
SPECIES
GENUS
FAMILY
ORDER
CLASS
PHYLUM
KINGDOM

By Sue Hubbell

How taxonomy helps us make sense out of the natural world

We all have a need to classify plants and animals, which is what the National Museum of Natural History does on a grand scale

In the past months I've come to know, tolerably well, a big, beautiful spider. She is blotchily orange and tan with darkly banded legs. Each day she spins a fine new round web somewhere in the garage. Her eyesight is none too good and she usually sits off the web, hidden against a protecting beam, but when moths and flies blunder into her trap, she can feel the vibration on one of the web's guying threads and she rushes out. She eats the first and wraps the others in silken winding sheets to keep for later. I try to avoid tearing her web and save her repair work, but I know she is a quick and efficient spinner. Jonathan Coddington, the chairman of the entomology department and curator of spiders at the Smithsonian's National Museum of Natural History, tells me she eats each day's web and reprocesses the protein. Within 20 minutes of munching it down, she can spin recycled silk.

Her common name is barn spider. Her scientific one is *Araneus cavaticus*. Her genus, indicated by the first word in her scientific name, includes a greater number of species—more than 1,500—than any other spider genus. The genus name and that of her order, Araneae (the spiders), as well as that of her class, Arachnida (spiders plus a lot of kinfolk: ticks, daddy longlegs, scorpions and suchlike), echo the name Arachne, borne by a Lydian princess who was such a skilled weaver that Athena grew jealous of her. Terrified of the goddess' wrath, Arachne hung herself from a rafter, and Athena transformed her into a spider and her rope into a web.

It took scientists many years to develop our present-day classification system but it remains in constant flux.

As spiders go, *A. cavaticus* is famous. She is the heroine of the E. B. White book *Charlotte's Web,* in which she saves the life of Wilbur the pig by writing messages in her web. So far I've not seen TERRIFIC embroidered in the garage, but for someone like Jon Coddington, the barn spider's web *does* have messages. Jon is a specialist in spider behavior and taxonomy.

Back at the beginning of time, when I took introductory biology, living things were divided into a neat hierarchical series of inter-nesting boxes, called taxa, with the higher taxa containing the lower: kingdom, phylum, class, order, family, genus, species. Of the first, kingdom, there were two: animal and vegetable, although even then bacteria were something of a problem, off to one side. The whole lot was presented in an ascending order with mankind triumphant at the top. In those days, taxonomy was mainly a matter of identifying and naming what few species remained to be discovered.

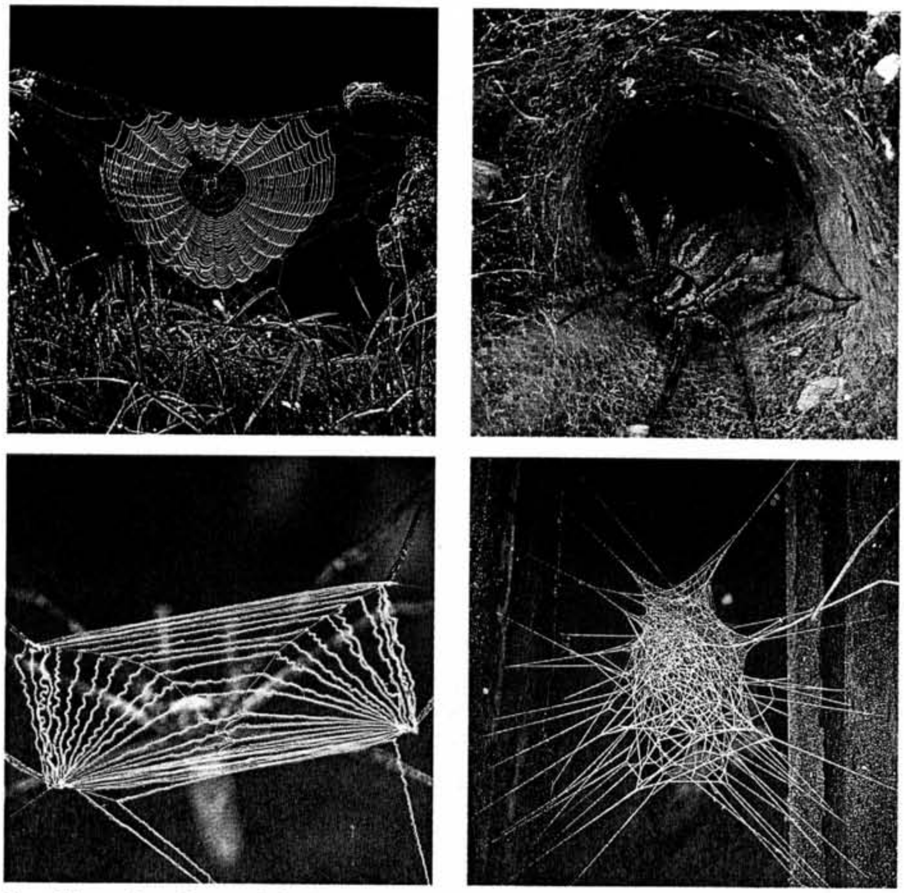
Well, the world hasn't changed, but our understanding of it has, and taxonomy is no longer so simple. The biological source book I now use lists eight kingdoms, elevating several kinds of bacteria, slime molds and other organisms to that status. Other reputable texts list as many as 30. Interlarded between all those old familiar taxa are such new ones as "superfamily" and "subgenus."

