Palaeontology

Early evolution of birds

Joel Cracraft

OUR understanding of the evolutionary history of the main taxonomic groups relies heavily on knowledge provided by fossil organisms. Reciprocally, it is usually not possible to obtain an accurate assessment of the phylogenetic relationships of fossil taxa without a prior hypothesis based on extant organisms. Fossil organisms can provide information on character-state distributions not found among living taxa, but without diagnostic characters, fossil specimens can be little more than old scraps of bone. Thus, palaeontology's great contribution to the study of the history of life is not so much that it adds a time dimension, although that contribution is undeniably important, rather that it yields copious character-state data that can be used to reconstruct genealogical relationships. When new, critical fossils are discovered, palaeontologists are justified in kicking up their heels. One cause for celebration is a new fossil bird from the Lower Cretaceous of Spain (Las Hoyas), which is the subject of a report by J. L. Sanz, J. F. Bonaparte and A. Lucas on page 433 of this issue[1]. Although this find does not lead us to restructure our ideas on early avian relationships, it clarifies our knowledge of character evolution and provides important new interpretations regarding the early diversification of birds (Fig. 1).

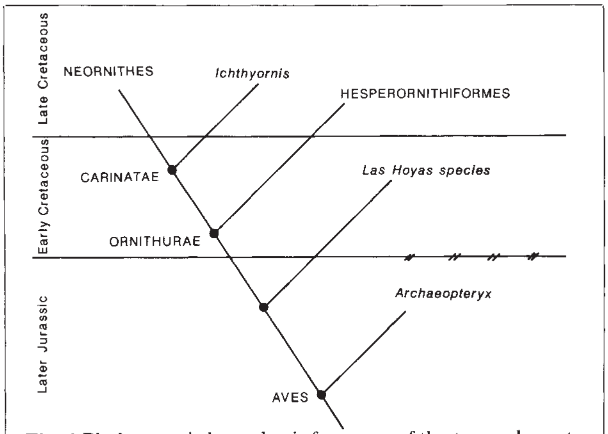

Fig. 1 Phylogenetic hypothesis for some of the taxa relevant to the early history of birds. Present information on the Las Hoyas species suggests it is the sister-group of the Ornithurae.

The Late Jurassic species *Archaeopteryx lithographica* is widely acknowledged to be among the most important fossils in demonstrating a phylogenetic link between two major groups of organisms. Indeed, all discussions of the origin of birds begin with the data provided by *Archaeopteryx*[2-4]. Primarily because it possesses feathers, the avian relationships of *Archaeopteryx* have seldom been questioned, but its more distant affinities to one or more reptilian groups have been strongly debated[3]. For the past decade or so, an increasing amount of data point to the conclusion that *Archaeopteryx* and all other birds are more closely related to some theropod dinosaurs than to any other reptilian taxon[5-8]. This important finding provides a critical comparative foundation for interpreting evolutionary character transformations that took place during the early history of birds and has led to my phylogenetic hypothesis for some of the main avian lineages[9].

The Las Hoyas specimens can be interpreted relative to this scheme of relationships. As Sanz and colleagues note[1], the new fossil bird is seemingly not so primitive as *Archaeopteryx* nor as advanced as all other birds (collectively called the Ornithurae). The Las Hoyas fossil and the Ornithurae share a strut-like coracoid and pygostyle, both absent in *Archaeopteryx*. The Ornithurae have fused pelvic elements, complete fusion of the metatarsals, and complete fusion of the tarsals distal to the metatarsals. The Las Hoyas specimen, in contrast, lacks these features, as does *Archaeopteryx*. Given this character distribution, the conclusion of Sanz *et al.*, that the Las Hoyas specimen is the sister-group of the Ornithurae, appears justified (see Fig. 2).

If this phylogenetic hypothesis is correct then the Spanish discovery implies several anomalous character transformations and necessitates refinements in our interpretation of the evolution of the Late Cretaceous toothed divers, the hesperornithiforms. The apparent anomalies in the Las Hoyas specimen are that it is said to possess first, an astragalus and calcaneum that are not fused to the tibia and second, an unfused metatarsus. Remarkably, both of these features seem to be more primitive than the condition in *Archaeopteryx*[5], and the latter character is paralleled to some extent in the Late Cretaceous enantiornithine[10] birds (see also ref. 9). Whether these differences will be resolved following a more detailed description of the Las Hoyas material remains to be seen. In any case, to accommodate these character conflicts it may be necessary to postulate that fusion, or possibly even loss of fusion, of the tarsal and metatarsal elements occurred more than once.

