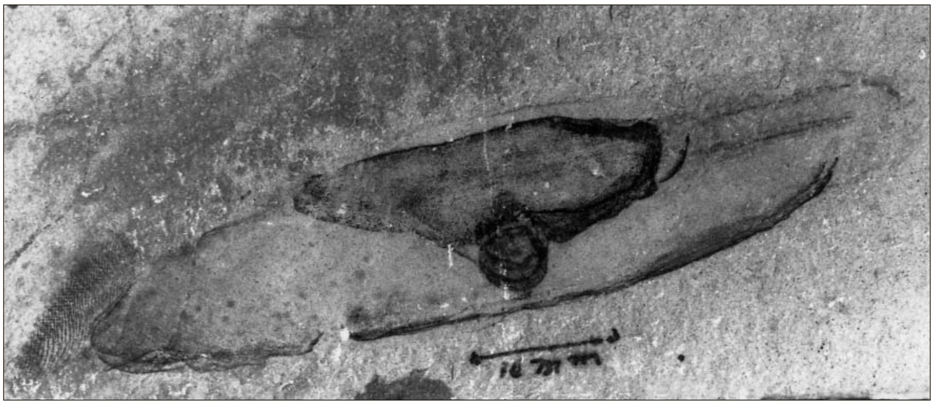


1: Could this Carboniferous fossil be an alien goldfish? (Simon Conway Morris)

Aliens like us?

Simon Conway Morris explains that as and when (and indeed if) we meet the extraterrestrials, they will look eerily like us.

Some years ago, I had the chance to study some very peculiar fossils from Montana (figure 1). They are Carboniferous in age, and so coincident with the great coal forests, giant dragonflies and millipedes the size of Alsatians. This beast, however, lived in the warm waters of a giant lagoon. For reasons that need not detain us, these 320 million-year-old fossils had already earned a certain notoriety, and they certainly had a very peculiar appearance: vaguely fish-like, but neither fish nor like any other known group of animals (Conway Morris 1990). A real evolutionary enigma, and at the time of writing this article these fossils still represent an unsolved problem.

When serious scientists with huge beards aren't looking, I jocularly refer to these fossils as my alien goldfish. Picture the scene: the giant spaceship is parked on a wide beach, and kicking pebbles Commodore Grafnik is in a filthy mood. Yet another planet with hundreds of millions of years to go before intelligence evolves, not even at the zorkquaan stage, for Threga's sake! And as for his pet vlantans!! Purchased at huge expense, all they do is feed voraciously and then fall asleep. Still fuming, Grafnik carries the bowl down to the lagoon edge and (contrary to every regulation in the AIPC [Access to Inhabited Planets Code]) tips the vlantans out. They dart away and several months later enter the fossil record of a planet where they have no right to be.

Pure fantasy, or so I suppose. Yet this scenario raises interesting questions, of relevance to all astronomers. Why isn't there (apparently!) any evidence for us having been visited by extraterrestrials? More importantly, if they did come how might we recognize either them (er, footprints?) or their liberated "goldfish"? If, one day, we go to the stars, what can we expect to find? Here evolutionary expertise, which is almost entirely neo-Darwinian, is largely unanimous. The emergence of a human-like intelligence is, for all intents and purposes, an evolutionary fluke. Such is the declaration. Very interesting to us, but in the grand scale of things no more significant than tape-worms or tulips. Such reasoning is largely based on the apparently reasonable view that evolution is largely a catalogue of accidents; an asteroid impact here, a super-volcano there, not to mention the constant rumble of chance mutations. This view has been argued for by many leading biologists, perhaps most forcibly by Jared Diamond and the late Stephen Jay Gould. If correct, this suggests that the Search for Extraterrestrial Intelligence (SETI) (e.g. Lamb 2001, Ulmschneider 2003) is most probably a complete waste of time.

But is it correct? Neo-Darwinian as I am, I take diametrically the opposite view. Human-like intelligence is evolutionarily inevitable. It ought, therefore, to be universal, but paradoxically it seems not to be. Bold and controversial claims, so what is the evidence? The details are laid out in my book *Life's Solution* (Conway Morris 2003) and here I will only provide a sort of summary and one slanted to the astronomical community. In essence, I think the evidence we can glean from the evolution of life on Earth compellingly supports the thesis that a human-like intelligence is evolutionarily inevitable. To be sure, it may be centuries before we can test this hypothesis against an alien biosphere. But who knows, perhaps the answer will arrive quicker than anyone expected?

Universal life, universal biochemistry?

