text YD BAR-NESS


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ON THE BIG TREE OF LIFE

Branching patterns and biodiversity

YOU could conceive of the biodiversity of the Earth as a branching tree. This analogy of biodiversity as a conceptual tree is a tool of great power and simplicity with which to understand the natural world.

Where did this tree take root? How does it grow – and shrink? Let's climb into the big Tree of Life and observe for ourselves. When was this idea first proposed? How does it fit into the modern theory of evolution? Is it a network of branches or a series of names, or both? As we climb along these conceptual branches, let's look down the long trunk and try to understand how this fantastically complicated tree grows into such a wonderful shape with so many fascinating limbs. In the canopy of this vast tree, let's try to figure out where we belong and let's pay special attention to the difference between the leaves and the branches.

Over time, humans have created an elaborate understanding of the bloodlines, varieties, types and species of life on Earth, organising it into an intricately branched structure. Humans, *Homo sapiens*, appear as a small branch on this conceptual tree in the field of study known as taxonomy – the naming of branches. The list of branches keeps growing, and humans use the analogy of a tree to keep our knowledge in a usable form. Branching patterns can be found everywhere: in Nature, in human artifice and, of course, in trees themselves.

And if humanity is one branch of life, then all humans, everywhere, are leaves on the big tree. All bloodlines, all ethnicities, all nationalities – these are just clusters of leaves on our single human branch.

In *The Origin of Species*, Darwin wrote eloquently of the Tree of Life, describing the relationships between living things – the different groupings such as plants, animals, and fungus, which had previously been presumed to have originated independently

BRANCHINGS OF THE TREE OF LIFE

It is a fundamental pillar of the biological sciences that all life on Earth descends from one initial ancestor, which came into existence by unknown forces almost four billion years ago. It is impossible to know just what the nature of this first living thing was, because it is so far removed from our understanding of life that we lack the vocabulary with which to describe it. But we do know that using the "raw materials" available in that ancient environment, this first thing somehow replicated itself, and so on and so forth.

Because each parent could give rise to multiple progeny, a branching pattern of relationships began: the start of the big Tree of Life on Earth. A visual representation of the relationships between these living things would take on the branching form that we would instantly recognise from living trees.

DIFFERENT NAMES, DIFFERENT BRANCHES

It is also a fundamental pillar of the physical sciences that a so-called complex system will inevitably shift into a more chaotic one. As the replications of these living things continued, through the transmission of genetic information, small errors sometimes crept in, and accumulated. Some of the new, slightly altered replicates didn't manage to replicate themselves, and they were eventually broken down into their raw materials. Some of the new, slightly altered replicates were successful, and they and their descendants were now different from their earlier ancestors. Over time, they were no longer recognisable at all. This is how the diversity of life began.

Phil Schermeister/Corbis

Today, zoologists, botanists, mycologists (scientists that study fungi), bacteriologists and others work to catalogue the animals, plants, fungi, bacteria and other varieties of life on Earth. From the combined work of so many specialists, vast arrays of organisms have been named. Using the conceptual model of the Tree of Life, we recognise that animals, plants and other groupings are named branches.

From these main branches, smaller branches sprout: from animals sprout birds, reptiles, insects, mammals, fish and more. These can be divided again and again and so on until the level of individual species is reached. Beyond this point, the branchlets are indistinguishable from each other. The exact arrangement of these branches in relation to one another is always subject to revision, as scientists learn in more detail about the intricate pattern.

