CHAPTER 1

The Queen's Orang-Utan

In 1842 Queen Victoria went to London Zoo. She was less than amused: "The Orang Outang is too wonderful . . . he is frightfully, and painfully, and disagreeably human." The animal was not a male but a female called Jenny, and Charles Darwin had, some years earlier, visited its mother. He too spotted the resemblance between the apes on either side of the bars. The young biologist scribbled in his notebook: "Man in his arrogance thinks himself a great work. More humble and I believe true to consider him created from animals." Seventeen years after Victoria's visit, in 1859, he published the theory that established the Queen's and his own kinship to Jenny, to every inmate of the Zoo, and to all the inhabitants of Earth.

The Origin of Species led to an uproar among the Empress of India's subjects. Her Chancellor, Benjamin Disraeli, asked: "Is man an ape or an angel? My Lord, I am on the side of the angels. I repudiate with indignation and abhorrence these new fangled theories." Many of his fellow citizens agreed. Even so, in time, and with some reluctance, the notion that every Briton, high or low, shared descent with the rest of the world was accepted. A quarter of a century later, W. S. Gilbert penned the deathless line "Darwinian man, though well behaved, at best is only a monkey shaved," and the idea of *Homo sapiens* as a depilated ape became part of popular culture. Victoria herself congratulated one of her daughters for turning to *The Origin*: "How many interesting, difficult books you read. It would and will please beloved Papa."

As the Queen had noticed, the physical similarity of men to apes is clear. In 1859 Charles Darwin came up with the reason why. A certain caution was needed in promoting the idea that what had made animals had also produced men and women, and he waited for twelve years before expanding on the subject. *The Descent of Man* describes how—and why—*Homo sapiens* shares its nature with other primates. It uses our own species as an exemplar of evolution.

To the great biologist, man obeyed the same evolutionary rules as all his kin—in the book's final words, he reveals "the indelible stamp of his lowly origin." In moral terms *Homo sapiens* was something more: "Of all the differences between man and the lower animals, the moral sense or conscience is by far the most important. This sense . . . is summed up in that short but imperious word 'ought,' so full of high significance. It is the most noble of all the attributes of man, leading him without a moment's hesitation to risk his life for that of a fellow-creature." No ape understands the meaning of "ought," a word pregnant with notions quite alien to all species except one: but despite that essential and uniquely human attribute, every ape, like every other creature, is the product of the same biological mechanism.

The logic of evolution is simple. There exists, within all creatures, variation, which is passed from one generation to the next. More individuals are born than can live or breed. As a result, there develops a struggle to stay alive and to find a mate. In that battle, those who bear certain variants are more successful than others less well endowed. Such inherited differences in the ability to pass on genes—natural selection, as Darwin called it—mean that certain forms become more common as the generations succeed. In time, as new and advantageous versions accumulate, a lineage may change so much that it can no longer exchange genes with others that were once its kin. A new species is born.

Natural selection is a factory that makes almost impossible things. It generates what seems like design with no need for a designer. Evolution builds complicated organs like eyes, ears, or elbows by piecing together favoured variants as they arise and, almost as an afterthought, produces new forms of life. Its tale as told in *The Origin of Species* turns on the efforts of farmers as they develop new breeds from old, on changes in wild plants and animals exposed to the rigours of nature and the demands of the opposite sex, on the tendency of unique forms to evolve in isolated places, and on the silent words of the fossils that tell of a planet as it was before evolution moved on. The book's pages also speak of the embryo as a key to the past and of how structures no longer of value and others that appear unreasonably perfect are each testimony of the power of natural selection. The geography of life—on islands, continents, and mountains—is evidence of the common descent of mush-

CHAPTER 2

The Green Tyrannosaurs

Soaring above southern Venezuela is a hidden landscape, the sandstone plateau of Mount Roraima, an inaccessible peak often shrouded in mist. Arthur Conan Doyle used the place, or one much like it, as the location for his 1912 book *The Lost World*, a tale set in a land of evolutionary imagination—a place of dinosaurs, ape-men, and primitive humans, ready to be explored by the irascible Professor Challenger. It was a fearsome spot, but the bearded Englishman lambasted the lizards and saved the savages, just as any Edwardian reader would expect.

