How to Make a Mermaid

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LIFE'S SOLUTION: INEVITABLE HUMANS IN A LONELY UNIVERSE by SIMON CONWAY MORRIS
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In a letter in the Times on 8 September 1809, W.M. Munro, a schoolmaster, described seeing a mermaid off the coast of Caithness. Walking along the shore of Sandside Bay, his attention was 'arrested by the appearance of a figure resembling an unclothed human female, sitting upon a rock extending into the sea, and apparently in the action of combing its hair, which flowed around its shoulders', and was 'of a light brown colour'. 'The head was shaded on the crown, the forehead round, the face plump, the cheeks ruddy, the eyes blue, the mouth and lips of a natural form, resembling those of a man.' 'The breasts and abdomen, the arms and fingers were of the size of a full-grown body of the human species.'

Societies which lacked a clear notion of the mechanisms of biological transformation intuited nonetheless, in their evocation of creatures with fabulous morphological complexities, that life is above all else about the generation and transmutation of form. Only as a result of profound transformation have the human mind and consciousness come into existence. Without the capacity for reflective thought and symbolic representation, we would still be red in tooth and claw, yet were they configured only slightly differently, our brains might not allow us to conceive such moral injunctions as thou shalt not kill.

Has life on Earth, the human race included, developed as it has simply as the result of an extraordinary sequence of chance evolutionary events, or was this development inevitable? Or, to put the question differently, if we stumbled across the inhabitants of another Earth-like planet in some distant galaxy, would our morphology appear as remarkable to them as a centaur's does to us, or would it be reassuringly familiar? One way of settling the issue, suggested by the late Stephen Jay Gould, would be to wind the tape of life back to its origins, around four and a half billion years ago, then let the tape run again and see what happens. Ideally, we'd repeat this a few thousand times, and if then all of the reruns ended up producing humans, we could assert with reasonable confidence that humans are a more or less inexorable consequence of any evolutionary process beginning on Earth at the time of life's origin.

The existence of alternative worlds, populated by creatures morphologically unlike ourselves, is a very real possibility. As for mythical creatures such as mermaids, we could allow that they might have come about as the result of natural evolutionary processes. Indeed, we might one day be able to build some from scratch. There are molecular biologists, among whom Sydney Brenner is probably the most vociferous, who espouse such a 'constructional' approach to biology. To build a mermaid from first principles one might begin by comparing the gene sequences of a fish with those of a female human. The trick would then be to determine whether the genes that generate a silver tail could somehow be integrated seamlessly with those that generate a female body, minus the legs. It's possible that such a combination of features might turn out to be a logical impossibility: fusing the silver scaled tail with a female's upper torso would be tricky, and it might be too difficult to manage the simultaneous construction of lungs and gills. On the other hand, the task might be so simple it could be completed in an afternoon.

The extraordinary combinatorial complexity of the DNA molecules from which genes are constructed allows infinite uses to be made of finite means, so that it's possible to imagine an immense hyperspace we might call the Zoo of All Possible Creatures. This would include the familiar cats, dogs, elephants and beetles, the familiar but extinct dodos, pterosaurs and sabre-toothed tigers, but also the never before realised: frogs the size of the Empire State Building or miniature humans with octopus eyes and spider legs. We aren't surprised, after all, at the existence of creatures such as seahorses and the duck-billed platypus. By the lights of Darwinism, the forces that have guided nature through this ocean of morphological possibility are natural selection, historical contingency and the laws of self-assembly and self-organisation. Butterflies with wingspans the size of tennis courts or mammals that lack respiratory systems are destined for the Zoo of Unrealisable Creatures. Evolution observes constraints. Some of these are historical, but others are a matter of logic. The gigantic horns of the male dung beetle Onthophagus sprout out above their eyes and are used to fend off competing suitors. Given that their reproductive success correlates with horn size, one might expect that across successive generations their horns would get larger and larger, but a fundamental constraint appears to limit horn size. Douglas Emlen has shown that males with big horns have proportionally smaller eyes, indicating that there is a trade-off between big eyes and big horns. Beetles bred to have enormous horns were virtually blind. But this isn't to say one couldn't artificially uncouple the developmental pathways of these beetles so as to facilitate the construction of creatures with both huge horns and good vision.

Another constraint on morphological possibility is the limitedness of the available set of basic body design plans, or phyla. The animal kingdom has more than thirty of them, including echinoderms (starfish and sea urchins) and chordates (vertebrates). Had echinoderm precursors been eliminated by a contingent event in the early history of life, it's unlikely that any starfish or sea urchins would exist today, just as the deletion of our chordate antecedents would have precluded human existence. Once evolution has locked into a design, it can modify its details but is unable to change its core. There is no evidence of new phyla evolving since the emergence of multicellular life in the Cambrian, and it seems inconceivable that the body plan for an echinoderm could, for example, mutate into that of a chordate. The appearance and subsequent deletion of phyla in the early fossil record – those of Xidazoon and Fuxianhuia bear little resemblance to those of contemporary creatures – suggest that modern phyla have been selected from a repertoire of different possibilities. The set that emerges depends, it seems, not just on what can be produced, but also on historically contingent events. A rerun of Earth's history might produce an entirely new and unfamiliar set of phyla.

