Natural History. 1995. June Vol. 104 no. 6

Why Cladistics?

by Eugene S. Gaffney, Lowell Dingus, and Miranda K. Smith

In June 1995, an array of dinosaurs absent from the exhibition halls of the American Museum of Natural History for three long years will reappear. The renovation of the two halls that will house these magnificent examples from the Museum's collection has involved much more than refurbishing the surroundings and placing the dinosaurs in more dynamic, realistic poses. The halls now reflect the newest and most rigorously tested scientific perspective on these creatures and their evolution. The old Halls of Early and Late Dinosaurs—organized as a "walk through time"—have been replaced by the Hall of Saurischian Dinosaurs and the Hall of Ornithischian Dinosaurs, which offer the visitor a chance to explore the many-branched dinosaur family tree. Rather than juxtaposing creatures that lived at the same time, we have grouped them according to their evolutionary relationships. Thus, stegosaurs, duckbills, and ankylosaurs are among the dinosaurs in the ornithischian hall, while giant sauropods, bipedal carnosaurs, and birds—the latter being the living representatives of the dinosaur line—contribute to the variety of the saurischian hall. The American Museum is the first institution to present a major exhibition based on cladistics, the best current scientific method for reconstructing evolutionary relationships.

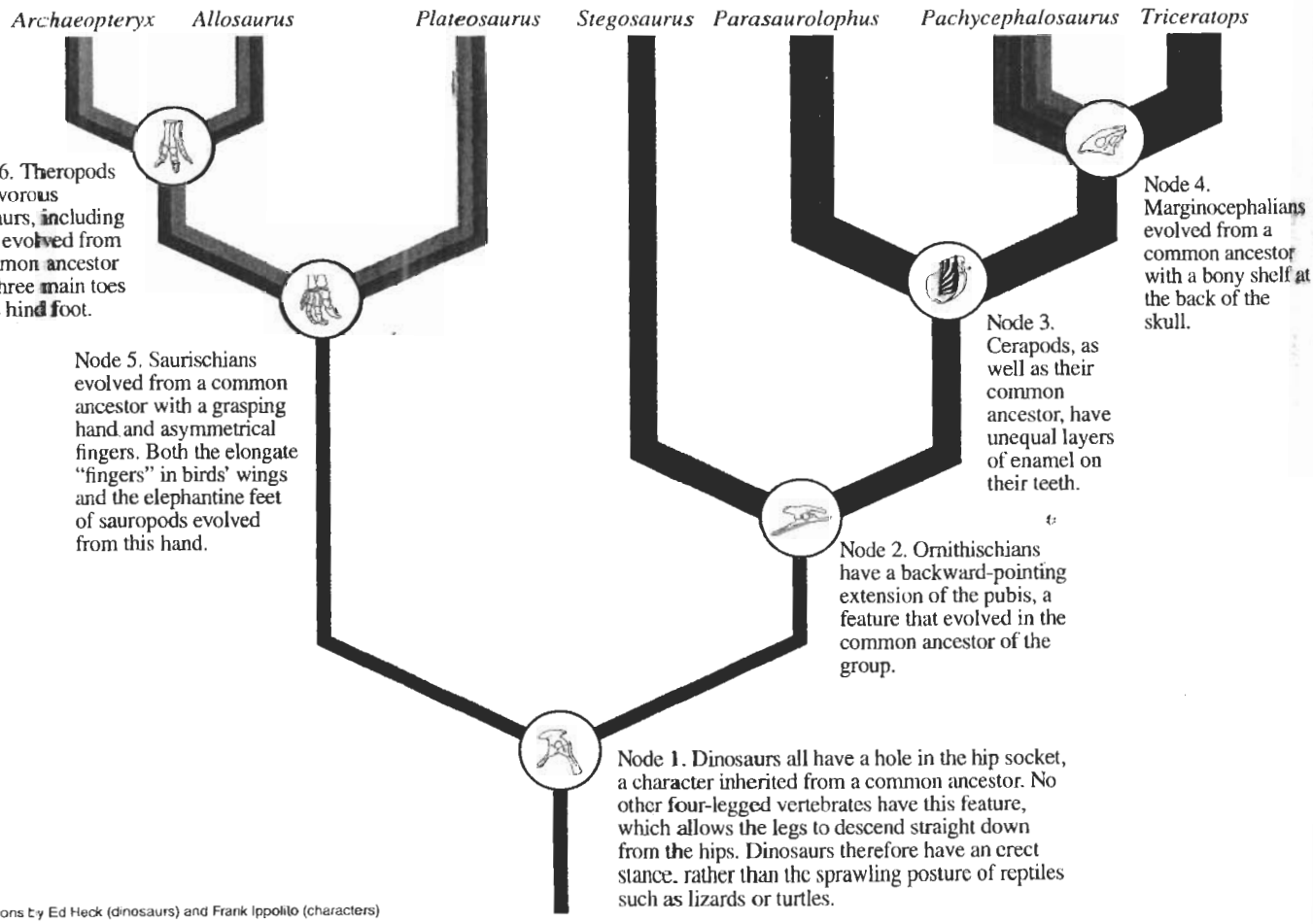
Also called phylogenetic systematics, cladistics is a method of determining the evolutionary relationships of organisms—both living and extinct. It was developed about forty years ago by a German entomologist, Willi Hennig. In the late 1960s,

