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EVOLUTION CONTROLS ITSELF

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If you ask a British student to say a few words about biological evolution the chances are you'll hear "survival of the fittest" "adaptation" "primitive" "natural selection". These are aggressive concepts and have become accepted as the driving forces controlling changes in the history of life by both professional scientists and others. Although Darwin himself was caught in the rift between the institutions of the church and the scientific establishment, he lived fairly and squarely in Victorian England with its associated formative capitalist values taken for granted. So it appears that little has changed for more than a hundred years. Mendelism and the Genetic Code may have added to our knowledge of the mechanisms of evolution but most people accept that the basic principles are the same.

The latest spin by scientists as well as media take the action a stage further with images of meteorites hitting the earth to cause nuclear winters (some geologists and astronomers suggest this may happen every 26 million years) and dinosaurs eating people in parks. We humans are alright, the fittest and most advanced able to survive the winters (the next is conveniently 13 million years away, they say), happy that dinosaurs are extinct. The well-tested conventional view was proposed almost 25 years ago (see Gould & Eldredge 1993) is that evolution proceeds from one "mass-extinction" to another. There have been five really big ones over the last 600 million years, the last causing the extinction of the dinosaurs and the majority of other species 65 million years ago. The view is that between these events species came and went in relatively small numbers. Presumably in these quiescent intervals evolution in the form of genetic recombination and molecular change was happening within the cells, not showing up in the morphology of the fossils and biochemistry not being preserved (Boulter *et.al.* 1998). These neo-Darwinist views are consistent with the original ideas of the evolutionary process, albeit adding that the rate of evolution shows up as fluctuations caused by changes in environment without which there are only minor origins and extinctions.

Now, there is another view, generated from the analysis of the latest reviews of fossil data by a new mathematical method, and stimulated by a systems approach to natural things that change through time, on any scale: such a time-series may range over seconds to millions of years. When these methods are used to consider the whole of a changing system surprisingly similar patterns emerge. Each such system is a distinct entity not having control from outside; there may be external effects but the system can recover and correct the trajectory itself. The best known example of such a so-called system of "Self-Organised Criticality" is the sand pile experiment (Bak 1997). A constant flow of sand falls to form a cone. Everything is equal, grain size, surface features, the rate of flow. Through time the system will adjust to the increase in grains and react from within to cause avalanches. These are unpredictable but do give a pattern of change through time which can be plotted as a smooth wavy line with a characteristic shape. A plot of the logarithm of the fluctuations gives a straight line called a power law, mathematically significant to mean an independently changing system (demonstrating "Self-Organised Criticality").

As well as sand pile avalanches, other comparable patterns show up in data that emerge from music, traffic jams, stock market changes and many other time-series. None are predictable. All give comparable wavy lines and power laws. In each of these concise systems the patterns of change come from forces within. Through time there is a rhythmic change in the notes that settles to a curve that can characterise that tune. The cars on a busy motorway slow down with one another and accelerate off again in waves that are generated by the system itself. No crash or obstacle from outside the system is necessary, the cars themselves create the changes (though of course if there is a crash, it shows up in the time-series curve as well, and the system recovers).

The latest data of biological evolution comprise the geological times when all family groups of animals and plants first originated and finally became extinct. When these data are put into the same number-crunching software we get the same. Although the fossil record is patchy (incomplete and sometimes incorrect, though we don't have anything better) the curves that emerge show strong signs of Self-Organised Criticality, wavy lines and power laws (Hewzulla *et al.* 1998). The same shaped curves emerge when the times of first and last appearance of pollen from the Plant Fossil Record database are analysed by the same procedures. This means that Gould and Eldredge's step-wise punctuated evolution is unnecessarily complex: evolution follows a simple exponential curve. The deviations from this exponential, which may indeed be caused by environmental changes and catastrophic events, are culls which stop the exponential rising to the vertical and causing all life on this planet to end. Just as the avalanches on the sand pile they can come from within the system and are essential to keep it going. Of course, if someone blows at the sand pile, or if an asteroid hits the planet, the system will respond.

Plots of the values of the deviations from the exponential show very similar patterns to those coming from standard Self Organised systems like the sand pile and traffic jams. They are known as the one over *f* (1/*f*) family of noises (Halley 1996) and mean that the biological system's natural evolutionary path is exponential. The curves from our data move away from this in a way that can be explained by 1/*f* noise. These are called red brown and pink (giving curves with very characteristic shapes) and appear to be created only by natural systems, quite different, say, from the flat hiss of the white noise such as an empty radio signal.

So we are left to reconsider the popular notion of evolution being an angry competitive fight for survival on the restricted stage of power on this planet. For if this new model of exponential change is correct there are no such regular exchanges. Instead, the adjustments that are necessary from time to time come mostly from within the system itself though they are often increased by environmental change (just as a crash on a motorway will effect the natural pattern of waves in a traffic jam). The mathematics shows that the main capacity for sudden change is from within the biological system (as in a sand pile) and comprises extinctions and origins (sand pile avalanches) seeded by the increase in diversity (sand).

Several questions remain. How can Gould and Eldredge have reached such different conclusions, and have been supported by most of their peers for a quarter of a century? Surely major catastrophic events within the environment pay a toll on the diversity of life? Do rates of mutations and recombinations show up to follow a trend? How will life continue?

Like so many controversies in science, the answer to the first question concerns both method and data. Gould and Eldredge made straightforward plots with no correction factors and no patterns to emulate. Indeed, their clear and straightforward presentation of the logistic (step-wise) curve of families through time has recently been confirmed by two French physicists using statistical techniques to check the interpretation. However, they ignore the concepts of Self Organised Criticality and 1/*f* noise which are so important in natural time-series. Also, their data are based on species entirely from the marine realm and comprise only the invertebrates. The times of origins of land animals and plants (let alone fish) have not been considered by them. But with the idea of such a compact system of life we can begin to look for signals that might represent the responses from environmental change, mutation and recombination. To predict the future progress of the system from a resulting computer model shows further family extinctions, yet an overall increase in their numbers.

In his 'Poverty of Historicism ' Popper (1957) argued that in the relatively short time-series of human history the social sciences cannot be used as the basis to predict future events. Here, with much longer time-series, the precise timing of events is still impossible, but overall trends in the direction of change do show up. We can say how things are going to happen but not when.

Complete databases for fossil plant and animal data, times of first and last appearance of taxa above the rank of genus, are available on the internet at http://www.biodiversity.org.uk or at http://ibs.uel.ac.uk/ibs where you can make plots of the ranges of the taxa of your choice, at every one million year interval through the Phanerozoic. You can also include the number of originations and extinctions on the same curves.

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A curious twist to this story will amuse the cynical. While it means that the evolutionary process is more passive than is usually thought, the consequences of what is happening to our environment by human activity point to an imminent end to all large mammal families, including ours. We are living through the time of a mass extinction, perhaps one just as significant as any of the "big five". So the same patterns that are seen in the fossil record will show similar new trends away from the exponential in the near future. At least, life on the planet will continue to diversify, albeit in new directions away from man's aggressive forces.

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