Conan Doyle was born in the year of *The Origin*. By his fifty-third birthday, the theory of evolution had become so widely accepted that a literary hack could use it as the centrepiece of a work of fiction. Doyle (who had read the reports of the British explorer who discovered the unique island in the sky) seized the chance, and his book sold hundreds of thousands of copies to a well-primed public.

In reality the dinosaurs had disappeared from Roraima millions of years earlier, and the local "savages" never made it to the top. Even so, its remote summit is a genuine lost world, not of giant anthropophagous lizards but of unassuming plants with similar dietary habits. Those green carnivores eat not human flesh but insects. They must do so or starve.

Their practice is widespread. Almost six hundred insect-eating plants, from all over the world and from a wide variety of groups, have been discovered. Such a way of life has evolved independently many times, and the tactics used to trap and digest prey are varied indeed. Separate lineages, starting from different places, have taken up an identical diet. They have come to solutions that at first sight seem remarkably similar when it comes to the need to find, digest, and absorb food. Charles Darwin had used such convergent evolution, as the process is known, as evidence for natural selection in *The Origin of Species*. The physical resemblance of Australian marsupials such as the Tasmanian wolf to the mammalian wolves elsewhere in the world, or of wings in birds and bats, was, he saw, powerful proof of its action. Different creatures faced with the same challenges adopt structures and habits that look much the same but have very different roots. Life can, as a result, reach what seems an identical end by quite distinct pathways: as he put it in *The Origin*, "In nearly the same way as two men have sometimes independently hit on the very same invention, so natural selection, working for the good of each being and taking advantage of analogous variations, has sometimes modified in very nearly the same manner two parts in two organic beings, which owe but little of their structure in common to inheritance from the same ancestor."

We know many such examples—flight, not just in birds and bats but in squids, fish, dinosaurs, flying squirrels, and the marsupial sugar-glider of Australia (not to speak of the flying snake whose flattened body allows it to glide from tall trees). We ourselves are not immune to convergence, for plenty of creatures have lost their hair, grown their brains, or even (like the meerkats of Africa, who instruct their infants how to eat poisonous insects) stood upright and gained some simulacrum of culture.

Convergent evolution in response to a common challenge is almost universal. It has been so effective that it can disguise the real shape of family trees. Many natural pedigrees have now been revealed with DNA. Sometimes it shows that creatures thought to be close relatives are in fact not kin: thus, the vultures of the Old and New World, similar as they appear, do not have a recent common ancestor. The former are eagles and the latter storks. Anteaters and aardvarks, lions and tigers, moles and mole-rats—all hide a bastard ancestry beneath their shared appearance. The process goes further: on Roraima itself, for unknown reasons, melanism is rife and the rocks harbour black lizards, black frogs, and black butterflies. The mutation responsible is the same, or almost so, in zebra-fish, people, mice, bears, geese, and Arctic skuas (and perhaps in lizards and frogs) and has been picked up by natural selection in each. On a more intimate scale, the complicated chemical used as a sexual scent by certain species of butterfly does the same job for elephants (which is riskier for one partner in the relationship than for the other). Within the cell, too, shared evolutionary pressures have produced enzymes

CHAPTER 3

Shock and Awe

MANY AMERICAN COMMENTATORS HAVE GLOATED THAT ZACARIAS Moussaoui, the Frenchman accused of involvement in the September 11 attacks, will certainly go mad as a result of his solitary confinement in the Colorado maximum security prison where he will spend the rest of his life. As the judge who passed sentence said: "You will never get a chance to speak again . . . and will die with a whimper."

Men do fall into insanity in such places, but much as vengeful right-wingers might celebrate such mental decay, some among them would be dismayed to learn that Moussaoui will lose his mind for Darwinian reasons. Guy the Gorilla, star of London Zoo in the 1950s, was admired for his solemn disposition. In fact the animal was deeply depressed, kept as he was for years alone in a small cage. *Homo sapiens* is a social primate, descended, like gorillas or chimpanzees, from an ancestor with the same habits. Had our forefathers been more solitary beasts like the orangutan (which spends much of the year alone), the worst of all punishments would not be solitary confinement but an endless dinner party. The constant exchange of subtle emotional cues around the table would drive those present to their wits' end.

