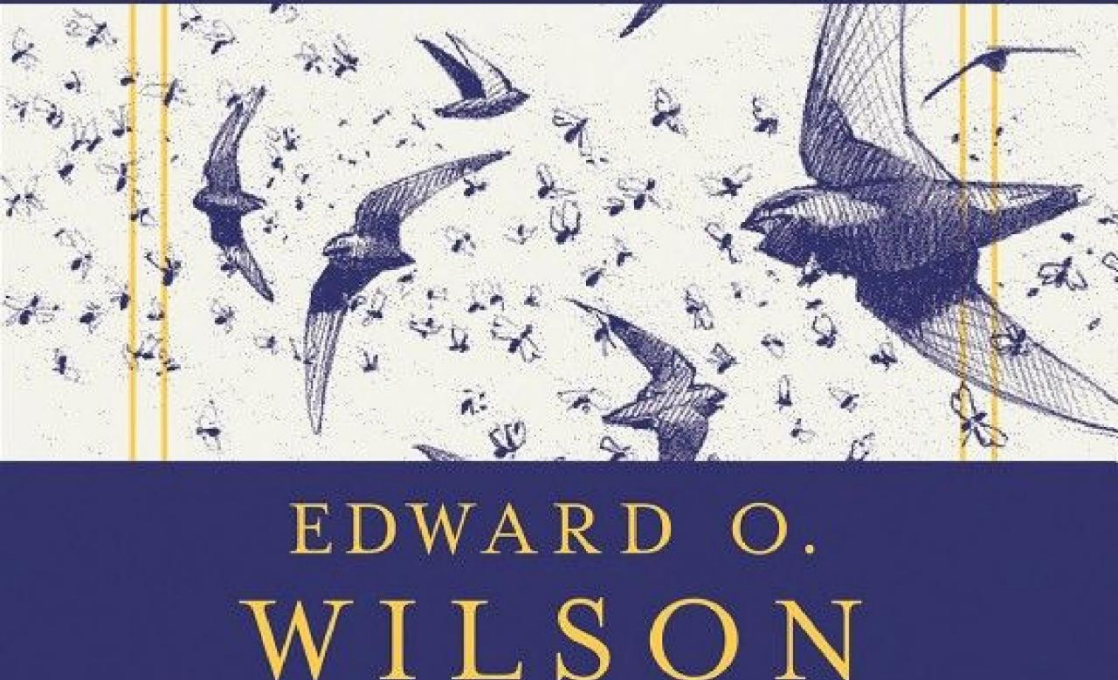
GENESIS

THE DEEP ORIGIN OF SOCIETIES



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WINNER OF THE PULITZER PRIZE

CONTENTS

PROLOGUE

ALL QUESTIONS OF PHILOSOPHY THAT ADDRESS the human condition come down to three: what are we, what created us, and what do we wish ultimately to become. The all-important answer to the third question, the destiny we seek, requires an accurate answer to the first two. By and large, philosophers have lacked confirmable answers to the first two questions, which concern the deep prehuman and human past, thereby remaining unable to answer the third question, which addresses the human future.

As I now approach the end of a long career studying the biology of social behavior in animals and humans, I've come better to understand why these existential questions defy introspection by even the wisest of thinkers, and, more importantly, why they have been so easily enslaved by religious and political dogma. The principal reason is that while science and its attendant technology have grown exponentially, with a doubling time of one to several decades according to discipline, they have only recently begun to address the meaning of human existence in an objective and persuasive manner.

For most of history, organized religions have claimed sovereignty over the meaning of human existence. For their founders and leaders the enigma has been relatively easy to solve. The gods put us on Earth, then they told us how to behave.

Why should people around the world continue to believe one fantasy over another out of the more than four thousand that exist on Earth? The answer is tribalism, and, as I will show, tribalism is one consequence of the way humanity originated. Each of the organized or otherwise public religions as well as scores of religion-like ideologies defines a tribe, a tightly knit group of people joined by a particular story. The history and moral lessons it contains, often colorful, even bizarre in content, are accepted as basically unalterable and, more importantly, superior to all competing stories. The members of the tribe are inspired by the special status the story gives them, not just on this planet but on all other of the multitude of planets in each of the trillion galaxies estimated to compose the known universe.

