CHAPTER 1

HOW EVOLUTION SHAPES OUR LIVES

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OUTLINE

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Many people think of evolution as a fascinating topic, but one with little relevance to our lives in the modern world. After all, most people first encounter the idea of evolution in museums, where they see the fossilized remnants of organisms that lived long ago. Later exposure to evolution may come in courses that present the basic theory along with evidence from the tree of life and the genetic code shared by all life on earth. For those enamored of wildlife, evolution might also be discussed in programs about exotic organisms in far-away lands, often showing nature "red in tooth and claw." So it is easy to overlook the fact that evolution is important for understanding who we are, how we live, and the challenges we face.

The comic strip shown here comes from Garry Trudeau's *Doonesbury* series, and it reminds us that evolution is highly relevant to our lives and to society. In fact, it touches on several themes in this volume. The conversation between the doctor and patient reminds us that despite our efforts to control nature, we remain targets for organisms that have evolved, and continue to evolve, to exploit our bodies for their own propagation. At the same time, the cartoon emphasizes that humans have acquired another mode of response—the use of technology—that allows us to combat diseases far more quickly (and with less suffering)

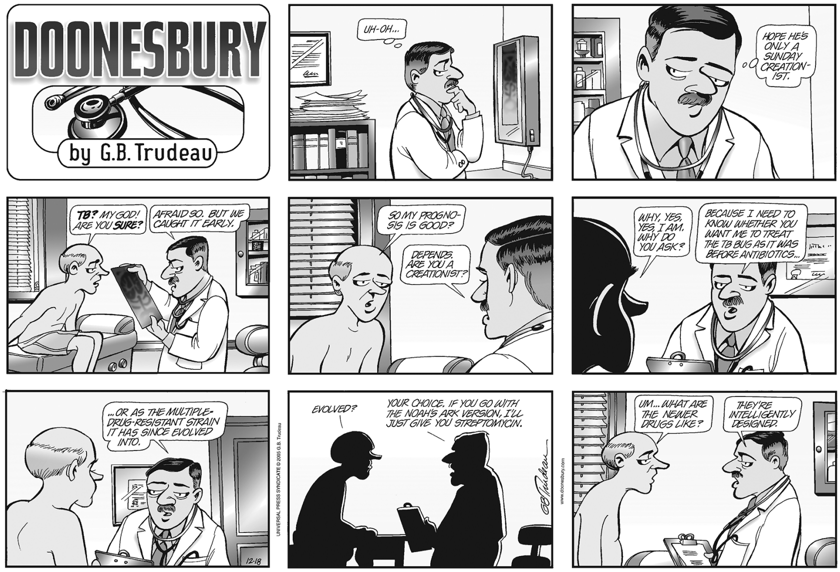

Figure 1-1. Cartoon strip reminding us that evolution is highly relevant to our lives. (DOONESBURY Copyright 2005 G. B. Trudeau. Reprinted with permission of Universal Uclick. All rights reserved.)

than if we had to rely on a genetically determined evolutionary response. More subtly, the technology, institutions, and language (including humor) that make human societies what they are today all reflect a process of cultural evolution that emerged from, and now often overwhelms, its natural counterpart by virtue of the speed and flexibility of cultural systems. Finally, Trudeau jabs us with the needle of the conflict between evolutionary science and religion that dominates many discussions of evolution in the public sphere, despite the overwhelming and continually growing body of evidence for evolution.

1. BIOLOGICAL FOUNDATIONS

To set the stage, we begin this volume with a question: What is evolution? From subtle shifts in the genetic makeup of a single population to the entire tree of life, evolution is the process by which life changes from one generation to the next and from one geological epoch to another.

The study of evolution encompasses both the historical pattern of evolution—who gave rise to whom, and when, in the tree of life—and the ecological and genetic mechanisms that underlie the evolutionary process (see chapter 2).

When Charles Darwin published *The Descent of Man* in 1871, he used the comparative method to make sense of the evolution of our species. That is, he looked to the similarities and differences in the appearance and behavior of humans and our living relatives to understand how we came into being. Some Neanderthal bones had been discovered, but otherwise there was no fossil record of hominids—the taxonomic family that includes humans and the great apes—in his time. It would be several decades before much older fossils were discovered that began to fill in some of the so-called "missing links," and the insights from DNA lay more than a century ahead. Today we have a bounty of fossil hominids, and DNA from both living organisms and fossils is providing new insights into what makes us human, where we came from, and even who mated with whom (see chapter 3).