Scientists are often asked to explain what makes men different from chimpanzees or orangs, but in some ways that is scarcely an issue for science. Such questions deal not with the body or the brain but with the mind, a topic that many biologists consider to be outside their expertise. Even so, as science compares man's behaviour with that of his relatives, it finds that biology says something about how humans became what they are. *Homo sapiens* is, says all the evidence, a creature that craves company. To satisfy that yearning, men and women spend much of their time in silent and sometimes subliminal conversation. Those who for one reason or another cannot join in pay a high price.

To Sartre, hell was other people. Rousseau, too, saw man as in decline from a pure and animal state and modern society as a corruption of what the world should be. "Savage man, left by Nature to bare instinct alone . . . will begin with purely animal functions. . . . His desires do not exceed his physical needs: the only goods he knows in the Universe are food, a female, and rest." The true life was near-solitude, on a remote island best of all, with a bare minimum of interaction with anyone else. The philosopher's ideas were romantic but wrong. Members of all primate communities, human or otherwise, must negotiate to maintain peace, have sex, and reap the benefits of cooperation. They use signals both self-evident and subtle to test the mental state of their fellows and to advertise their own (and even the solitary orang hoots now and again to impress its neighbours). Civilisation is based on the ability to respond to other people's sentiments.

In 1879, at the Derby, Darwin's cousin Francis Galton found he could assess "the average tint of the complexion of the British upper classes" as he observed the crowd through his opera glass. Then the race started, and in a letter to *Nature* entitled "The Average Flush of Excitement" he noted that that average complexion became "suffused with a strong pink tint, just as though a sun-set glow had fallen upon it." A shared hue was a statement of a common passion, and Galton could work out what it was even when he could not distinguish one person from the next. In the same way, someone exposed to an image of a group of individuals bearing a range of expressions from happy to miserable can sense their general state of mind far faster than he could by scanning each visage. Our brain, it seems, has a filter that picks up not just how many individuals are in a crowd, but how they feel. The ability has its downside. It means that mass hysteria can spread through society as shared feelings feed on themselves; as Charles Mackay put it in his 1841 book *Extraordinary Popular Delusions and the Madness of Crowds*, an account of the South Sea Bubble and other fantasies, men "go mad in herds, while they only recover their senses slowly, and one by one."

In 1872, in *The Expression of the Emotions in Man and Other Animals*, Charles Darwin discussed the role of signals in the herds, packs, flocks, schools, towns, and cities in which social animals live. The book was a first attempt to understand sentiment in scientific terms. Darwin was interested in how mental actions are manifest in the face and body, and he realised how

CHAPTER 4

The Triumph of the Well Bred

Charles Darwin was worried about his plans for marriage. Perhaps the whole idea was a mistake because of the time diverted to family life at the expense of science. His diary records how he agonised over the pros and cons of matrimony, and his decision: "Marry, marry, marry!" In the end he did.

His spouse was his cousin, Emma Wedgwood. In falling for a relative he stuck to a clan tradition. The Darwins, like many upper-crust Victorians, had long preferred to share a bed with their kin. Charles's grandfather Josiah Wedgwood set up home with his third cousin Sarah Wedgwood. Their daughter Susannah chose Robert Darwin, Charles's father. Charles's uncle—Emma's father—had nine offspring, four of whom married cousins. The great evolutionist's own marriage was, in the end, happy, with ten children (and when his wife was in her early forties he wrote that "Emma has been very neglectful of late for we have not had a child for more than one whole year"). Even so, in Queen Victoria's fecund days the Darwin-Wedgwood dynasty did less well than most, for among the sixty-two uncles, cousins, and aunts (Emma and Charles included) who descended from Josiah, thirty-eight had no progeny who survived to adulthood.

Six years after his wife's last confinement, Darwin began to think about the dangers of inbreeding. His concern was picked up from another of his cousins, Francis Galton, the founder of eugenics, who had pointed out the dangers of marriage within the family.