OTHER PERSPECTIVES OF THE TREE OF LIFE

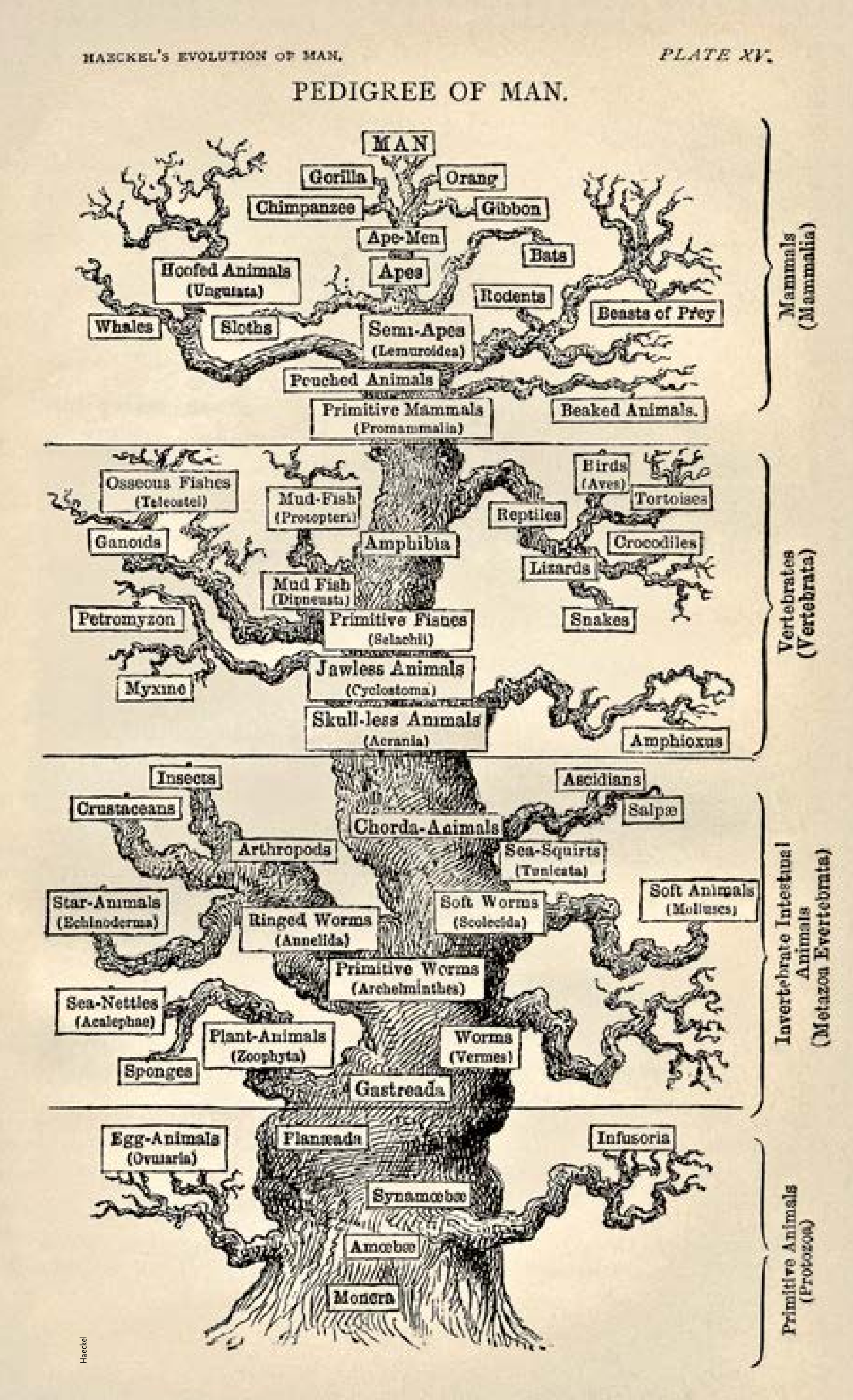
A tree spans the land of the human world with the skies of the celestial world. The idea of a Tree of Life is an old one, with its roots in mythology worldwide. In some of the earliest written records, 6,000 years old, a stylised Tree of Life appears in Assyrian archeology. The ancient Norse Vikings imagined a fantastic World-Tree known as Ygdrassil and in its branches existed all of the worlds of human, elf, god and demon.

For Muslims, Jews and Christians, a Tree of Life grew in the Garden of Paradise, along with a Tree of Knowledge. These untouchable trees were to remain inviolate and beyond human conception. Followers of the Bahai faith have a metaphorical image of God as the root of a tree, and of humanity as leaves upon that tree.

