

Where d'you get those peepers

Dawkins, Richard, *Where d'you get those peepers?.*, Vol. 8, *New Statesman & Society*, 06-16-1995, pp 29.

Creationist claims that organs like eyes are too complex to have evolved naturally are way wide of the mark, says Richard Dawkins. In fact, eyes have evolved many times, often in little more than a blink of geological history

Creationism has enduring appeal, and the reason is not far to seek. It is not, at least for most of the people I encounter, because of a commitment to the literal truth of Genesis or some other tribal origin story. Rather, it is that people discover for themselves the beauty and complexity of the living world and conclude that it "obviously" must have been designed. Those creationists who recognise that Darwinian evolution provides at least some sort of alternative to their scriptural theory often resort to a slightly more sophisticated objection. They deny the possibility of evolutionary intermediates. "X must have been designed by a Creator," people say, "because half an X would not work at all. All the parts of X must have been put together simultaneously; they could not have evolved gradually."

Thus the creationist's favourite question "What is the use of half an eye?" Actually, this is a lightweight question, a doddle to answer. Half an eye is just 1 per cent better than 49 per cent of an eye, which is already better than 48 per cent, and the difference is significant. A more ponderous show of weight seems to lie behind the inevitable supplementary: "Speaking as a physicist, I cannot believe that there has been enough time for an organ as complicated as the eye to have evolved from nothing. Do you really think there has been enough time?" Both questions stem from the Argument from Personal Incredulity. Audiences nevertheless appreciate an answer, and I have usually fallen back on the sheer magnitude of geological time.

It now appears that the shattering enormity of geological time is a steam hammer to crack a peanut. A recent study by a pair of Swedish scientists, Dan Nilsson and Susanne Pelger, suggests that a ludicrously small fraction of that time would have been plenty. When one says "the" eye, by the way, one implicitly means the vertebrate eye, but serviceable image-forming eyes have evolved between 40 and 60 times, independently from scratch, in many different invertebrate groups. Among these 40-plus independent evolutions, at least nine distinct design principles have been discovered, including pinhole eyes, two kinds of camera-lens eyes, curved-reflector ("satellite dish") eyes, and several kinds of compound eyes. Nilsson and Pelger have concentrated on camera eyes with lenses, such as are well developed in vertebrates and octopuses.

How do you set about estimating the time required for a given amount of evolutionary change? We have to find a unit to measure the size of each evolutionary step, and it is sensible to express it as a percentage change in what is already there. Nilsson and Pelger used the number of successive changes of x per cent as their unit for measuring changes of anatomical quantities.

Their task was to set up computer models of evolving eyes to answer two questions. The first was: is there a smooth gradient of change, from flat skin to full camera eye, such that every intermediate is an improvement? (Unlike human designers, natural selection can't go downhill not even if there is a tempting higher hill on the other side of the valley.) Second, how long would the necessary quantity of evolutionary change take?

In their computer models, Nilsson and Pelger made no attempt to simulate the internal workings of cells. They started their story after the invention of a single light-sensitive cell--it does no harm to call it a photocell. It would be nice, in the future, to do another computer model, this time at the level of the inside of the cell. to show how the first living photocell came into being by step-by-step modification of an earlier, more general-purpose cell. But you have to start somewhere, and Nilsson and Pelger started after the invention of the photocell.

They worked at the level of tissues: the level of stuff made of cells rather than the level of individual cells. Skin is a tissue, so is the lining of the intestine, so is muscle and liver. Tissues can change in various ways under the influence of random mutation. Sheets of tissue can become larger or smaller in area. They can become thicker or thinner. In the special case of transparent tissues like lens tissue, they can change the refractive index (the light-bending power) of local parts of the tissue.

