If you have read the introduction to *Denial: Self-Deception, False Beliefs, and the Origins of The Human Mind* by Ajit Varki and Danny Brower, you will know that the book is based on a rough manuscript that was written by Danny Brower before his death. Danny was not ready to have a lot of people read it in this nascent stage. He sent it to a few people for comments and feedback, but it was a work in progress and he knew that there was still a lot of research and writing to be done before it was complete. In spite of this, we are making his original version available here for those interested in the derivation of this book. It is impossible to know exactly what this book would have become had Danny finished it, but I believe that Ajit has taken it in the direction that Danny was headed, and it has remained true to Danny's intentions

—Sharon Brower, February 2013

Preface

What makes us different from other animals? This is a simple one - we are smarter than all the rest. Less simple is the question, why are we SO MUCH smarter than any other animals? Also not obvious is the reason why, if being smart is good (from an evolutionary point of view), then how come we are the only animals that got really smart?

I started thinking about these questions some years ago. Part of this was driven by various papers published in the scientific literature, in which the authors proposed that some genetic change or other event was important for allowing our brains to grow or our nerves to make more connections or some such thing. Most of these seemed rather far-fetched to me, as my background in developmental genetics suggested that none of these factors should be limiting the evolution of greater levels of intelligence. This stimulated me to search for more fundamental answers. As detailed in this book, I think there is a single answer to both of the not-so-simple questions in the opening paragraph. That answer is not where most scientists have been looking, although it is based on rather simple evolutionary principles.

It was not easy to decide how to write this book. The main ideas are novel, and I could have written this as a hard-core, academic treatise. Instead, I decided to write a short treatment that can be read by anyone who is willing to think, even just a little. This decision was guided by two realizations. First, the logical progressions are all really very simple. It does not require a PhD in evolutionary biology to follow the thread that I will weave, and the arguments can be put very plainly without losing any of their rigor. Second, the evolutionary steps that were required for us to become smart have left a huge genetic imprint on the human race. This evolutionary baggage has serious repercussions, for our individual lives, for our societies, and even for our survival as a species. Because the lesson herein has such broad implications, I chose to write a book that could be widely read. These are ideas for everyone.

Because this is intended for a wide audience, the first few chapters necessarily contain some basic background biology. Those familiar with the essentials of the theory of evolution by natural selection and the workings of genes and proteins can easily skip ahead. For the rest, I hope the treatment of these subjects will not be so detailed as to be painful, and especially not discouraging. The next chapters set out, among other things, some of the reasons why it should not be so difficult to become smart, and reasons why it should. This leads up to the fundamental answer to the two not-so-simple questions we started with. Finally, I will discuss some of the potential repercussions that all of this has for us as humans.

Our knowledge of the world we inhabit has expanded tremendously over the last century. This includes dramatic insights into the molecular workings of living organisms, as well as an appreciation for the expanse of the cosmos. The advance of science has created a moving target for the more ancient trade of philosophy. It is difficult to ponder the meaning of "things" when the "things" themselves are in a constant state of flux. I have believed for some time that the most successful philosophers of our age are humorists, and especially those whose work can be found on the comics page of the local newspaper. Where appropriate, I have included examples of their work. These contributions do more than insert some humor, they often provide some focus on the larger issues at hand. Indeed, these issues are often too serious for many of us to ponder without the injection of a laugh here and there. As attested by the century-old quotes that begin each chapter, we have often found it easier to contemplate important issues when they are lightly flavored with a chuckle.

The human race has one really effective weapon, and that is laughter.
Mark Twain

1. Evolution - what it is, and what it isn't

A man who carries a cat by the tail learns something he can learn in no other way.
Mark Twain

Evolution by natural selection is a fact. There are those who innately resist the basic idea that something as exquisite as a human could have been generated by a supposedly random process. It is true that both good and not so good modifications on the genetic plans that make an organism are being tried continuously by nature. However, the unforgiving force of selection ensures that the lessons of both the positive and negative trials are imprinted strongly in the genetic heritage of future generations. In this chapter, we will briefly examine some of the basic tenets of evolution by natural selection, and see some examples of the types of evidence that make this an idea that is no longer debated by the scientific community.

