

## Modern Darwins

The father of evolution would be thrilled to see the science his theory has inspired.

By Matt Ridley

Just two weeks before he died, Charles Darwin wrote a short paper about a tiny clam found clamped to the leg of a water beetle in a pond in the English Midlands. It was his last publication. The man who sent him the beetle was a young shoemaker and amateur naturalist named Walter Drawbridge Crick. The shoemaker eventually married and had a son named Harry, who himself had a son named Francis. In 1953, Francis Crick, together with a young American named James Watson, would make a discovery that has led inexorably to the triumphant vindication of almost everything Darwin deduced about evolution.

The vindication came not from fossils, or from specimens of living creatures, or from dissection of their organs. It came from a book. What Watson and Crick found was that every organism carries a chemical code for its own creation inside its cells, a text written in a language common to all life: the simple, four-letter code of DNA. "All the organic beings which have ever lived on this earth have descended from some one primordial form," wrote Darwin. He was, frankly, guessing. To understand the story of evolution—both its narrative and its mechanism—modern Darwins don't have to guess. They consult genetic scripture.

Consider, for instance, the famous finches of the Galápagos. Darwin could see that their beaks were variously shaped—some broad and deep, others elongated, still others small and short. He surmised (somewhat belatedly) that in spite of these differences, all the Galápagos finches were close cousins. "Seeing this gradation and diversity of structure in one small, intimately related group of birds," he wrote in *The Voyage of the Beagle*, "one might really fancy that from an original paucity of birds in this archipelago, one species had been taken and modified for different ends."

This, too, was inspired guesswork. But by analyzing the close similarity of their genetic codes, scientists today can confirm that the Galápagos finches did indeed descend from a single ancestral species (a bird whose closest living relative is the dull-colored grassquit).

DNA not only confirms the reality of evolution, it also shows, at the most basic level, how it reshapes living things. Recently, Arhat Abzhanov of Harvard University and Cliff Tabin of Harvard Medical School pinned down the very genes responsible for some of those beak shapes. Genes are sequences of DNA letters that when activated by the cell make a particular protein. Abzhanov and Tabin found that when the gene for a protein called BMP4 is activated (scientists use the word "expressed") in the growing jaw of a finch embryo, it makes the beak deeper and wider. This gene is most strongly expressed in the large ground finch (*Geospiza magnirostris*), which uses its robust beak to crack open large seeds and nuts. In other finches, a gene expresses a protein called calmodulin, which makes a beak long and thin. This gene is most active in the large cactus finch *G. conirostris*, which uses its elongated beak to probe for seeds in cactus fruit.

In another set of islands, off the Gulf Coast of Florida, beach mice have paler coats than mice living on the mainland. This camouflages them better on pale sand: owls, hawks, and herons eat more of the poorly disguised mice, leaving the others to breed. Hopi Hoekstra, also at Harvard, and her colleagues traced the color difference to the change of a single letter in a single gene, which cuts down the production of pigment in the fur. The mutation has occurred since the beach islands formed less than 6,000 years ago.

Darwin's greatest idea was that natural selection is largely responsible for the variety of traits one sees among related species. Now, in the beak of the finch and the fur of the mouse, we can actually see the hand of natural selection at work, molding and modifying the DNA of genes and their expression to adapt the organism to its particular circumstances.

Darwin, who assumed that evolution plodded along at a glacially slow rate, observable only in the fossil record, would be equally delighted by another discovery. In those same Galápagos finches, modern Darwins can watch evolution occur in real time. In 1973, Peter and Rosemary Grant, now of Princeton University, began annual observations of the finch populations on the tiny Galápagos island of Daphne Major. They soon discovered that the finches in fact evolved from one year to the next, as conditions on the island swung from wet to dry and back again. For instance, Daphne Major initially had only two regularly breeding ground finches, one of which was the medium ground finch (*G. fortis*) that fed on small seeds. When severe drought struck the island in 1977 and small seeds became scarce, the medium finches were forced to switch to eating bigger, harder seeds. Those with larger beaks fared better and survived to pass on the trait to their offspring.

Another shift took place after a competitor arrived in 1982: the large ground finch (*G. magnirostris*), which also eats large, tough seeds. For many years the two species coexisted, and in 2002 both became unusually abundant. But then drought struck, and by 2005, only 13 large and 83 medium ground finches remained alive. Remarkably, instead of adjusting to the drought by eating bigger seeds as they had 28 years before, the surviving medium finches experienced a marked reduction in the size of their beaks, as in competition with their larger cousins they struggled to carve out a niche by surviving on very small seeds. A finch with a smaller beak is not a new species of finch, but Peter Grant reckons it might take only a few such episodes before a new species is established that would not choose to reproduce with its parent species.