The first premise is that all life is what we call carbaquist – that is, based on the unique properties of carbon, not least its ability to form long flexible chains and rings, and that strangest of fluids, water. Of course, it is well worth thinking of alternatives, and would not the universe be that much the richer if life extended beyond the carbaquist: the perennial favourite is silicon-based life forms, but why not interstellar organisms embedded in giant gas clouds, dirigible-like floaters cruising in the atmosphere of gas giants, and then don't forget there are neutron stars… Well, maybe, but speculation tends to run ahead not only of hard science, but as importantly the problem of deciding exactly what *is* life; that strange self-replicating entity that generates complexity in a shimmering network of molecular machinery, but machines built on a nano-scale that run at an incredible efficiency and power everything from a flagellar motor to thought?

Let's be modest and stick to carbaquist. Is that all life will have in common? Among molecular biologists there is a strong hunch that the familiar terrestrial biochemistry could be universal. In fundamental operations such as the primary metabolic cycles, possibly photosynthesis and maybe DNA and its replication, there are few, if any, alternatives. Consider also the puzzle of amino acids. Their chemical synthesis in a truly remarkable range of environments – almost certainly including interstellar gas clouds – is relatively unproblematic. But with the exception of the simple and symmetric glycine, all amino acids can form as mirror images (enantiomorphs). Why then does all life, practically without exception, use the left-handed variety? Plenty of speculation surrounds this question, with many regarding it as simply a "frozen accident": by chance the first life chose the L-enantiomorph rather than the D-variety, and due to their mutual incompatibility there was no turning back. In certain carbonaceous meteorites, however, there is a clear preponderance of the L-form, so the expected 50:50 chiral ratio is broken (Pizzarello *et al.* 2003). One hypothesis is that this is a result of the circular polarization of ultraviolet radiation in deep space. This may be a hint that many of the other building blocks of life, and perhaps even their subsequent assembly, might be controlled by extraterrestrial processes.

Evolutionary convergence

Beyond that, however, the consensus is still very much that the evolutionary trajectories are almost entirely open-ended. As already noted from a neo-Darwinian point of view, it is very difficult to justify the SETI enterprise. Here on Earth there are humans and humming-birds, but on Threga IX who knows? Maybe something vaguely plant-like, even quasi-animals or pseudo-fungi, but intelligence, let alone technology? Forget it; alien biospheres will be, well, truly alien. Maybe so, but what if there were general rules to evolution, ones that confer predictability to the outcome not only on Earth but *anywhere*?

The clue lies in the phenomenon known as evolutionary convergence (Conway Morris

Abstract

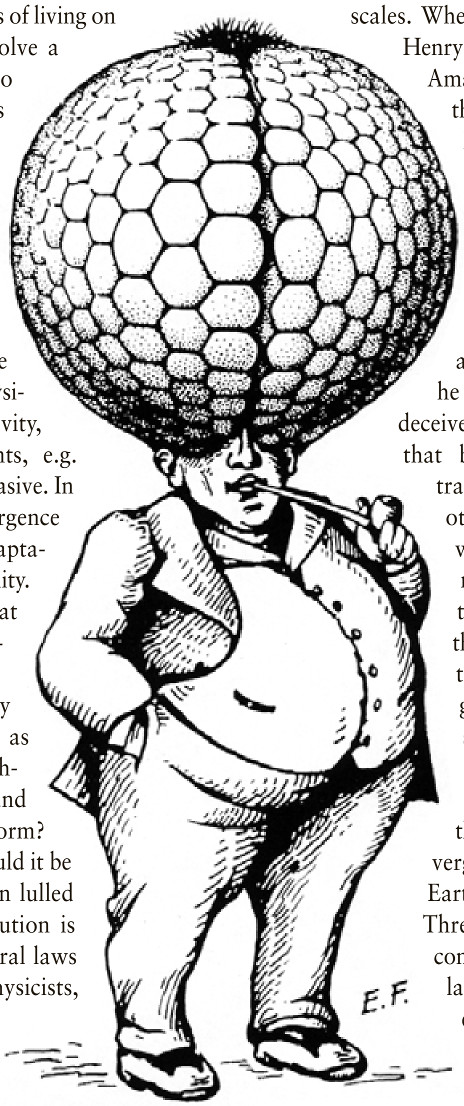
So what are they going to be like, those long-expected extraterrestrials? Hideous hydrocarbon arachnoids, waving laser cannons as they chase screaming humans, repulsively surveying the scene through empathy-free compound eyes? Or maybe laughing bipeds, chatting away, holding a glass of wine, a bit like us?

