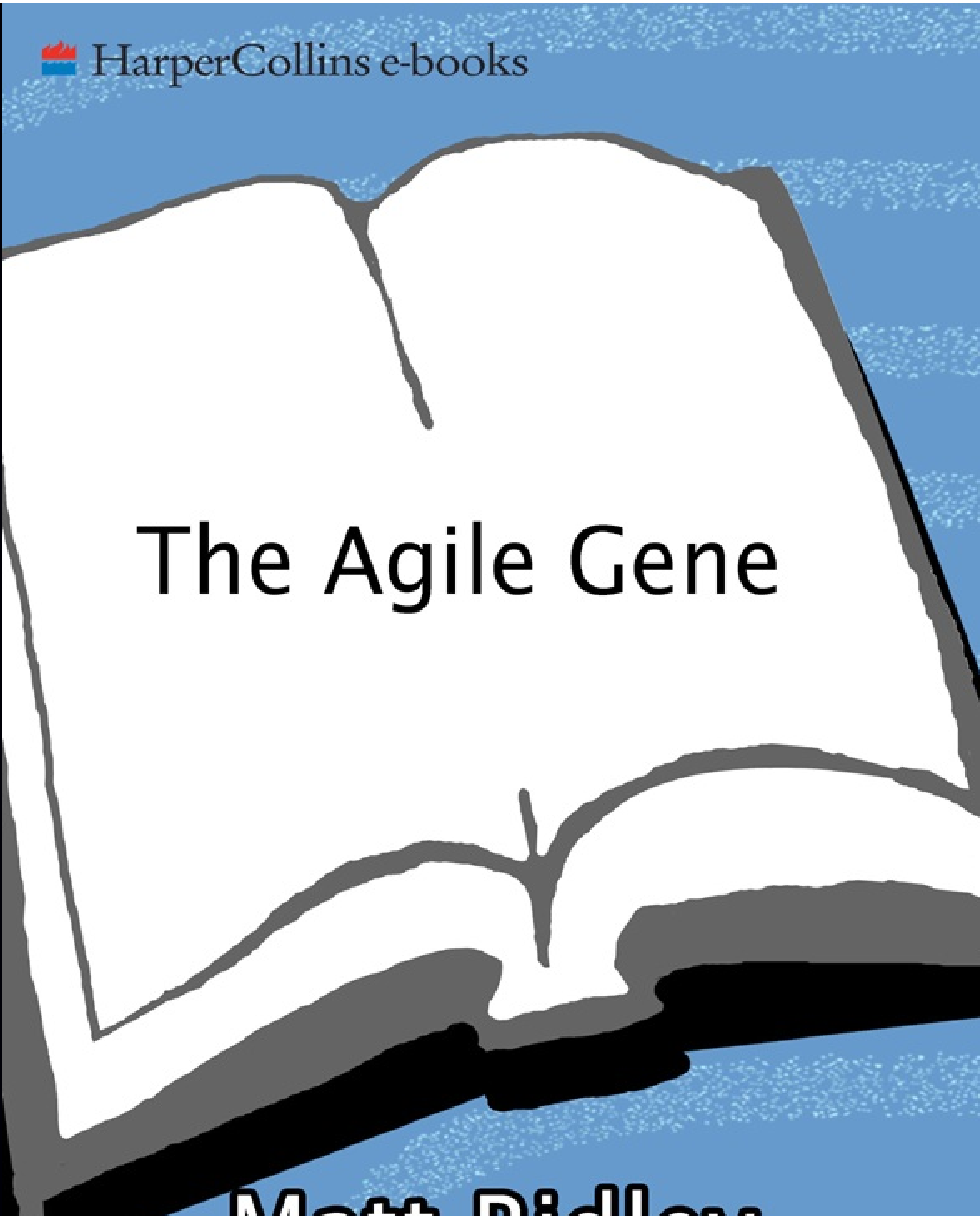
HarperCollins e-books
The Agile Gene
Matt Ridley

THE AGILE GENE

How Nature Turns on Nurture

Matt Ridley

Perennial
An Imprint of HarperCollins*Publishers*

DEDICATION

For Jim

CONTENTS

PROLOGUE

Twelve hairy men

Perverse Mankind! Whose wills, created free,
Charge all their woes on absolute Decree;
All to the dooming Gods their guilt translate,
And follies are miscall'd the crimes of Fate.

Homer's *Odyssey*, translated
Alexander Pop

"Revealed: the secret of human behaviour," read the banner headline in the British Sunday newspape the *Observer* on 11 February 2001. "Environment, not genes, key to our acts." The source of the story was Craig Venter, the self-made man of genes who had built a private company to read the full sequence of the human genome (his own) in competition with an international consortium funded by taxes and charities. That sequence—a string of three billion letters composed in a four-letter alphabe containing the complete recipe for building and running a human body—was to be published later in the week. The first analysis had revealed that there were just 30,000 genes in the human genome, not the 100,000 that many had been estimating up until a few months before.

Details had already been circulated to journalists, though under an embargo. But Venter spilled th story at an open meeting in Lyon on 9 February. Robin McKie of the *Observer* was in the audience a recognized at once that the figure 30,000 was now public. He went up to Venter and asked him if he realized that this broke the embargo; he did. Not for the first time in the increasingly bitter rivalry over the genome project, Venter's version of the story would hit the headlines before that of his rival "We simply do not have enough genes for this idea of biological determinism to be right," Venter sai to McKie. "The wonderful diversity of the human species is not hard-wired in our genetic code. Our environments are critical."[2]

Seeing the *Observer*'s first edition, other newspapers followed suit. "Genome discovery shocks scientists: genetic blueprint contains far fewer genes than thought—DNA's importance downplayed," proclaimed the *San Francisco Chronicle* later that Sunday.[3] The scientific journals promptly lifted th embargo and the story was in newspapers around the world. "Analysis of human genome discovers fa fewer genes," intoned the *New York Times*.[4] Not only had McKie scooped the story; Venter had set th theme.

This was the making of a new myth. In truth, the number of human genes changed nothing. Venter's remarks concealed two massive non sequiturs: first, that fewer genes implied more environmental influences; and second, that 30,000 genes were "too few" to explain human nature where 100,000 would have been enough. As Sir John Sulston, one of the leaders of the human genom project, put it to me a few weeks later, just 33 genes, each coming in just two varieties (such as on or off), would be enough to make every human being in the world unique. There are more than 10 billio ways of flipping a coin 33 times. So 30,000 is not such a small number after all. Two multiplied by itself 30,000 times produces a number larger than the total number of particles in the known universe ~~Besides, if fewer genes meant more free will, that would make fruit flies freer than people, bacteria~~ freer still, and viruses the John Stuart Mills of biology.

Fortunately, there was no need for such sophisticated calculations to reassure the population. People were not seen weeping in the street at the humiliating news that our genome had fewer than twice as many genes as a worm's. Nothing had been hung on the number 100,000, which was just a bad guess. But it was fitting after a century of increasingly repetitive argument over environment versus heredity that the publication of the human genome should be broken on the procrustean bed of nature versus nurture. It was, with the possible exception of the Irish question, the intellectual argument that had changed least in the century just ended. It had divided fascists from communists a neatly as their politics. It had continued unabated through the discovery of chromosomes, DNA, and Prozac. It was fated to be just as bitterly debated in 2003 as it was in 1953, the year of the discovery the structure of the gene, or in 1900, the year modern genetics began. Even the human genome, at its birth, was being claimed for nurture versus nature.

For more than 50 years sane voices have called for an end to the debate. Nature versus nurture ha been declared everything from dead and finished to futile and wrong—a false dichotomy. Everybody with an ounce of common sense knows that human beings are a product of a transaction between the two. Yet nobody could stop the argument. Immediately after calling the debate futile or dead, the typical protagonist would charge into the battle himself and start accusing others of overemphasizing one or the other extreme. The two sides of this argument are the nativists, whom I will sometimes ca geneticists, hereditarians, or naturians; and the empiricists, whom I will sometimes call environmentalists or nurturists.