Critics of evolution (i.e., religious fundamentalists) will contend that even biologists don't agree as to the validity of the theory. It is true that scientists argue as to specifics concerning the course of evolution. For example, one broad discussion concerns the timing of evolutionary change; is it more common to have continuous gradual change or is a species' history characterized by periods of relative stability punctuated by episodes of fairly rapid change. But these are details. The evidence for the fundamental tenets of the "theory" of evolution by natural selection is overwhelming, and no reputable biologist disputes it. Similarly, one often hears evolution critics shout that evolution is "only a theory", and assert that other explanations for the wonderful diversity of life need to be considered. This is a bogus semantic argument. The only reason we still refer to it as a "theory" is that biologists are less dogmatic, or perhaps more lazy, than physicists, who would have declared this the "law" of evolution long ago. We will see that the acceptance of evolution is critical for much of modern medical research. By the end, I hope to convince you that acceptance of evolution, and its repercussions, may be critical for our survival as a species.

The theory of evolution by natural selection was arrived at independently by Charles Darwin and Alfred Russel Wallace. Everyone knows about Darwin, who got there a little before Wallace but who sat on his idea for years while he tried to accumulate evidence in support of it. There are those who further suspect that Darwin, fully aware of the philosophical and religious implications of the theory, even hoped to delay publication until after his death, in order to avoid the controversy that would erupt. Finally, when word reached Darwin that Wallace had come to similar conclusions, his ideas and those of Wallace were presented to the Linnaean Society of London on July 1, 1858.

The essential components of the proposal are very simple. We know, for example, that Darwin was influenced by the insight of Thomas Malthus, an economist, who noted that since the human population size tends to increase geometrically and food availability does not, famine often results. Darwin generalized this idea to all animals, and the resources they need to flourish. For example, if each mated pair of a species with males and females can produce four successful offspring (generally a quite conservative number), the population size will double at each generation. If unchecked, geometric increases of this sort get out of hand very quickly. For example, the common gut bacterium E. coli divides (reproduces) approximately every 20 minutes if grown under ideal conditions. The microscopic E. coli cell (bacteria such as these are composed of only a single living cell) is roughly two millionths of a meter long, so rapid increases in the numbers of the little buggers may seem to pose no particular problem. However, because of the exponential rate of geometric increases, one E. coli cell could produce enough bacteria to cover the earth in a layer one foot deep in a mere 36 hours! Of course, this assumes that they will continue to divide at the maximum rate, which requires ideal growth conditions (plenty of food, etc.). Clearly, the conditions will become less than ideal long before this number of bacteria is reached.

So, we can conclude that for a geometrically expanding population, resources will quickly become limiting. "Resources" includes all of the things that an organism needs to survive and reproduce: e.g., food, shelter, and for sexually reproducing organisms, mates. It does not really matter which resource(s) initially becomes limiting, the rules are the same regardless. Once some component that is necessary for optimal expansion becomes scarce, there will be competition between organisms for that component. Competition can be between different types of organisms for a single resource (for example, different predators may be feasting on the same prey animal), or between different members of a single species. For many animals, a particularly important example of the latter is the competition for mates.

Of course, all the members of a given species are not identical. This is very obvious to us for humans if we simply look around in a crowded room, however, we might think that all field mice are pretty much alike. But to a field mouse, the differences are probably as obvious as the differences between humans are for us. For just about any population of animals, some are bigger, faster, stronger, or smarter than others. Some are better able to survive hard times, such as extended droughts, because of slight variations in metabolism. Those that are better competitors for whatever resources are limiting at any given time will leave more progeny in the next generation. A sickly lion cub will not survive to adulthood, and will leave behind no progeny. A big, strong male lion will rule a harem of females, and have many more than his "share" of sons and daughters. Another male may find plenty of zebras to eat, but have to sneak in for an infrequent mating opportunity with another lion; he will have some progeny, but many fewer than the dominant male. Darwin and Wallace understood that most of the differences between these males are based on their genetic traits, and that these are passed on in some way to their progeny. It was many decades before we understood what these "genes" are and how they work, but they had the basic idea spot on.

