EVOLUTIONARY BIOLOGY

Preparing the Ground for a Modern 'Tree of Life'

Next week, biologists meeting in New York City will discuss an ambitious project to map the origins of and relationships among Earth's species

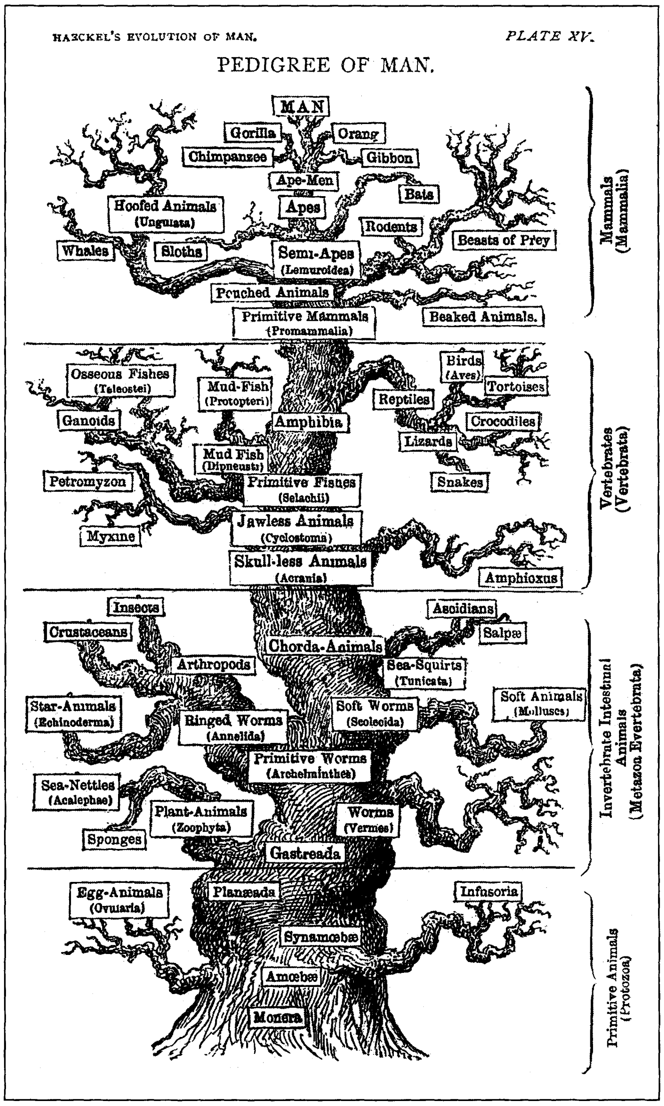
Without question, the human genome project has been a technical tour de force. It has also stimulated the DNA sequencing of many other organisms, from microbes to mammals. But biology needs to look beyond genomes now, says an expanding group of evolutionary biologists who are pushing for a new initiative. They want to build a "tree of life" that would map the evolution of Earth's species and show how they split off from one another over time. The project, which would make use of genetic and morphological data, might be more expensive than the human genome project and take longer to complete. But it would be well worth the effort, they say.

Because the tree of life reflects evolutionary relationships, says David Hillis, an evolutionary biologist at the University of Texas, Austin, it "is not just a list of all the fundamental units but an organizing principle" that would enable researchers to make predictions. For example, it might help them estimate the similarity of two organisms' proteins or genes, depending on their placement on the tree.

Last year, the National Science Foundation (NSF) gave initial backing to this idea, sponsoring three exploratory workshops over several years. Their purpose is to lay out the goals for a series of phylogenetic studies for a modern tree of life. Hoping to jump-start this work, a group of biologists is meeting on 20 to 22 September at the American Museum of Natural History in New York City to take stock of what they have learned so far and discuss what to do next.

The agenda for this gathering, "Assembling the Tree of Life," reads like an inventory of Noah's Ark, with talks covering the history and diversity of plants, animals, and microbes. "It's the most comprehensive single meeting on the tree of life" ever planned, says co-organizer Joel Cracraft, an ornithologist at the museum. He and co-organizer Michael Donoghue, a botanist at Yale University, want to develop a consensus among the thousands of biologists who study organisms and evolution. Over 20 years, "we've gotten quite a ways down the road," Donoghue notes. "It's high time" to try to put together a single modern tree of life.

The concept of a tree of life, derived from earlier studies of evolution, is straightforward. Close to the tree trunk are the most ancient and simplest life-forms, the prokaryotes and the archaea. Branches that split off later include the eukaryotes, out of which plants and animals have sprouted. Farther out on branches are mammals and other animals, and humans, goats, and pocket mice are at the tips of twiglets. Although researchers have created many small trees that include 100 to 1000 species, few have been combined. The objective is to merge as many as possible, while resolving conflicts over the placement of species. "It's an ambitious project," concedes James Rodman, an NSF program director. "Our ballpark figure is that it could take 10 to 15 years."



Due for an update? Ernst Haeckel's late 19th century illustration offers a metaphor for modern attempts to sort out the species.

The September workshop comes at a time when "society is using tree-of-life stuff more and more to solve problems," Cracraft says. Increasingly, biomedical researchers are using phylogenetic principles to understand how pathogens become resistant to treatment and how emerging diseases make their way into humans. Genome researchers are finding that they, too, need help from evolutionary biologists to compare proteins from different species. "We have to know how a genome has changed over time," notes Charles Delwiche, a plant molecular systematist at the University of Maryland, College Park. Efforts to sequence the mouse, rat, and other organisms, he points out, are attempts to add a phylogenetic perspective to the human genome.

