simple liquid until the work of Katayama et al.[3].

Previously, Brazhkin and colleagues observed large changes in the electrical conductivity of simple liquids (iodine, sulphur and selenium) at high pressure, which were attributed to liquid–liquid phase transitions[4,7]. But these changes could equally well occur in a two-state regime within a single liquid phase[4]. Katayama *et al.*[3] provide a method to determine which type of thermodynamic behaviour is associated with changes in liquid properties as the pressure varies. They use synchrotron X-ray diffraction methods to study directly the structure of liquid phosphorus at high pressures and temperatures. They observe at a pressure near one gigapascal, a sharp transition between the molecular liquid present at atmospheric pressure and a high-density polymeric form. The two forms coexist within a narrow pressure range, as determined by the composite X-ray spectrum, and the transition could be reversed by lowering the pressure — providing direct evidence for a pressure-driven structural transition in the liquid above the melting point.

The evidence now available indicates that first-order phase transitions do occur in the liquid state, and that the phenomenon is probably widespread[1–4]. We must revise our conventional picture of liquids as entities with continuously varying averaged structure. Instead, each liquid is constrained by distinct 'configurational landscapes' that are explored within a given range of density (or pressure)[8]. Liquid polymorphs with different structures and physical properties have landscapes that are separated by high-energy barriers that determine the first-order nature of liquid–liquid transitions[2]. This 'configurational landscape' model may even be applied to biomolecules, in which transformations between unfolded and folded structures of proteins may be modelled by analogous phase transitions[8].

Multiple liquid–liquid transitions may occur for a given substance as the pressure is varied[1,4,7]. At the lowest density, the liquid–gas transition is then the 'final' member of a suite of such transitions. The experiments of Katayama *et al.*[3] point the way not only to structural investigations of liquid polymorphs, but also to gaining a broader understanding of relationships between liquids and gases, by providing direct confirmation that pressure-driven transitions between different liquid phases do occur. An even more intriguing possibility is that first-order transitions may occur between gases. A 'normal' gas is already recognized as distinct from an ionized plasma. Perhaps transitions between non-ionized gaseous phases might occur at extremely low temperatures and at low densities. ■

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Palaeontology

Fossil fish up for election

Meemann Chang

The bony fishes (osteichthyans) were the progenitors of tetrapods, without which none of us would be here. So we have good reason to be interested in bony-fish evolutionary history. The group is divided into the ray-finned and lobe-finned fishes, and recently discovered early bony-fish specimens have a mixture of characters of each type. Moreover, these specimens show some features formerly thought to be present only in the more primitive cartilaginous fishes (chondrichthyans — sharks and rays) and an extinct group called placoderms. So palaeontologists have been puzzling over which group the new forms should be assigned to, and how all of the various groups are related to each other.

On page 185 of this issue[1], Basden *et al.* report on another bony-fish fossil that comes from southeastern Australia and is designated AM101607. It looks ray-fin-like, but it also exhibits some characters previously found only in lobe-finned fishes and others found only in chondrichthyans and placoderms. Last year, Zhu *et al.*[2] discussed another fish of this kind, *Psarolepis*, from China and Vietnam, which had been earlier described by Yu[3] and is more lobe-fin-like in appearance. Both *Psarolepis* and AM101607 are from the Early Devonian period, about 400 million years ago, and so are among the oldest bony fishes known. The respective authors[1,2] each propose that the specimen they describe is a candidate to be a member of the basal group (the 'ancestor') of bony fishes, but Basden *et al.*[1] consider that their fish is the more promising contender.

Specimen AMF101607 consists only of a large portion of a braincase, but its three-dimensional preservation reveals many anatomical details. In several respects it resembles two well-preserved ray-finned fishes, *Mimia* and *Moythomasia*, from the Late Devonian (about 350 million years ago) of western Australia[4]: similarities lie in the ornamentation of the dermal bones; in the pattern of the skull roof (Fig. 1a, b), and of the sensory canal and pit line; and in the structure of the lateral wall of the orbito-temporal region of the braincase. It also has some characters in common with *Psarolepis* and other lobe-finned fishes. Other characters, however, are shared with ray-finned fishes and chondrichthyans, rather than lobe-finned fishes (the postorbital process; the broad spiracular groove; and the lateral commissure joining the base of the orbito-temporal region of the braincase). But, most strikingly, AMF101607 has some features never found in either lobe-finned or ray-finned fishes, such as an eyestalk.