Let me at once put my cards faceup. I believe human behavior has to be explained by both nature and nurture. I am not backing one side or the other. But that does not mean I am taking a "middle of the road" compromise. As Jim Hightower, a Texas politician, once said: "There ain't nothing in the middle of the road but a yellow line and a dead armadillo." I intend to make the case that the genome has indeed changed everything, not by closing the argument or winning the battle for one side or the other, but by enriching the argument from both ends till they meet in the middle. The discovery of how genes actually influence human behavior, and how human behavior influences genes, is about to recast the debate entirely. No longer is it nature versus nurture but nature via nurture. Genes are designed to take their cues from nurture. To appreciate what has happened, you will have to abandon cherished notions and open your mind. You will have to enter a world where your genes are not pupp masters pulling the strings of your behavior but puppets at the mercy of your behavior; a world where instinct is not the opposite of learning, where environmental influences are sometimes less reversible than genetic ones, and where nature is designed for nurture. These cheap and seemingly empty phras are coming to life for the first time in science. I intend to tell bizarre stories from the deepest recesse of the genome to show how the human brain is built for nurture. My argument in a nutshell is this: th more we lift the lid on the genome, the more vulnerable to experience genes appear to be.

I imagine a photograph taken in the year 1903. It is of a group of men gathered at some international meeting, in a fashionable spot like Baden-Baden or Biarritz, perhaps. "Men" is not quit the right word, for though there are no women, there is one little boy, along with one baby and one ghost; but the rest are middle-aged or elderly men, mostly rich and all white. There are 12 of them and, as befits the time, there is a great deal of facial hair. There are two Americans, two Austrians, tv Britons, two Germans, one Dutchman, one Frenchman, one Russian, and one Swiss.

It is, alas, an imaginary photograph, for most of these people never met each other. But, like the famous group photograph of physicists at Solvay in 1927—the one that includes Einstein and Bohr and ~~Marie Curie and Planck and Schrödinger and Heisenberg and Dirac—my picture would capture~~ that moment of ferment when a scientific endeavor throws up a host of new ideas.[5] My 12 men were the ones who put together the chief theories of human nature that came to dominate the twentieth century.

The ghost hovering overhead is Charles Darwin, dead for 21 years by the time of the photograph, and with the longest beard of all. Darwin's idea is to seek the character of man in the behavior of the ape and to demonstrate that there are universal features of human behavior, like smiling. The elderly gent sitting bolt upright on the far left is Darwin's cousin, Francis Galton, 81 years old but going strong; Galton's whiskers hang down the sides of his face like white mice. Galton is the fervent champion of heredity. Next to him sits the American William James, 61, with a square, untidy beard. He is a champion of instinct and maintains that human beings have more impulses than other animals not fewer. On Galton's right is a botanist, out of place in a group concerned with human nature, and frowning unhappily behind his straggly beard. He is Hugo De Vries, 55, the Dutchman who discovere the laws of heredity only to realize that he had been beaten to them more than 30 years before by a Moravian monk named Gregor Mendel. Beside De Vries is a Russian, Ivan Pavlov, 54, his beard full and gray. He is a champion of empiricism, believing that the key to the human mind lies in the conditioned reflex. At his feet, uniquely clean-shaven, sits John Broadus Watson, who will turn Pavlov's ideas into "behaviorism" and famously claim to be able to alter personality at will merely b training. To Pavlov's right stand the plump, bespectacled, mustachioed German Emil Kraepelin and the neatly bearded Viennese, Sigmund Freud, both 47 and both in the throes of influencing generation of psychiatrists away from "biological" explanations and toward two very different notions of personal history. Beside Freud is the pioneer of sociology, the Frenchman Émile Durkheim, 45 and especially bushy in beard, insisting on the reality of social facts as more than the sum of their parts. His soul mate in this regard is standing next to him: a German-American (he emigrated in 1885), the dashing Franz Boas, 45, with drooping mustaches and a dueling scar; Boas is increasingly inclined to insist that culture shapes human nature, not the other way around. The little boy in the front is the Swiss Jean Piaget, whose theories of imitation and learning will come to fruition, beardless, in mid-century. The baby in the carriage is the Austrian Konrad Lorenz, who in the 1930s will revive the study of instinct and describe the vital concept of imprinting, while growing a fine white goatee.

I am not going to claim that these were necessarily the greatest students of human nature, or that they were all equally brilliant. There are many, both dead and unborn, who would otherwise deserve inclusion in the photograph. David Hume and Immanuel Kant ought to be there, but they had died lon ago (only Darwin manages to cheat death for the occasion); so should the modern theorists George Williams, William Hamilton, and Noam Chomsky, but they were unborn. So should Jane Goodall, who discovered individuality in apes. So perhaps should some of the more perceptive novelists and playwrights.

But I am going to claim something rather surprising about these 12 men. They were right. Not right all the time, not even wholly right, and I do not mean morally right. They nearly all went too fa in trumpeting their own ideas and criticizing each other's. One or two of them deliberately or accidentally give birth to grotesque perversions of "scientific" policy that will haunt their reputation forever. But they were right in the sense that they all contributed an original idea with a germ of trut in it; they each placed a brick in the wall.

Human nature is indeed a combination of Darwin's universals, Galton's heredity, James's instincts, De Vries's genes, Pavlov's reflexes, Watson's associations, Kraepelin's history, Freud's formative experience, Boas's culture, Durkheim's division of labor, Piaget's development, and Lorenz's ~~imprinting. You can find all these things going on in the human mind. No account of human~~ nature would be complete without them all.

But—and here is where I begin to tread new ground—it is entirely misleading to place these phenomena on a spectrum from nature to nurture, from genetic to environmental. Instead, to understand each and every one of them, you need to understand genes. It is genes that allow the huma mind to learn, to remember, to imitate, to imprint, to absorb culture, and to express instincts. Genes are not puppet masters or blueprints. Nor are they just the carriers of heredity. They are active during life; they switch each other on and off; they respond to the environment. They may direct the construction of the body and brain in the womb, but then they set about dismantling and rebuilding what they have made almost at once—in response to experience. They are both cause and consequenc of our actions. Somehow the adherents of the "nurture" side of the argument have scared themselves silly at the power and inevitability of genes and missed the greatest lesson of all: the genes are on their side.

CHAPTER ONE

The paragon of animals

Is man no more than this? Consider him well: Thou owest the worm no silk, the beast no hide, the sheep no wool, the cat no perfum
—Ha! here's three of us are sophisticated!—Thou art the thing itself: unaccommodated man is no more but such a poor, bare, fork
animal as thou art.

King Lea

Similarity is the shadow of difference. Two things are similar by virtue of their difference from another; or different by virtue of one's similarity to a third. So it is with individuals. A short man is different from a tall man, but two men seem similar if contrasted with a woman. So it is with species A man and a woman may be very different, but by comparison with a chimpanzee, it is their similarities that strike the eye—the hairless skin, the upright stance, the prominent nose. A chimpanzee, in turn, is similar to a human being when contrasted with a dog: the face, the hands, the 32 teeth, and so on. And a dog is like a person to the extent that both are unlike a fish. Difference is the shadow of similarity.

Consider, then, the feelings of a naive young man, as he stepped ashore in Tierra del Fuego on 18 December 1832 for his first encounter with what we would now call hunter-gatherers, or what he would call "man in a state of nature." Better still, let him tell us the story:

It was without exception the most curious & interesting spectacle I ever beheld. I would not have believed how entire the difference between savage & civilized man is. It is much greater than between a wild & domesticated animal, in as much as in man there is greater power of improvement…. [I] believe if the world was searched, no lower grade of man could be found.[2]

The effect on Charles Darwin was all the more shocking because these were not the first Fuegian natives he had seen. He had shared a ship with three who had been transported to Britain, dressed in frocks and coats, and taken to meet the king. To Darwin they were just as human as any other person Yet here were their relatives, suddenly seeming so much less human. They reminded him of … well, of animals. A month later, on finding the campsite of a single Fuegian limpet hunter in an even more remote spot, he wrote in his diary: "We found the place where he had slept—it positively afforded no more protection than the form of a hare. How very little are the habits of such a being superior to those of an animal."[3] Suddenly, Darwin is writing not just about difference (between civilized and savage man) but about similarity—the affinity between such a man and an animal. The Fuegian is so different from the Cambridge graduate that he begins to seem similar to an animal.