Most importantly, Darwin and Wallace combined these insights into a realization that there must therefore be selection for the traits that are best suited for the conditions of the time. That is: 1) Resources are limiting. 2) The members of a population of organisms are genetically heterogeneous (different). 3) These differences make some better able to compete for the limiting resources. 4) The genetic traits are passed on to one's progeny. 5) Therefore the traits that create better competitors will become more common, relative to those that don't work so well. 6) Organisms will therefore change over time, either because different conditions select for particular traits or genetic changes keep occurring, creating better adapted organisms. These are the basic components of evolution by natural selection.

The above summary makes it clear that a species will change with the times, but it does not automatically explain how a new species is created. A precise definition of a species can be tricky, as we shall see, but generally we say that creatures are different species if they cannot reproduce (and give rise to fertile progeny) with one another. As indicated by the title of his original book (The Origin of Species), Darwin realized what the next critical step would be (even if he did not have a very good explanation for it). If two populations of a single species become isolated from one another, they will be free to evolve independently, and can change genetically in ways that make them different enough to be considered separate species.

How do species become isolated? An obvious answer occurs when some geographic barrier isolates different populations. An example that influenced Darwin is the different but similar types of finches on various islands of the Galapagos group. In this case, small numbers of birds, perhaps single pregnant animals, had colonized islands in rare migratory events, and then the populations had been free to evolve independently from one another for many years, under selective pressures that varied from island to island. One environmental difference was in the main types of seeds used as food, which selected for morphologically different bills in the birds. This was a case where the birds were similar enough to suggest their common ancestry, but different in ways that could easily be explained by variations in the environments.

We now know that there are other ways that a species can split into two. Any change that isolates two groups genetically will sow the seeds of potential speciation. That is, if genes cannot pass between groups, even infrequently, those groups are free to evolve independently. There are various potential mechanisms for genetic isolation between populations that occupy the same, or overlapping, territories. Some of these are themselves genetic events; for example, chance rearrangements in the organization of an animal's chromosomes can make those chromosomes genetically incompatible with other members of its original species. The two types may mate, but the chromosomal differences prevent the generation of viable or fertile offspring. This provides a barrier to gene flow that is every bit as effective as a separating ocean; any genetic changes that arise in one group can no longer be transferred to the other population, and they will evolve independently. Behavioral changes can also lead to genetic isolation between populations. For example, if a mutation in a tree causes it to flower at a different time of year from its cohort, then there will be little or no chance of cross-pollination. Again, this genetic isolation can then allow evolution to proceed independently in the genetically isolated groups, until the changes become sufficient to recognize two species.

Darwin and Wallace knew nothing about the molecular basis of traits and how they might be passed to new generations. We now know in great detail what genes are made of, how the information is copied at the molecular level when each living cell divides, and how these instructions are translated into specific chemical entities (proteins), whose activities are manifested as traits. More importantly, we can measure the rate at which errors in the copying mechanisms lead to mutations, which create the genetic variations that allow different members of a population to compete better, or less well, for available resources. There is plenty of genetic variability on which selection can work, and more is being generated every minute.

Indeed, with the detailed molecular understanding that we currently have, evolution by selection must be unavoidable. Genetic changes (mutations) are occurring every time a cell divides. Each offspring will be a little different, and some will be better able to succeed than others in the competitive world. If one wishes to argue that God(s) created all of the various life forms from scratch, one must also include the corollary that he/she/they are also spending a considerable and continuous effort preventing the evolutionary changes that otherwise must be occurring. One must also add that he/she/they also created a huge number of astronomical, geological and biological artifacts to confuse us as to the advance of evolution on earth. Finally, we will see that the whole idea that all life forms can be separated into discrete species is not so simple.