Charles was anxious about his children: his tenth and last, Charles the younger, died while a baby; he was "backward in walking & talking, but intelligent and observant." Henrietta had a digestive illness not unlike her father's and took to her bed for years, and he feared that his son Leonard was "rather slow and backward" (which did not stop him from marrying his own cousin and serving as president of the Eugenics Society), while Horace had "attacks, many times a day, of shuddering & gasping & hysterical sobbing, semi-convulsive movements, with much distress of feeling." His second daughter, Elizabeth, "shivers & makes as many extraordinary grimaces as ever." George's problem was an irregular pulse, which hinted at "some deep flaw in his constitution" and, worst of all, his beloved Annie expired at the age of ten, throwing her parents into despair. As he wrote, "When we hear it said that a man carries in his constitution the seeds of an inherited disease there is much literal truth in the expression." At one point the naturalist even wrote to a friend that "we are a wretched family & ought to be exterminated." Might his illness and those of his sons and daughters be due to his own and his ancestors' choices of relatives as life partners? Was inbreeding a universal threat?

Darwin's first statement of concern came three years after *The Origin*, as an afterword to his book *On the Various Contrivances by Which British and Foreign Orchids Are Fertilised by Insects, and on the Good Effects of Intercrossing*. The last paragraph of that hefty work, most of it devoted to botanical minutiae, ends: "Nature thus tells us, in the most emphatic manner, that she abhors perpetual self-fertilisation. This conclusion seems to be of high importance, and perhaps justifies the lengthy details given in this volume. For may we not further infer as probable, in accordance with the belief of the vast majority of the breeders of our domestic productions, that marriage between near relatives is likewise in some way injurious,—that some unknown great good is derived from the union of individuals which have been kept distinct for many generations?"

The idea that children born to related parents might be in peril was already in the air. The first study of its risks came in 1851, when Sir William Wilde (father of Oscar) found, in work years ahead of its time, an increased incidence of deafness among the progeny of cousins. Sir Arthur Mitchell, the Deputy Commissioner in Lunacy for Scotland, had earlier claimed that the inbred fishing communities of northeast Scotland had an average hat size of six and seven-eighths, a quarter-inch less than that of their more open-minded agricultural neighbours—proof, he thought, of the malign effects of the marriage of kin upon the mental powers.

Sex within the family has a venerable history. The pharaohs lived through

CHAPTER 5

The Domestic Ape

"LET THEM EAT CAKE!" SAID THE QUEEN, AND THEY DID. TWO CENTURies after the demise of Marie Antoinette, the poor are fat and the rich are thin. Across the globe, death from excess has, for the first time in history, overtaken that from deficiency. Eight hundred million people are hungry while a billion are overweight. The problem comes from evolution, as manipulated by man.

Darwin saw how farmers had bred from the best to produce new forms of life and used that notion to introduce the idea of natural selection. His argument is set out in the first chapter of *The Origin of Species*. Given time, with conscious or unconscious selection by breeders, new and improved versions of creatures—from potatoes to pigs and pigeons—will soon emerge. Were they to be found in nature rather than in fields, sties, or lofts, many would be recognised by naturalists as distinct species.

In *Variation of Animals and Plants Under Domestication*, published a decade after *The Origin*, Darwin went further in exploring the tame as the key to the wild. The book speaks of ancient times, when "a wild and unusually good variety of a native plant might attract the attention of some wise old savage; and he would transplant it, or sow its seed." That interesting event—the choice of favoured parents to form the next generation—was a microcosm of the process that had moulded life since it began. The variety of breeds seen on the farm, he wrote, was "an experiment on a gigantic scale," both a test of his theory and a proof of its power.

Savages have been replaced by scientists. Their work has produced many new varieties of plants and animals and reveals the eccentric history of the food on our plates. Modern biology has transformed farming. Planned breeding—directed evolution—has led to an enormous drop in the effort needed to feed ourselves. The British spend a sixth of their income on breakfast, lunch, and dinner and the Americans even less: a proportion down by half in the past five decades and by far more in the past five centuries. For most people, shortage has given way to glut. As a result, for many citizens of the developed world food is in effect free.

