

The navigation of biological hyperspace

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Abstract: A recurrent argument against the reality of biological evolution is the claim that there is insufficient time for the emergence of biological complexity. Such a view is a staple of creation ‘scientists’, but even cosmologists and biochemists have been overheard murmuring similar sentiments. Certainly the stock response, that the scientific evidence for evolution is overwhelming, must be made. However, it is also the case that whilst the efficacy of natural selection is not in dispute, it is context-free and fails to explain the specificities of life. This observation is usually greeted with a Gallic shrug: ‘Yes, the biosphere is very rich, but so what?’ Indeed, the standard scientific response is that evolution is dogged by contingent happenstance, with the implication that a given complexity, say intelligence, is an evolutionary fluke. This, however, is inconsistent with the ubiquity of evolutionary convergence. Here I outline the argument for such convergence providing a ‘road-map’ of possibilities that arguably has universal applications and as importantly points to a much deeper structure to life.

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Introduction

Biological systems clearly belong to the natural order, and in common with many other systems they show a clear hierarchy: molecules to societies. Change, that is evolution, can be identified at all levels, but it is a largely unsolved problem as to: (a) how the identified levels interact (‘is there, for example, a gene for aggression?’); (b) whether one or other level is of primary importance; (c) whether given levels have a distinct identity that is more than the sum of its parts; and (d) how different time-scales, from milliseconds to geological intervals, impinge on these levels.

Another important dimension to biological thought is the role of random factors and constraint. The former is largely visualized in terms of molecular events, notably mutation, although ecological catastrophes (including bolide impacts) are other jokers in the pack. Constraint, on the other hand, is linked to ideas of epigenetic ‘landscapes’ and historical ‘burdens’, whereby organisms are constantly being channelled into shapes and niches from which there seems to be no exit. Thus, although hierarchies and constraints provide some sort of boundaries within which the random processes of selection reward the well adapted, biology remains a famously messy subject. Laws, principles and theorems may be erected, but the fun is in finding the exceptions. Anyone who proposed a general theory of the biosphere would probably find only lukewarm interest. Even proponents of the Gaia hypothesis claim to identify quasi-stable systems dependent on homeostatic feedbacks, rather than a predictive sequence of biological systems.

It is my argument, however, that a search for a deeper structure to life and thereby an explanation rather than

simply a description of evolution may not be futile. The detailed case is set out elsewhere (Conway Morris 2003), and principally revolves around the phenomenon of evolutionary convergence. There are, as it happens, innumerable instances. Some are very familiar (e.g. the camera-eye; see below), others apparently arcane (e.g. purring, see Peters 2002). So too it is not easy to discern any general pattern because examples of convergence can be found at all levels, from molecules (e.g. antifreeze proteins), anatomical structures (e.g. eyes), to societies (e.g. the ‘colossal’ convergence between elephants and sperm-whales; Weilgart *et al.* 1996). The treatment of convergence tends, therefore, to be anecdotal, although I find it revealing that in their descriptions the researchers often draw upon adjectives of surprise: ‘remarkable’, ‘astonishing’ and even ‘uncanny’ are commonly used epithets. But why the surprise? To my way of thinking this terminology actually reveals a teleological uneasiness that the Watchmaker is not Blind, only wearing sunglasses.

Biological universals?

The search for a deeper, even timeless, structure in biology has already received some attention. Denton *et al.* (2002), for example, explore how protein design can be re-thought in the context of the fold-types, e.g. α -helices, as effective archetypes or platonic forms that emerge ‘spontaneously’ given the available amino acids. Because there are also a number of reasons to think that not only are amino acids universal to life, but even a majority of those employed on Earth will be used anywhere else, then the proteins found in terrestrial organisms will be far from parochial. At a still

deeper level Williams & Fraústo da Silva (2003) explore the chemical systems upon which evolution must act. They conclude that not only is there an 'inevitable progression', but the routes to increasing complexity are strongly constrained. Both Denton *et al.* (2002) and Williams and Fraústo da Silva (2003), in their different contexts, are evidently content to think of evolutionary inevitabilities. In either case the likelihood is that the principles used by life on Earth are effectively universal. Such sentiments are also consistent with earlier expressed views to the effect that one terrestrial biochemistry is unlikely to be much different from that found anywhere else (Pace 2001). To paraphrase George Wald's famous remark: students of biochemistry on Earth should be able to pass their exams with flying colours on a planet orbiting Arcturus.

If proteins and the citric acid cycle, not to mention DNA and chlorophyll (see Conway Morris 2003), are universals, it is still unlikely that the majority of biologists would be so persuaded that similar principles ought to apply to more complex biological systems. Here on Earth we are familiar with such features as eusociality and intelligence, but are these the norm in extraterrestrial settings? The majority answer would almost certainly be the exact reverse. It is a widely held opinion, by such evolutionary luminaries as G.G. Simpson and J. Diamond, that human-like intelligence is simply one more evolutionary fluke, at one level as interesting (or banal) as humming-birds or the flowers of angiosperms.