One of the important attributes of humans is that we live in social groups that require a substantial level of cooperation—in hunting game, rearing a family, and dividing the tasks of labor seen in modern societies. But cooperation is not unique to humans, or even to our close relatives (see chapter 4). Social insects, for example, exhibit remarkable cooperation and division of labor. Within ant colonies and beehives, most individuals forgo reproduction while supporting reproduction by their queen, who is usually the sister of the nonreproductive workers. In other cases, unrelated individuals cooperate, as in mutualisms involving different species, such as the fungi and algae that together make lichens. Understanding the evolutionary forces that promote these different forms of cooperation sheds light on our own behaviors as humans, as well as on some of our commonalities with other organisms whose behaviors have been shaped by these same forces.

One approach to understanding the evolution of human behavior is to ask whether our actions are, in some sense, optimal. Do humans consume food in a manner that optimizes nutritional status? Are children born at intervals that maximize reproductive success? The recognition that there might be trade-offs—for example, between the number of children and the probability they will survive to adulthood—allows the possibility, at least, of defining optimal strategies in mathematical terms (see chapter 5). However, the conditions in which our species exists have changed greatly as a result of our ancestors' migrations across the planet, as well as technological innovations that affect food availability, life expectancy, and so on. As a consequence, there might be critical mismatches between the behaviors that were evolutionarily advantageous in the past—which continue to influence how we respond—and those that would be most beneficial at present (see chapter 6). By understanding how evolution helped shape our psychology, individuals and societies might make better decisions about how to respond to the challenges and choices we face today.

2. EVOLUTION IN HEALTH AND DISEASE

Diseases are usually studied with a focus on proximate causes. For example, what organ is having problems, and how can it be repaired? Did an infectious agent cause the problem, and if so, how can it be eliminated? But one can also ask questions about the evolutionary forces that shape disease, although this is rarely done, and that failure may leave important stones unturned (see chapter 7). For example, why might one group of people be more susceptible to a particular disease than another group? Why are some diseases more prevalent now than in the past, despite improved sanitation and increased access to food? Why do we senesce, losing our reproductive capacity as we age (see chapter 8)? And why, in particular, do human females lose the capacity to reproduce even while they are still healthy and vigorous?

Turning our attention to infectious diseases: why do some pathogens and parasites make us very sick, or even kill us, when closely related microbes are harmless? For many years the conventional wisdom was that evolution would favor those parasites and pathogens that were harmless to their hosts. If parasites killed their hosts (so the thinking went), then they would drive their hosts and themselves to extinction. From this perspective, a highly virulent parasite was seen as a transient aberration, perhaps indicative of a pathogen that had recently jumped to a new host—one that would, over time, evolve to become less virulent if it did not burn out first. But this view has been challenged by more rigorous analyses. Even lethal infections do not usually drive their hosts extinct, and the optimum virulence, from the parasite's perspective, likely depends on the balance between within-host growth and between-host transmission (see chapter 9).

The antibiotics that scientific researchers and pharmaceutical companies developed to treat bacterial infections were hailed as a triumph of technology over nature. Only a few decades ago, the most dangerous infections were largely conquered in developed countries. Schools of public health shifted their attention from infectious diseases to other threats, while the public looked forward to a cure for the common cold (along with personal jet packs). This benign outlook was shaken, however, in the 1980s by the AIDS epidemic and the discovery that it was caused by a virus. And it continues to be shaken by reports of emerging and reemerging diseases that threaten denizens of even the wealthiest nations, from the SARS virus and bird flu (the H5N1 influenza virus) to multidrug-resistant strains of dangerous bacteria including *Mycobacterium tuberculosis* and *Staphylococcus aureus*. The reemergence of these bacterial pathogens reflects the evolution of varieties resistant to some or all of the antibiotics that were previously used to treat them (see chapter 10). Thousands of tons of antibiotics are used each year, causing intense selection for bacteria that can survive and grow in their presence. As a consequence, pharmaceutical companies must spend vast sums to develop new antimicrobial compounds that will allow us, we hope, to keep up with fast-evolving microbes. Meanwhile, emerging diseases that are new to humankind typically derive from pathogens that infect other animals.

The toolbox of molecular evolution and phylogenetic methods is now widely used to determine the source of zoonotic infections and to track a pathogen's transmission through the host population based on mutations that arise as the pathogen continues to evolve during an outbreak. And if these challenges were not enough, some terrorists have deployed pathogens. Investigators must identify the precise source of the microbes deployed in an attack, using evolutionary approaches similar to those used to track natural outbreaks. The "Amerithrax" case, in which spores of *Bacillus anthracis* (the bacterium that causes anthrax) were spread via the US Postal Service, demonstrated the power of new genome sequencing methods to discover tiny genetic differences among samples that may identify relevant sources (see chapter 11).