Eyestalks are rod-like structures that grow out of the inner wall of the orbit and have a flat, rounded knob at the end which abuts against the eyeball[5]. They were thought to be unique to chondrichthyans and placoderms, where they (and the endocranium as a whole) are cartilaginous and can be seen in full only in recent sharks and rays (Fig. 2a). In placoderms, now represented only by fossils, the cartilaginous endocranium is frequently lined with a thin layer of calcified cartilage. In these fishes, the eyestalk itself is not preserved. Even its base, which is part of the endocranium, has been found in only a few taxa, such as *Jagorina* and *Macropetalichthys*[6], where it is evident as a stub (Fig. 2b). In most cases there is only a hole in the inner wall of the orbit at the site for eyestalk attachment[7] (Fig. 2c).

It seems that the minerals filling the base of the eyestalk in Basden and colleagues' specimen were etched out during acid preparation of the fossil, and there is only an opening left in the inner wall of the orbit. Yet the rim of the opening is clearly everted,

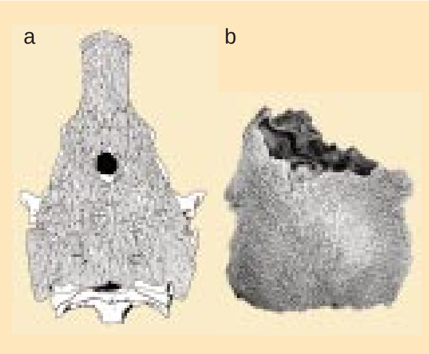

Figure 1 **Similar patterning of the skull roof of Devonian fossil ray-finned fishes from Australia.** a, ***Mimia*, from the Late Devonian[4].** b, **The new specimen AMF101607 from the Early Devonian, as described by Basden *et al.*[1].**

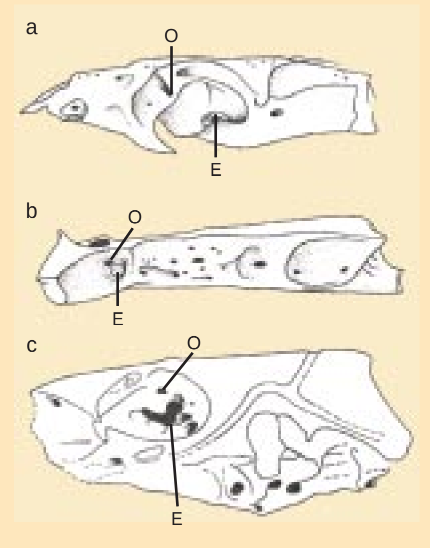

Figure 2 **Fish braincases in lateral view, showing the eyestalk, or its base or site of attachment (all marked as E; see also Fig. 2 on page 186). The eyestalk is a diagnostic feature that was thought to be unique to chondrichthyans and placoderms, but is evident in Basden and colleagues' fish[1].** a, ***Chlamydoselachus*** **(chondrichthyan), a recent shark[5].** b, ***Jagorina*****, a placoderm[6].** c, ***Brindabellaspis*****, a placoderm[1]. O, the opening for the optic nerve.**

matching the condition in *Jagorina*. So there is no doubt that AMF101607 had an eyestalk. In consequence, eyestalks can no longer be considered to be unique to chondrichthyans and placoderms.

This is not a trivial point. Changing knowledge about the distribution of key characteristics often radically alters our understanding of the evolutionary relationships of their bearers. Take feathers, for example — as soon as it was found that theropod dinosaurs possessed them, feathers could no longer be regarded as unique to birds. The revelation that the new fish from Australia had an eyestalk has similar significance (if less public appeal).