While we're on this theological tangent, it should be pointed out that no one can say with any conviction how life originated. Scientists can demonstrate that the molecules necessary for life as we know it could have arisen from the components of the primal earth, but it is not obvious how it ever could be proven that this actually happened. It is also feasible that life originated on Mars, which may have possessed a more hospitable environment in the very early solar system, when the sun was much warmer than it is now. In this scenario, primitive life made the journey to Earth in the rocks that are known to blast off of the surface of Mars when it is impacted by large incoming meteorites. Estimates as to the rate of Mars-to-Earth transfer vary, but it is generally accepted that we are bombarded by many pounds (even hundreds of pounds) of ejected Martian rocks each year. Most of these take millions of years to reach us, but a small fraction appear to make the journey within a few years, and without suffering large scale internal heating that would kill any living organisms. Of course, extraterrestrial origins for life don't solve the problem, they just transport it to another world. The bottom line is, although we have a pretty good idea as to the evolutionary history of creatures (especially bigger ones like plants and animals) over the past few hundred million years, anyone who asserts that God(s) did not start the ball rolling is basing that belief on the same sort of faith as those who make the counter argument.

For most people, the most obvious evidence for evolution is the fossil record. We can see in fossilized rocks the remains of creatures that ceased to exist many millions of years ago. The dinosaurs, which inhabited the Earth for hundreds of millions of years, are just one variety of now extinct precursors of modern animals. (Interestingly, we now suspect that the entire dinosaur lineage may not have come to an abrupt end. Recent evidence suggests that birds may be direct descendants of these majestic creatures.)

More importantly, numerous contemporary animals are nowhere to be found in ancient fossils. Large mammals appear in numbers only after the dinosaurs were decimated by the impact of a giant extraterrestrial meteorite or comet. Granted, fossilization involves the replacement of bones or other remains with minerals, that eventually solidify to become rock. This requires a specific series of events, which most often take place in rivers, swamps, or oceans, and the vast majority of deceased animals simply decay. Still, it is hard to believe that large mammals existed during the hundreds of millions of years that dinosaurs roamed the Earth, yet somehow none of their remains managed to be preserved among all of the thousands of dinosaur fossils discovered around the world. Clearly, new species have been formed over the course of time.

The fossil record is not a complete, continuous account of the process of evolution. A lack of intermediate forms, the so-called missing links between two types of animals, is sometimes cited as evidence for the absolute, permanent integrity of different species. However, as large as it is, the fossil record remains an incomplete sampling, when one considers that speciation has been occurring for many hundreds of millions of years, all across the planet. Moreover, as the numbers of fossils excavated increases, evolutionary intermediates are beginning to emerge. One such group that is exciting scientists now in the early 21st century is "reptiles" with feathers. As we shall see below, other examples of "missing" links are being uncovered by new types of evolutionary data.

Fossils provide a dramatic visual link with past animals and plants. However, evolution has left another footprint that is perhaps even more striking; the similarities between organisms that currently inhabit the planet. Structure that is similar in two different organisms is said to be "homologous" when that similarity is the result of a common ancestry. Such homologies are often obvious; all vertebrates have a backbone because they all evolved from common ancestors with backbones, who lived around 500 million years ago. Evolution has made countless elaborations on the theme; the vertebral columns of humans, giraffes, whales, frogs and pythons are all obviously different from one another, but the basic structural feature of the backbone and ribs has remained unchanged. Less obvious are the homologies of the vertebrate limb. Although the forelimb is used to run in a horse, grasp in a human, fly in a bird wing and swim in a whale fin, all of these structures are comprised of a homologous set of bones. That is, the bones of the whale's fin can be identified as corresponding on a one-to-one basis with the bones in your arm. This underlying conservation of structure results from the fact that evolution typically takes a structure that exists and modifies it for new uses, as opposed to generating new structures from scratch.

Vestigial structures are perhaps the oddest structural homologies, and provide the strongest evidence that evolution has occurred, or at least that animals are not necessarily designed very intelligently. A vestigial structure is one that serves no useful purpose, but is present in an animal because it was present in its evolutionary ancestors. Examples are the pelvic bones, typically greatly reduced, that remain in some snakes and whales. Vestigial structures are often found only in the most primitive members of a group, which are evolutionarily most similar to the precursor organisms. For example, pelvic bones are found in the primitive boas and pythons, but not in the more advanced vipers or colubrid snakes. Other examples of vestigial structures are common in animals that have made relatively abrupt shifts in life style. For example, non-functional remnants of eyes are often found in isolated species that are adjusting (in an evolutionary sense) to an existence in dark caves.