The blessings so brought are equivocal. The real price of sugar, starch, and fat has plummeted. Famine disguised as feast has spread across the globe. Evolution on the farm transformed society ten millennia ago and is doing the same today. The early farmers were powerful agents of selection on wheat, maize, cows, pigs, chickens, and more; but the influence of those domestic creatures on the biology of the farmers themselves was almost as great. It began as soon as the wild was domesticated, ten thousand years ago, and led people to evolve the ability to deal with new kinds of food. Today's shift in diet will, in time, have equally potent effects on the genes of our descendants.

A new global power is on the move. The empire of obesity began to flex its stomach in the 1980s and shows no sign of retreat. Twenty years before that dubious decade there was, in spite of a collapse in the real price of food, little sign of the coming wave of lard. Then, thanks to technology, came the industrialization of diet, the latest step in the scientific exploitation of the Darwinian machine. Now a tsunami of fat has struck the world, and the world is paying the price.

It does not take much to alter a nation's waistline. The rise in American obesity over the past thirty years can be blamed on an increase in calories equivalent to no more than an extra bottle of fizzy drink for each person each day. At the present rate, two-thirds of Americans and half of all Britons will be overweight by 2025, and Britain will be the fattest nation in Europe. Among industrial powers, only China and its neighbours are insulated from the scourge.

This twenty-first century plague is a side effect of the triumph of scientific farming—of planned evolution—and many of those afflicted suffer as a result of the inability of their own genes to deal with the new diet. Some will die young or fail to find a mate. As a result the obesity that emerges from modern agriculture will soon be—like the advent of farming itself—a potent agent of natural selection.

The people who laid out the first fields lived above the rivers that snaked across a green and leafy Levant. For millennia they had hunted game and

CHAPTER 6

The Thinking Plant

Deep in the Amazon jungle, a creature snakes into the light. As it climbs cautiously through the branches it senses a brighter spot on a distant tree. After weighing up the risks of abandoning its present post it plunges back into the gloom of the forest floor and creeps across the ground until at last it reaches its target, scrambles upwards, and triumphs to bask high in the tropical sunshine. The vine—for such it is—shows every sign of foresight in its behaviour. The notion that a plant might act in what appears to be an intelligent way seems alien; less so, perhaps, than before time-lapse films speeded up the circling of shoots or the opening of flowers, but at least unexpected. Can such a simple creature really plan ahead?

Romantics have long been convinced that the vegetable kingdom has a mind of its own. Gardeners talk to their crops in the hope that they will flourish, while real enthusiasts for botanical intelligence believe that cacti grow fewer spines when exposed to soft music and put them out again when a cat draws near. The Japanese even enter into two-way conversations with their green friends. They have patented an electronic device through which a flower can chat with its owner (or, when thirsty, ask for water). In the 1920s the great Indian physicist Chandra Bose, a pioneer in the study of electromagnetic waves, worked on electrical activity in plants. His subjects generated a measurable current when damaged (an observation that led to genuine scientific advances)—but Bose was also certain that music and kind words could set off the response.

Dubious as such claims might be, the mental universe of plants is, if nothing else, useful fuel for metaphor. Shelley writes of a garden in which a mimosa droops in response to a rejected lover's despair: "Whether the sensitive Plant, or that / Which within its boughs like a Spirit sat, / Ere its outward form had known decay, / Now felt this change, I cannot say." The Latin name for Shelley's sympathetic subject is *Mimosa pudica*, in reference to its bashful nature (the Chinese call it "shyness grass"). Whatever the plant's mental state, it does respond to the outside world. Most of the time, a mimosa's branched leaf stands proud; but a slight touch, or a gust of wind, causes it to droop. It can take hours to recover. At night, no doubt exhausted by the emotional turmoil of the day, the leaves close up and their owner goes to sleep.

Shelley's lines are both a literary device and an accurate observation. They also say something about the relationship of mind and brain. If a mimosa can act in an apparently rational way without any hint of cerebral matter, what does the endless debate on that topic mean? Philosophers, like poets, should pay more attention to botany.