Convergent complexities

These two examples of humming-birds and flowers, however, were deliberately chosen, because both show interesting convergences. Thus, despite their very different body-plans the sphinx moths have a number of striking convergences with humming-birds. The case of the angiosperms (that is the flowering plants) is, in some respects, more interesting because while it is now widely accepted that the inflorescences of a group known as the Gnetales evolved independently, the common ancestor (that presumably lived in the Jurassic (or earlier)) already possessed the necessary prerequisites for the subsequent assembly of the complex reproductive structure we call flowers. These observations lead to a related point, which is to do with inherency and so by implication evolutionary inevitability.

By the term inherency I have in mind the recognition of the necessary components of a complex system that only requires a particular 'instruction manual' (that may in itself be surprisingly simple) to be actually assembled. It is certainly the case that this concept is not easy to address in an evolutionary context, simply because it seems to depend on the inestimable benefits of hindsight. Yet in principle I suggest it could confer a predictive principle to evolution, not least in the area of extraterrestrial life. So I suggest that the evolutionary inherency (and potential) of the common ancestor of angiosperms and gnetales make the appearance of flowers actually unsurprising.

So too for many other complex systems, including those that presumably are a *sine qua non* for the emergence of intelligence. The eye provides the premier example, although just the same arguments could be put forward for any of the other sensory systems, such as olfaction, audition, echolocation and electro-reception. To a first approximation, to function the eye must achieve two goals. These are to provide a transparent window (and usually a lens) and to transduce photons into an electrical signal. Both entail particular types of protein, respectively crystallins and opsins. The point, however, is not only are crystallins certainly convergent (and quite possibly opsins as well), but in addition these proteins evolved in microbial organisms long before the appearance of animals, let alone eyes. Given the availability of these building blocks and the adaptive advantages of light perception, then the evolution of eyes *per se* seems to have had a very high probability. It might be argued, of course, that the evolution of the eye necessitated other crucial steps that were, for one reason or another, extraordinarily unlikely, but the fact that the camera and compound eyes have evolved independently at least ten times makes this seem less likely.

There seems, therefore, an argument that here on Earth it was very likely, perhaps even inevitable, that sooner or later an eye would see a flower, perhaps even to pluck it? And if so on Earth, then perhaps elsewhere? Yet this view of life also opens up the question of an indefinite regress: if each level of complexity is dependent on prior circumstances, yet at each level convergence is the norm, then it may transpire that although evolution of the biosphere must be set in specific historical circumstances, in essence its manifest complexity and richness is inherent from the first cell, if not before.

Unique events?

One priority, therefore, is to try and determine whether one or more key evolutionary steps were genuine flukes of circumstance, without which the history of life would have been either radically diverted or even derailed. Perhaps the most obvious instance concerns the acquisition of symbiotic prokaryotes by some sort of early eukaryote, so as to provide ultimately respiratory (as mitochondria, once free-living aerobic bacteria) and photosynthetic (as chloroplasts, once free-living cyanobacteria) capabilities. Whilst these are the premier examples of so-called primary endosymbiosis, the fact that there are examples of secondary endosymbiosis (typically where one eukaryote engulfs another, or some component of it; see McFadden 2001) suggests that such occurrences, whilst rare, do define a general biological principle.

In addition, whilst both the acquisitions of the mitochondria and chloroplasts have been regarded as unique, and so arguably fluke events, there is now evidence to suggest that in the case of the chloroplasts this may have occurred at least three times (Stiller *et al.* 2003; see also Palmer 2003). This case is particularly interesting because it is argued that the molecular constraints connected with gene loss from the

plastid are so considerable that the historical 'signal' is effectively lost. Such functional constraints may be far more pervasive than generally realized, and reinforces the point that in many key cases the historical component of evolution (not, of course, without its intrinsic interest) is effectively transcended by navigation to a similar end-point, i.e. convergence.

Incumbency: an evolutionary stumbling block?

While the ubiquity of evolutionary convergence strongly suggests that there are defined stable nodes of existence, it is also important to remember the evolutionary principle of incumbency. Sitting tenants can be very difficult to dislodge. In essence, in the biological context incumbency means that once in place given fixtures, and the mitochondria may be one such example, occupy the 'high ground' and are highly tenacious of their niche. Whilst it must be somewhat conjectural, the sheer success of the mitochondria and the recurrence of secondary endosymbiosis suggest that such a structure might be a biological universal for any aerobic eukaryote. In other words, if the mitochondria we know had, for whatever reason, failed to evolve, something with very similar functional capabilities would have still emerged.