Other fields can benefit as well, says Donoghue. Conservationists, for example, might be able to predict the course of invasions of alien species if they have information about the natural history of indigenous relatives. Moreover, "the tree of life can give us the big picture of biodiversity and help us make wise decisions about what to conserve," Delwiche says. And basic researchers, such as developmental biologists, have a better chance of interpreting the organisms they study with a clearer evolutionary perspective. "Once you have a tree, you can start asking questions in a way that has a historical framework," Cracraft explains. "Everybody is getting into it, because it's a powerful way of doing biology."

But the task of building the tree of life is huge. Of the 1.75 million species now cataloged, only about 50,000 have been placed in minitrees, and little effort has been made to merge them. Nevertheless, the project's advocates are undaunted, citing their access to better software and powerful new analytical methods. "The branches are slowly but steadily taking shape," insists Michael Lee, who studies turtles and other reptiles at the University of Queensland in Australia. According to reports from earlier workshops, the number of phylogenetic analyses is doubling every 5 years. "For many, many years to come, there will be legitimate hand-wringing and unresolved issues," Donoghue explains. "But I think the data speak loud enough to say" that a consensus will eventually develop.

Progress has been slow so far. Since the days of Darwin, taxonomists have grouped organisms based on morphological characters such as the number of legs and body shape. But in the past 2 decades, phylogenetic biologists have introduced other classification methods. For example, most now assess relatedness of species according to the degree of similarity in equivalent stretches of DNA. Sometimes the morphological and molecular data clash, although Lee says that, "on the whole, morphological and molecular data have been in broad agreement."

Researchers have found that the more data they collect, the more confident they can be about the lines of a species, and this has encouraged many to incorporate several kinds of data in their analyses. Those who rely mainly on molecular data also take stock of morphological analyses and the fossil record. Fitting all the pieces together will remain a challenge, though. The sequencing of microbial genomes has flooded systematists with new genomes, but it also has revealed extensive gene transfer among microbial species. Thus microbial trees no longer consist simply of bifurcating branches; they look more like tangled brambles.

Plant and bacterial species can be very tricky to sort out. For example, there are about 1000 proteins in *Arabidopsis* that are clearly cyanobacterial in origin, most of them expressed in photosynthesizing components of plant cells called chloroplasts but some expressed elsewhere in the cell. And the origins of some algae can be hard to pin down, according to Delwiche. They appear to have two chloroplasts, at least one of which was acquired when the algae's ancestor ate another photosynthetic eukaryote. What resulted "is like a Russian doll, with a eukaryote inside a eukaryote inside a eukaryote," he explains. Who is to say which is the true ancestor?

Resolving these problems and building a tree of life will require a big-science approach involving "a lot of money, a lot of people, and a lot of effort," says Terry Yates, a systematic biologist at the University of New Mexico in Albuquerque. Indeed, "a human genome–scale effort would be marvelous," adds Tim Littlewood, a systematist at the Natural History Museum in London. The first task, argue Hillis and Donoghue, should be to develop the computational tools needed to collect lots of data rapidly and to compute ever-larger trees. They call this new field "phyloinformatics." "If we can dramatically increase the rate of discovery about the tree of life, it will pay off enormously in the long run," Hillis insists.

Although a tree-of-life project might sound expensive, advocates say it would make systematics more efficient by encouraging greater coordination. "Currently," says Littlewood, the field "is rather like a cottage industry with key groups around the world working in isolation." Evolutionary biologists aren't the only ones who might gain: DNA sequencers might use the tree to set priorities. "We don't need to sequence entire genomes for every bit of life on Earth," Yates notes. A tree of life can clarify which organisms would yield the most insights. Given the huge costs of sequencing, he argues, building a tree of life might be well worth the money.

–ELIZABETH PENNISI

PALEOANTHROPOLOGY

What—or Who—Did In the Neandertals?

Was it a changing climate, competition with modern humans, or both? Experts who debated the topic at a high-level meeting couldn't agree

GIBRALTAR—About 100 experts in human evolution paused atop the Rock of Gibraltar to admire the view: Stretched out below were the golden shores of southern Spain, and on a clear day the mountainous coast of Morocco is visible some 30 kilometers away across the blue straits. A moment later, the group began a dizzying descent down 300 stone steps cut into the sheer limestone cliffs to the rocky beach below. Their destination: two sandy caves that were occupied by Neandertals at least 90,000 years ago. Recent excavations in these caves have turned up important new evidence that Neandertals butchered marine mammals, including seals and possibly dolphins, and exploited a much wider range of animal resources than they are often given credit for.

This field trip capped a high-level gathering* at which researchers sought answers to some pivotal questions about the relationship between Neandertals and modern humans, who coexisted in Eurasia for several thousand years before the Neandertals finally went extinct about 25,000 years ago. How much interaction was there between the two groups? Was competition with modern humans responsible for Neandertal extinction?

In recent years, Neandertals, once viewed as subhuman brutes, have increasingly earned respect, even if most experts today relegate them to a different species from our own. There is a growing consensus among researchers that the Neandertals were not easily shoved aside when *Homo sapiens* ventured into their territory and possibly even continued to advance culturally and technologically (*Science*, 2 March, p. 1725). But whereas some researchers argued at the meeting that there may have been no competition at all between the two groups, others saw the appearance of modern humans as the ultimate death knell for the Neandertals. The participants also got their first detailed look at the evidence behind a controversial claim that the skeleton of a 4-year-old child—first reported in early 1999 from Portugal—was the result of interbreeding between Neandertals and modern humans.

At home in the Rock. Neandertals butchered marine mammals at Gorham's Cave (left) and Vanguard Cave.

CREDIT: CLIVE FINLAYSON

No contest?

The meeting kicked off with biologist Clive Finlayson,

---

* Neandertals and Modern Humans in Late Pleistocene Eurasia, Gibraltar, 16–19 August.