It turns out also that there are more species we don't know anything about than we ever dreamed of in introductory biology. Vertebrates, of which we are one kind, are big and obvious and fairly well known, but better sampling techniques are finding millions of new invertebrates from the treetops to the ocean bottoms.

Taxonomists of Jon's sort ask questions about what is going on at the higher taxonomic levels: What constitutes spiderishness? How does one family of spiders differ from another? What is the evolutionary relationship of taxa of spiders that spin different kinds of webs? Asking questions like these was the way Jon overturned a long-held notion about spider phylogeny, or evolutionary history.

Spiders spin a variety of webs peculiar to their own kind. Sheet-web spiders, for instance, make webs that look like flattened hammocks. Theridiid spiders are the ones that spin those cobwebs that tidy people dust out of basement corners. My *A. cavaticus* and others spin the familiar orb-shaped webs.

It had long been assumed that orb webs were the highest achievement of spiderly craft and were, adaptively speaking, the most advanced. Such webs were thought to be maximally efficient, which is why their production had evolved independently in different taxa



Familiar orb web, top left, is made by the barn spider. Funnel-web spider, top right, perches on its handiwork. Rectangular grid, bottom left, is made by the Australian net-casting spider. At lower right is web of cobweb spinner.

of spiders. They were certainly worthy of the sort of spider who could lay out SOME PIG in her web.

After careful observation, however, Jon inferred that rather than being the ultimate web, the orb web is primitive, ancestral. The cobweb is actually much denser, more protective and more efficient for trapping prey than the orb web, and more elaborately engineered, as well. He concluded that the cobweb evolved from the orb web, rather than vice versa. The earlier spider classifications that separated orb weavers into differing taxa based on anatomical differences have been generally scrapped, Jon tells me, because consolidating all orb weavers in a single line is a much better representation of what we know about their behavior.

I am sitting in his office on the third floor of the Natural History museum as he explains this to me. The sun floods through his windows overlooking the Mall beyond. Jon is a tall, lanky, rumple-haired young man. He is dressed in an open-necked shirt, khakis and Birkenstocks. Every year more than five million people visit the museum. They remember the elephant in the rotunda, the nice lady at the information booth or dinnertime for the tarantula in the Insect Zoo. But what they do not see is the undisplayed 99 percent of the collections, numbering 122 million objects, or the 400 scientists and technicians who work with them. To be precise, there are 108 Smithsonian scientists and another 25 to 30 scientists from federal agencies whose research duties keep them in the museum full time. Together, the scientists, support staff and collections make up the largest research museum in the nation and one of the preeminent in the world.

Jon's sunny office is filled with books, files of arachnological papers and a scattering of vials containing spiders afloat in alcohol. He shows me a flat container with a real web in it—that of a brown recluse spider, whose bite is as dreaded by many people as that of a black widow. "Good taxonomy," says Jon, "has predictive value, which is often useful. For instance, there is a spider in South Africa known as *Sicarius*—the name means 'murderer'—that can give a serious bite. No one has done much work on it, but we do know it is in the family Sicariidae, which is, taxonomically, the sister group of the family Loxoscelidae, the family to which the brown recluse belongs. We *do* know rather a lot about the brown recluse, so we can make predictions about the biology of *Sicarius* and know how to treat the bites."