LEAVES VERSUS BRANCHES

Returning to our scientific analogy, let's make a distinction between branches and leaves. In the Tree of Life model, the branches are the groupings of living things. They are categories in which multiple individuals are placed. The species level, such as *Homo sapiens*, is the smallest size of branch. Below this level, there are subspecies, varieties and pedigrees, but these divisions are minor: individuals of different subspecies and pedigrees can interbreed.

But every person knows that even though they are a part of the human species, they are also singular individuals. Let's extend our concept of the Tree of Life to include the individuals within each species – and let's call them leaves. Thus, we are all leaves on the human branch; we are all individuals within the human species.



Haeckel

◄ Haeckel's Tree of Life: Haeckel's chart attempts to synthesise the plant and animal kingdoms into a single genealogical record of life on Earth

◄ ◄ ▼ On the uniquely biodiverse living planet, there are many wonderful species that are continually giving rise to new species yet to appear

LINES VERSUS BRANCHINGS VERSUS NETWORKS

A branching network can be thought of as a level of complexity in a system that is midway between simple linearity and hyper-complex networking. In the first, linearity, one thing follows from another. Change may occur over generations, but it will only happen to one individual at a time. In Nature, a coastline is an example of a linear object.

In a network, each individual, or node, can be both a parent and a child of another. Conceptually, a network is more than just a branching pattern that connects back onto itself – it is a hyperlinked structure that quickly grows beyond our ability to organise clearly. Like a spider's web, different segments connect in a multidimensional pattern.

The most famous example of a hyperlinked network is the World Wide Web. Another powerful illustration of a network is the ties of friendship and acquaintances that connect all people in human society.

In Nature, networks can be found that are connected to branching structures. Banyan trees, which are giant fig trees that grow into fantastically sized labyrinths of wood, are formed as the wooden branches of the tree connect and fuse. Within our own brains, the branched structures become interconnected in limitless pathways of connectivity. The electrical activities of our minds pass from neuron to neuron in a complex web far beyond our ability to measure or understand.

BRANCHING STRUCTURES IN NATURE

The core conceptual analogy of a Tree of Life is neither linear nor networked – it is branching. Branching patterns can be seen in Nature in many contexts. Most obviously, of course, are the branches of a physical tree or plant. In the botanical world, a seed gives rise to a stem, and a stem will give rise to multiple buds, which will each give rise to a single stem.

At a finer scale, leaves also have their own branching pattern – venation – which facilitates the distribution of water and collection of sugar from the smallest cells of the living organism. The cones, flowers and fruits of plants, which also come from buds, are also branched and divided. Less obviously, the roots of a plant hidden underground follow a branching pattern, which dig into the earth in search of water or nutrition.

In the landscape, the hydrological pattern of rivers and streams flow together in a reverse branching pattern. Whenever two streams, known as tributaries, meet, they come together as a larger stream. As you travel upstream from the mouth of a river, each junction of confluence gives rise to multiple pathways. In cold regions, flowing glacial rivers of ice may meet and form a branched tributary pattern.

Large rivers may have braided patterns in their main channel, as they deposit sediment to form islands within the stream. These braided regions resemble a network, as water may divide when it meets an island as it travels downstream. However, the water often rejoins itself once beyond the island, so the river is only a network in visual aspect only. When a river carries enough sedimentary material, such as the Ganges, the Nile or the Mississippi, a large triangular delta of sand will flow into the ocean. This accumulated land may have a "distributary" pattern or a linked network of streams that cut their own dividing pattern to the ocean.

In the skies, the forked lightning bolts that momentarily link the clouds and the Earth are branches, bringing together different energy sources scattered throughout the storm to meet at a single point on the

"The most famous example of a hyperlinked network is the World Wide Web. Another powerful illustration of a network is the ties of friendship and acquaintances that connect all people in human society."