And best of all, cosmic faith is the bargain price asked for guaranteed personal immortality.

In *The Descent of Man* (1871), Charles Darwin brought the whole subject into the purview of science by suggesting that humanity descended from African apes. Shocking as that was at the time, and still unacceptable to many, the hypothesis has nonetheless proved correct. An understanding of how the great transition from ape to human occurred has been steadily improved since, chiefly by a consortium of researchers in five modern disciplines: paleontology, anthropology, psychology, evolutionary biology, and neuroscience. As a result of the combined labors of scholars in these disciplines we have today an increasingly clear picture of the real creation story. We know a good deal about how humanity was born, and when, and how.

This factual story of the creation has turned out to be vastly different from that first believed not just by theologians but also by most scientists and philosophers. It fits the evolutionary histories of other, nonhuman lines, of which seventeen have so far been found to possess advanced societies based on altruism and cooperation. These are the subjects of the sections immediately to follow.

In later pages I'll take up a closely related subject, also in an early stage of investigation by scientists. What was the force that made us? What, exactly, replaced the gods? This remains a source of contention among scientists, which I will try fully and fairly to address.

GENESIS

1

THE SEARCH FOR GENESIS

THE KEY TO THE LONG-TERM SURVIVAL OF HUMANity depends on full and correct self-understanding, not just of the past three thousand years of literate history, not across the ten thousand years of civilization begun during the Neolithic revolution, but back two hundred thousand years, with the emergence of fully formed *Homo sapiens*. And still farther back, across millions of years of prehuman lineage. With this self-understanding it should then be possible to answer with confidence the ultimate question of philosophy: What was the force that made us? What replaced the gods of our ancestors?

The following can be posed with near certainty. Every part of the human body and mind has a physical base obedient to the laws of physics and chemistry. And all of it, so far as we can tell by continuing scientific examination, originated through evolution by natural selection.

To continue the basics: evolution consists of a change in the frequency of genes in populations of species. A species is defined (often imperfectly) as a population, or series of populations, whose members freely interbreed or are capable of freely interbreeding under natural conditions.

The unit of genetic evolution is the gene or ensemble of interacting genes. The target of natural selection is the environment, within which selection favors one form of a given gene (called an allele) over other forms (other alleles).

During the biological organization of societies, natural selection has always been multilevel. Except in the case of "superorganisms," as found in a few kinds of ants and termites, where subordinates form a sterile working class, each member competes with other members for rank, mates, and common resources. Natural selection simultaneously operates at the level of the group, affecting how well each group performs in competition against other groups. Whether individuals form groups in the first place, and how, and whether the organization grows more complex, and to what effect—all this depends on the genes of its members and on the environment in which fate has placed them. To understand how the laws of evolution include multilevel selection, first consider what both levels are. Biological evolution is defined generally as any change in the genetic constitution of a population. The population consists of the freely interbreeding members of either an entire species or of a geographic segment of the species. Individuals freely interbreeding under natural conditions are defined as constituting a species. Europeans, Africans, and Asians freely interbreed (when not separated by culture), hence we are all members of the same species. Lions and tigers can be hybridized in captivity, but never did so where they once lived together in the wild in southern Asia. Hence they are considered different species.

Natural selection, the driving force of biological evolution in both individual and group selection, is captured in a single phrase: *mutation proposes, the environment disposes.* Mutations are random changes in the genes of a population. They can occur either, first, by an alteration in the sequence of DNA letters of the genes, or second, by changes in the number of copies of the genes in the chromosomes, or third, by a shift in the location of the genes in the chromosomes. If the traits prescribed by a mutation prove relatively favorable in the surrounding environment to the survival and reproduction of the organism carrying it, the mutant gene will multiply and spread through the population. If on the other hand the traits prove unfavorable in the environment, the mutant gene will remain at a very low frequency or disappear entirely.

Let us imagine an example to explain simply (although no real example is ever completely textbook simple). Start with a population of birds comprising 80 percent with green eyes and 20 percent with red eyes. Green-eyed birds have lower mortality and thereby leave more offspring in the next generation. As a result the next generation of the population of birds has changed to 90 percent green-eyed individuals versus 10 percent red-eyed. Evolution by natural selection has occurred.