If the visual homologies between different organisms are impressive, the similarities between different creatures at the molecular level are nothing short of astounding. All living things on the planet use the same molecules to carry their genetic instructions (the nucleic acids DNA and RNA), and they all translate this information to build their protein machines in the same way. The metabolic reactions by which we extract energy from our food are essentially identical in all animals, and very similar to those in the bacteria that inhabit our gut. And at this microscopic level, we see similar examples of how something that does one job is modified by evolution to do a different but often similar function. For example, the motor molecules that transport tiny packages within individual cells were elaborated into organized machines that contract the muscles that power a sprinter down the track.

Humans do not like it much when someone wants to mess with their genes for an experiment. Thus, biomedical researchers have worked extensively with other animals to learn fundamental properties of animal biology. Often these experiments utilize unlikely critters, such as fruit flies, nematode worms, and even non-animal organisms, such as yeast. These non-vertebrates are especially useful for experiments that involve complex genetic methods, since they have rapid life cycles (important when breeding over multiple generations) and can be grown in large numbers (critical when searching for unlikely events, such as mutations). Thirty years ago it required a significant amount of faith that the biology of these organisms would be relevant to understanding events of medical relevance in humans. But now, even the most optimistic visionary of that time would be amazed to see how well that faith was justified. We now know that all animals are constructed of a similar toolbox of parts. Groups of proteins that comprise a cellular switch or signaling machine can be found in all animals, and these are used to control an assortment of events in every animal type. Thus, by understanding how the segments of an insect are established early in its development, we are also learning molecular details of the signaling events that, when misregulated, cause a human colon to become cancerous.

Perhaps the most visually striking example of the molecular conservation that results from evolution is the homeotic gene complexes. These were first discovered by noticing genetic mutations in fruit flies, where the misexpression of a single protein can cause a wholesale change in how a region of the body develops. For example, in the fly embryo, if the Antennapedia protein is expressed in the cells that normally would make the adult antenna, these cells will now make a leg instead; this protein functions as a master switch that tells cells to make structures characteristic of the middle part of the animal. Different homeotic genes code for proteins that similarly control the development of each region of the insect body. Although mammals do not have antennae, wings, or even segments similar to those of insects, we do have homologous sets of homeotic genes that are structurally and functionally similar to those of the fly. One thing that makes us different is that we have four sets of these genes, as compared to one set for the fly. Each human set is similar to the other three, and is homologous to one fly set. This indicates that both insects and mammals evolved from some ancestor that had a set of homeotic genes to control embryonic development, but during vertebrate evolution the chromosomal region containing the homeotic genes was duplicated three times. Over the course of time, the genes of each set have diverged very slightly, so that each can have some specialized functions. Thus, our molecular instructions function similarly to those of the fly, but we can construct more complex regulatory networks.

The molecular homologies between animals provide a very powerful tool to analyze the events of evolution. The sequence of bases (designated A,T,G and C) in the DNA of the chromosomes is a structure with homologies, similar to the bones of vertebrate limbs. However, the amount of information in the billions of bases in an animal genome is enormous compared to the number and organization of bones in a skeleton, and molecular techniques are unlocking these genetic sequences at an amazing rate. We now know virtually the entire chromosomal content of many animals, including humans. Because of the linear nature of the DNA sequence of bases, and the huge number in any given chromosome, one can determine a very precise quantitative measure of the degree of change between two organisms. That is, over a specific chromosomal region one can ascertain that the divergence between humans and mice might be 2%, and over another region 46%. Parts of the DNA contain the information to make the protein machines, and these evolve relatively slowly. However, extensive regions seem to contain little if any useful information for the organism. These sequences change relatively rapidly, since they are not under the same severe pressure of natural selection. Thus, different regions can be thought of as "molecular clocks" that run at different speeds, and provide data that can be used to measure evolutionary distances between organisms. Those sequences that contain important information (often for proteins) change slowly, and are most useful to determine divergence times for distantly related organisms. Those that are not strongly selected for and accumulate mutations relatively rapidly are best for comparing very closely related organisms, which have diverged recently. These sequences which are conserved (at least for some time) despite a lack of selection are somewhat similar to the vestigial structures mentioned above, but have the advantage that they can provide a precise numerical measure of the degree of divergence.