Based on the cranial features of AMF-101607 and of examples of other groups in the evolutionary tree constructed by Zhu *et al.*[2], and using a computer program called PAUP, Basden *et al.* produced several alternative positions of their fish and *Psarolepis* in the tree (see Fig. 3 on page 187). Their preference is for one with the new form at the base of the bony fishes and *Psarolepis* at the base of the lobe-finned fishes.

Uncertainty about the positions of the two forms in Basden and colleagues' tree arises mainly from insufficient information. Specimen AMF101607 is very similar to the two Late Devonian ray-finned fishes, so we ought to compare them more thoroughly. The eyestalk-attachment area in AMF-101607 seems to occupy exactly the same position as the opening for the optic nerve in *Mimia* and *Moythomasia* (and is almost the same shape and size), so it could be that these fishes also had an eyestalk. Comparison of the new form with *Mimia* and *Moythomasia* will help to identify the closest relative of bony fishes, and may even tell us something about the evolution of jawed vertebrates as a whole.

Other new knowledge also has to be taken into account. The characters previously held to be unique to osteichthyans have recently been identified in a chondrichthyan from Bolivia[8], and a molecular study places the cartilaginous fishes within the bony-fish evolutionary tree[9]. All of these developments challenge our understanding of the relationships among the major groups of primitive back-boned animals and demand a profound change of conventional wisdom. The new form reported by Basden *et al.* is a welcome addition to the list of candidates for the position of 'ancestor' of the bony fishes. But whether it will be elected remains to be seen. ■

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Neurobiology

Internal model visualized

Masao Ito

How can we instantly recognize a familiar object? Probably because, in the brain, we already have a model of that object which is activated through vision. Similarly, we can quickly comprehend what we hear because the brain is likely to contain a model representing the meanings of the sounds we encounter. And we can probably carry out complex movements so easily and accurately because the cerebellum provides a model of what is to be moved. Such internal models provide an attractive explanation for the brain's subtle cognitive and control mechanisms, but there has been no way to investigate them experimentally. Now, however, on page 192 of this issue, Imamizu *et al.*[1] report a set of brain-imaging data that provide the first evidence for such a model being formed in the cerebellum.

The basis of the work done by Imamizu *et al.* is the unique theory[2] of the adaptive-control system with two degrees of freedom (Fig. 1). It works like this. When we move a hand, a desirable movement worked out somewhere in the brain is conveyed as an instruction to the motor area and its related regions in the cerebral cortex. These areas in turn generate command signals, which act on the hand/arm system to carry out the movement. Information about the realized movement is conveyed through the visual system back to the motor and related areas, and compared with the movement received as an instruction. This feedback ensures that

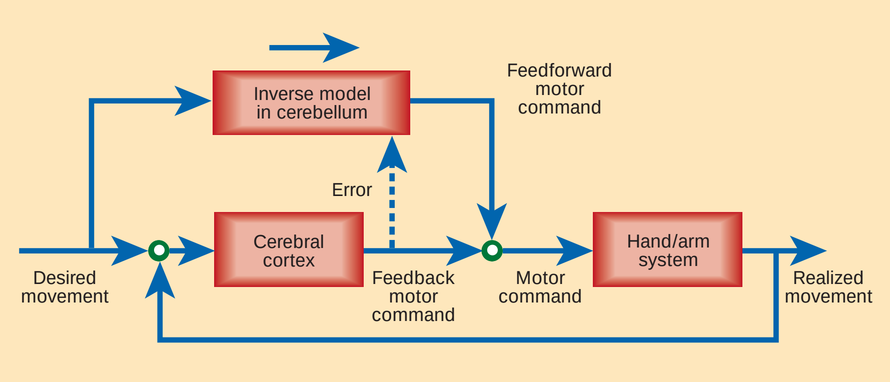

Figure 1 **Block diagram of the two degrees of freedom adaptive-control system with feedback-error learning mechanism. This system combines a feedback control by the cerebral cortex and a feedforward control by the cerebellum. The cerebral cortex compares the instructed, desired movement with a realized movement by sensory feedback, whereas the cerebellum receives only the instruction. To realize a desired movement without feedback of the realized movement, the cerebellum needs to form an inverse model of the hand/arm system, as visualized by Imamizu *et al.*[1] using brain-imaging data. (Modified from ref. 2.)**