To grasp the evolutionary process it is immensely important to answer two inevitable questions in a scientific manner. The first is, for variation in any trait that can be measured, such as size, color, personality, intelligence, and culture, how much is due to heredity and how much is due to environment? There is no either/or that fits each trait. There is instead heritability, which measures the amount of variation in a particular population at a particular time. Eye color has near total heritability. It is correct to say eye color is “hereditary,” or “genetic.” Skin color on the other hand has high but not total heritability; it depends on genetics but also on the amount of exposure to the sun and sunscreen. Personality and intelligence have middling heritability. A kind and extroverted genius can arise from a poor and uneducated family, and an ill-tempered dunce from wealth and privilege. Education, fitted to the needs and potential of all its members, is the key to a healthy society.

Are there enough genetic (high heritability) differences among human populations to distinguish as races—or, put more technically, subspecies? I bring this subject up because race remains a minefield through which stumble the politically self-serving left and right. The solution to the problem is to walk around the minefield and proceed to rationally more fertile ground. Races are defined as populations, and as a result are almost always arbitrary. Unless the population exists apart and to some degree isolated, it serves little purpose to distinguish races. The reason is that when genetic traits change across the geographic range of a species, they almost always do so discordantly. For example, size can vary north to south, color from east to west, and a diet preference in polka-dot pattern across the whole range of the species. And so forth indefinitely with other genetic traits, until the true pattern of geographical variation is hopelessly divided into a huge number of small "races."

Scientists consider
evolution no longer a
theory but a proven fact.
And natural selection
of random mutations
as the grandmaster
of evolution has been
convincingly demonstrated
through field observation
and experimentation.

Evolution is always occurring in every population. At one extreme, its pace has been swift enough to create a new species in a single generation. At the opposite extreme, the rate of change has been so slow that the defining traits of the species have remained close to those of distant ancestors of the species. These laggards are informally called "relicts" or "living fossils."

An example of relatively fast evolution was the growth of the hominid brain across a million years, from about 900 cubic centimeters in *Homo habilis* to 1400 cubic centimeters in its descendant *Homo sapiens*. In sharp contrast, species of cycads and crocodiles have changed in most of their traits relatively little during the past one hundred million years. They are correctly called "living fossils."

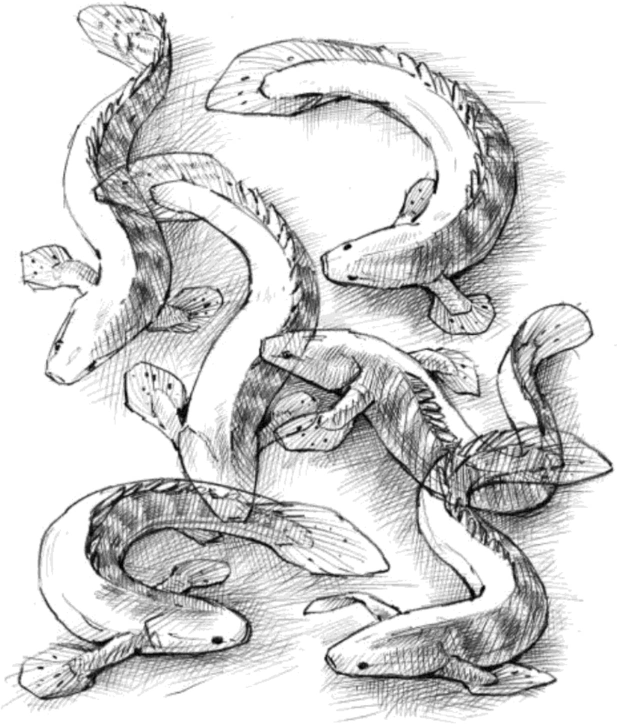
Let us turn now to another subject of sociobiology of basic importance to understanding the evolution of biological organization. It is phenotypic flexibility, the amount of change in a phenotype (the trait prescribed by a gene) through differences in the environment. The kind and amount of flexibility—since these are also genetic traits—can also evolve. At one extreme, the genes prescribing flexibility can be shaped by natural selection to allow only one trait out of many conceivable, such as one eye color inherited by a particular person. At the opposite extreme, flexibility can also evolve to generate multiple possible responses, each fitted to a particular challenge from the environment. In this case the phenotypic flexibility still prescribes a rigidly genetic rule, as in *eat fresh food, avoid spoiled food* (unless you are a blowfly or a vulture).