The order Hesperornithiformes includes

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Fig. 2 Left, an artist's impression of *Archaeopteryx* by Maurice Wilson (courtesy of the Natural History Museum, London). Right, an ultraviolet image of the new Mesozoic bird from the Neocomian outcrop of Las Hoyas (courtesy of G. F. Kurtz; see ref. 1).

a few flightless species which are highly specialized for diving[11]. Despite possessing many highly modified features associated with the loss of flight and locomotion through an aquatic medium, hesperornithiforms have many primitive characters that exclude them from the carinates[9,12]. Although it has been commonly assumed that hesperornithiforms are secondarily flightless, my cladistic analysis[9] of available data does not support this hypothesis, chiefly because there are no more primitive taxa with characters indicating an ability to fly. The Spanish specimen could resolve this issue.

If the relationships of the Las Hoyas bird are as envisioned by Sanz *et al.*, then the hesperornithiforms were probably secondarily flightless. A pygostyle, a strap-like coracoid having a well-defined articulation with the sternum, and a furcula with a hypocleidium found in the Spanish material all suggest that the bird could fly. At the same time as the Las Hoyas specimens clarify the evolutionary history of the hesperornithiforms, they also require avian palaeontologists to re-evaluate the diagnostic characters of the carinates themselves. Many of these characters will undoubtedly be found to define a larger group, namely all birds other than *Archaeopteryx*. A further implication of this result is that many morphological features characterizing modern birds arose very early in the history of birds. ☐

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Biological modelling

What's evolving in artificial life

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If we ever discover extraterrestrial life, the implications for biology will be enormous. We would be forced to confront the unavoidable parochialism of a science whose body of knowledge is built on only one variety of life, namely, life on Earth.

Contemplating the possibility of extraterrestrial life raises some basic questions: which features of life are universal? Which are specific to Earth — how much of the life that we see around us is a 'frozen accident' of evolution? This immediately leads to a host of more specific questions: must life be based on carbon chemistry; must the genotype – phenotype distinction exist; do life forms need to be organized into species, with branching phylogenies?

We may or may not encounter extraterrestrial life, but whether or not we do, many of the same questions might be addressed by studying 'artificial life'. With advances in software, hardware and 'wetware', it may be possible to create lifelike 'organisms'. They might be carbon-based, created inside a laboratory, or robots, built out of silicon-based chips, or abstractions that exist only inside a computer. Artificial organisms can provide a laboratory to study various fundamental questions about life that cannot easily be addressed in ordinary biological experiments. Included in this are attempts to analyse the fundamental features of the 'logic of life', and to assess the conditions under which complex systems made of simpler components can self-organize and adapt in complex environments.

*Artificial beauty — computer-generated life forms can demonstrate patterns of morphogenesis. Below, development of a sympodial inflorescence (*Lychnis coronaria*) generated by a DOL-system (pictures courtesy of Chris Langton, Los Alamos National Laboratory).*

An interdisciplinary group met recently* for the first conference on artificial life. Models of the origin of life, of morphogenesis and of co-evolution in simulated environments were discussed. The first set of models tried to account for the spontaneous emergence of self-reproducing systems in simulations of the prebiotic environment.

The second set of models followed a line of thought that dates back to Goethe. Richard Dawkins (University of Oxford) and others presented elegant examples of morphogenesis of animal and plant-like forms, by the recursive application of simple developmental mechanisms. Slight modifications in the parameters can lead to slight alterations in the resulting morphologies in some cases, but large alterations in others. Thus, evolution explores a space of parameter values which generate a family of recursively related forms. However, it remains unclear how to incorporate a natural notion of fitness into these models.

Artificial ecosystems presented at the conference represent a third approach to the study of artificial life forms. Various models were presented: abstract animals living on a two-dimensional grid, with selection occurring on high-level properties such as 'aggression'; a model for the social interaction of bees; a 'movable finite automata' world in which the laws of 'chemistry' cause a virus molecule to self-

A simple recursive genetic description consists of a set of rules that define the pattern of change across generations. The following is a simple example:

(1) A → CB
(2) B → A
(3) C → DA
(4) D → C

Once the initial state is determined, each successive state is determined accordingly.

Time	Structure	Rules applied (L to R)
0	A	(initial 'seed')
1	C B	(rule 1 replaces A with CB)
2	D A A	(rule 3 replaces C with DA and rule 2 replaces B with A)
3	C C B C B	(rule 4 replaces D with C and rule 1 replaces the two As with CBs)
4	. . . . (etc)	

More complex rules can include branching, and can lead to the type of recursive patterns represented in the figure.

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*21–25 September 1987 held at the Los Alamos National Laboratories, New Mexico.