Forming a tubelike crest, the elongated nasal passages of Parasaurolophus *are its most prominent feature. But a better clue to its place on the dinosaur family tree lies in its tooth enamel.*

Denis Finnin AMNH

Building a Cladogram

	Archaeopteryx	*Allosaurus*	*Plateosaurus*	*Stegosaurus*	*Parasaurolophus*	*Pachycephalosaurus*	*Triceratops*
Hole in hip socket							
Posterior process of pubis	Absent	Absent	Absent				
Unequal enamel layers on teeth	Absent	Absent	Absent	Absent			
Shelf at back of skull	Absent	Absent	Absent	Absent	Absent		
Grasping hand				Absent	Absent	Absent	Absent
Three-toed hind foot			Absent	Absent	Absent	Absent	Absent



Illustrations by Ed Heck (dinosaurs) and Frank Ippolito (characters)

under the leadership of curator Gareth Nelson, the American Museum became a center for the further development and practice of this new methodology. During the past two decades, cladistics has come to dominate the study of evolutionary relationships and has had profound effects on the way in which scientists worldwide attempt to solve biological problems, from the origin of birds to the geographic distribution of animals. By putting the fossils into a cladistic context, the new exhibition halls exemplify the research in which scientists at the American Museum are currently engaged.

Cladistics differs from older methods of reconstructing evolutionary relationships by using the distribution of features, called shared derived characters, to test relationships. We look for patterns of features present in different animals. This distribution of characters usually forms a hierarchy of nested groups, with smaller groups contained within larger ones. For example, the group designated "dinosaurs" is contained within the larger group "vertebrates," because dinosaurs, along with all other vertebrates, have a backbone. The backbone is known as a shared derived character for the group called vertebrates. Each group, or clade, is defined by a set of such shared derived characters inherited from a common ancestor.

Although this is not a perfect method (all scientific probing is subject to criticism and testing), cladistics is more reliable and objective than using the age of fossils, or their occurrence in particular layers of rock, to determine relationships. For example, cladistic analyses show that birds evolved from a small, carnivorous dinosaur, probably very like *Deinonychus* or *Velociraptor*. These dinosaurs, which belong to a group called dromaeosaurs, lived in the Cretaceous, between 107 million and 72 million years ago. Yet the oldest-known bird, *Archaeopteryx*, lived in the late Jurassic, about 140 million years ago. If we relied on relative geological age, we might conclude that the earliest birds gave rise to animals like *Deinonychus* and *Velociraptor*, rather than the other way around. Cladistic analysis indicates that the fossil record is probably not complete and that an animal very similar to *Deinonychus* gave rise to both the birds and later to the dromaeosaurs, including *Deinonychus* and *Velociraptor*. However, we have yet to find fossils of this creature. By using characters in cladistic analyses, we can test hypotheses about phylogenies, or family trees, but we do not seek to specify ancestors and descendants. We only hypothesize which animals are most closely related to each other. While using the geological age of fossils does not result in the most reliable phylogenies, it does provide an important context in which phylogenies can be placed. With cladistics, we thus have a much more realistic and objective view of where evolutionary lineages fit within geological time and where gaps exist in the fossil record of these lineages.