Programmed phenotypic plasticity can be much more subtle than any brief description is able to convey. For example, a species' genes can be altered to prescribe what psychologists call prepared learning, a tendency to learn quickly and respond to particular stimuli more strongly than to other stimuli of similar kind. "Imprinting" is the most familiar form. With one experience the young animal learns a particular appearance or scent out of many competing in the environment, and thereafter responds fully to it alone. Newly hatched goslings attach not just to their mother goose but to the first moving object they encounter after hatching. A newborn antelope fixates on the scent of its mother, and she similarly commits to her offspring's odor. An ant learns the odor of her natal colony within the first several days after eclosion into six-legged maturity and remains allegiant to it for the rest of her life. If captured as an immature pupa by a colony of slave-making ants, she imprints on the alien's odor and attacks her own sisters from the mother colony.

An especially significant paradigm of phenotypic plasticity is provided by the Nile bichir (*Polypterus bichir*), one of the lungfishes that can leave the water and crawl on land. The bichir and others among the world's lungfishes are often cited as close in ancestry to the original species that left the water during the Paleozoic Era over 400 million years ago, subsequently evolving into land-dwelling amphibians. In other words, it is an evolutionary line from one world into another. A recent series of experiments reported by Emily M. Standen at the University of Ottawa and her coworkers has added credibility to this scenario. These researchers confined newly-hatched bichirs on land for eight months, then mixed them with other bichirs raised in water. The land-reared group walked faster and more skillfully than did the water-reared ones. They held their heads higher and undulated their tails less. Even their anatomy changed: the bones of their anterior body region grew in a way that gave the fins greater power to serve as substitute legs.

These and similar examples from living species illustrate how the plastic expression of genes in anatomy and behavior can ease major changes in adaptation—and might well have done so in the case of the principal transitions.

To take this argument further, the multiplication of castes in ants and termites was achieved in evolution by extreme forms of phenotypic plasticity. It was Darwin who made this discovery, and by his own account used it to save the theory of evolution by natural selection. Worker ants, which are highly modified sterile females, nearly defeated the great naturalist. He found them, as reported in *The Origin of Species*, “the special difficulty, which at first appeared to me insuperable, and actually fatal to my whole theory. I allude,” he said, “to the neuters or sterile females in insect-communities: for these neuters often differ widely in instinct and in structure from both the males and fertile females, and yet, from being sterile, they cannot propagate their kind.”



*The Nile bichir (*Polypterus bichir*), a lungfish able to modify its legs and behavior within a life span to accommodate the land or the water. This example is widely believed to illustrate how the land was originally conquered by vertebrate animals, including our own, very distant ancestors.*

Darwin's solution in *The Origin* presents the first account of the concept of evolution of flexibility of genes. It also introduces the idea of group selection, in which advanced social evolution is driven by the hereditary traits of entire colonies, as opposed to individuals within colonies, which for their part serve as the targets of natural selection:

The difficulty, though appearing insuperable, is lessened, or, as I

> *believe, disappears, when it is remembered that selection may be applied to the family, as well as to the individual, and may thus gain the desired end. Thus, a well-flavored vegetable is cooked, and the individual is destroyed; but the horticulturist sows seeds off the same stock, and confidently expects to get nearly the same variety . . . Thus I believe it has been with social insects: a slight modification of structure, or instinct, correlated with the sterile condition of certain members of the community, has been advantageous to the community: consequently the fertile males and females of the same community flourished, and transmitted to their fertile offspring a tendency to produce sterile members having the same modification. And I believe this process has been repeated, until that prodigious amount of difference between the fertile and sterile females of the same species has been produced, which we see in many social insects.*

These two processes, the origin of controlled flexibility in gene expression and group selection, were foreshadowed by Darwin to save his theory of evolution by natural selection. I'll now show how they help make possible our modern understanding of the greatest advances of evolution, including the origin of societies and our place in the world.