The variation seen among the Galápagos finches is a classic example of "adaptive radiation," each species evolving from a common ancestor to exploit a special kind of food. Another famous radiation took place on a different set of islands—lands of water rather than land. The lakes and rivers of Africa's Great Rift Valley contain some 2,000 species of cichlid fish that have evolved from a few ancestors, some in an instant of geologic time. For example, Lake Victoria, the largest of those lakes, was completely dry just 15,000 years ago. Its 500 diverse species of cichlid have all evolved since then from a handful of species of uncertain origin. Like the finches, cichlid fish species have adapted to diets in different habitats, such as rocky or sandy patches of lake beds. Some species eat algae and have densely packed teeth suited to scraping and pulling plant matter, while others feed on snails and have thick, powerful jaws capable of crushing open their shells. And what gene is responsible for thickening those jaws? The gene for the protein BMP4—the same gene that makes the Galápagos ground finch's beak deep and wide. What better evidence for Darwin's belief in the commonality of all species than to find the same gene doing the same job in birds and fish, continents apart?

In *The Origin of Species*, Darwin tactfully left unspoken how his theory would extend that commonality to include humankind. A decade later he confronted the matter head-on in *The Descent of Man*. He

would be delighted to know that a certain gene, called *FOXP2*, is critical for the normal development of both speech in people and song in birds. In 2001 Simon Fisher and his colleagues at the University of Oxford discovered that a mutation in this gene causes language defects in people. He later demonstrated that in mice, the gene is necessary for learning sequences of rapid movement; without it, the brain does not form the connections that would normally record the learning. In human beings, presumably, *FOXP2* is crucial to learning the sophisticated flicker of lips and tongue with which we express our thoughts.

Constance Scharff of the Free University of Berlin then discovered that this very same gene is more active in a part of the brain of a young zebra finch, just when the bird learns to sing. With fiendish ingenuity, her group infected finches' brains with a special virus, carrying a mirror-image copy of part of the *FOXP2* gene, which stifled the gene's natural expression. The result was that birds not only sang more variably than usual but also inaccurately imitated the songs of adults—in much the same way as children with mutant *FOXP2* genes produce variable and inaccurately copied speech.

If natural selection is survival of the fittest (a phrase coined by the philosopher Herbert Spencer, not by Darwin), then sexual selection is reproduction of the sexiest. It has the delightful effect of generating weapons, ornaments, songs, and colors, especially on male animals. Darwin believed that some such ornaments, such as stags' antlers, helped males fight each other for females; others, such as peacocks' tails, helped males "charm" (his word) females into mating. It was, in truth, an idea born of desperation, because useless beauty worried him as an apparent exception to the ruthlessly practical workings of natural selection. He wrote to the American botanist Asa Gray in April 1860 that "The sight of a feather in a peacock's tail, whenever I gaze at it, makes me sick!"

His notion of sexual selection was politely ignored by most Victorian opinion, which was mildly scandalized by the thought of females actively choosing a mate, rather than submitting coyly to the advances of males. Even biologists dropped the idea for roughly a century, because they became obsessed with arguing that traits evolve to suit the species, rather than to suit the individual. But we now know Darwin was right all along. In all sorts of species, from fish and birds to insects and frogs, females approach the males with the most elaborate displays, and invite them to mate.

Darwin did not speculate much on why a female would choose an ornamented male. It is a question that still excites biologists, because they have two equally good answers to it. One is simply fashion: When females are choosing gorgeous males, other females must follow suit or risk having sons that do not attract females. The other is more subtle. The tail of a peacock is an exhausting and dangerous thing for the bird to grow. It can only be done well by the healthiest males: parasites, starvation, and careless preening will result in duller plumage. So bright plumage constitutes what evolutionary biologists call an "honest indicator of fitness." Substandard peacocks cannot fake it. And peahens, by instinctively picking the best males, thereby unknowingly pass on the best genes to their offspring.

In one of his flights of fancy, Darwin argued that sexual selection might account for human racial differences: "We have seen that each race has its own style of beauty. ... The selection of the more attractive women by the more powerful men of each tribe, who would rear on an average a greater number of children, [would] after the lapse of many generations modify to a certain extent the character of the tribe." The jury is still out on that particular idea, but there are hints that Darwin might be at least partly right.