The beauty of simulating an eye, as distinct from, say, the leg of a running cheetah, is that its efficiency can be easily measured. The eye is represented as a two-dimensional cross-section, and the computer can easily calculate its visual acuity, or spatial resolution, as a single real number. It would be much harder to come up with an equivalent numerical expression for the efficacy of a cheetah's leg or backbone. Nilsson and Pelger began with a flat retina atop a flat pigment layer and surmounted by a flat, protective transparent layer. The transparent layer was allowed to undergo localised random mutations of its refractive index. They then let the model deform itself at random, constrained only by the requirement that any change must be small and must be an improvement on what went before.

The results were swift and decisive. A trajectory of steadily mounting acuity led unhesitatingly from the flat beginning through a shallow indentation to a steadily deepening cup, as the shape of the model eye deformed itself on the computer screen. The transparent layer thickened to fill the cup and smoothly bulged its outer surface in a curve. And then, almost like a conjuring trick, a portion of this transparent filling condensed into a local, spherical subregion of higher refractive index. Not uniformly higher, but a gradient of refractive index such that the spherical region functioned as an excellent graded-index lens.

Graded-index lenses are unfamiliar to human lens-makers, but they are common in living eyes. Humans make lenses by grinding glass to a particular shape. We make a compound lens, like the expensive violet-tinted lenses of modern cameras, by mounting several lenses together, but each one of those individual lenses is made of uniform glass through its whole thickness. A graded-index lens, by contrast, has a continuously varying refractive index within its own substance. Typically, it has a high refractive index near the centre of the lens. Fish eyes have graded-index lenses. Now it has long been known that, for a graded-index lens, the most aberration-free results are obtained when you achieve a particular theoretical optimum value for the ratio between the focal length of the lens and the radius. This ratio is called Mattiessen's ratio. Nilsson and Pelger's computer model homed in unerringly on Mattiessen's ratio.

And so to the question of how long all this evolutionary change might have taken. In order to answer this, Nilsson and Pelger had to make some assumptions about genetics in natural populations. They needed to feed their model plausible values of quantities such as "heritability". Heritability is a measure of how far variation is governed by heredity. The favoured way of measuring it is to see how much monozygotic (that is, "identical") twins resemble each other compared with ordinary twins. One study found the heritability of leg length in male humans to be 77 per cent. A heritability of 100 per cent would mean that you could measure one identical twin's leg to obtain perfect knowledge of the other twin's leg length, even if the twins were reared apart. A heritability of 0 per cent would mean that the legs of monozygotic twins are no more similar to each other than to the legs of random members of a specified population in a given environment. Some other heritabilities measured for humans are 95 per cent for head breadth, 85 per cent for sitting height, 80 per cent for arm length and 79 per cent for stature.

Heritabilities are frequently more than 50 per cent, and Nilsson and Pelger therefore felt safe in plugging a heritability of 50 per cent into their eye model. This was a conservative, or "pessimistic", assumption. Compared with a more realistic assumption of, say, 70 per cent, a pessimistic assumption tends to increase their final estimate of the time taken for the eye to evolve. They wanted to err on the side of overestimation because we are intuitively skeptical of short estimates of the time taken to evolve something as complicated as an eye.

For the same reason, they chose pessimistic values for the coefficient of variation (that is, for how much variation there typically is in the population) and the intensity of selection (the amount of survival advantage improved eyesight confers). They even went so far as to assume that any new generation differed in only one part of the eye at a time: simultaneous changes in different parts of the eye, which would have greatly speeded up evolution, were outlawed. But even with these conservative assumptions, the time taken to evolve a fish eye from fiat skin was minuscule: fewer than 400,000 generations. For the kinds of small animals we are talking about, we can assume one generation per year, so it seems that it would take less than half a million years to evolve a good camera eye.

In the light of Nilsson and Pelger's results, it is no wonder "the" eye has evolved at least 40 times independently around the animal kingdom. There has been enough time for it to evolve from scratch 1,500 times in succession within any one lineage. Assuming typical generation lengths for small animals, the time needed for the evolution of the eye, far from stretching credulity with its vastness, turns out to be too short for geologists to measure! It is a geological blink.

XXXXXXXXXXXXXXXXXX