Charles Darwin had no real interest in such metaphysical ideas (although he did claim that plants sometimes recoiled in "disgust"). He was nevertheless curious about plants' ability to react to the conditions in which they are placed, and wrote two books on the subject. *The Movements and Habits of Climbing Plants* of 1875 deals with how ivy, brambles, and the like find and scramble up their vertical helpers. *The Power of Movement in Plants*, published five years later, asks wider and more radical questions about how plants respond to the outside world. It had, he wrote, always pleased him "to exalt members of the botanical world in the scale of organised beings," and in those volumes he succeeded. Together they discuss three hundred species and place the plant kingdom on a higher scientific plane than ever before. His experiments laid the foundations of modern experimental botany.

The great naturalist's home county was in those days famous for hops. So fond was the British working man of beer that Kentish fields were filled with poles and wires up which the bitter vines were trained. Each September, tens of thousands of labourers and their families came from London to pick the crop and have what, in Victoria's glorious days, passed as a holiday. *Climbing Plants* asks a simple question. How does a hop find a support and climb up it? Its shoots as they peep above the soil must seek out an upright of the right size, even if it is a foot or more away. Then they must twine around it to

CHAPTER 7

A Perfect Fowl

Sir Robert Moray was a spy for Cardinal Richelieu, a freemason, a member of the Scottish army that took Newcastle from the English in 1640, and in his spare time the first president of the Royal Society. He wrote extensively on the natural history of his native land and made a remarkable discovery, published in the Society's *Philosophical Transactions* in 1677. On a log on the shores of the island of Uist, he saw "multitudes of little shells; having within them little birds perfectly shaped, supposed to be barnacles. . . . This bird . . . I found so curiously and completely formed, that there appears nothing wanting, as to the external parts, for making up a perfect Sea-Fowl; . . . the little bill like that of a goose, the eyes marked, the head, neck, breast, wings, tail and feet formed like those of other water fowl, to my best remembrance." Sir Robert had the honesty to admit that he had never observed any of the adult animals but told his readers that "credible persons have assured me that they have seen some as big as a fist."

The myth of the shell-born birds—barnacle geese as we call them today—the shells themselves supposed to be the seeds of a certain tree, was widespread. So embedded was the notion that for a time the barnacle goose was counted as a fish and could be eaten by Catholics on Fridays. Their breeding grounds are in the Arctic, which baffled those who saw them only in the winter (although Thomas Henry Huxley suggested that the mistake came because such birds were common in Hibernia, Ireland, and that the linguistic shift from *Hiberniculae* to *Barnaculae*, or barnacles, was easy enough).

The idea of a bird-bearing tree is foolish, but it arises from the ancient and accurate observation that the adult form of many creatures is quite distinct from that of their eggs or embryos. The untrained eye finds it hard to tell juveniles apart. A month-old human fetus is almost identical to that of a chimpanzee, the inside of a goose egg looks much like that of an ostrich, and a barnacle larva is not very different from those of its relatives among the lobsters and crabs. Even the founder of modern embryology, Karl von Baer, found it difficult to sort them out. In 1828 he wrote that "I have two embryos preserved in alcohol that I forgot to label. At present I am unable to determine the genus to which they belong. They may be lizards, small birds, or even mammals."

The word *evolution* was first applied to the unfolding of the body as egg is transformed into adult. Development is the imposition of pattern upon a formless mass. Most animals, from barnacles to geese, share the same basic types of cells. As the embryo grows they are organised to make a crab or a barnacle, a goose or an ostrich, a man or a bat. That grand reshuffling builds new and complicated body shapes from the same raw material. As it does, it hides the blueprint from which their bodies are built. *The Origin* used the similarity of the juvenile stages of apparently unrelated beings to argue that "community of embryonic structure reveals community of descent." Adult anatomy makes sense only when seen through the eyes of an embryo.

