Life Ascending

The Ten Great Inventions of Evolution

Chapter 7: Sight

Nick Lane

Biochemist and writer

About

Dr Nick Lane is a British biochemist and writer. He was awarded the first Provost's Venture Research Prize in the Department of Genetics, Evolution and Environment at **University College London**, where he is now a Reader in Evolutionary Biochemistry. Dr Lane's research deals with evolutionary biochemistry and bioenergetics, focusing on the origin of life and the evolution of complex cells. Dr Lane was a founding member of the UCL Consortium for Mitochondrial Research, and is leading the UCL Research Frontiers Origins of Life programme. He was awarded the 2011 BMC Research Award for Genetics, Genomics, Bioinformatics and Evolution, and the 2015 Biochemical Society Award for his sustained and diverse contribution to the molecular life sciences and the public understanding of science.

Life Ascending

The Ten Great Inventions of Evolution

Chapter 7: Sight

Sight is quite a rarity. Eyes are absent, at least in a conventional sense, from the plant kingdom, as well as from the fungi, algae and bacteria. Even in the animal kingdom eyes are not at all common property. There are said to be thirty-eight fundamentally different models of body plan – phyla – in the animal kingdom, yet only six of them ever invented true eyes. The rest have endured for hundreds of millions of years without the benefit of seeing anything at all. Natural selection did not scourge them for lacking sight.

Set against this spartan background, the evolutionary benefits of eyes loom large. All phyla are not equal, and some are far more equal than others. The Chordata, for example, the phylum that includes ourselves and all other vertebrates, comprises more than 40,000 species; the Mollusca, including slugs, snails and octopuses has 100,000; and the Arthropoda, including crustaceans, spiders and insects, numbers more than a million, making up 80 per cent of all described species. In contrast, most of the lesser known phyla, including such oddities as the glass sponges, rotifers, priapulid worms and comb jellies, mostly known only to classically trained zoologists, have relatively few species, tens or hundreds; the Placozoa, just one. If we add them all up, we find that 95 per cent of all animal species have eyes: the handful of phyla that did invent eyes utterly dominates animal life today.

Of course, that might be no more than chance. Perhaps there are other subtle advantages to the body plans of these particular phyla that we have missed, quite unrelated to eyes, but that seems unlikely. The evolution of proper eyes, capable of spatial vision rather than simply detecting the presence or absence of light, gives every appearance of having transformed evolution. The first true eyes appeared somewhat abruptly in the fossil record around 540 million years ago, close to the beginning of that 'big bang' of evolution, the so-called Cambrian explosion, when animals burst into the fossil record with breathtaking diversity. In rocks that had been virtually silent for aeons, almost all the modern phyla of animals sprang into existence practically without warning.

The close correspondence in time between the explosion of animal life in the fossil record and the invention of eyes was almost certainly no coincidence, for spatial vision must have placed predators and prey on an entirely different footing; this alone could, and perhaps did, account for the predilection for heavy armour among Cambrian animals, and the much greater likelihood of fossilisation. The biologist Andrew Parker, at the Natural History Museum in London, has made a plausible case that the evolution of eyes drove the Cambrian explosion, in an entertaining, if at times infuriatingly partisan, book. Whether eyes really could have evolved so abruptly (or whether the fossil record is misleading in this regard) is a question we 'll consider later. For now let's just note that sight gives far more information about the world than smell, hearing, or touch possibly can, for the earth is drenched in light, and we can hardly avoid being seen. Many of the most marvellous adaptations of life are a response to being seen, whether strutting for sex in the case of a peacock or a flower, parading the great armoured plates of a stegosaurus, or careful concealment in the world of a stick insect. Our own societies are so image conscious that I scarcely need to labour the point.

Beyond utility, the evolution of sight is culturally iconic, because eyes appear so perfect. From Darwin onwards, eyes have been perceived as an apotheosis, a challenge to the very notion of natural selection. Could something so complex, so perfect, really evolve by unguided means? What possible use, say sceptics, is half an eye? Natural selection calls for a million gradations, each of which must be better than the last, or the half-built structure will be ruthlessly purged from the world. But the eye, say these sceptics, is perfect in the same way as a clock – it is irreducible. Remove a few of the bits and it won't work any more. A clock without hands is worth little, and an eye without a lens or a retina is worthless, or so we're told. And if half an eye is no use then the eye cannot have evolved by natural selection or any other means known to modern biology, and so must be evidence of celestial design instead.

The many vitriolic arguments over perfection in biology rarely do more than entrench already hardened positions. Defenders of Darwin counter that the eye is actually far from perfect, as anyone who wears glasses or contact lenses, or who is losing their sight, knows only too well. This is certainly true, but there is a danger in this kind of theoretical argument, which is to gloss over the many subtleties that undoubtedly exist. Take the human eye, for example. A common argument has it that the design flaws run very deep and are in fact good evidence of the way in which evolution has cobbled together inept unplanned structures, crippled by its own lack of foresight. A human engineer, we ’re told, would do a much better job; indeed an octopus does. This glib assertion overlooks the mischievous rule known as the second law of Leslie Orgel: Evolution is cleverer than you are.