Six years after his encounter with the Fuegian natives, in the spring of 1838, Darwin visited London zoo and there for the first time saw a great ape. It was an orangutan named Jenny, and she wa the second ape to be brought to the zoo. Her predecessor, Tommy, a chimpanzee, had been exhibited the zoo for a few months in 1835 before he died of tuberculosis. Jenny was acquired by the zoo in 1837, and like Tommy she caused a small sensation in London society. She seemed such a human animal, or was it such a beastly person? Apes suggested uncomfortable questions about the distinctio between people and animals, between reason and instinct. Jenny featured on the cover of the *Penny* ~~*Magazine of the Society for the Diffusion of Useful Knowledge*; an editorial reassured readers that~~ “extraordinary as the Orang may be compared with its fellows of the brute creation, still in nothing does it trench upon the moral or mental provinces of man.” Queen Victoria, who saw a different orangutan at the zoo in 1842, begged to differ. She described it as “frightful and painfully and disagreeably human.”[4]

After his first encounter with Jenny in 1838, Darwin returned to the zoo twice more a few months later. He came armed with a mouth organ, some peppermint, and a sprig of verbena. Jenny seemed to appreciate all three. She seemed “astonished beyond measure” at her reflection in a mirror. He wrote in his notebook: “Let man visit Ouran-outang in domestication … see its intelligence … and then let him boast of his proud pre-eminence… Man in his arrogance thinks himself a great work, worthy the interposition of a deity. More humble and I believe true to consider him created from animals.” Darwin was applying to animals what he had been taught to apply to geology: the uniformitarian principle that the forces shaping the landscape today are the same as those that shaped the distant pas Later that September, while reading Malthus’s essay on population, he had his sudden insight into what we now know as natural selection.

Jenny had played her part. When she took the mouth organ from him and placed it to her lips, she had helped him realize how high above the brute some animals could rise, just as the Fuegians had made him realize how low beneath civilization some humans could sink. Was there a gap at all?

He was not the first person to think this way. Indeed, a Scottish judge, Lord Monboddo, had speculated in the 1790s that orangutans could speak—if educated. Jean-Jacques Rousseau was only one of several Enlightenment philosophers who wondered if apes were not continuous with “savages. But it was Darwin who changed the way human beings think of their own nature. Within his lifetime, he saw educated opinion come to accept that human bodies were those of just another ape modified b descent from a common ancestor.

But Darwin had less success in persuading his fellow human beings that the same argument could apply to the mind. His consistent view, from his earliest notebooks written after he read David Hume’s *Treatise of Human Nature* to his last book, about earthworms, was that there was similarity, rather than difference, between human and animal behavior. He tried the same mirror test on his children that he had tried on Jenny. He continually speculated on the animal parallels and evolutionar origins of human emotions, gestures, motives, and habits. As he stated plainly, the mind as much as the body needed evolution.

But in this he was deserted by many of his supporters, the psychologist William James being a notable exception. Alfred Russel Wallace, for example, the co-discoverer of the principle of natural selection, argued that the human mind was too complex to be the product of natural selection. It mus instead be a supernatural creation. Wallace’s reasoning was both attractive and logical. It was based, again, on similarity and difference. Wallace was remarkable for his time in being mostly devoid of racial prejudice. He had lived among natives of South America and southeast Asia, and he thought of them as equals, morally if not always intellectually. This led him to the belief that all races of humanity had similar mental abilities, which puzzled him because it implied that in most “primitive” societies, the great part of human intelligence went unused. What was the point of being able to read or do long division if you were going to spend all your life in a tropical jungle? Ergo, said Wallace, “some higher intelligence directed the process by which the human race was developed.”[5]

We now know that Wallace’s assumption was entirely right, where Darwin’s was wrong. The gap between the “lowest” human and the “highest” ape is enormous. Genealogically, we all descend from a very recent common ancestor who lived just 150,000 years ago, whereas our last common ancestor ~~with a chimpanzee lived at least 5 million years ago. Genetically, the differences between a human~~ being and a chimpanzee are at least 10 times as numerous as those between the two most dissimilar human beings. But Wallace's deduction from this assumption, that therefore the human mind require a different kind of explanation from the animal mind, is not warranted. The fact that two animals are different does not mean they cannot also be similar.

René Descartes had decreed firmly in the seventeenth century that people were rational and animals were automata. Animals "act not from knowledge but from the disposition of their organs… Brutes not only have a smaller degree of reason than men, but are wholly lacking in it."[6] Darwin dented this Cartesian distinction for a while. Freed at last from the need to think of the human mind a a divine creation, some of Darwin's contemporaries, the "instinctivists," began to think of humans as automatons driven by instinct; others, the "mentalists," began to credit the animal brain with reason and thought.

The mentalists' anthropomorphism reached its apogee in the work of the Victorian psychologist George Romanes, who eulogized the intelligence of pets, such as dogs that could lift latches and cats that seemed to understand their masters. Romanes believed that the only explanation for their behavior was conscious choice. He went on to argue that each species of animal had a mind just like the human mind, only frozen at a stage equivalent to a child of a certain age. Therefore, a chimpanze had the mind of a young teenager, while a dog was equivalent to a younger child, and so on.[7]

Ignorance of wild animals sustained this notion. So little was known about the behavior of apes that it was easy to go on thinking of them as primitive versions of people, rather than sophisticated animals that were brilliantly good at being apes. Especially with the discovery of the seemingly fierc gorilla in 1847, encounters between human beings and wild apes were exclusively brief and violent. When apes were brought to zoos, they had little opportunity to show their repertoire of wild habits, and their keepers seemed to evince more interest in their ability to "ape" human customs than in wha came naturally to them. For instance, from the very first arrival of chimpanzees in Europe, there seems to have been an obsession with serving them tea. The great French naturalist Georges Leclerc, Comte de Buffon, was one of the first "scientists" to see a captive chimp, in about 1790. What did he find worth remarking? That he watched it "take a cup and saucer and lay them on the table, put in sugar, pour out its tea, leave it to cool without drinking."[8] Thomas Bewick, a few years later, reporte breathlessly that an ape "shewn in the London some years ago was taught to sit at table, make use of spoon or fork in eating its victuals."[9] And when Tommy and Jenny reached the London zoo in the 1830s, they were quickly taught to eat and drink at the table for the benefit of a paying audience. The tradition of the chimpanzee tea party was born. By the 1920s it was a daily ritual at the London zoo; the chimps were trained both to ape human customs and to break them: "There was the ever present danger that their table manners would become too polished."[10] The chimpanzee tea parties at zoos ra for 50 years. In 1956, the Brooke Bond company made the first of many hugely successful television commercials for its tea using a chimps' tea party, and Tetley did not drop its advertisements showing chimps' tea parties until 2002. By 1960, human beings still knew more about chimps' ability to learn tea-table manners than about how the animals behaved in the wild. No wonder apes were viewed as ridiculous apprentice people.

In psychology, mentalism was soon ridiculed and demolished. The early twentieth-century psychologist Edward Thorndike demonstrated that Romanes's dogs invariably learned their clever tricks by accident. They did not understand how a door latch worked; they simply repeated any actior that accidentally enabled them to open the door. In reaction to the credulity of mentalism, psychologists began to make the opposite assumption: that animal behavior was unconscious, automatic, and reflexive. The assumption soon became a creed. The radical behaviorists who brushed aside the mentalists in the same decade as the Bolsheviks brushed aside the Mensheviks asserted brusquely that animals did not think, reflect, or reason; they just responded to stimuli. It became heresy even to talk about animals' having mental states, let alone to attribute human understanding to them. Soon, under Burrhus Skinner, the behaviorists would apply the same logic to human beings. After all, people do not just anthropomorphize animals; they accuse toasters of perversity and thunderstorms of fury. They also anthropomorphize other people, crediting them with too much reason and too little habit. Try reasoning with a nicotine addict.