3. RESHAPING OUR WORLD

Some 10,000 years ago, humans began to harness the power of evolution by selectively breeding various plants and animals for food, clothing materials, and transportation. However, humans were not the first species to invent agriculture. That distinction belongs to ants, some of which began cultivating fungi for food millions of years ago (see chapter 12). Some ants even tend other insects, such as aphids. Humans and other farming species change the environment of domesticated species by providing them with shelter, nutrients, and reproductive assistance. Selection in this protective environment reshapes the morphology, physiology, and behavior of the domesticated varieties. While we usually think of the farmer as controlling the domesticated species, their relationship is really a mutualism; the farmer, too, may evolve greater dependence on agriculture. For example, humans have evolved an unusual trait among mammals that enables many (but not all) adults to continue to produce lactase, an enzyme that allows milk sugar to be digested.

Agriculture is the most familiar way in which humans use evolution for practical purposes, but it is not the only way. Over the past few decades, molecular biologists have developed systems that allow populations of molecules to evolve even outside the confines of living cells (see chapter 13). For example, RNA molecules have been selected to perform new functions in vitro, such as binding to targets of interest. After a random library of sequences has been generated, sequences that have bound to the target are separated from those that have not. The former are then amplified (replicated) using biochemical methods that introduce new variants by mutation and recombination. This Darwinian process of replication, variation, and selection is repeated many times, allowing the opportunity for further improvement in binding to the target. Similar approaches allow the directed evolution of proteins, so that today RNA and protein molecules produced by directed evolution are used to treat certain diseases.

Perhaps even more remarkably, computer scientists and engineers are harnessing evolution to write code and solve complex problems (see chapter 14). They do so by implementing the processes of biological evolution—replication, variation, and selection—inside a computer. This approach has been used in biology to test hypotheses that are difficult to study in natural systems, and in engineering to facilitate the discovery of solutions to complex problems. For example, the design for an antenna used on some NASA satellites was generated not by a team of engineers but in a population of evolving programs (variant codes) that were selected based on the predicted functional properties of the objects encoded in their virtual genomes. Of course, it was necessary to build the physical objects and test them to see whether they would perform as intended, which they did.

With the success of agriculture and other technologies, the human population has grown tremendously in size and pushed into geographic areas that would otherwise be inhospitable to our species. As a result, humans have altered—by habitat destruction, introduction of nonnative species, and pollution—many environments to which other organisms have adapted and on which they depend, leading to the extinction of some species and threatening many others. Evolutionary biology contributes to conservation efforts in several ways (see chapter 15). For example, phylogenetic analyses are used to quantify branch lengths on the tree of life and determine, in effect, how much unique evolutionary history would be lost by the extinction of one species or another. Given limited resources for conservation efforts, this information can inform where those resources will have the biggest impact. Also, the mathematical framework of population genetics, which underpins evolutionary theory, is widely used in the management of endangered populations. In particular, captive-breeding programs and even the physical structure of wildlife reserves can be designed to maximize the preservation of genetic diversity and minimize the effects of inbreeding depression. However, the challenges are only growing. Through many of the activities we take for granted—the production of desirable products, our travel for work and pleasure, and the heating and air-conditioning that keep us comfortable—we are changing the earth's climate (see chapter 16). As we do so, we impose selection on many other organisms. Which species and lineages will survive, and which will go extinct because they cannot cope with the changes? And how will the survivors cope? Might they simply migrate to new habitats and locations that match their previously evolved requirements? Or will they evolve new preferences and traits that allow them to tolerate their altered world?

4. EVOLUTION IN THE PUBLIC SPHERE

Evolutionary biology attracts substantial public attention for two reasons. First, many people find it fascinating to understand how humans and other species came into being. Indeed, that question has interested people since the dawn of history, with different cultures and religions providing diverse narratives about the origins of the world and its inhabitants. Second, evolutionary biology often attracts attention because its findings are inconsistent with those narratives. The resulting tension is complex, with many different positions held by scientists and nonscientists alike (see chapter 17). Some people reject religions whose narratives are contradicted by established bodies of scientific evidence. Others emphasize the difference between evidence and faith, viewing them as separate domains of human understanding; these people may retain some religious beliefs and sensibilities while rejecting the literal interpretation of prescientific narratives. Yet other people have suggested that evolution may, in fact, illuminate theology by providing a deeper understanding of nature as it was created.

While some view evolution as an affront to their religion, evolutionary biologists often feel that their field of study is under attack, especially in the United States, where opposition to teaching evolution is a hot-button issue that generates loud and emotional responses. However, the opposition is far from unified; instead, it is a coalition of creationists expressing views that are inconsistent not only with the scientific evidence but also with the beliefs of other coalition members (see chapter 18). Efforts have been made to unify the creationist coalition and give it a veneer of credibility by hiding these differences and obscuring their religious basis under the gloss of "intelligent design." However, several US court decisions have recognized the religious nature of the opposition to evolution and they have disallowed such nonscientific ideas to be presented as scientific alternatives to evolution in public schools.