Let’s consider this case briefly. The octopus has an eye much like our own, a ‘camera’ eye, with a single lens at the front and a light-sensitive sheet, the retina, at the back (equivalent to the film in a camera). Because the last ancestor we shared with the octopus was probably some sort of worm, lacking a proper eye, the octopus eye and our own eye must have evolved independently and converged upon essentially the same solution. This inference is supported by a detailed comparison of the two types of eye. Each develops from different tissues in the embryo and ends up with distinct microscopic organisation. The octopus eye seems to be far more sensibly arranged. The light-sensitive cells of the retina point out towards the light, while the neuronal wires pass back directly to the brain. In comparison, our own retina is often said to be plugged in backwards, an apparently idiotic arrangement. Rather than jutting out, the light-sensitive cells sit at the very back, covered by neuronal wires that pass forwards on a roundabout route to the brain. Light must pass through this forest of wires before it can reach the light-sensitive cells; and worse still, the wires form a bundle that plunges back through the retina as the optic nerve, leaving a blind spot at that point.

But we should not be too quick to dismiss our own arrangement. As so often in biology, the situation is more complex. The wires are colourless, and so don’t hinder the passage of light much; and insofar as they do, they may even act as a ‘waveguide’, directing light

The many vitriolic arguments over perfection in biology rarely do more than entrench already hardened positions. Defenders of Darwin counter that the eye is actually far from perfect, as anyone who wears glasses or contact lenses, or who is losing their sight, knows only too well. This is certainly true, but there is a danger in this kind of theoretical argument, which is to gloss over the many subtleties that undoubtedly exist. Take the human eye, for example. A common argument has it that the design flaws run very deep and are in fact good evidence of the way in which evolution has cobbled together inept unplanned structures, crippled by its own lack of foresight. A human engineer, we 're told, would do a much better job; indeed an octopus does. This glib assertion overlooks the mischievous rule known as the second law of Leslie Orgel: Evolution is cleverer than you are.

Let's consider this case briefly. The octopus has an eye much like our own, a 'camera' eye, with a single lens at the front and a light-sensitive sheet, the retina, at the back (equivalent to the film in a camera). Because the last ancestor we shared with the octopus was probably some sort of worm, lacking a proper eye, the octopus eye and our own eye must have evolved independently and converged upon essentially the same solution. This inference is supported by a detailed comparison of the two types of eye. Each develops from different tissues in the embryo and ends up with distinct microscopic organisation. The octopus eye seems to be far more sensibly arranged. The light-sensitive cells of the retina point out towards the light, while the neuronal wires pass back directly to the brain. In comparison, our own retina is often said to be plugged in backwards, an apparently idiotic arrangement. Rather than jutting out, the light-sensitive cells sit at the very back, covered by neuronal wires that pass forwards on a roundabout route to the brain. Light must pass through this forest of wires before it can reach the light-sensitive cells; and worse still, the wires form a bundle that plunges back through the retina as the optic nerve, leaving a blind spot at that point.

But we should not be too quick to dismiss our own arrangement. As so often in biology, the situation is more complex. The wires are colourless, and so don't hinder the passage of light much; and insofar as they do, they may even act as a 'waveguide', directing light vertically on to the light-sensitive cells, making the best use of available photons. And probably more importantly, we have the advantage that our own light-sensitive cells are embedded directly in their support cells (the retinal pigment epithelium) with an excellent blood supply immediately underneath. Such an arrangement supports the continuous turnover of photosensitive pigments. The human retina consumes even more oxygen than the brain, per gram, making it the most energetic organ in the body, so this arrangement is extremely valuable. In all probability the octopus eye could not sustain such a high metabolic rate. But perhaps it doesn't need to. Living underwater, with lower light intensity, the octopus may not need to re-cycle its photopigments so quickly.

My point is that there are advantages and disadvantages to every arrangement in biology, and the outcome is a balance of selective forces that we don't always appreciate. This is the trouble with 'just-so' stories: all too often we see only half the picture. Arguments too conceptual in nature are always vulnerable to counterblasts. Like any scientist, I prefer to follow the train of data. And here the rise of molecular genetics in the last decades furnishes us with a wealth of detail, giving very particular answers to very particular questions. When these answers are all threaded together, a compelling view emerges of how the eye evolved, and from where – a surprisingly remote and green ancestor. In this chapter, we'll follow this thread to see exactly what use is half an eye, how lenses evolved, and where the light-sensitive cells of the retina came from. And in piecing together this story, we'll see that the invention of eyes really did alter the pace and flow of evolution…

Nick Lane

Biochemist and writer

www.nick-lane.net