But since nobody took Skinner all that seriously on the subject of people, the behaviorists had unwittingly restored the distinction between the human and the animal mind to exactly where Descartes had placed it. Sociologists and anthropologists, with their emphasis on the peculiarly human attribute called culture, had outlawed all talk of human instinct. By the middle of the twentieth century, it was heresy to speak of animal minds and heresy to speak of human instincts. Difference, not similarity, was all.

THE SIMIAN SOAP OPERA

That was all to change in 1960, when a young woman virtually untrained in science began to watch chimpanzees on the shores of Lake Tanganyika. As she later wrote:

> How naïve I was. As I had not had an undergraduate science education I didn't realise that animals were not supposed to have personalities, or to think, or to feel emotions or pain…. Not knowing, I freely made use of all those forbidden terms and concepts in my initial attempts to describe, to the best of my ability, the amazing things I had observed at Gombe.[11]

As a result, Jane Goodall's account of life among the chimps of Gombe reads like a soap opera about the Wars of the Roses written by Jane Austen—all conflict and character. We feel the ambition, the jealousy, the deception, and the affection; we distinguish personalities; we sense motives; we cannot help empathizing:

> Gradually, Evered's confidence returned—partly, no doubt, because Figan was by no means always with his brother: Faben was still friendly with Humphrey, and Figan, wisely, steered clear of the powerful male. Moreover, even when the brothers were together, Faben did not *always* help Figan: sometimes he just sat and watched.[12]

Though few realized it until later, Goodall's anthropomorphism had driven a stake through the heart of human exceptionalism. Apes were revealed not as blundering, primitive automatons, who were bad at being people, but as beings with social lives as complex and subtle as ours. Either human beings must be more instinctive, or animals must be more conscious than we had previously suspected. The similarities, not the differences, were what caught the attention.

Of course, the news that Goodall had narrowed the Cartesian gap traveled very slowly across the divide between animal and human sciences. Even though the very purpose of Goodall's study, as conceived by her mentor, the anthropologist Louis Leakey, was to shed light on the behavior of ancient human ancestors, anthropologists and sociologists were trained to ignore animal findings as irrelevant. When Desmond Morris spelled out the similarities in his book *The Naked Ape* in 1967, he was generally dismissed as a sensationalist by most students of humankind.

Defining human uniqueness had been a cottage industry for philosophers for centuries. Aristotle said man was a political animal. Descartes said we were the only creature that could reason. Marx sa we alone were capable of conscious choice. Now only by heroically narrow definitions of these concepts could Goodall's chimps be excluded.

Saint Augustine said we were the only creature to have sex for pleasure rather than procreation. (reformed libertine should know.) Chimpanzees begged to differ, and their southern relatives, bonobo were soon to blow the definition to smithereens. Bonobos have sex to celebrate a good meal, to end a argument, or to cement a friendship. Since much of this sex is homosexual or with juveniles, procreation cannot even be an accidental side effect.

Then we thought we were the only species to make and use tools. One of the first things Jane Goodall observed was chimpanzees fashioning stalks of grass to extract termites, or crushing sponge of leaves to get drinking water. Leakey telegraphed her ecstatically: "Now we must redefine tool, redefine man, or accept chimpanzees as humans."

Next we told ourselves that we alone had culture: the ability to transmit acquired habits from one generation to the next by imitation. But what are we to make of the chimpanzees of the Tai forest in west Africa, which for many generations have taught their young to crack nuts using wooden hamme on a rock anvil? Or the killer whales that have utterly different hunting traditions, calling patterns, a social systems according to which population they belong to?[13]

We had assumed we were the only animal to wage war and to kill our fellows. But in 1974 the chimps of Gombe (and subsequently most other colonies studied in Africa) put paid to that theory by raiding silently into the territory of neighboring troops, ambushing the males, and beating them to death.

We still believed we were the only animal with language. But then we discovered that monkeys have a vocabulary for referring to different predators and birds, while apes and parrots are capable o learning quite large lexicons of symbols. So far there is nothing to suggest that any other animal can acquire a true grasp of grammar and syntax, though the jury is still out for dolphins.

Some scientists believe that chimpanzees do not have a "theory of mind": that is, they cannot imagine what another chimpanzee is thinking. If so, for example, they could not act upon the knowledge that another individual holds a false belief. But experiments are ambiguous. Chimps regularly engage in deception. In one case, a baby chimp pretended that he was being attacked by an adolescent in order to get his mother to allow him to suckle from her nipple.[14] It certainly looks as if they are capable of imagining how other chimps think.

More recently, the argument that only human beings have subjectivity has been revived. The author Kenan Malik argues that "humans simply are not like other animals and to assume we are is irrational…. Animals are objects of natural forces, not potential subjects of their own destiny."[15] Malik's point is that because we, uniquely, possess consciousness and agency, so we alone can break out of the prison of our heads and go beyond a solipsistic view of the world. Yet I would argue that consciousness and agency are not confined to human beings, any more than instinct is confined to nonhuman animals. See almost any passage of Goodall's books for evidence. Even baboons have recently performed well enough at computer discrimination tasks to show they are capable of abstrac reasoning.

~~This debate has been running for more than a century. In 1871 Darwin drew up a list of human~~ peculiarities that had been claimed to form an impassable barrier between man and animals. He then demolished each peculiarity one by one. Though he believed only man had a fully developed moral sense, he devoted a whole chapter to the argument that a moral sense was present, in primitive form, in other animals. His conclusion was stark:

> The difference in mind between man and the higher animals, great as it is, is certainly one of degree and not of kind. We have seen that the senses and intuitions, the various emotions and faculties, such as love, memory, attention, curiosity, imitation, reason, &c., which man boasts, may be found in an incipient, or even sometimes in a well-developed condition, in the lower animals.[16]

Wherever you look there are similarities between our behavior and that of animals, which cannot be simply swept under the Cartesian carpet. Yet, of course, it would be perverse to argue that people are no different from apes. The truth is that we are different. We are more capable than any other animal of self-awareness, of calculation, and of altering our surroundings. Clearly, in some sense, thi sets us apart. We have built cities, traveled in space, worshiped gods, and written poetry. Each of the things owes something to our animal instincts—shelter, adventure, and love—but that rather misses the point. It is when we go beyond instinct that we seem most idiosyncratically human. Perhaps, as Darwin suggested, the difference is one of degree rather than kind; it is quantitative, not qualitative. We can count better than chimpanzees; we can reason better, think better, communicate better, emote better, perhaps even worship better. Our dreams are probably more vivid, our laughter is more intens our empathy is more profound.

Yet that leads straight back to mentalism, equating an ape with an apprentice person. Modern mentalists have diligently tried to teach animals to “speak.” Washoe (a chimp), Koko (a gorilla), Kanzi (a bonobo), and Alex (a parrot) have all done remarkably well. They have learned hundreds of words, usually in the form of sign language, and have learned to combine these words into primitive phrases. Yet, as Herbert Terrace pointed out after working with a chimpanzee called Nim Chimpsky, all these experiments have taught us is how bad these animals are at language. They rarely even rival two-year-old child, and they seem incapable of using syntax and grammar except by accident. As Stalin is reputed to have said of military force, quantity has a quality all its own. We are so much better at language than even the cleverest ape that it really could be called a difference of kind, not degree. That is not to say human speech does not have roots and homologies in animal communication, but then a bat’s wing has homology with a frog’s front foot, and a frog cannot fly. T concede that language is a qualitative difference does not imply that we can set human beings apart from nature, though. Trunks are unique to elephants. Spitting venom is unique to cobras. Uniqueness is not unique.