Molecular studies are now solving a number of problems that have confounded evolutionary biologists who were limited for many years by relatively gross structural analyses. For example, both insects and vertebrates see with their eyes. However, the structures of insect and vertebrate eyes are very different; instead of one large lens that focuses light onto a large field of sensory cells (as in vertebrates), an insect eye may be comprised of hundreds of discrete sensing structures, each of which focuses light independently. Because of this gross structural and other differences, it was believed by most that eyes arose independently in the two lineages that eventually gave rise to humans and flies. Thus we would say that vertebrate and arthropod eyes were not homologous, since their similarity apparently did not derive from the fact that they shared a common ancestor with eyes. However, it has been shown recently that in both flies and mammals a similar protein controls the formation of eyes. That is, eye development is homologous structurally and functionally at the molecular level, indicating that the morphological differences reflect variations in the way that a common structure was elaborated over time in the two lineages. This developmental homology is so strong that if one expresses the mouse eye-development protein in a fly, it will instruct the cells to make an eye, even if expressed, say, in the leg. Of course, since the cells do not have the genetic blueprints required to make a mouse eye, they construct a typical fly eye even though the "make an eye" command came from a mouse protein.

These master regulatory genes can be major sites for the molecular changes that lead to macro-evolution, or the noteworthy evolution of visible characteristics. In closely related species, the protein parts are extraordinarily similar. Between chimps and humans, for example, the sequences of the amino acid building blocks of proteins are more than 99% identical, and 29% of the thousands of proteins are completely identical. Even at the level of the genetic instructions of the chromosomes, the sequences of the informational A,T,G and Cs are only about 1% different (although the total variation is closer to 4%, due to regions that are deleted, etc., in one or the other species). However, without changing the sequence of a master regulatory protein, one can bring about major changes in the adult animal by variations in when, where, and how much of the protein is expressed. We saw two examples earlier, where expression of a single protein could turn a fly antenna into a leg, or cause an eye to form on a leg. The signals that control the expression of these proteins are found in parts of the chromosome near the region that encodes the protein itself, and very small changes here can lead to large scale changes in expression. These relatively minor mutational events in regulatory DNA can have major impacts on the course of evolution.

The most detailed description of our evolutionary history is seen in a historical context, via the analysis of fossils or the residue of our common heritage present in visible or molecular structures. However, we can also see evolution in real time. Some of the clearest examples of rapid change result from instances in which human activities create relatively "unnatural" selection. Almost all high school textbooks describe the case of a species of moth in England (*Biston betularia*). Around the middle of the 19th century, when extensive burning of coal darkened the potential roosting places of the moths, there was a rapid selection for a darker (melanistic) form of the moth, which blended better with the darker trees, rocks, etc. Naturalists at the time noted that the dark form was more common in the sooty urban areas (going from very rare to over 90% of the moths in Manchester), while the lighter moths were most common in the coutryside. Experiments were even performed that indicated at least one aspect of the selective difference; birds were more likely to lunch on the color forms that matched less well. As pollution controls improved later in the 20th century, the trees lightened up, as did the overall color of the moths.

Some examples of ongoing selection are especially important from a public health perspective. Antibiotic drug resistance is a massive problem. During the 20th century, we developed a large number of antibiotic compounds that were able to cure most bacterial infections. Unfortunately, a small subset of bacteria were resistant to these drugs to varying degrees, and as the drugs are used more and more, we select for the resistant bugs. Particularly in hospitals, where the selection is the strongest, antibiotic resistant varieties are becoming quite prevalent. And, we seem to be falling farther and farther behind in the race to keep up with the bacteria.