Fortunately, the exciting discoveries of evolutionary biology also receive considerable media attention (see chapter 19). The field has many gifted writers and communicators among its practitioners, and the excitement draws reporters and authors, some of whom have immersed themselves in the questions and evidence. Newspapers, books, and television once dominated the media coverage of evolution and usually exerted some quality control; but today websites, blogs, and tweets present a more complex and uneven terrain, even as they provide more opportunities than ever for the public to explore and examine the discoveries and implications of evolutionary biology.

5. NATURE AND NURTURE

How have humans become such an unusual and dominant species on earth? Agriculture, medicine, and other technological innovations are certainly key elements of this story. But the development of technologies depended on the prior emergence of other traits, including the language and culture that enable us to communicate among individuals and across generations, building on prior discoveries and allowing innovations to spread far more quickly than if they had to be hardwired into our genomes. In essence, culture provides a second, and extraordinarily powerful, way of evolving. Other organisms communicate with sounds, chemicals, or visual displays, but human language is unique in its compositional form, which allows an infinite variety of ways for ideas to be combined and expressed (see chapter 20). It is not known when our ancestors evolved language, but studies comparing the morphology and genomes of humans with our relatives (in some cases even extinct species) are providing clues as to how and when the potential for speech evolved. Of course, understanding the capacity for speech does not explain *why* it evolved, but it seems likely that the evolution of human language and social behaviors were tightly connected. In any case, once language emerged, it underwent rapid diversification, with the patterns and processes that govern linguistic evolution similar in some respects to biological evolution. Even so, there are important differences between the evolution of culture and that of biology (see chapter 21). Genes encode information about phenotypic solutions to problems that organisms encountered in the past, and that information is transmitted only from parents to offspring. By contrast, cultural information—knowledge, technology, ideas and preferences—can be disseminated broadly, and the information can accumulate within a single generation. We all obtain our genetic information in discrete bits from just two individuals (our parents), whereas we can obtain cultural information from many sources and blend that information in myriad ways. Moreover, cultural information offers the potential to plan for the future—for example, by anticipating and ameliorating changes caused by our actions—in ways that biological evolution does not.

Although technological innovation and other cultural influences dominate modern life, we are also the products of biological evolution. As a consequence, we differ from one another by virtue of our genealogical pedigrees as well as our cultural and biological environments, and these differences lead to debates about the contributions of "nature" and "nurture" to various attributes. The most obvious differences among individuals (in terms of being quickly perceived) are the varied colors of our skin and hair. Based on these superficial differences, people are then categorized into different races. Are these races biologically meaningful, or are they cultural constructs? The word *race* has a particular meaning in biology, corresponding to a genetically distinct lineage within a species (see chapter 22). Indeed, one can quantify the amount and distribution of individual variation within and among populations of the same species. For example, chimpanzees were split into four races, or subspecies, based on morphological differences, whereas genetic analyses indicate there are only three chimpanzee races. Even so, these racial differences account for about 30 percent of the genetic variation in chimpanzees. By contrast, studies of human genetic diversity do not support the existence of biologically defined races. Although differences in ancestry can be detected and associated with geography, "races" account for only a few percent of the variation among humans. Moreover, even those small differences indicate a history of genetic admixture as populations spread around the world. Still, humans have adapted to their local environments; variation in pigmentation, for example, likely reflects compromises between avoiding damage to cells caused by UV radiation and producing vitamin D, which requires UV radiation. However, local adaptation is not equivalent to biological races owing to the few genes involved and the history of population admixture.

And what does the future hold for human evolution (see chapter 23)? Has our biological evolution stopped now that cultural evolution, including agriculture and medicine, has become so powerful? In fact, the opposite may sometimes be true. As agriculture spread across the globe, so, too, did the standing water that mosquitoes need to breed; and with mosquitoes came malaria, leading to recent evolution in some human populations by favoring mutations that confer disease resistance. Medicine, too, may promote evolution by relaxing constraints. The large heads that hold the brains that give our species the capacity to communicate and innovate pose a severe risk during childbirth, one that has caused the deaths of countless mothers and infants. Will our species evolve even larger brains and greater intelligence as cesarean births become increasingly common? As Yogi Berra said, “It’s tough to make predictions, especially about the future.” But one prediction seems safe, namely, that the small genetic differences among populations will eventually disappear as a consequence of the increased migration our technologies allow—that is, unless the colonization of other planets, or some catastrophe here on earth, produces new barriers to migration and gene flow.