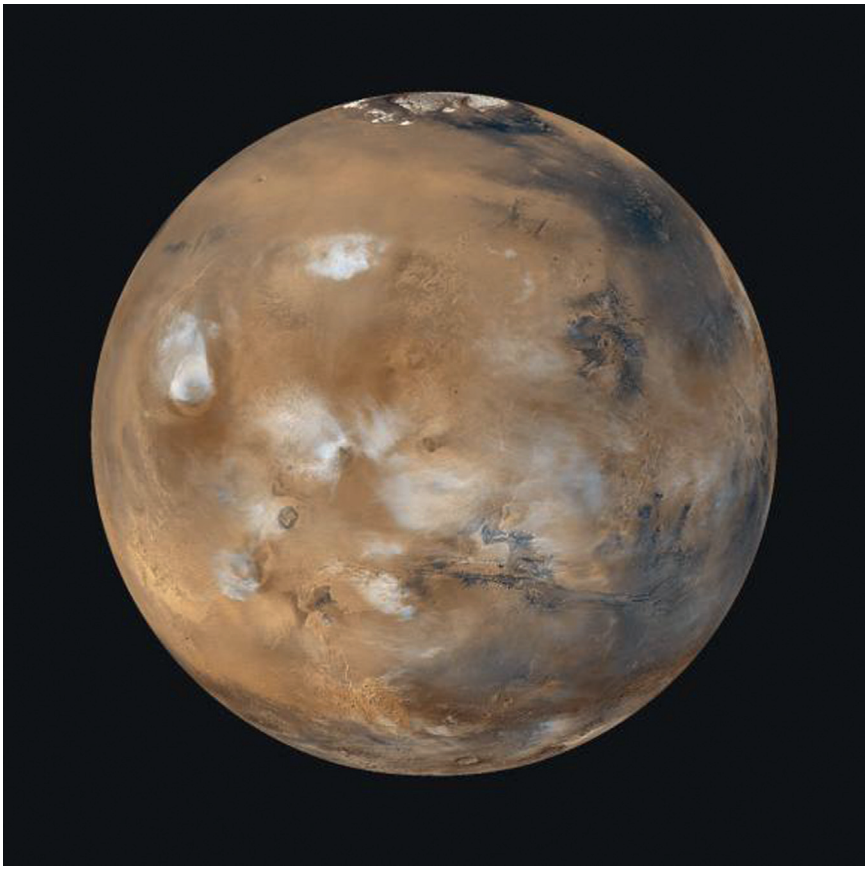
Feature

How life shaped Earth

Earth is much more complex than all the other solar system objects that we know. Thanks to its rich and diverse geology, our planet can offer habitats to a wide range of living species. Emerging insights suggest that this is not just a happy coincidence, but that life itself has in many ways helped to shape the planet. **Michael Gross** reports.

On July 14th, NASA's New Horizons mission flew past the dwarf planet Pluto at a distance of just 12,472 kilometres and sent back images that intrigued many of the inhabitants of its home planet. Images of Pluto's ice mountains as high as 3,500 metres and surprisingly smooth patches that suggest a surface being remodelled by geological processes, as well as at least five moons, will keep scientists busy for months to come, while New Horizons speeds on to its provisional next target, the Kuiper Belt Object 2014MU69.

Crowning a mission that had been in preparation since 2000 and in flight since January 2006, the flyby also continued a long string of successful solar system missions in this century. Other notable achievements include orbiting of and deposition of a lander on comet 67P/Churyumov–Gerasimenko as well as the multiple missions currently active on Mars. Most spectacularly perhaps, the Mars rover Opportunity is still going strong in its 12th year of exploration, while the Curiosity rover, with its advanced



Dead planet: While the intensive exploration of our neighbour may yet discover traces of past life, it is clear that planet Mars is much simpler in terms of mineral composition and has not been shaped by life as our planet has been for billions of years. (Photo: NASA/JPL-Caltech/MSSS.)