So which are we, similar to apes or different from apes? Both. The argument about human exceptionalism, today as in Victorian times, is mired in a simple confusion. People still insist that their opponents must take sides: either we are instinctive animals or we are conscious beings, but we cannot be both. Yet both similarity and difference can be true at the same time. You do not have to abandon an ounce of human agency when you accept the kinship of our minds with those of apes.[17] Neither similarity nor difference wins; the two coexist. Let some scientists study the similarities whi others study the differences. It is time we abandoned what the philosopher Mary Midgley has called “the strange segregation of humans from their kindred that has deformed much of enlightenment thought.”[18]

There is one way in which behavior seems to evolve differently from anatomy. In the case of anatom most similarities are the result of common descent, or what evolutionists call phylogenetic inertia. F example, human beings and chimpanzees both have five digits on each hand and foot. This is not because five is the perfect number for the lifestyle of both species but because among the early amphibians, one happened to have five digits and most of its myriad descendants, from frogs to bats, have not altered the basic pattern. Some, like birds and horses, do have fewer digits, but none of the apes do.

The same is not true of social behavior. By and large, ethologists have found very little phylogenetic inertia in social systems. Closely related species can have very different social organization if they live in different habitats or eat different food. Distant relatives can have very similar social systems by convergent evolution if they inhabit similar ecological niches. Where two species show similar behavior, it tells you less about their common ancestor and more about the pressures of the environment that shaped them.[19]

A good example is the sex life of the African apes. As primatologists delved further into the lives of apes, they found that alongside the similarities were some intriguing contrasts. These contrasts were thrown into sharper relief by the studies of George Schaller and Diane Fossey on gorillas and Birute Galdikas on orangutans, and the later studies of Takayoshi Kano on bonobos. In the zoo, a chimp looks a bit like a small gorilla. The skeletons of large chimpanzees have been confused with those of small gorillas. In the wild, however, there is a marked difference in their behavior. It all star with diet. Gorillas are herbivores, eating the stems and leaves of green plants such as nettles or reeds as well as some fruit. Chimpanzees are principally frugivores, seeking out fruit in trees, but adding ants, termites, or monkey meat when they can. This difference in diet dictates a difference in social organization. Plants are abundant but not very nutritious. To thrive on them, a gorilla must spend nearly all day eating and need not move very far. This makes a group of gorillas rather stable and eas to defend. This in turn has tempted male gorillas into evolving a polygamous mating strategy: each male can monopolize a small harem of females and their immature young, driving away other males.

Fruit, however, appears unpredictably in different places. Chimpanzees need to have large home ranges to be sure of finding a fruiting tree. But when a tree is found there is plenty of food to go around, so the animals can share their home range with many other chimps. But because of the large home range, these groups often split up temporarily. Consequently, for the male chimp, the polygamy strategy does not work. The only way to control access to such a large group of females is to share th job with other males. Hence the sexual favors of a troop of chimps are shared among an alliance of males. One becomes the “alpha” male and takes a greater share of the matings, but he does not monopolize.

This difference in social behavior, stemming from a difference in diet, was wholly unsuspected until the 1960s. And it was only in the 1980s that a remarkable consequence became clear. The difference has left its mark on the anatomy of the two ape species. For gorillas the reproductive rewards of owning a harem of females are so great that males which take great risks to get them have generally proved more fecund ancestors than males of a more cautious disposition. And one risk that is worth running is growing to a very large size—even though it takes a lot of food to run a big body. Consequently, an adult male gorilla weighs about twice as much as a female.

Among chimpanzees, males are not under such pressure to be big. For a start, being too big make it harder to climb trees and also means that you have to spend more time eating. Better to be only a little larger than a female and use cunning as well as strength to rise to the top of the hierarchy. ~~Besides, there is no point in trying to suppress all sexual rivals, because you will sometimes need~~ them as allies to defend the home range. However, because most females are mating with lots of males within the troop, the male chimps that most often became ancestors were in the past the ones that ejaculated often and voluminously. The competition between male chimps continues inside the female vagina in the form of sperm competition. Consequently, male chimpanzees have gigantic testicles and prodigious sexual stamina. As a proportion of body weight, chimpanzee testicles are 16 times greater than gorilla testicles. And a male chimp has sex approximately 100 times as often as a male gorilla.

There is a further consequence. Infanticide is common among gorillas, as it is among many primates. A bachelor male infiltrates a harem, grabs a baby, and kills it. This has two effects on the baby's mother (apart from causing her great, though transient, distress): first, by halting her lactatior it brings her back into estrus; second, it persuades her that she needs a new harem master who is bette at protecting her babies. And who better to choose than the raider? So she leaves her mate and marrie her baby's killer. Infanticide brings genetic rewards to males, who thereby become more fecund ancestors than males that do not kill babies; hence most modern gorillas are descended from killers. Infanticide is a natural instinct in male gorillas.

But in chimps females have "invented" a counterstrategy that largely averts infanticide: they shar their sexual favors widely. The result is that any ambitious male, if he were to start his reign with a killing spree, might be killing some of his own babies. Males that hold back from killing babies therefore leave more offspring behind. To confuse paternity by seducing many males into possible fatherhood, the females have evolved exaggerated sexual swellings on their pink bottoms to advertiz their fertile periods.[20]

The size of a chimp's testicles is meaningless on its own. It makes sense only by comparison wit the gorilla's testicles. That is the essence of the science of comparative anatomy. And having looked at two species of African ape in such a way, why not include a third? Anthropologists are fond of claiming an almost limitless diversity of behaviors in human cultures, but there is no human culture so extreme that it even begins to compare with the social system of either the chimpanzee or the gorilla. Not even the most polygamous human society is exclusively organized into harems that are passed from one male to another. Human harems are built up one by one, so that most males, even in societies that encourage polygamy, have only one wife. Likewise, despite various attempts to invent free-love communes, nobody has succeeded in achieving, let alone sustaining, a society in which every man has repeated brief affairs with every woman. The truth is that the human species has just a characteristic a mating system as any other: characterized by long pair bonds, usually monogamous, but occasionally polygamous, embedded in a large chimp-like troop or tribe. Likewise, however variable testicle size is among men, there is no man living whose testicles (as a proportion of body weight) are as small as a gorilla's or as big as a chimpanzee's. As a proportion of body weight, men's testicles are nearly five times as large as gorillas' and one-third the size of chimpanzees'. This is compatible with a monogamous species showing a degree of female infidelity. The difference betwee species is the shadow of the similarity within the species.

An intriguing explanation of the human pair bond once again focuses on food. The primatologist Richard Wrangham puts it down to cooking. With the taming of fire and its adoption for cooking—which is a form of predigestion of food—there came a reduced need for chewing. Suggestive evidenc for the controlled use of fire now goes back to 1.6 million years ago, but circumstantial evidence hint that it may have happened even earlier. At around 1.9 million years ago the teeth of human ancestors shrank at the same time as the body size of females grew. This indicates a better diet, more easily digested, which in turn sounds like cooking. But cooking requires you to gather food and bring it to the hearth, which would have provided ample opportunities for bullies to steal the fruits of others' labor. Or, since males were at that time much bigger and stronger than females, for males to steal foo from females. Accordingly any female strategy that prevented such theft would have been selected, and the obvious one was for a single female to form a relationship with a single male to help her guar the food they both gathered. These increasingly monogamous males would then not be competing wi each other so fiercely for every mating opportunity, which would result in their becoming smaller relative to females—and the sex difference in size began to shrink 1.9 million years ago.[21] Later, the pair bond developed into something even deeper when ancestral human beings invented a sexual division of labor. Among all hunter-gatherers, men are usually more interested in and better at hunting; women are more interested in and better at gathering. The result is an ecological niche that combines the best of both worlds—the protein of meat and the reliability of plant food.[22]

But, of course, there are not three species of African apes; there are four. The bonobos that live to the south of the Congo River may look rather like chimpanzees, but they have been evolving apart fo 2 million years, ever since the river split their ancestral range in two. Like chimps, they eat fruit; like chimps, they live in large home ranges shared by multi-male troops. It follows that their sex lives, an their testicle size should be like those of chimpanzees. But, as if to teach us scientific humility, they are astonishingly different. In bonobos, females are usually able to dominate and intimidate males. They do this by forming coalitions and coming to each other's aid. A male bonobo in trouble can count on his mother's support more than he can count on that of his male friends. An adult female bonobo, supported by her best friends, can usually outrank any male.[23]

But why? The secret of the bonobo sisterhood lies in sex. The bond between two female best friends is cemented by frequent and intense bouts of "hoka-hoka," which scientists unromantically translate as genitogenital rubbing. Under the benign rule of cooperative and loving sisterhoods, the society of the bonobo reads more like a feminist fantasy than something real. That it should come to be understood only in the 1980s, when male-biased science was under challenge, is an uncanny coincidence. (The mind boggles at how the Victorians would have described hoka-hoka.)