Bad taxonomy, on the other hand, can be expensive. Many millions of dollars have been spent to eradicate the gypsy moth in this country; it was imported from Europe a little more than one hundred years ago as a consequence of mistaken taxonomy. Leopold Trouvelot, a French amateur naturalist and astronomer, was using the gypsy moth in an attempt to develop a better silkworm when it escaped from his laboratory near Boston. Undeterred by natural predators, it has been eating its way through our Eastern forests ever since. In Trouvelot's time, the gypsy moth was classified in the genus *Bombyx*, that of the silkworm, which was and still is *Bombyx mori*. The gypsy moth was, but no longer is, *Bombyx dispar* (meaning a silkworm with males and females of different color). Trouvelot probably would not have experimented with it had he known it by today's name, *Lymantria dispar*. Lymantria means "destroyer."

On Jon's desk are specimen spiders that have been collected in the

Sue Hubbell has written recently about square dancing, tabloids and the annual Fourth of July butterfly count.

Cameroons. Jon tries to spend about a third of his time in the field collecting spiders and studying their behavior. He passes the spiders, along with the exact location where they were collected, to a colleague who enters information about them into the computer record and prints out labels that identify them and tell the who, when and where of their collection. Groups of individual vials containing the new specimens are packed into straight-sided, half-liter, alcohol-filled bottles that resemble old-fashioned home-canning jars because they are closed with a rubber gasket and a metal clamp.

Jon takes me back to a room filled with tan metal cabinets that look like map cases with fat drawers. Within the drawers the half-liter jars are stored, arranged alphabetically by family and subarranged by genus and species, if known, and geographical origin. He pulls out a drawer containing my *A. cavaticus.* There are two vial-filled jars of them, but many more of other species of *Araneus.* All told, Jon estimates, the museum's spider collection contains some 116,000 specimens.

The museum's entire entomological collection, which includes not only spiders but insects and myriapods (the millipedes and centipedes), contains almost 300 times that number, or 31 million specimens. "It is," Jon tells me, "one of the most inclusive and accessible entomological collections in existence. The only other of equal importance is the one at the British Museum."

Jon Coddington holds tarantula fror the Insect Zoo at Natural History.

Specimens, preserved and classified, make up what is called a "synoptic" collection. That means that it is a synopsis, a holding of representatives of major taxa from all over the world. "This collection," says Jon, "contains one of the greatest synoptic collections of insects and their relatives on Earth. This is where diversity can be studied."

Each year some 9,000 scholars visit the museum to use its collections. One famous researcher who made that sort of a visit was Hirohito, better known as a divine emperor than as a marine biologist. When he came to Washington on a state visit in 1975, he was keen to examine the museum's coelenterates, a sampling of the hydra, jellyfish, sea anemones and corals of the world, to identify some of the species in his own collection. So keen was he, in fact, that once he began work, he overstayed the brief time his State Department handlers had allotted and, to their dismay, refused to leave until he was done. "This may be one of the few times that protocol has given way to natural history," according to Ellis Yochelson, the museum's historian.

These collections, then, are the heart of the museum. Anna K. Behrensmeyer, the acting associate director for science, points out: "We must have the objects themselves to serve as the factual basis for knowledge, the final arbiter in matters of contested identity or meaning, the 'ground truth' that underlies our understanding of the world we inhabit."

Researchers can borrow from the museum. Last year more than 140,000 specimens from the entomological collections were sent out on loan. "Let's say someone is trying to figure out if they've found a new species," Jon says. "He has two females, slightly different, and no males. Are they one species or two? He needs a much larger series—that is, a number of specimens reflecting the range of variation within the taxon—to make the decision, so he borrows what we have." A loan is normally made for 2 years but can be renewed, and sometimes specimens are kept for 10 or even 15 years by qualified researchers.

Facilitating this kind of scientific scholarship is one of the Smithsonian's main reasons for being. The act of Congress that created the Institution in 1846 specified that it should collect, classify and arrange "objects of natural history." Today the Natural History museum is one of the largest and most important centers of classificatory biology in the world.