John Carnemolla/Australian Picture Library/Corbis

Kent Kobersteen/National Geographic Society/Corbis

▲ The “extinct species”, which we know from fossils or by anatomical inference, are analogous to the thicker, parent branches, which gave, rise to the current, living species

◄ Leaves have their own branching pattern – venation – which facilitates the distribution of water and collection of sugar

ground. At this point, where the bolt strikes, the sum of energy collected throughout the cloud is delivered to the ground in a titanic instant.

Branching patterns occur in the most proximate of places – our own bodies. The fingers on our hands are immediate examples of a branching structure. The nerves that radiate from our networked brain out into our bodies, along our spinal cords, are branched. The arteries and veins that transport blood throughout our bodies are branching systems that work in parallel. The veins work as tributaries, collecting blood from various places back to the heart, and the arteries work as distributaries, sending blood from the heart to different parts of the body.

FRACTAL PATTERNS

Beyond the relationship structure of a branching system, there is sometimes a structure of scale. Do large branches give rise to large sub-branches? How big is a tributary stream relative to the river into which it flows? The pattern of scales at different levels is known as the fractal structure of a system.

Fractals have attracted artistic and technical interest alike, because they are often beautiful, and instantly recognisable. The silhouette of a fern, the spiral of a seashell, or the pattern of ridges and valleys on a mountain: these are all fractal patterns.

Mathematicians have been able to decode the numerical patterns that underlie these natural patterns, and their discoveries have allowed graphic artists to artificially generate imaginary landscapes and natural shapes of extraordinary realism. As one changes their scale of focus to smaller and smaller sizes, the same pattern is viewed. The small streams that tumble down the high mountain slope may look identical to the larger valleys on the lower slopes; when a fractal pattern is strong, they differ little except in their size.

Geologists, especially, are familiar with this. When they photograph rocks, they always include a coin, pen or some other familiar object to give scale to their images. Without it, it is often hard to tell whether it is a photograph of small pebbles or large mountain slopes.

SCIENTIFIC BEGINNINGS OF THE TREE

In the rationalistic, scientific paradigm of thought, the study of the Tree of Life is a vast undertaking. University departments, museums, botanical herbaria and entire government agencies are devoted to the study of taxonomy. The Tree of Life now includes almost two million named species, and it is well understood that there are many, many more to be found and described.

The basic naming structure of the taxonomic tree of life is credited to the Swedish scientist Carl Linnaeus (1707–


Michael Melford/National Geographic Society/Corbis

1778), who was also the first to coin the word "taxonomy". Devising a systematic naming pattern, Linnaeus created nested categories for all of the living organisms he could study. He used a hierarchy, or a layering system, of classifications, in which the smaller classes are contained within the larger ones. The biological classifications – species (e.g., *Homo sapiens*), genus (*Homo*), family (*Hominidae*), order (Primates), and so on – were formalised, creating a simple, versatile way to name the branches of the Tree of Life.

Charles Darwin (1809–1902), who – along with Alfred Russell Wallace (1823–1913) – described the method of evolution via natural selection by which the Tree of Life grows and loses branches, also sketched out the analogy of a tree. He described, in his paradigm-shifting book, *On the Origin of Species*, the concept of the tree:

> The affinities of all the beings of the same class have sometimes been represented by a great tree... 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.
> – *On the Origin of Species*, 6th ed. 1872

At about the same time that Darwin and Wallace were articulating their philosophies, the German naturalist Ernst von Haeckel (1834–1919) was producing scientific treatises and visual art of stunning quality. Haeckel was a gifted illustrator and science communicator, who invented the word "ecology" (and, more tragically, the phrase "First World War"). He created wonderfully symmetric and pleasing. prints showing the anatomy and relationships of different organisms, and two of his most celebrated artworks show life on Earth represented as a tree.

MODERN TAXONOMY

Modern taxonomy has expanded the Tree of Life beyond the ability of any one person to understand in detail. In a vast cooperative effort, scientists have catalogued almost two million species and stored this information in print and computer archives such as the online Tree of Life Web, the Wikispecies portal and the Encyclopedia of Life. These catalogues are continuously being reorganised and redefined.