As predicted by feminist doctrine, male bonobos have reacted to the new female-dominated regime by evolving kinder, gentler natures. There is much less fighting and shouting, and so far murderous raids on members of other troops are unknown. Since female bonobos are even more sexually active than chimps and have sex nearly 10 times as often (and 1,000 times as often as gorillas), the ambitious male bonobo's best strategy for attaining fatherhood is to save his energy for the bedchamber, not the boxing ring. I would like to be able to tell you that bonobo testicles are even bigger than chimpanzee testicles, but—although they are certainly very large—nobody has yet managed to weigh them.[24] In her book *Sexual Selections*, Marlene Zuk describes how the timely discovery of bonobos' sex lives has made them the latest animal celebrities, supplanting the dolphins which had rather blotted their eco-friendly image by indulging in something that looks very like kidnapping and gang rape. Inevitably, sex therapists have begun trumpeting the "bonobo way" of sex Dr. Susan Block (of the Dr. Susan Block Institute for the Erotic Arts and Sciences in Beverly Hills) proclaims that these "horniest apes on earth" are models for us all if we are to live in peace. "Liberat your inner bonobo," she urges. "You can't very well fight a war while you're having an orgasm." She pledges a share of the profits from her "ethical hedonism" television and Internet shows to bonobo conservation.[25]

These are just our closest cousins. The apes of Asia—orangutans and gibbons—have entirely different sex lives again. So do the many and various species of monkeys, presenting a bewildering variety of social and sexual stratagems, each one suited to its habitat and food. Forty years of field primatology have confirmed that we are a unique species, completely unlike any other. There is no exact parallel to the human scheme. But in the animal kingdom, there is nothing exceptional in being unique. Every species is unique.

ENTER GENETICS

The argument about human exceptionalism, swaying between Darwinian similarity and Cartesian difference, shows no sign of ending. Each generation is doomed to fight the same old battles. If you arrive in the world at a time when people have strayed a bit far into anthropomorphic similarity, then you can find a fresh argument for how different animals and people are. If the air is full of difference then you can champion the similarities. Philosophy is like this: eternally unsettled and only occasionally disturbed by new facts.

Then came an unexpected threat to this pleasant debate—a threat of a resolution, a threat of defining once and for all, at root, what the difference is between a person and a chimpanzee; what yo would have to do to a chimpanzee to make it into a person.

It happened at about the same time that Jane Goodall was undermining the exceptionalism of human behavior. Almost completely forgotten until it was rediscovered in the 1960s was an extraordinary experiment by a Californian named George Nuttall in 1901 while he was at Cambridge University. Nuttall noticed that the more closely related two species were, the more their blood produced the same immune reaction in a rabbit. He injected blood from, say, a monkey, into a rabbit repeatedly for some weeks, then a few days after the last injection extracted serum from the rabbit's blood. That serum, mixed with the blood of a monkey, caused it to thicken as the immune reaction se in. Mixed with the blood of a different animal, it thickened more according to how closely related th species were. By this means Nuttall established that human beings were more closely related to apes than they were to monkeys. This ought to have been obvious from the lack of a tail and other features but it was still controversial at the time.

In 1967 at Berkeley, Vincent Sarich and Allan Wilson revived Nuttall's biochemical techniques i a more sophisticated form and used them to construct a "molecular clock" that measured the actual length of time since two species had shared a common ancestor. They concluded that human beings had shared a common ancestor with the great apes not 16 million years ago, as was then conventiona wisdom, but only about 5 million years ago. Anthropologists, whose fossils implied a more ancient split, reacted with contempt. Sarich and Wilson stuck to their guns. In 1975, Wilson asked his studen Marie-Claire King to repeat the exercise for DNA in order to find the genetic differences between human beings and apes. She came back disappointed. It was impossible to find differences, she said, because human DNA and chimpanzee DNA were so astonishingly similar: close to 99 percent of the DNA in a human being was identical to that in a chimpanzee. Wilson was thrilled: the similarity was more exciting than the difference.

That figure has meandered a little since the 1970s. Most estimates place it at 98.5 percent, although two recent detailed studies of actual stretches of genome came to a figure of 98.76 percent.[2] However, just as the figure 98.5 percent was seeping into the public consciousness, Roy Britten wrote a dramatic paper in 2002 showing that it was out by a mile. He confirmed that if you count only ~~substitutions—i.e., letters in the text that are different between human and chimpanzee genes—~~you d indeed get a figure of 98.6 percent. But if you then add in the textual insertions or deletions, the figur drops to 95 percent.[27]

Whatever. It was still a terrible shock to science to discover just how small was the genetic distance between the two species. “The molecular similarity between chimpanzees and humans is extraordinary because they differ far more than many other [closely related] species in anatomy and way of life,” wrote King and Wilson.[28] An even greater shock was in store in 1984, when Charles Sibley and Jon Ahlquist at Yale found that chimpanzee DNA was more like human DNA than it was like gorilla DNA.[29] This was a moment of human dethronement similar to Copernicus, placing the Earth within the solar system as just another planet. Sibley and Ahlquist placed the human species within the ape family as just another ape. From having our own distinct ape lineage stretching back 1 million years, we were now forced to admit that not only did we share a common ancestor not much more than 5 million years ago, but we were the most recent branch of the family. Our common ancestor with the chimp lived after the common ancestor of both with the gorilla and long after the common ancestor of all three with the orangutan. Incredible as it may seem, chimpanzees are more closely related to human beings than they are to gorillas (a conclusion that Britten’s reanalysis of the precise number does not alter). Nothing in the anatomy or fossil record of the African apes suggestec such a possibility. Human beings are not the odd ones out.

Time has dulled these shocks. But there are more coming. Reading the DNA of a human being alongside that of a chimpanzee might once and for all define the difference between them. At the tim of writing, the complete genome of the chimpanzee is not yet available. Even when it is, proving which differences are the ones that matter may be tricky. The human genome contains about 3 billior “letters” of code. Strictly speaking, these are chemical bases on a molecule of DNA, but since it is their order, not their individual properties, that determines what they produce, they can be treated as digital information. The difference between two individual human beings amounts, on average, to 0.1 percent, so there are 3 million different letters between me and my neighbor. The difference betweer human being and a chimpanzee is about 15 times as great, or 1.5 percent. That equates to 45 million different letters. That is about 10 times as many letters as there are in the whole Bible, or 75 books th length of this one. The book of digital differences between our two species, unannotated, would fill 1 feet of bookshelf. (The bookshelf of similarities, by contrast, would stretch to 250 yards.)

Look at it another way. Scientists now reckon that there are about 30,000 human genes. That is, scattered throughout the genome are 30,000 distinct stretches of digital information that are directly translated into protein machinery to run and build the body, a gene being a recipe for a protein. Chimpanzees almost certainly have roughly the same number of genes. Since 1.5 percent of 30,000 is 450, it seems to follow that we have 450 different, uniquely human genes. Not such a big number. Th other 29,550 genes are identical in us and chimps. But this is actually most unlikely. It could instead be that every single human gene is different from every single chimp gene, but only 1.5 percent of its text is different. The truth is bound to lie somewhere between the two. Many genes will be identical i closely related species; many will be slightly different. A very few will be utterly different.

The most visible difference is that all apes have one more pair of chromosomes than people do. The reason is simple enough to find: at some point in the past, two middle-sized ape chromosomes fused together in the ancestors of all human beings to form the large human chromosome known as chromosome 2. This is a surprising rearrangement, and it almost certainly means that chimp–human hybrids would be sterile if they could survive at all. It may have helped create what evolutionists delicately call “reproductive isolation” between the species in the past.