We humans have the sorts of brains that cannot handle nature raw. We have to arrange all of the bits and pieces into piles, and if there are too many piles, we arrange *those* into clusters. Without ordering systems, which is what taxonomies are, we can't think, communicate, live or work. We would find it hard to make our way through our shopping list at the grocery store if we didn't have in our head mental categories. Without, for instance, the category "orange," we would have to remember each time we shopped that we wanted those orange things with sweet, juicy orange stuff inside and not the yellow things with tart juice inside. What's more, we want the oranges and lemons grouped together, in a citrus row. And, please, put all fruits and vegetables in one big section called Produce, not mixed in with the coffee and kitty litter. That's taxonomy.

From Aristotle to Foucault, the world's heavy (and sometimes not so heavy) thinkers have seized upon taxonomy as an intellectual joy as well as a practical exercise. It is so much fun to create neat systems! Early taxonomists generally selected single characteristics with which to divide up the living world. Aristotle used blooded and bloodless to make the first division, and subdivided by other characteristics, such as hairiness or hairlessness. Linnaeus, who invented the system of binomial Latin scientific names, divided up all the insects by their wing styles. And we still use many of his names for the insect orders: butterflies and moths, for instance, go by the Linnaean name of Lepidoptera, those beings with scaly wings. Fabricius, a sometime pupil of Linnaeus, thought jaws were all, and a relict of his classification lives on in our current name for the order to which dragonflies belong: Odonata, the "tooth-jawed." These single-character ordering schemes, known as keys, are like a game of Twenty Questions. When applied to trees, for example, a key might ask: Stems—fuzzy or smooth? Leaves—opposite or alternating? And so on until an identification is made.

Other thinkers had other ways of looking at the world, however. The 18th-century French naturalist Michel Adanson believed that those single-character ordering systems were "artificial," and he developed a Universal System that made use of all known characters. He believed such a system was more "natural," but in his time his system was considered too unwieldy, and Adanson was thought to be an eccentric. He sounds like a sweet man; toward the end of his life he requested that his grave be marked with a garland of flowers from the 58 plant families he had elucidated.

Others looked for a natural system; they believed that life's mystical unity could be revealed if only the presumed relationships and affinities between all the bits of it could be arranged in the proper configuration. One of these was the Great Chain of Being, a ladder-like arrangement with lowly plants and animals at the bottom and humans on the very top rung. Then there were the Quinarians, who held that all life could be divided into systems of five: five circles arranged in a greater circle. Affinities were found where the circles touched, or "osculated." Each circle could be subdivided into additional fives, such as a circle of five-pointed stars of the family of crows and ravens.

Goethe, one of the best-known of the thinkers who hoped to work out a natural system, coined the word "morphology" to mean the study of form or shape. With a bow toward Plato, he believed that all plant forms could be derived from an Ideal, a dawn-plant, an *Urpflanze* that could be thought into reality. And if this sounds slightly mad today, it is well to keep in mind that it did not at the time, and that years from now our deep thoughts and worldview will appear unhinged in light of what the process of discovery called science will have revealed.

No one until the age of Darwin considered organisms except as they existed, fixed in form and time. The most empirical classifiers examined body parts, measured genitalia, compared color, speculated on the function of organs of the dead specimens to hand. Darwin's evolutionary thinking forever changed taxonomy by introducing a principle of history into natural history. The additional dimension of history was eventually to revolutionize taxonomy for a couple of reasons. First, it was real: all organic diversity arose through evolution, and evolution is "descent with modification." Second, the history of an organism is unique, singular: organisms have only one history. There is only one true evolutionary tree.


Japanese emperor Hirohito studies marine specimens at Natural History.

This was by no means an instant revolution, however. Darwin's influence on religion and science was profound, but his ideas had little immediate effect on classification. Taxonomists stayed with the systems they had built and did not rush to change them to one based on evolution rather than appearance. It was not until the 1960s, in fact, that evolutionary, or phylogenetic, classification came into its own. The system that eventually emerged is known as cladistics, and while not accepted 100 percent by taxonomists, it is now in use at major museums and universities throughout the world.

Cladistics is a "laser-like effort" to find the one true tree, Jon says. It defines a given taxon by making use of unique traits, believed to be of such recent evolutionary origin that they set the members of that taxon apart from any other taxa on the family tree. These traits are drawn from summaries of everything known about the animals within the taxon: their biology, behavior, molecular profiles, biochemistry, and fossil history if known. When the animals defined by specific traits are grouped, therefore, it is assumed that they diverged from a common ancestor and are closely related.

