Sense of history

The Oxford historian Edward Hallett Carr once suggested that the notion of history entered natural science through the work of the French geologist Charles Lyell. In the 1830s, Lyell argued in his *Principles of Geology* that in geological phenomena we shouldn't seek the traces of timeless mathematical order, but of slow processes acting over extreme periods of time. The book influenced Charles Darwin, who apparently read Volume I while on the survey voyage of the HMS *Beagle*.

But if Lyell brought history into science, Darwin pushed it further, introducing the notion that everything in biology that exists does so, in some sense, by chance, as a result of accidents that left ineradicable marks on the future.

Much of science then, as now, was wrapped up with the pursuit of the timeless fundamental laws that describe the Universe. But most of science deals with the contingent — with systems 'afflicted' (in the Platonic view) with disorder and distortions, or with complex structures unable to relax to ordered simplicity. Darwin gave science a way to proceed in this setting by identifying underlying historical processes — algorithms, if you will — which may be simple in outline, yet lead to consequences of surprising complexity.

There is, indeed, little simplicity in biology. To take one example, Darwin never managed to explain the creation of new species, focusing rather on the gradual phenotypic change of existing species — the lengthening of beaks, or the changing of colours. Today, it's increasingly clear that speciation probably takes place through a variety of mechanisms, such as so-called allopatric speciation, driven by the division of populations into geographically isolated sub-populations, which may then evolve divergently with time. But experiments and theory over the past two decades suggest that speciation may also take place without geographical isolation, through the ordinary dynamics of evolution.

One elegant mechanism was described only 10 years ago, 190 years after Darwin, by Ulf Dieckmann and Michael Doebeli (*Nature* **400,** 354–357; 1999). It involves population splitting through a process not unlike a phase transition. Suppose that, in some environment, the optimal beak

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length for a bird — if you're a bird hunting for insects on your own — is 4 cm. Birds with beaks of other lengths catch food, but not as much as those with the optimal 4 cm beak, perfect for catching the most nutritious flies. Naturally, a population of such birds would be expected to evolve toward this optimal phenotype, the distribution of beak lengths evolving to a narrow distribution about 4 cm.

But Dieckmann and Doebeli pointed out that this needn't be the end of the story. After all, the large number of birds with beaks near the optimal size creates intense competition for the best flies. This competition may be so strong that it actually changes what is optimal — making it slightly better for birds to have beaks slightly shorter or longer than 4 cm, and more suitable for catching insects other than flies. Such birds avoid the mainstream competition.

As a result, in the right circumstances — which depend on the strength of competition between birds of similar beak size — what is optimal may rapidly change from one to two values, triggering a subsequent splitting of the population. My description doesn't begin to capture the subtleties of the argument, which appears to hold for organisms reproducing sexually as well as those reproducing asexually. Evidence in the past few years suggests this mechanism may indeed be active in hotspots of rapid speciation, such as the cichlid fishes in the African Great Lakes. Yet the mechanism is simple and therefore likely to be present more widely, which is the most important point.

Darwin in his day had essentially zero chance of seeing the subtle mechanism that Dieckmann and Doebeli described. His era lacked the mathematics, and perhaps more importantly the computational tools, to gain insight into such difficult problems depending on non-trivial collective dynamics. Even so, it seems to me fair to place with Darwin — although Lyell and whoever inspired him deserve credit as well — the very beginnings of the appreciation that complex phenomena can emerge from relatively simple dynamical origins, a notion that resonates strongly with much of modern physics.

Today we are all influenced by this thinking and find it hard to see how revolutionary it was initially. In physics we're used to models in which accidents count and accumulate and end up driving outcomes — models of self-organized criticality, applied in contexts ranging from earthquake dynamics to mass extinctions, models for fracture dynamics, erosion or deposition, crystallization and so on. If the timeless laws of classical physics and quantum mechanics attempt to wipe history away, or at least demote it to secondary status, processes based on evolution — in a general sense — focus on the accidental and how it gets locked into place. This is part of the broad legacy of Charles Darwin, even if it has little to do with biology.

Perhaps the most influential metaphor inspired by Darwin's thinking is the notion of the fitness landscape, first suggested by Sewall Wright, depicting the variation of organism fitness with phenotype. Evolution drives populations towards the peaks of such landscapes, but they may also get hung up on local peaks, unable to jump across chasms of low fitness to reach higher peaks elsewhere. This insight has been enormously effective in the visual depiction and understanding of evolution, and its use extends further — perhaps even to the process of scientific discovery itself.

As some physicists have recently argued (http://pirsa.org/06050010), the essential challenge for any bold scientist lies in leaving the comfortable confines of the accepted theoretical framework of their day and launching themselves out into territory unknown, often driven by a vision of another, higher peak far away. This inevitably means traversing a valley of low 'fitness' in between, which includes the usual ridicule and opposition facing all those with disruptive ideas which inevitably start out ill- and incompletely formed. We owe the greatest scientific discoveries to those who shoulder such risks, of whom Darwin himself may be the greatest example. ❐

MARK BUCHANAN