But the rearrangement of the chromosomes does not necessarily imply a difference in genetic tex at that spot. Although the chimpanzee genome is still largely terra incognita, already there are significant textual differences known between human and chimp (or other ape) genes. For example, whereas people have a mixture of A, B, and O blood groups, chimpanzees have only A and O, while gorillas have only B. Likewise, there are three common variants of a human gene called APOE, and chimpanzees have only one—the one most associated with Alzheimer’s disease in people. There seems to be a distinct difference in the way thyroid hormones work in people compared with other apes. The significance of this is unknown. And a family of genes on chromosome 16 underwent several bursts of duplication in the apes after they had separated from the monkey lineage 25 million years ago. Each set of these so-called “morpheus” genes in human beings diverged rapidly in sequen from each other and from those in other apes—evolving at nearly 20 times the normal rate. Some of these morpheus genes might indeed be described as uniquely human genes. But exactly what these genes do, or why they are evolving apart so rapidly in apes, remains mysterious.[30]

Most of these differences are also variable among people; there is nothing here unique to human beings as a whole. In the mid-1990s, however, the first genetically unique feature universal to all people and absent from all apes was discovered. Several years before, a medical professor in San Diego named Ajit Varki became intrigued by a unique form of human allergy: an allergy to a particular kind of sugar (a certain “sialic acid”) found attached to proteins in animal serum. This immune reaction is partly responsible for the severe reaction that people often have to horse serum used as an antidote for snakebite, for example. We human beings simply cannot tolerate this “Gc” version of sialic acid, because we do not have it in the human body. Varki, together with Elaine Muchmore, soon discovered the cause by first noting that unlike human beings, chimpanzees and other great apes did have Gc. The human body does not manufacture Gc sialic acid, because it lacks the enzyme for making Gc from Ac sialic acid. Without the enzyme, human beings cannot add an oxygen atom to the Ac form. All human beings lack the enzyme, but all apes have it. To repeat, this was the first universally true biochemical difference between us and them. Fittingly, at the end of a millennium that saw us humiliatingly demoted from the center of the universe and the apple of God’s eye to just another ape, Varki now seemed to suggest that we differ by just a single atom on a humble sugar molecule, and an omission at that! Not a promising locus for the soul.

By 1998 Varki knew why we were peculiar: a 92-letter sequence was missing from a gene called CMAH on chromosome 6 in human beings, a gene that codes for the enzyme that makes Gc. Next he discovered how it had gone missing. Right in the middle of the gene was an Alu sequence, a sort of “jumping gene” of a kind that infests our genome. In the ape genome there is a different and more ancient Alu, but the one in the human gene was of a sequence known to be unique to human beings.[31] So sometime after the divergence of the human and chimp lineage, this Alu had done what it does best, which is to jump into the CMAH gene, swap places with the older Alu, and accidentally remove the 92-letter chunk of the gene while it was about it. (If this all sounds like double genetic Dutch, try thinking of it this way: a computer virus has destroyed one of your files.)

Varki’s discovery initially raised a big yawn from the scientific establishment. So what? they cried, you have found a gene that is bust in human beings but not in apes. Big deal. Varki is not easil discouraged, and by now he was interested by the whole subject of the difference between human beings and other apes. The first issue was to pinpoint when the mutation had occurred. DNA cannot b recovered from ancient fossils of human ancestors, but sialic acid can be. He found that Neanderthals were like us in having Ac but no Gc; but older fossils (from Java and Kenya) were all from warmer climates, and their sialic acids had degraded too far. However, by counting the number of changes in the defunct human CMAH gene and using a molecular clock, his colleague Yuki Takahata has been able to estimate that the change happened about 2.5 million or 3 million years ago in some human being who is now one of the ancestors of all people alive.

Varki began to investigate other possible consequences of the mutation. Most other animals, ever sea urchins, seemed to have the working gene, but if the gene is “knocked out” in the embryo of a mouse, the mouse grows up healthy and fertile. Sialic acid is a sugar found on the outside of cells, lik a sort of flower growing from the cell surface. It is one of the first targets for infectious pathogens, including botulism, malaria, influenza, and cholera. Lacking one of the common forms of sialic acid might make us more or less vulnerable to these diseases than our ape relatives (cell-surface sugars seem to be a sort of first line of defense in the immune system). But the most intriguing thing about the Gc form of sialic acid is that it is easily found throughout the body of mammals except in the brain. Varki’s gene is almost entirely switched off in the brains of mammals. There must be some reason why you cannot operate a mammalian brain properly unless you switch this gene off almost completely. Perhaps, muses Varki, the expansion of the human brain, which accelerated about 2 million years ago, was made possible by going one further and switching the gene off altogether throughout the body. He admits it is a “wild idea” for which he has no evidence; he is in uncharted territory. Intriguingly, he has since found another gene concerned with processing sialic acid that is also knocked out in human beings.[32]

Even esoteric research like this may have practical consequences. It gives a strong reason to abandon the idea of xeno-transplantation, the transplanting of animal organs into people: allergic reactions to the Gc sugars in animal organs are almost inevitable. Since you can find traces of Gc sialic acid in human tissues, presumably from animal food, Varki has been drinking diluted Gc sialic acid recently to test how his own body handles it. He wonders if some of the diseases that are caused by eating “red meat” may be associated with encountering this animal version of the sugar. But Vark is the first to admit that the vast range of differences between human beings and apes cannot be boile down to one kind of sugar molecule.

We use roughly the same set of genes as other mammals, but we achieve different results with them. How can this be? If two sets of near-identical genes can produce such different-looking animal as a human being and a chimpanzee, then it seems superficially obvious that the source of the difference must lie elsewhere than in the genes. Nurtured as we are in nature–nurture dichotomies, th obvious alternative that occurs to us is nurture. Well, then, do the obvious experiment. Implant a fertilized human egg into the womb of an ape, and vice versa. If nurture is responsible for the difference, the human will give birth to a human and the chimp to a chimp. Any volunteers?

It has been done, though not in apes. In zoos, surrogate mothers have been made to lend their wombs to fetuses from other species in the cause of conservation. The results have been mixed at bes Wild oxen called gaur and banteng have been gestated in cattle, but until now they have died soon after birth. Similar failures have been achieved in wild moufflon gestated in sheep, bongo antelope in eland antelope, Indian desert cat and African wild cat in domestic cats, and Grant’s zebra in domesti horses. The failure of these experiments suggests that a surrogate human mother could not carry a chimpanzee fetus to term. But they do at least prove that in every case, the baby comes out looking like its biological parent, not like its gestational parent. That, indeed, is the point of the experiment: t save rare species by mass-producing them in domestic animals’ wombs.[33]

It is such an obvious outcome that the experiment seems pointless. We all know that a donkey embryo in a horse womb would develop into a donkey, not a horse. (Donkeys and horses are slightly more similar, genetically, than people and chimps. Like the two ape species, they also differ from each other in that horses have one more pair of chromosomes. This mismatch in chromosome numbe accounts for the sterility of mules and implies that a man mated to a female chimp just might produc a viable baby who would grow into a sterile ape-person with considerable hybrid vigor. Rumours of Chinese experiments in the 1950s notwithstanding, nobody seems to have tried this simple but unethical experiment.)

So the conundrum deepens. The genes, not the womb, determine our species. Yet despite having roughly the same set of genes, human beings and chimpanzees look different. How do you get two different species from one set of genes? How can we have a brain that is three times the size of a chimp's and is capable of learning to speak, and yet not have an extra set of genes for making it?

THROWING SWITCHES

I cannot resist a literary analogy. The opening sentence of Charles Dickens's novel *David Copperfiel* reads: "Whether I shall turn out to be the hero of my own life, or whether that station will be held by anybody else, these pages must show." The opening sentence of J. D. Salinger's novel *The Catcher ir the Rye* reads: "If you really want to hear about it, the first thing you'll probably want to know is where I was born, and what my lousy childhood was like, and how my parents were occupied and all before they had me, and all that David Copperfield kind of crap, but I don't feel like going into it." Ir the pages that follow, to a close approximation, Dickens and Salinger use the same few thousand words. There are words that Salinger but not Dickens uses, like elevator or crap. There are words that Dickens but not Salinger uses, like caul and pettish. But these will be few compared with the words they share. Probably there is at least 90 percent lexical concordance between the two books. Yet they are very different books. The difference lies not in the use of a different set of words but in the same set of words used in a different pattern and order. Likewise, the source of the difference between a chimpanzee and a human being lies not in the different genes but in the same set of 30,000 genes use in a different order and pattern.