An example of how cladistics works can be seen in the chart on the opposite page. We have chosen seven genera that represent a wide range of dinosaurs. (In an actual study, we would choose as many genera as are represented by good fossil specimens.) Which features, or characters, do we use to determine the evolutionary relationships of these dinosaurs? For living animals, we can look at genetic, chemical, and even behavioral characters, but for fossils, we are limited to the morphology of the skeleton. Even within this limitation, however, we find numerous characters, so which do we choose to work with? Many characters are too limited in distribution; for example, "armor" is found in only one of our representatives (*Stegosaurus*) and therefore gives no clues as to relationships among these particular dinosaurs. A character such as "four limbs" is found in all dinosaurs, as well as in many other animals, and thus is too widespread to be informative. A search for characters with more restricted distributions greatly reduces the number of potentially useful ones.

For simplicity, the chart here has only six characters, but in an actual study, we would use between twenty and one hundred characters to decipher evolutionary relationships. In the Museum's two new dinosaur halls, we have selected a single, derived character for each group. This character is represented by a model that can be touched by the visitor.

By carefully comparing skeletons and charting character distributions, we are looking for patterns of characters that repeatedly form the same group. Computer programs are available to assist with this search. In almost every study, conflicting distributions of characters require the investigator to reexamine specimens and answer such questions as whether the specimens are well enough preserved and whether the characters are really the same, not just similar in appearance. The set of relationships is then depicted graphically in a cladogram. The cladogram that is supported by the greatest number of characters is chosen as the best one, but only as the best one for further work, not as the best and last. Nothing is ever final in science; new theories are proposed, many are rejected, and a few are adopted but remain subject to scientific testing. Cladograms, including those within the new halls, are subject to such testing and may be only temporarily the best.

Those features that define larger groups are called primitive because they are thought to have evolved earlier, whereas features shared by smaller groups evolved later and are called derived, or advanced. Used in this way, the terms primitive and advanced are relative and do not imply that one feature is any better than another. In our chart and cladogram, the character "hole in hip socket" defines the group Dinosauria, which contains all dinosaurs, including birds. Within all vertebrates, having a "hole in hip socket" is unique to the Dinosauria, and we say that it is derived with respect to other vertebrates. But when we are studying subgroups within the dinosaurs, this character is termed primitive. Similarly, four of our dinosaur examples, which form the group Ornithischia, are united by the derived character "posterior process of pubis," that is, a backward-pointing extension of the pubic bone. Within the ornithischians, however, this character is relatively primitive, that is, it evolved early on.

While groups such as mammals and fishes have been the subject of much cladistic analysis, relatively few such studies have been done to establish evolutionary relationships among dinosaurs. Rather, popular interest in dinosaurs has led to numerous studies of their lifestyles and behavior, which in many cases are speculative, rather than based on hard evidence. Although cladograms are often changing as new fossil discoveries are made and our understanding of relationships becomes more refined, cladistic methodology is a good, objective method for testing the paths of evolution. No other museum has the richness and diversity of dinosaur fossils now on display at the American Museum of Natural History. Seeing this collection in a cladistic context emphasizes the real knowledge that can be obtained from fossils.

Name_____

***Why Cladistics?* Reading Questions**

What kinds of characters does cladistics use to determine evolutionary relationships?

What is a clade?

What are primitive characters?

What kinds of characters can we use to determine the evolutionary relationships among living organisms? Among fossils?

How does a scientist deal with characters that support different cladograms (e.g. suggest different evolutionary relationships among the same group of organisms)?

Material developed for the University of Hawaii-Manoa GK-12 program (NSF grant #05385500).
Website: www.hawaii.edu/gk-12/evolution. Duplication for educational purposes only.