Such a conclusion would seem to demand that we either dispense with or reinvent our religious beliefs. The fact that mankind represents only one of an apparently limitless biological set of possibilities, and the indifference of an evolutionary process that selects on the criterion of fitness irrespective of outcome, suggest that if the tape of life were rewound and allowed to run again, it is vanishingly unlikely that anything like human beings would appear again. According to this view, we are flukes.

Not so, says Simon Conway Morris in Life's Solution. There are 'deeper structures and potentialities, if not inevitabilities' at the heart of organic evolution, and biological possibility may, because of 'physical constraints, be much more limited than is usually supposed'. Conway Morris states early on that he wants to 'reopen the portals' to find 'a metaphysic for evolution'. His new approach, which he hopes might 'at last allow a conversation with religious sensibilities rather than the more characteristic response of either howling abuse or lofty condescension', is based on the well documented but poorly understood phenomenon of molecular and morphological convergence.

Convergence refers to the appearance in the biological world, by independent evolutionary routes, of similar and sometimes identical structures, organisations or behaviours. The problem with identifying instances of convergence is that, often, biological features that appear to have converged independently turn out to share a common descent. Penguins, humans and fruitflies, for example, have all developed similar light-sensitive eye-like structures for perceiving the outside world. (Other species have not: bats, for instance, rely on echo location.) Here, the apparent convergence most likely reflects a common, though very distant evolutionary history. But in certain cases, such as the convergence of ants and humans on societal organisation as the optimal 'solution' to certain problems associated with their day to day life, or on agricultural behaviour for the procurement of food, the similarity has most likely arisen because two processes have arrived independently at the same solution to a common problem. Only in such a case should we properly refer to the similarity as the result of 'convergence'.

It's a shame that Conway Morris makes this attempt to furnish theology with a spurious and unnecessary biological credibility, for his focus on the issue of convergence and factors that constrain the exploration of genetic hyperspace is of great importance. In Conway Morris's world there could be no mermaids:

> Evolution is indeed constrained, if not bound. Despite the immensity of biological hyperspace . . . nearly all of it must remain forever empty. It matters little what our starting point may have been: the different routes will not prevent a convergence to similar ends. The landscape of biological form, be it at the level of proteins, organisms, or social systems, may in principle be almost infinitely rich, but in reality the number of roads through it may be much, much more restricted. Life shows a kind of homing instinct.

In Conway Morris's constrained and teleological scheme, a finite set of usual suspects, including trilobites, wiwaxia, pikaia, triceratops, snails, plankton, antelopes, bison, camels and man, would always be the issue of an evolutionary process, irrespective of whether the process unfolds on Earth or in some other region of the cosmos.

Conway Morris compares life's tendency to converge repeatedly and inexorably on the same forms to the remarkable ability of the seafaring Polynesians to locate new land. In The Prehistoric Exploration and Colonisation of the Pacific (1992), Geoffrey Irwin suggests that their discovery of Easter Island more than a thousand years ago was a virtual inevitability, as they had developed a sophisticated search strategy which involved subdividing the ocean into precise quadrants and widening their search systematically century by century. Conway Morris believes that there are similarly 'inevitable and preordained trajectories of evolution', and implies that these might result from a metaphysical as opposed to a purely physical agency.

He begins by asking whether the biochemistries of hypothetical aliens on another planet would bear any resemblance to our own. (Agencies such as Nasa have already had to address this question when devising strategies to search for evidence of life on other planets.) In principle, living entities need not be restricted to using DNA and proteins as their genetic hardware. Any number of artificial DNA molecules can be constructed in the laboratory, and no doubt genes, too, could be constructed from polymers bearing no resemblance to DNA. Conway Morris is right that 'finding viable alternatives to DNA in any sort of natural context may be difficult, and perhaps even impossible.' If it did indeed turn out to be the case that no such alternative existed, then the suggestion might be that DNA was an inevitable product of the evolutionary process. But these are early days and much work remains to be done. Certainly nature is infinitely more inventive than the human mind, and might well be able to generate landscapes thus far unnavigated by evolutionary processes.