I say this with confidence for one main reason. The most stunning surprise to greet scientists whe they first lifted the lid on animal genomes was the discovery of the same sets of genes in wildly different animals. In the early 1980s, fly geneticists were thrilled to discover a small group of genes they called the hox genes that seemed to set out the body plan of the fly during its early development —roughly telling it where to put the head, the legs, the wings, and so on. But they were completely unprepared for what came next. Their mouse-studying colleagues found recognizably the same hox genes, in the same order, doing the same job. The same gene tells a mouse embryo where (but not how) to grow ribs as tells a fly embryo where to grow wings: you can even swap this gene between species. Nothing had prepared biologists for this shock. It meant, in effect, that the basic body plan o all animals had been worked out in the genome of a long-extinct ancestor that lived more than 600 million years before and had been preserved ever since in its descendants (and that includes you).

Hox genes are the recipes for proteins called "transcription factors," which means that their job i to "switch on" other genes. A transcription factor works by attaching itself to a region of DNA calle promoter.[34] In creatures such as flies and people (as opposed to bacteria, say), promoters consist of about five separate stretches of DNA code, usually upstream of the gene itself, sometimes downstream. Each of those sequences attracts a different transcription factor, which in turn initiates (or ~~blocks) the transcription of the gene. Most genes will not be activated until several of their~~ promoters have caught transcription factors. Each transcription factor is itself a product of another gene somewhere else in the genome. The function of many genes is therefore to help switch other genes on or off. And the susceptibility of a gene to being switched on or off depends on the sensitivit of its promoters. If its promoters have shifted or have changed sequence so that the transcription factors find them more easily, the gene may be more active. Or if the change has made the promoters attract blocking transcription factors rather than enhancing ones, the gene may be less active.

Small changes in the promoter can therefore have subtle effects on the expression of the gene. Perhaps promoters are more like thermostats than switches. It is in the promoters that scientists expe to find most evolutionary change in animals and plants—in sharp contrast to bacteria. For example, mice have short necks and long bodies; chickens have long necks and short bodies. If you count the vertebrae in the neck and thorax of a chicken and a mouse, you will find that the mouse has 7 neck ar 13 thoracic vertebrae; the chicken has 14 and 7 respectively. The source of this difference lies in one of the promoters attached to one of the hox genes, Hoxc8, a gene found in both mice and chickens whose job is to switch on other genes that lay down details of development. The promoter is a 200-letter paragraph of DNA, and it has just a handful of letters different in the two species. Indeed, changes in as few as two of these letters may be enough to make all the difference. The effect is to alter the expression of the Hoxc8 gene slightly in the development of the chicken embryo. In the chicken embryo, the gene is expressed in a more limited part of the spine, giving the animal a shorte thorax compared with a mouse.[35] In the python, Hoxc8 is expressed right from the head and goes on being expressed for most of the body. So pythons consist of one long thorax—they have ribs all dow the body.[36]

The beauty of the system is that the same gene can be reused in different places and at different times simply by putting a set of different promoters beside it. The “eve” gene in fruit flies, for example, whose job is to switch on other genes during development, is switched on at least 10 separa times during the fly’s life, and it has eight separate promoters attached to it, three upstream of the gene and five downstream. Each of these promoters requires 10–15 proteins to attach to it to switch o expression of the eve gene. The promoters cover thousands of letters of DNA text. In different tissue different promoters are used to switch on the gene. This, incidentally, seems to be one reason for the humiliating fact that plants usually have more genes than animals. Instead of reusing the same gene b adding a new promoter to it, a plant reuses a gene by duplicating the whole gene and changing the promoter in the duplicated version. The 30,000 human genes are probably used in at least twice as many contexts during development, thanks to batteries of promoters.[37]

To make grand changes in the body plan of animals, there is no need to invent new genes, just as there is no need to invent new words to write an original novel (unless your name is Joyce). All you need to do is switch the same ones on and off in different patterns. Suddenly, here is a mechanism fo creating large and small evolutionary changes from small genetic differences. Merely by adjusting th sequence of a promoter, or adding a new one, you could alter the expression of a gene. And if that gene is itself the code for a transcription factor, then its expression will alter the expression of other genes. Just a tiny change in one promoter will produce a cascade of differences for the organism. These changes might be sufficient to create a wholly new species without changing the genes themselves at all.[38]

In one sense, this is a bit depressing. It means that until scientists know how to find gene promoters in the vast text of the genome, they will not learn how the recipe of a chimpanzee differs from that of a person. The genes themselves will tell them little, and the source of human uniqueness will remain as mysterious as ever. But in another sense it is also uplifting, reminding us more forcefully than ever of a simple truth that is all too often forgotten: bodies are not made; they grow. The genome is not a blueprint for constructing a body; it is a recipe for baking a body. The chicken embryo is marinated for a shorter time in the Hoxc8 sauce than the mouse embryo. This is a metapho I shall return to frequently in the book, for it is one of the best ways of explaining why nature and nurture are not opposed to each other but work together.

As the hox story illustrates, DNA promoters express themselves in the fourth dimension: their timing is all. A chimp has a different head from a human being not because it has a different blueprin for the head, but because it grows the jaws for longer and the cranium for less long than does the human being. The difference is all timing.

The process of domestication, by which the wolf was turned into the dog, illustrates the role of promoters. In the 1960s, a geneticist named Dmitri Belyaev was running a huge fur farm near Novosibirsk in Siberia. He decided to try to breed tamer foxes, because however well they had been handled and however many generations they had been kept in captivity, foxes were nervous and shy creatures in the fur farm (with good reason, presumably). So Belyaev started by selecting as breeding stock the animals that allowed him closest before fleeing. After 25 generations he did indeed have much tamer foxes, which, far from fleeing, would approach him spontaneously. The new breed of foxes not only behaved like dogs; they looked like dogs. Their coats were piebald, like a collie’s coat their tails turned up at the end; the females came on heat twice a year; their ears were floppy; their snouts were shorter and their brains smaller than those of wild foxes. The surprise was that merely by selecting tameness, Belyaev had accidentally achieved all the same features that the original domesticator of the wolf had gotten—and that was probably some race of the wolf itself, which had bred into itself the ability not to run away too readily from ancient humans’ rubbish dumps when disturbed. The implication is that some promoter change had occurred which affected not one but many genes. Indeed, it is fairly obvious that in both cases the timing of development had been altered so that the adult animals retained many of the features and habits of pups: the floppy ears, the short snout, the smaller skull, and the playful behavior.[39]

What seems to happen in these cases is that young animals do not yet show either fear or aggression, traits that develop last during the forward growth of the limbic system at the base of the brain. So the most likely way for evolution to produce a friendly or tame animal is to stop brain development prematurely. The effect is a smaller brain and especially a smaller “area 13,” a late-developing part of the limbic system that seems to have the job of disinhibiting adult emotional reactions such as fear and aggression. Intriguingly, such a taming process seems to have happened naturally in bonobos since their separation from the chimpanzee more than 2 million years ago. For i size the bonobo not only has a small head but also is less aggressive and retains several juvenile features into adulthood, including a white anal tail tuft, high-pitched calls, and unusual female genitals. Bonobos have unusually small area 13s.[40]

So do human beings. Surprisingly, the fossil record suggests that there has been a rather steep decline in the size of the human brain during the past 15,000 years, partly but not wholly reflecting a shrinking body that seems to have accompanied the arrival of dense and “civilized” human settlements. This followed several million years of more or less steady increases in brain size. In the Mesolithic (around 50,000 years ago) the human brain averaged 1,468 cc (in females) and 1,567 cc (i males). Today the numbers have fallen to 1,210 cc and 1,248 cc, and even allowing for some reductio sample content of The Agile Gene: How Nature Turns on Nurture

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