2: Evolutionary convergence. The hawk-moth may look like a hummingbird, but the two creatures evolved from very different ancestors. (Jim McGlasson, Space for Nature http://www.wildlife-gardening.org.uk/)

2003). To biologists this is a familiar concept, but one that has been oddly neglected. In essence it is a feature of evolution whereby organisms arrive at very similar biological solutions, but from very different starting points. All is not possible, so the metaphorical wheel is reinvented many times. Ironically, evolving a biological wheel seems perfectly plausible, but it is one of the excluded options because of the functional constraints of living on planets that need to evolve a technology that likes to build roads before wheels are permitted (LaBarbera 1983). But the wheel is the exception that proves the rule. Indeed, in many ways evolutionary convergence is hardly surprising. Organisms must live in a real world where physical realities, such as gravity, and chemical constraints, e.g. kinetic rates, are all pervasive. In one sense all convergence demonstrates is that adaptations are a biological reality.

Yet the adjectives that almost invariably accompany descriptions of convergence are distinctly curious: words such as "remarkable", "astonishing", even "stunning" and "uncanny" are the norm? Why should that be? Could it be that biologists have been lulled into believing that evolution is really free of those general laws and principles that physicists, chemists and indeed astronomers, take for granted and indeed without which simply could not operate?

But does evolutionary convergence really point to general principles? After all, isn't it just like the rest of biology, a myriad of examples, but typically anecdotal: in the end, so what? There is certainly some truth in this observation, yet two features of convergence stand out. First is its pervasiveness, from molecular to the organization of societies, and second the degree of similarity in complex, highly integrated systems.



3: A compound eye would have to be 1 m high to provide the same visual detail as our camera eye. (K Kirschfeld 1976 in *Neural Principles of Vision* ed. F Zettler and R Weiler [Springer-Verlag])

Consider two examples, and at two different scales. When the famous biologist Henry Bates was exploring the Amazon, he was struck by the convergence between hummingbirds and hawk-moths (figure 2). On occasion he levelled his rifle, took careful aim at a hummingbird and found to his surprise he had shot a hawk-moth. Nor was he the only one to be deceived. The locals insisted that bird and moth could transmute, one into the other. As any biologist will tell you, the hummingbird is a close relative of the dinosaur and the moth of a shrimp, yet the degree of convergence in not only body shape but also vital components such as energy budgets is startlingly similar. If this convergence occurred on Earth, then why not on Threga IX? Now consider convergence at the molecular level, specifically the enzyme carbonic anhydrase. It is a pretty impressive catalyst, serving to accelerate the hydration of carbon dioxide by more than a million times. On Earth it plays a key role in processes as disparate as photosynthesis, respiration and biomineralization: could, indeed, any biosphere manage without such an enzyme? Yet carbonic anhydrase is patently convergent, having evolved independently at least three times (Liljas and Laurberg 2000).

Eyes to brains

If convergence is so pervasive – and I can give you thousands of examples ranging from the independent evolution of flowers to eusociality, or myoglobin to trichomatic colour vision – then can we be so sure that human intelligence is as unique as commonly supposed? And if it isn't, then the implications for extraterrestrial equivalents will be obvious. Moreover, we can approach this question by several avenues, any one of which will give intriguing insights into the nature of convergence. One could discuss, for instance, the independent evolution of warm-bloodedness. This is a *sine qua non* for a stable brain state, and as such is quite familiar in terms of its convergent evolution in mammals and birds. But did you know several ocean-going fish have also arrived at the same solution (Fritsches *et al.* 2005), again independently?

Here, however, I will briefly discuss sensory assimilation on the reasonable assumption that one prerequisite of intelligence is the neural interpretation of external stimuli, be they photons (vision), pressure waves (hearing) or molecular signals (olfaction, taste). Eyes, of course, are one of the standard topics of evolution. It is still legitimate to share Darwin's amazement at this biological machine, even though we know a great deal more of its origin and evolution. That the emergence of eyes is practically inevitable is evident from the fact that they have evolved independently many times, but importantly the principal molecular building blocks necessary for the successful operation of the eye evolved thousands of millions of years before the first eye. Key in this regard are those proteins that confer transparency, known as crystallins. These have clearly been repeatedly co-opted, from functions typically involved with stress management in microbes. Equally essential are those molecules that transduce light into electrical signals. They are known as opsins, e.g. rhodopsin. These too evolved long before the first eye, and in themselves are also probably convergent.

There are many types of eye, but you see the world through a so-called camera eye and odds are if you go for a stroll (or a swim) the creature gazing back will also be using either a camera eye or a compound eye. The latter, as the name suggests, is made of many lenses and is most familiar in the insects. Yet both have evolved independently many times, the camera eye six or more times, and the compound eye at least four times (Conway Morris 2003). They are both outstandingly successful designs, and it might seem reasonable to conclude that despite their manifest differences they are otherwise pretty much equivalent. Let us, however, undertake a thought-experiment and ask: Imagine some dictat, from a conveniently unspecified source, that declared that the evolution of camera eyes is forbidden. Humans are forced to use compound eyes, yet reasonably we still demand the same level of visual acuity. The conclusion is sobering. As the distinguished German physiologist Kuno Kirschfeld has calculated, the resultant eye would have to be at least a metre across (figure 3)! For that reason alone we can be pretty sure that if there are any extraterrestrial astronomers they will be looking at us through camera eyes, very similar to our own.