Take blue eyes. Darwin, like many Europeans, had blue eyes. In early 2008, Hans Eiberg and his colleagues at the University of Copenhagen announced that they had found the genetic mutation common to all pure blue-eyed people. The mutation is a single letter change, from A to G, on the long

arm of chromosome 15, which dampens the expression of a gene called *OCA2*, involved in the manufacture of the pigment that darkens the eyes. By comparing the DNA of Danes with that of people from Turkey and Jordan, Eiberg calculated that this mutation happened only about 6,000-10,000 years ago, well after the invention of agriculture, in a particular individual somewhere around the Black Sea. So Darwin may have gotten his blue eyes because of a single misspelled letter in the DNA in the baby of a Neolithic farmer.

Why did this genetic change spread so successfully? There is no evidence that blue eyes help people survive. Perhaps the trait was associated with paler skin, which admits more of the sunlight needed for the synthesis of vitamin D. That would be especially important as people in less sunny northern climates became more dependent on grain as a food source, which is deficient in vitamin D. On the other hand, blue-eyed people may have had more descendants chiefly because they happened to be more attractive to the opposite sex in that geographic region. Either way, the explanation leads straight back to Darwin's two theories—natural and sexual selection.

Intriguingly, the spelling change that causes blue eyes is not in the pigment gene itself, but in a nearby snippet of DNA scripture that controls the gene's expression. This lends support to an idea that is rushing through genetics and evolutionary biology: Evolution works not just by changing genes, but by modifying the way those genes are switched on and off. According to Sean Carroll of the University of Wisconsin at Madison, "The primary fuel for the evolution of anatomy turns out not to be gene changes, but changes in the regulation of genes that control development."

Perhaps more scientists should have realized this sooner than they did. After all, bodies are not assembled, like machines in factories; they grow and develop, so evolution was always going to be about changing the process of growth rather than specifying the end product of that growth. In other words, a giraffe doesn't have special genes for a long neck. Its neck-growing genes are the same as a mouse's; they may just be switched on for a longer time, so the giraffe ends up with a longer neck.

Just as Darwin drew lessons from both fossil armadillos and living rheas and finches, his scientific descendants combine insights from genes with insights from fossils to understand the history of life. In 2004, Neil Shubin of the University of Chicago and his colleagues found a 375-million-year-old fossil high in the Canadian Arctic—a creature that fit neatly in the gap between fish and land-living animals. They named it *Tiktaalik*, which means "large freshwater fish" in the local Inuktitut language. Although it was plainly a fish with scales and fins, *Tiktaalik* had a flat, amphibian-style head with a distinct neck, and bones inside its fins corresponding to the upper and lower arm bones and even the wrists of land animals: a missing link, if ever there was one. It may even have been able to live in the shallows or crawl in the mud when escaping predators.

Equally intriguing, however, is what *Tiktaalik* has taught Shubin and his colleagues in the laboratory. The fossil's genes are lost in the mists of time. But, inspired by the discovery, the researchers studied a living proxy—a primitive bony fish called a paddlefish—and found that the pattern of gene expression that builds the bones in its fins is much the same as the one that assembles the limb in the embryo of a bird, a mammal, or any other land-living animal. The difference is only that it is switched on for a shorter time in fish. The discovery overturned a long-held notion that the acquisition of limbs required a radical evolutionary event.

"It turns out that the genetic machinery needed to make limbs was already present in fins," says Shubin. "It did not involve the origin of new genes and developmental processes. It involved the redeployment of old genetic recipes in new ways."

Though modern genetics vindicates Darwin in all sorts of ways, it also turns the spotlight on his biggest mistake. Darwin's own ideas on the mechanism of inheritance were a mess—and wrong. He thought that an organism blended together a mixture of its parents' traits, and later in his life he began to believe it also passed on traits acquired during its lifetime. He never understood, as the humble Moravian monk Gregor Mendel did, that an organism isn't a blend of its two parents at all, but the composite result of lots and lots of individual traits passed down by its father and mother from their own parents, and their grandparents before them.

Mendel's paper describing the particulate nature of inheritance was published in an obscure Moravian journal in 1866, just seven years after *The Origin of Species*. He sent it hopefully to some leading scientists of the day, but it was largely ignored. The monk's fate was to die years before the significance of his discovery was appreciated. But his legacy, like Darwin's, has never been more alive.

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