2

THE GREAT TRANSITIONS OF EVOLUTION

EARTH'S BIOLOGICAL HISTORY BEGAN WITH THE spontaneous origin of life. It led across billions of years through the formation of cells, then organs and organisms, and finally, in an episode lasting a relatively mere two to three million years, it created species able to understand what had been going on. Humanity, gifted with an infinitely expanding language and the power of abstract thought, was able to visualize the steps that led to its own origin. Called the "great transitions of evolution," they unfolded as follows.

1. The origin of life
2. The invention of complex ("eukaryotic") cells
3. The invention of sexual reproduction, leading to a controlled system of DNA exchange and the multiplication of species
4. The origin of organisms composed of multiple cells
5. The origin of societies
6. The origin of language

There exist residues of all the great transitions in your body and mine; they carry the products of every step in the history of life. First there was the origin of microbes, represented by modern species of bacteria teeming in our alimentary tract and elsewhere throughout our bodies, ten times more in number than cells that carry our personal DNA. Next are the genetically human cells, whose ancestors were made more complex very early by the fusion of microbial cells followed by their transformation into mitochondria, ribosomes, nuclear membranes, and other components that make possible the efficiency of the present-day cell formations. The cells are called "eukaryotic" to distinguish them from the simple "prokaryotic" cells of bacteria. Next in our personal corporeal history book are our organs, constructed from masses of the eukaryotic cells by jellyfish and sponges and other creatures of the ancient sea. And finally came the human person, programmed to form societies organized by a complex blend of language, instinct, and social experience.

So here we stand, and walk, and when agitated run, having arrived helter-skelter after 3.8 billion years of lineage endowed with no certain purpose beyond carrying still forward the vagaries of mutation and natural selection, erect, bipedal, bone-strutted bags of salty water led by guidance systems engineered back in the Age of Reptiles. Many of the chemicals and molecules circulating in our liquid (by weight 80 percent of the body) are roughly the same as in the primordial sea. Our thought and literature remain energized by the widespread belief that all of prehistory and history, including every great transition, somehow served the purpose of placing us upon the Earth. Everything, it has been argued, from the origin of life 3.8 billion years ago was meant for us. The spread of *Homo sapiens* out of Africa and around the habitable world was somehow preordained. It was meant to establish our rule of the planet with the inalienable right to treat it as we please. That mistake, I suggest, is the true human condition.

So let us look more closely at the great transitions. The first transition and the most difficult to visualize is the origin of life itself. The event has been very broadly and accurately conceived, but a lot of uncertainty remains in the fine detail. The first organisms on Earth, by general assent closely similar to bacteria and bacteria-like Archaea, were self-assembled into replicating systems out of the virtually endless random combinations of molecules present in the primordial sea. The particular habitat of this breakthrough is not known, but present opinion favors underwater volcanic vents. Existing cracks in the ocean floor constantly heat and churn chemical-rich water, as it did in primordial times. Outward from the center of the erupting spumes network occur an abundance of physical and chemical gradients that serve as a natural laboratory for random molecular engineering.

How did it all start? We will have a much better idea of the place and manner of the origin of life when biologists create it, when they take chemical compounds synthesized in the laboratory and construct organisms comparable to those living in the world.

A great deal more will be learned if we find life on other planets, whether in distant star systems or those close to home. The most likely sites in our own solar system include the kilometer-deep aquifers of Mars. Let's drill and see! Perhaps more promising is the ice-encased ocean of Jupiter's moon Europa, made accessible by deep fissures in the surface. Let us drill them through to the liquid water and find out. An engineering feat of this magnitude was recently made by the drilling of a thick ice cap in Antarctica to reach the million-year-old waters of Lake Vostok. An astonishing variety of organisms were found living within it, all awaiting biological research.

Another prime candidate is the liquid water likely to be pooled on the ground around the fiery spumes that continuously explode from Saturn's moon Enceladus. The water immediately vaporizes to enter the ring around Saturn formed by Enceladus, but (perhaps!) not before forming liquid short-lived pools. Within which . . .