Darwin saw that many creatures showed "unity of type," a deep similarity hidden by the complexity of mature animals but manifest in their young. Many embryos—those of barnacles included—consist of repeated segments that multiply, reduce, or rearrange themselves to produce an adult. An increase or decrease in number or a shift in pattern of growth generates a vast diversity of sizes and shapes. Evolution works as much by manipulating repeated units as by tinkering with individual organs as they grow.

The idea finds new life in modern biology. DNA, like the bodies it builds, is a series of variations on a structural theme. Complex organs—eyes, ears, hands, and brains—are pieced together from units that can be seen only in the early days of development or, even earlier, revealed to be hidden in the recesses of the double helix.

Nowhere is the contrast between young and old more remarkable than among the barnacles. Such creatures were once thought to be snails because of their solid shells (a distinguished professor of zoology—or of biochemistry masquerading as that science—once tried to convince me that they do belong to that family). In fact they are arthropods, jointed-limb animals related to crabs, spiders, and flies. Their ancestors lived free in the oceans, but many now spend most of their lives in a prison. Barnacles are close kin not to lim-

CHAPTER 8

Where the Bee Sniffs

A GIFT OF ORCHIDS IS A STATEMENT OF A GENTLEMAN'S INTENTIONS towards a potential partner. A man willing to spend so much on his mate must be devoted indeed—or rich enough not to care, which often comes to more or less the same thing. An orchid, with its extravagant flowers and price tag, is a test of his readiness to invest in a relationship.

The plants feel much the same. Their Latin name, the *Orchidaceae*, means "testicle," after the interesting shape of their roots. Orchids advertise their sexual prowess with expensive and often bizarre blooms. So great are their carnal powers that the English herbalist Culpeper called for caution when they were used as aphrodisiacs. In *The Descent of Man and Selection in Relation to Sex* Charles Darwin showed how, in the animal kingdom, the battle to find a mate was as formidable an agent of selection as the struggle to stay alive. Males, in general, have the potential to have far more offspring than do members of the opposite sex—if, that is, they can fight off their rivals and persuade enough females to play along with their desires. Losers in the battle reach the end of their evolutionary road. Their genes go nowhere. Natural selection as played out in the universe of sex is as pitiless as that which turns on survival. Sexual selection can lead to gigantic antlers, a vivid posterior, or—for species interested in such things—fast cars and Armani suits.

He also examined the sexual struggles of the second great realm of life, the plants. He showed how the search for a partner is even more of a challenge for a flower than it is for a peacock. The sexual habits of the botanical kingdom were obscure (and their existence often denied) until the seventeenth century, but within a hundred years or so the basic machinery was worked out. Flowers were the site of the reproductive organs and a statement of erotic needs. Darwin found that they had arisen in much the same way as an animal's sexual advertisements and were subject to the same evolutionary forces. Their structure was often equally bizarre. For plants, as for animals, sex was full of dishonesty and discord, with everyone involved ready to cheat whenever necessary.

Botanical marriages are more crowded than their animal equivalents, for a third party is needed to consummate them. For some species, wind or water step in to help; but most flowers need a flying penis—a pollinator—to carry their DNA to its goal. Darwin saw how antagonism between plants and their sperm delivery service is as powerful an agent of selection as is the balance of female choice and male competition that gives rise to the peacock's tail (although his acquaintance John Ruskin advised his female readers not to enquire "how far flowers invite or require flies to interfere in their family affairs"). Flower and pollinator, trapped in each other's embrace, enter an evolutionary race that ends in structures as unexpected as anything in the animal world.

The interests of those who manufacture the crucial DNA and those who carry it are different. From the point of view of a female flower (or the female part of a hermaphrodite plant), one or a few visits by a winged phallus is enough to do the job (although the more callers she gets, the greater choice she has of which sex cell to use). To beat its rivals, though, a male is forced to attract the distribution service again and again—and that can be expensive.

In his 1862 volume *On the Contrivances by Which British and Foreign Orchids Are Fertilised by Insects and on the Good Effects of Intercrossing*, Darwin studied the divergence of interest of flower and pollinator. He used the showiest and most diverse of all plants as an exemplar. As he wrote, "The contrivances by which Orchids are fertilised, are as varied and almost as perfect as any of the most beautiful adaptations in the animal kingdom." As well as an exhaustive account of the structure and relationships of the orchids themselves ("I fear, however, that the necessary details will be too minute and complex for any one who has not a strong taste for Natural History"), his work introduced the idea—much developed in *The Descent of Man and Selection in Relation to Sex*—that parts of evolution turn on the ancient and endless sexual conflict that crafts the future of all those drawn in.