New understandings of different disciplines have brought the analogy into different realms entirely. The term "meme" is used to describe any idea that is transmitted from one person to another. As we share an idea with other people, it is not always replicated faithfully, and those small changes accumulate. Over time, some ideas survive, and others die. This branching pattern of shared ideas can be understood using the analogy of a branching tree.

◄ Most organisms that were once alive, in the very distant past, were not successful in the long run. Today, all of the new species, the "modified descendants" originate from a small portion of the things that once existed

► ▼ Haeckel Hepaticae: Ernst's Haekel's Kunstformen der Natur (1904), depicting organisms classified as Hepaticae (a group of gametophytes and sporophytes)

> **"These organisms, while still related to all other life, can share information between each other, literally sharing their identity with other bacteria besides their direct children."**

Languages, for example, can be thought of as living species, with a common ancestor tongue, which may have sprung directly from the architecture of the human brain.

Specimens, both living and preserved, are physically archived in reference collections throughout the globe: in universities, herbaria, private collections and museums worldwide. New specimens are regularly collected in every imaginable corner of the globe: deep underwater, high in the mountains, in the darkest caves and in the tops of forest trees. By comparing these specimens to one another, scientists can slowly piece together the shape of the unfathomably complex tree.

New puzzles have been discovered, most particularly the "lateral" transfer of genetic information that is performed by bacteria. These organisms, while still related to all other life, can share information between each other, literally sharing their identity with other bacteria besides their direct children. This not only forces us to redefine what makes an organism an individual, but also forces us to consider that life may not be a branching tree but actually a hyperlinked network.

At a finer scale than the branch level, the study of the leaves of the tree is also continuing. Some aspects of this study, such as the pedigree of purebred animals or the genealogy of a royal family, are performed with more clarity than others. The study of human ethnicity has, in this era of genetic and molecular biology, become even more complicated. The old subdivisions of the human branch into different races and peoples have been minimised by new understandings of our common humanity: we are all just leaves on the same branch of the big tree.

THE FUTURE OF THE TREE

In those four billion years since life began, there have been five major extinction events, where the Tree of Life lost many branches. These have all been linked to geological events, where the chemistry of Earth's atmosphere and oceans altered drastically. After each of these events, the tree sprouted in an explosion of new branches and new species.

We are now in a sixth era of extinction, one that is caused by human activities, and species are going extinct faster than we can describe them. They are also going extinct far, far faster than they evolve, and each branch lost is lost forever. The British ecologist Mark Carwardine describes endeavouring to conserve Earth's biodiversity as running through a burning library, writing down the names of books before they go up in smoke. When branches are trimmed from the Tree of Life, they return to the raw, chaotic materials from which they were formed. No branch is immortal – nor is any species.


Haeckel Hepaticae

▶ Living species – Earth's biodiversity – are analogous to "twigs" and branches on this conceptual tree

▼ Haeckel Gamochonia: Ernst Haeckel's Kunstformen der Natur (1904), depicting organisms classified as Gamochonia (a group of Invertebrates)

▶ ▼ Some of the more curious members in the biological world, such as the Australian platypus or the South American lungfish, may not seem to fit neatly into a single category. These members may resemble two other "branch" categories because their ancestors branched off from those categories at an early stage. These "branches springing from a fork low down" have seemingly survived in a safe or lucky circumstance


Paul Souders/Corbis


Haeckel Gamochonia


David Watts/Visuals Unlimited/Corbis

You can be confident that as we climb the big Tree, we have our own wonderful branch that we can call our own. The study of taxonomy continues, and you can add to it yourself by identifying and naming the living things that you encounter. But remember, no matter how symmetrically curious the flower, how strangely alien the spider, or how foreign the human, we are all just leaves on the big Tree of Life. **AG**

YD Bar-Ness is an outreach ecologist based in Fremantle, Western Australia, on a long-term quest searching for the Kalpavriksh, the Wish-Fulfilling Tree of ancient Indian myth. He hasn't found it yet, but will make sure to tell you when he does. As a scientist, he specialises in climbing trees to explore the canopy biodiversity, and as a conservationist, he seeks to use geography and photography to create environmental education materials.

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