"Cladistics," Jon says, "is the quantitative analysis of comparative data used to reconstruct evolutionary trees. It took numerical analysis and wedded it to our biological understanding of evolutionary history. It is also simply the most efficient way that has yet been devised to store and retrieve biological information."

On a simple level, here's how it works. Let's say that when you are studying the order of spider, "eight-leggishness" would not be considered a "derived" trait because all of the class Arachnida—ticks, daddy longlegs and mites, as well as spiders—have eight legs. For this purpose, it is a primitive trait that emerged early in the evolutionary history of the class. You would define spiders as an order by other, more recent characteristics, two of which might be "having silk-spinning organs at the

In whimsical sketch, Charles Darwin holds an evolutionary "tree of life."

nether end of the body" and "having fangs equipped with poison glands." For cladistic analysis *within* the order of spiders, those two traits would become primitive because all spiders possess them, and other characteristics would be looked for to sort out families, genera and species.

I asked Jon to give me an example of what separated a cobweb spider from my barn spider, *A. cavaticus.* He told me that cobweb spiders (and a few of their relatives) hurl huge droplets of sticky silk to attack their prey. *A. cavaticus* can only hang sticky silk in its webs. The sticky-silk attack is always the same in cobweb weavers. It is unique. It is a derived trait.

Jon pulls from under a pile of papers a computer printout that he calls, proudly, "*the* matrix," which contains 49,000 observations of spiders accumulated to date by him and his colleagues. It applies 354 traits or characteristics along one axis to 139 genera of spiders along the other axis. Points in the matrix include spiders' body structure, behavior, biochemical makeup, web-building patterns—anything that can be found in the literature. These 49,000 observations are coded digitally so that comparisons may be sorted out by computer. The family trees worked out from these comparisons, called cladograms, are visual representations of this analysis. Having them enables us to make major predictions about newly discovered organisms, especially "exotics," those that have arrived from elsewhere. The cladograms tell us instantly what other organisms share the same behavior. In agriculture and disease control, such knowledge can be worth billions.

The origins of cladistic analysis lie in the work of a little-known German entomologist, Willi Hennig, who died in 1976. Hennig wanted to create a taxonomic system that emphasized phylogeny (the evolutionary history of a genetically related group of organisms) in groupings by using recent characteristics instead of older ones.

During World War II, Hennig was held prisoner by the British in Italy. While he was there he wrote a book in which he sketched a "phylogenetic systematics" that, he hoped, would prove to be nothing less than "the general reference system of biology."

The book was largely unnoticed until the late 1960s, when a revised edition was translated into English as *Phylogenetic Systematics.* A group from the American Museum of Natural History adapted the computer techniques of the numerical taxonomists to Hennig's ideas. Numerical taxonomy is a kind of computer systematics that uses all of an animal's characteristics to create an "objective, repeatable classification scheme."

As taxonomists continue to identify more and more new species and revise ever upward their estimates about how many others remain to be discovered, taxonomy itself has come increasingly to resemble a numbers game. In Coddington's specialty alone, there are today something better than 36,000 known species of spiders and perhaps another 100,000 as yet unknown.

"Look," Jon says, "there are only 7,000 families of all kinds of life on this planet. Of those 7,000 families, there are 105 that are spiders. We have, right here in the museum, representatives of nearly all of them." Taking it to the next level, he tells me there are 3,000 genera of spiders of which the museum has about 600 named and identified (many more are waiting in those jars). He is working fast to collect the rest of them before they are extinguished, to fill out the synopsis the world's museums hold. Jon is an engaging man who wears his erudition lightly. He smiles easily, but when he speaks of this aspect of his work as curator, he is intense, serious.

"You know what I want to do?" Jon continues. "I want to create, as quickly as possible, a synoptic collection of the chunk of life for which I am responsible. Because 200 years from now there's going to be a news conference held here, right in the museum. There will be the Minister of Environmental Affairs, who will announce that the inventory of life on Earth is complete: 5,748,941 species. And some reporter will stand up and ask, 'But Madame Minister, didn't they say 200 years ago that there were 12 million, 15 million, 30 million, even 80 million species?'

"Madame Minister will be able to answer in only one of two ways. Either she'll say, 'Well, we lunched them all,' or she'll say, 'They didn't know what they were doing 200 years ago.' I want to make it impossible for her to give that last answer." ♜