Both the creation of artificial organisms and the discovery of extraterrestrial life elsewhere in the solar system would be so stunning in impact, and so far-reaching in potential scientific advance, as to earn the status of the seventh and eighth great transitions on this planet.

The second major evolutionary advance, meanwhile, was the transformation of bacterium-level cells into much more complex eukaryotic cells, of which the human parts of our bodies are made. This step, achieved at about 1.5 billion years ago, was the acquisition of mitochondria, nuclear membranes, ribosomes, and other organelles ("little organs") principally by the capture of some kinds of cells by others. The ensemble of organelles yielded a far more effective division of labor of elements within each cell. And that achievement set the stage for larger, more complex organisms.

The third advance, the invention of sex—the controlled and regular exchange of DNA between cells—produced greater variability in adaptation to the environment. Evolution was thereby equivalently accelerated.

The fourth major transition was the assembly of eukaryotic cells into multicellular organisms. Parallel to the organelles within each cell, the collectivity of cells tightly interlocked and organized into an organism permitted the origin of specialized organs and tissues and by that means provided a far greater range in size and form of living creatures. From the oldest known fossils, we can place the origin of multicellular organisms, including the ancestors of all animal species, at no later than 600 million years before the present.

The fifth transition was the assembly of individual organisms of the same species into groups. The culmination of this new step was the emergence of eusocial groups, defined as the high level of cooperation and division of labor in which some specialists reproduced less than others. In other words, eusocial species are those practicing altruism. The earliest known origins of eusocial colonies occurred in the termites, dating back to the Early Cretaceous Period, about two hundred million years before the present. The termites were followed by the ants roughly fifty million years later, and the two together—the termites consuming dead vegetation and the ants consuming termites and other small prey—thereafter came to dominate the ecology of the insect world. Among the African hominin ancestors of the present-day human species, eusociality was most likely reached—by the ancestral *Homo habilis*—no later than two million years before the present.

Cooperation among individuals in a group can be envisioned as originating and evolving by various forms of interaction. First, there is kin selection, in which action of an individual promotes the survival and production of relatives other than offspring. The closer the degree of kinship (as between siblings compared to cousins), the more effective the influence. Even if the altruist suffers losses, the genes it carries shared with the relative by their common descent are benefitted. Most people are more likely to risk life and fortune to help a brother, for example, than a third cousin. Intuitively viewed, kin selection is most likely to promote favoritism within groups, but there are circumstances in which it could help to originate groups.

A second practice that can favor the origin of cooperation is direct reciprocity, a trade between individuals. Ravens, vervets, and chimpanzees are among the many animals prone to form groups by individuals summoning fellow members to newly discovered food. Individual songbirds "mob" with others of their own and other species to harass and chase away hawks and owls that try to settle nearby.

Among the millions of species around us are survivors, evolutionary products that one way or another reveal the six major steps of evolution leading from single-celled bacteria and other single organisms to humanity's advanced capacity for language, empathy, and cooperation.

THE MAJOR EVOLUTIONARY TRANSITIONS POSE among them one of the premier questions not only in biology, but in the humanities as well: how can altruism arise by natural selection? In particular, at every transition how was it possible to increase the personal longevity of organisms and their reproduction in competition with other group members without lowering their own fitness? What process of evolution can simultaneously increase the welfare of the group at the expense—sometimes fatal—of its individual group members?

The consequences of the transitions dilemma range throughout biology and the deep history of human social behavior. How are we to explain the heroic full measure of a soldier killed in battle, or a monk's lifetime vow of poverty and abstinence? How the ferocity of self-negating patriotism and religious faith?

The same challenge exists in the growth and reproduction of cells that form an organism. Some of the cells, for example epidermal cells, red corpuscles, and lymphocytes, are programmed to die at a specified time in order to keep the other cells alive. Failure to do so precisely on time and in the right place can cause a disease that puts all the cells at risk. Suppose that just one of the many kinds of cells chooses to reproduce selfishly. Then, acting like a bacterium dropped into a large pot of nutrients, it multiplies out of turn to produce a mass of daughter cells. In other words, it turns into a cancer. Why should any one or all of your other trillions of cells not follow suit? Why, with no sense of the world to which it belongs, does it refrain from acting like a bacterium? That of course is the key practical question of cancer

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