One might wonder why there would be a genetic foundation for antibiotic resistance in a natural population of bacteria, if humans have only been using antibiotics relatively recently. The simple answer is that most antibiotics are based on natural compounds, that other organisms have been using to fight bacteria for eons. The most famous example is penicillin, which was discovered because Sir Alexander Fleming noticed that bacteria were unable to grow near the mold, *Penicillium notatum*. (As Fleming famously said, "I did not invent penicillin. Nature did that. I only discovered it by accident.") Thus, there has been a long and continuing natural struggle between bacteria and antibiotics over time. Resistance to penicillin often involves the production by bacteria of proteins that specifically destroy the drug. For other antibiotics, specific mutations can arise fairly easily that provide some resistance, for example by changing the specific site on a protein that the antibiotic must recognize. And finally, some general resistance is afforded by the expression of proteins that simply pump compounds, including many antibiotics, out of the bacterial cells.

If antibiotic resistance is good for a bacterium, then why don't all the bacteria carry the resistance genes or mutations? The answer is that, in the *absence* of the drug, these genetic variations typically make the cell slightly less good than those without the resistance factor. Cells with a mutation that makes them resistant to streptomycin generally make proteins less efficiently than cells without the mutation. That is, this mutation comes with a slight selective cost, that is balanced by the enormous advantage when the cells find themselves in the presence of streptomycin. This cost insures that the frequency of the resistance mutation will be low under most conditions, but there will often be one or more present in any large population, and these will multiply at the expense of the others in the presence of the antibiotic.

In many cases, genes are present which make a bacterium slightly resistant to an antibiotic. Under selection of the drug, this small set of cells may survive but grow slowly enough that your natural body defenses can ultimately eliminate them. However, if you stop taking the antibiotic too soon, this small pool can expand quickly into a large population of cells, all of which are now resistant to the drug to some degree. This why the doctor insists that you take the full course of antibiotic, even after you are feeling much better. If given a second chance, this new resistant infection will be much more difficult to eradicate.

This sort of selection for drug resistance is common whenever we apply a strong selective pressure to a large population of organisms by continuous application of a poison. Insects have become tolerant of pesticides in many parts of the world, unfortunately much more efficiently than many of the vertebrates that eat the insects or otherwise accumulate the pesticide. If you travel to the tropics, you are advised to take one specific anti-malarial, of the various drugs that exist, depending on the drug resistance properties common among the malaria parasites in each region. Worldwide, malaria is more common now than it was a few decades ago, largely because we have selected so well for drug resistance. And, the common use of antibiotics applied chronically to animal feed provides a fertile breeding ground for the selection of antibiotic resistant bugs that can then find their way into humans with disastrous results.

Another common medically important example of natural selection is the continuous battle between infectious agents and your immune system. The mammalian immune system is exquisitely designed to identify foreign substances, usually proteins, and attack anything that expresses something that does not belong. This is true for invading cells such as bacteria, and also for your own cells that have been infected by a virus. Moreover, your immune system is designed to "remember" foreign bodies that it has seen before, and attack these with special vigor should they return - this is why you don't get many diseases more than once, and underlies the ability of a vaccination to protect you from subsequent infection.

Although not living organisms in the true sense, viruses are genetic entities, with DNA or RNA genes, which then invade and hijack your own cells to reproduce themselves. Viruses typically mutate their genes at a relatively high rate. This rapid evolution of viral proteins is a mechanism used by the virus to try to keep one step ahead of the immune system. It often changes the virus enough so that it may eventually be able to reinvade the same animal. You have to get a new influenza shot each year, because a slightly different strain of the virus is expected to be more common each season. As the flu strains evolve, scientists try to guess which strain will be most common the next year and prepare the appropriate vaccine. Occasionally, a flu strain in another animal evolves so that it can infect humans. When these strains also evolve the genetic variations necessary to be transmissible from human to human, a completely new (to us) strain enters the human population, which is completely different from any that our immune systems have seen historically. These evolutionary jumps from another species into humans are responsible for the great influenza pandemics that can kill millions within months. After making the jump from birds, the Spanish flu of 1918 is estimated to have killed at least 1% of the world's population (more than 20 million people, by conservative estimates) in less than a year. It is no surprise, then, that another avian flu strain, which seems to have similarly high mortality rates in the relatively rare human infections to date, is causing such alarm in public health circles. In this age of air travel, any mutation that allows this to be human-human transmissible could result in a global pandemic within days. Recent analysis of the current strains of bird flu indicate that it has already accumulated a number of the mutations that permitted the 1918 influenza to make the successful jump to humans.