Convergences in sensory systems are by no means restricted to eyes and vision. In fact, across the board convergence is pervasive, but I would argue that it is also under-appreciated in its scope and significance. Thus, whether a particular animal learns about its outside world through the agency of echolocation, seismic communication, heat (infrared) perception, hearing, pressure waves, smell, touch or what is arguably the most alien (at least to us) of sensory systems, that dependent on the generation of electrical fields, these mechanisms of perception have evolved not only independently, but multiple times.

All deal with stimuli that ultimately depend on well-known (and universal) physical principles and their transduction via similar molecules (typical trans-membrane helical proteins) into electrical signals. These deeper similarities are also fascinating because they suggest that in at least some cases there is a more fundamental equivalence of sensory perceptions. In essence, you can "see" with sensory organs other than an eye. Not only that, but there is clear evidence of different sensory inputs being integrated. Dolphins, for example, "see" an object by both vision *and* echolocation. This in turn has some intriguing implications for theories of the mind and consciousness. We might expect these also to be universals. Extraterrestrial animals will not only see, they will think.

Evolutionary convergence may also inform us in other respects as to how likely extraterrestrial intelligence really is going to be. One key component is surely the transmission of complex information by vocalizations – and remember that this includes song. Here too there are many interesting parallels between different groups of animals. Young children have a remarkable babbling stage, before the language begins to crystallize. Close parallels are seen in other vocalizing groups such as birds, dolphins and monkeys. In addition, at least in the case of the birds, the convergent similarities between the neurology of vocalization and humans is striking. So too several groups show dialects and local vocal traditions, while at least the dolphins have the rudiments of semantic and syntactical ability. This is hardly surprising given their close cognitive convergence with the great apes (Marino 2004). Even human languages show some interesting convergences. No doubt at first hearing the chatter of extraterrestrials will sound very strange, but the universals of grammar suggest we will get their gist pretty quickly.

4: Convergent tools. A New Caledonian crow extracting bugs. (Alex Kacelnik, Oxford)

Convergent tools and technologies

Language, at least in its fully fledged form, is unique to humans, yet given what we know of evolutionary convergence, it is difficult to believe it is a fluke to circumstance. Rather waiting in the wings of the theatre of life are all the prerequisites of what is required to become human. And this applies to the technology that now equips us, for example, to look at and listen to the stars. Recall that even 500 000 years ago our technologies were pretty rudimentary. So to see yet more primitive manifestations, along with a sort of proto-culture in the Great Apes is scarcely surprising given our evolutionary proximity. A little more remarkable is that independent experiment in primate evolution, the radiation of the South American monkeys, where tool use again has emerged independently (Fragaszy *et al.* 2004). But it is in other groups, notably the New Caledonian crow (figure 4), that we see some of the most astonishing convergences in tool use (Kenward *et al.* 2005). Their skill in crafting probes and hooks is becoming legendary, and it also defines a nascent technology (Hunt and Gray 2003). In some ways, however, this capability is predictable given the many striking convergences between corvid and primate cognition (Emery and Clayton 2004). What is really important to stress, however, is that this convergence arises from brains with a structure radically different from that of the mammals. My strong hunch is that a human-like intelligence is a cosmic inevitability, but I have never said it should reside in a human-like brain.

Convergence is, in my opinion, not only deeply fascinating but, curiously, it is as often overlooked. More importantly, it hints at the existence of a deeper structure to biology. It helps us to delineate a metaphorical map across which evolution must navigate. In this sense the Darwinian mechanisms and the organic substrate we call life are really a search engine to discover particular solutions, including intelligence and – risky thought – perhaps deeper realities? Convergence confers, therefore, a predictability to evolution and as a general law what applies here should apply on any habitable planet, in this galaxy and beyond.

But here we run into Enrico Fermi's famous question: "Where are they?" This paradox surely is one of the biggest questions we face, not only among scientific questions but sociological and psychological, perhaps even theological. Something doesn't add up. My own view is that paradoxically we remain alone because the Earth is a very special planet indeed. Given the rate of discovery of extrasolar planets this may well seem to be increasingly incredible. If it is, then I think the only alternative is that "they" are here, "they" know all about us, and one day we'll be in for a small surprise. ●

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