The war between flowers and insects is an overture to a wider world of biological discord. It leads to spectacular bonds between improbable partners and reveals many details of the mechanism of evolution (including its

CHAPTER 9

The Worms Crawl In

The fields of Britain are crisscrossed by earnest men with metal detectors. Despised by archaeologists for the damage they cause, the "discoverists," as they call themselves, have turned up thousands of coins, swords, belt buckles, and the like. During Darwin's bicentennial year one Staffordshire enthusiast unearthed three million pounds' worth of gold objects. They were no doubt buried by their owner in a time of danger, but most such relics simply sank from sight. Why?

Charles Darwin, as usual, got it right. The past had been entombed by worms. He sings their praises in his last book, *The Formation of Vegetable Mould, Through the Action of Worms, with Observations on Their Habits:* "The plough is one of the most ancient and most valuable of man's inventions; but long before he existed the land was in fact regularly ploughed, and still continues to be thus ploughed by earth-worms. It may be doubted whether there are many other animals which have played so important a part in the history of the world." His literary swan song discusses the anatomy and habits of those creatures, their intellectual life (such as it is), and, most of all, their ability to disturb the surface of the Earth: to aerate, turn over, and improve the soil, and to bury anything that lies upon it. Although he claimed that he had produced no more than "a curious little book" on a matter that "may appear an insignificant one," the ravages of the plough since its invention thousands of years ago and the damage done to the Earth's surface by today's agriculture mean that the work of the worms is crucial not only to the history of the world but to its future.

The power of such small beings over the fate of objects far larger than themselves shows, once again, the huge consequences that can emerge from what might seem the trivial efforts of Nature. Darwin was aware of the potential of the worm as proof of the might of slow change; as he said of their efforts, "the maxim *de minimis non curat lex* [the law is not concerned with trifles] does not apply to science." They were the final test of his obsession with the cumulative potential of the small, and he was proud of his results. He dismissed the arguments of a Mr. Fish, who denied the animals' talents, as "an instance of that inability to sum up the effects of a continually recurrent cause, which has often retarded the progress of science, as formerly in the case of geology, and more recently in that of the principle of evolution."

The savant's attraction to earthworms started long before he thought of science. In his *Autobiography* he notes that, as a child, he had been so upset by their contortions when impaled on fish hooks that, as soon as he heard that it was possible to euthanize them with salt and water, he never again "spitted a living worm, though at the expense, probably, of some loss of success!" His later studies introduced a new world beneath our feet, gave life to the idea of animals as a geological force, and showed how even simple beings have a rich mental life. His work became the foundation of a science that has now, almost too late, noticed the dire state of much of the world's vegetable mould and begun to do something about it.

In 1837, just a year after the *Beagle* voyage, Darwin presented a paper on earthworms to the Geological Society. Later he published a few notes on the subject, which occupied him at odd moments for forty years. At last, at the age of seventy-two, he wrote *Vegetable Mould*, which was published at nine shillings in 1881, just six months before his death. The book was received with what he called "almost laughable enthusiasm," selling almost as many copies in its first few years as had *The Origin*.

Soil is where geology and biology overlap. Adam's name comes from *adama*—the Hebrew word for soil—and Eve from *hava*—living—an early statement of the tie between our existence and that of the ground we stand on (*Homo* and *humus* also share a root). The epidermis of the Earth is no more than one part in twenty million of its diameter (our own skin, in contrast, is about one five-thousandth as thick as the average human body). Leonardo da Vinci wrote that "we know more about the movements of the celestial bodies than of the soil underfoot," and until *Vegetable Mould* that was still almost true. Since then, earthworms and their relatives have been studied by geologists, ecologists, molecular biologists, and many others. Archaeologists also have reason to be grateful for their efforts, for without them our insight into