The concept of incumbency has also exerted a powerful grip in another area of evolution, specifically the notion that without the removal of the dinosaurs at the end of the Cretaceous by the agency of a giant bolide impact, then the subsequent radiation of mammals would have been forestalled. From a local perspective this is undoubtedly correct, but as I argue elsewhere (Conway Morris 2003) there is another view. On Earth-like planets for various reasons (linked to the amount of atmospheric carbon dioxide and the ever-shifting continents and seaways) glacial intervals are almost certainly unavoidable. Imagine that the giant asteroid has missed, and the dinosaurs survive. What next? Some 35 million years later the planet begins to refrigerate. Bad news for dinosaurs, at least in the temperate and polar zones, as temperatures plummet. Good news for the warm-blooded birds and mammals, which now seize their opportunity. Recall also that both the groups had evolved during the time of the dinosaurs. Birds and mammals are literally waiting in the wings and shadows of the theatre of life. In our historical reality the bolide opens the gates of opportunity, in my not-so-counterfactual world it is an ice-age. Either way, convergence will ensure that sooner or later intelligent tool-makers emerge. From that time, in the counter-factual world, the days of the dinosaurs are numbered as the hunters spread north and south. A different history to be sure, but a rather similar end-point. In conclusion, mass extinctions do not cancel history, they only postpone it.

The road to intelligence

The examples discussed so far may be relatively uncontroversial. Cells and their organelles, multicellularity and cell

communication, molecular signalling and reception, developmental switches and homoetic genes, even sexual reproduction, seem to be amongst the basics that any biosphere would possess. However, the general view, as already indicated, is that specific complexities, most notably human intelligence, are simply fortuitous evolutionary accidents.

Such a conclusion is arrived at in a number of different ways. One set of ideas revolves around the idea that both a large brain and its capacities, e.g. an ability to perform algebraic calculations, are by-products of some other process; 'spandrels' in the terminology of S.J. Gould. Another line of thought argues that the massive encephalization of hominids is a unique evolutionary event. Both, however, are questionable. In the former case there is abundant evidence for adaptation being a key force in the evolution of the brain (e.g. de Winter and Oxnard 2001). If at least part of the explanation of brain size increase in the hominids was social interactions and co-operation, then algebra may well be an inherent function. One can at least observe that in ordered societies mathematics emerges very early. So far as uniqueness of encephalization is concerned, this is difficult to square with the evidence for parallel developments in the dolphins (Marino 1998). So too it is likely that non-mammalian groups, especially the crows (e.g. Hunt & Gray 2003), cephalopod octopus (e.g. Sinn *et al.* 2001), and possibly some of the eusocial insects, may serve to widen our perspectives on intelligence. Certainly so far as the dolphins are concerned, the convergence with primate mentalities is very striking (Marino 2002).

Big brains and complex behaviours, however, cannot be considered in isolation. Amongst other associated complexities one might list: warm-bloodedness, social structure and parental care, sophisticated vocalization (and other communication), tool-making, cultural transmission, and even bipedality and female menopause. All are convergent (see Conway Morris 2003). It is perhaps necessary to add that simply because the emergence of a humanoid intelligence (and associated features as listed above) has a high evolutionary probability, this is not to claim that such a trajectory represents the sole 'purpose' of evolution. First, in the context of a Creation it would be strange if that was the case. Secondly, it needs to be set in the context of other complex biological structures, such as eusociality or insect agriculture, which are also convergent. Thirdly, although the emergence of a humanoid-like intelligence is a rare event, it is unlikely to be unique. Moreover, once emergent then it will be like any other evolutionary innovation (e.g. mitochondria, land plants). In each case the biosphere changes radically and irreversibly. A fruitful line of research might be to assess more critically these key evolutionary imprints.

There are some further interesting speculations. What, for example, of our evolutionary future? van Vark (1999) has argued that the process of hominization is not complete. On the other hand, Hofman (2001) has shown that there are ultimate constraints on any further increase of the hominid brain in terms of neural connectivity and relative proportions of white and grey matter. As Hofman observes

any extension of this intelligence trajectory is going to have to rely on technological assistance. This in turn has two interesting corollaries. First, just as tool-making is convergent, so too are probably technologies. Secondly, if humans were at the end of a metaphorical road, and even embarked on a self-destructive course, that too need not be the last word. It is an interesting thought that not only are there several independent routes to intelligence, but on other worlds it is a eusocial or octopoid civilization that succeeds in the long run, and is best capable to promoting a programme of interstellar colonization.

Conclusions

The immensity of combinatorial possibilities in biological systems, be they proteins or social systems, has long been used as an argument that the limited time biospheres can exist (on the grand scale of things) compared with the number of possible 'decisions' that can be made during this time for the exploration of a given 'hyperspace' means that (a) only a tiny fraction of this 'hyperspace' can be explored and correspondingly (b) on different worlds there is a vanishingly small probability of arriving at even a remotely similar 'destination'. This may be clearer when it is recalled that the average life of a biosphere is about 10^{17} s, whereas the combinatorial size of a typical biological system is between about 10^{50} and 10^{150} alternatives. The ubiquity of evolutionary convergence suggests, however, that the vast bulk (maybe >99%) of any biological 'hyperspace' is actually 'uninhabitable' and maladaptive. It also suggests that any such 'hyperspace' is largely defined by narrow 'roads' of potentiality, and that in some sense these are embedded at very deep levels indeed. It is along these roads that life navigates towards certain inevitable solutions. By reading this map we may be on the threshold of a new view of life, where natural selection is the mechanism but not the purpose.

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