The possibility that there might be an alternative to DNA as a carrier of genetic information is related to the problem of the origin of life. DNA is a complex technology, which requires the support of a great many enzymes in order to function properly. Some of these unzip the double-helical strands which compose the DNA; others copy it; others repair it when it gets damaged. The biochemistry is so complicated that it must have been preceded by a simpler technology. RNA is the prime candidate, as it can function simultaneously as both an informational molecule and an enzyme. But RNA, too, is complex, so what preceded it? How, indeed, was the first program programmed? The conventional answer has been that complex, so-called 'autocatalytic' metabolisms may under certain conditions have programmed themselves, or that the biological information carried by the first living things may have been analogue rather than digital. In any event all attempts so far to generate life in the laboratory have failed miserably. Conway Morris interprets this failure as indicating that the steps leading to the creation of life are strongly delimited and that there may, therefore, be a determinism underlying its origin: 'It may be found that when life evolves it can only do so by one route.' If this were the case, and there is no evidence that it is, newly generated life would always begin from the same starting point, and biological possibility would be tightly constrained from the start.

But the foundation of Conway Morris's argument is the phenomenon of convergence. The existence of two similar structures, mechanisms or functions in nature demands an explanation because the number of possible alternatives in any given instance is so great that one might expect nature consistently to find different solutions to a given structural problem rather than repeatedly converge on similar ones. The explanation may be, first, that the structures are homologous, which is to say they share a common evolutionary history and were derived from the same structure by common descent; second, that the similarity came about by a process of horizontal transmission, such as the acquisition of a gene from a different species by a bacterium; or, third, that the same biological feature appeared independently in two different cases, a true case of convergence. The question is whether evolution has found two similar ways of making the same wheel or has invented the same wheel twice. The first of these seems more likely in most cases, and the suggestion is that old genes have not been lost but suppressed, only to re-emerge in new contexts.

The chemical (Z)-7-dodecen-1-yl acetate is used by the females of more than a hundred species of insects, the Lepidoptera in particular, as a pheromone to attract males. The fact that female Asian elephants, Elephas maximus, use the same molecule to signal their readiness to mate would appear to be an example of highly convergent evolution. If this were a bona fide case of convergence, it would indicate that (Z)-7-dodecen-1-yl acetate must have remarkable properties – perhaps relating to its extreme volatility – that make it especially well suited to the task in hand. Given the immense repertoire of possible chemicals that could have been used for exactly the same purpose, the likelihood of random convergence is statistically exceptionally remote.

If this is a case of convergence, that would suggest that evolution has superlative search strategies for homing in on the best of all possible solutions. Alternative explanat-ions are either that the widespread use of this particular chemical is in fact statistically highly probable because it is, for example, a by-product of some common chemical reaction; or that its duplicated use is evidence of a very well concealed homology dating back to the last common ancestor between the two species in question. Convergence is difficult to prove; in the case of similar protein structures, the number of unambiguous examples of convergent evolution can be counted on a single hand. Furthermore, the probability of de novo creation of genes encoding convergent proteins is inversely proportional to the proteins' complexity. If two proteins have similar structures, therefore, it's most likely that this reflects common descent, rather than convergent evolution.

Another often cited instance of convergence is the evolution of eyes. The eyes of flies and of humans are thought to have evolved independently. In fact, it's been suggested that eyes in general have evolved independently up to four dozen times. Salvini-Plawen and Ernst Mayr were happy to write in 1977 that 'it requires little persuasion to become convinced that the lens eye of a vertebrate and the compound eye of an insect are independent evolutionary developments.' But how wrong intuition can be. The fact that a highly homologous molecule called Pax-6 is a key regulator in the morphogenesis of eyes in both flies and humans argues strongly for a common evolutionary origin rather than convergence. Indeed, so similar are the corresponding genes in different species that, despite being separated by more than 600 million years of independent evolution, the mouse Pax-6 gene, when transplanted into a fly, can still direct the formation of a compound insect eye. Pax-6 was most likely present in the ancestral genome of all animals with bilateral symmetry, and its activation in different situations represents, not the reinvention of the eye on independent occasions, but an exploration of the potential for an eye-like structure in different contexts. We should be extremely cautious about invoking convergence as a default explanation of such phenomena: in many cases the apparent convergence most probably reflects nothing more than our inadequate knowledge of the underlying biology and, perhaps, a history of common descent.

Towards the end of his book, Conway Morris sums up its purpose as a 'quest for a theology of evolution'. There are a number of ill-conceived jibes in the book at biotechnologists for treating the world as 'a sort of genetic play-dough' and planning to topple the natural order for commercial gain; there are references, too, to 'genetic meddling', as well as a list of 'salient facts of evolution' that are 'congruent with a Creation', and neo-Darwinist straw men who apparently attribute intentionality to genes. But if we look to rational explanations to substantiate theological claims, we are likely to be disappointed. From my own perspective, biology and theories of evolution can accommodate theology, and the protestations of Richard Dawkins and others to the contrary are unnecessary. Why look for God in the entirely explicable workings of nature – the processes of evolution, the way haemoglobin works, the shape of a snowflake – when the real mystery is surely in the infinite possibilities afforded by DNA, the mathematical potential for the creation of all possible, and impossible, living things?