No discussion of selection for resistance would be complete without mention of Human Immunodeficiency Virus (HIV), the causative agent of Acquired Immunodeficiency Syndrome (AIDS). HIV is a retrovirus, a type of RNA virus that mutates especially quickly and which can insert its genes into the chromosomes of the infected cell. HIV evolves resistance to drugs quite readily, and generally no single drug regimen is successful in the long term. And not only does the high rate of genetic change help the virus evade your immune surveillance, but HIV ultimately leads to the collapse of your immune system by destroying a particular type of cell that is essential for its function. HIV evolves so rapidly that the viral genomes that circulate toward the end of an infection (during full blown AIDS) are very different from the virus that initially infected the person 5-10 years previously.

So, we can see many examples of natural (or unnatural) selection working to change species in real time; in the case of microorganisms with short generation times, selection can occur with astonishing speed. It is more difficult to see selection leading to speciation (the derivation of two species from one) over short time frames. Although one could do this with populations of small organisms that reproduce very fast, using strong human-induced selective pressures, what is the proof that it happens in nature? As we described earlier, there are masses of historical remnants of such speciation. However, is it practical to watch it in real time, in nature?

Rather than follow a single speciation event over time, it is easier to identify various organisms in the various phases of speciation. Recognized species may be able to interbreed, but usually do not produce progeny that are themselves fertile. A common example is the mule, which results from the mating of a female horse and male donkey. Some rare hybrids are sometimes fertile, such as occasional female ligers (resulting from the mating of a male lion and female tiger). Male ligers are always sterile, however, and these hybrids virtually always result from artificial conditions of close associations found in captivity; lions and tigers are still recognized as distinct species.

Other examples are even more troubling to the absoluteness of the species concept. During the course of speciation, one might expect that two sub-populations will have little natural gene flow, but perhaps still be capable (at least theoretically) of interbreeding. Biologists who specialize in the classification of organisms (systematics) often break a species into subspecies based on traits such as color, size, etc. These subspecies are different populations that are typically characteristic of a particular geographic range, but they are still potentially or actually interbreeding with one another, albeit at a reduced rate. It is often very difficult to say that two populations are in fact genetically distinct, and it is telling that these classifications are constantly undergoing revisions. This is simply a result of the fact that speciation is a continuous process, and there is often no clear, distinct instant when one can say that extraordinarily rare genetic exchange has become no genetic exchange.

An example that illustrates the ambiguity of defining a species is as follows. Assume that a population of animals that is distributed in a largely linear distribution (such as along a chain of mountain ranges). These populations also vary continuously over their range. There may be interbreeding along the geographical range of the animal's distribution, but animals from the two geographical extremes may be genetically distinct to the point where they do not interbreed if brought together. Are these different species? Where can one draw a species boundary? This type of problem exists in nature. For example, the determination of species of Ensatina salamanders living in the coastal and interior mountains of California are providing such a debate. To give a similar example resulting from unnatural selection, all domestic dogs are considered to be one species. However, if all dogs were to disappear except for chihuahuas and great danes, there would likely be no interbreeding between these populations for obvious reasons of physical incompatibility. Would they then automatically be separate species? They certainly would then evolve independently, and would eventually become incompatible genetically as well as topologically.

In summary, the concept of a species is just that, a concept. In practice, speciation is a dynamic process, and we can find various organisms that are in all stages of becoming separate genetic entities. This ambiguity in the designation of "species" itself demonstrates the fact that life on the earth is evolving and changing into new forms even as we speak.

I will close this chapter with an observation on the relatively new fraud known as "creation science," which purports to debunk evolution and demonstrate the hand of God in the fundamentalist, biblical description of the origin of all living things. I recently witnessed a public discourse between a noted creation scientist and a local evolutionary biologist. The former is a champion of Christian fundamentalists and apparently writes and travels the country engaging in these debates. He uses a PhD to lend credence to the idea that there is such an entity as creation "science." What struck me most strongly was that all of his arguments boiled down to one contention, which can be paraphrased as, "If I can't easily explain something, then it must be the work of a creator." Unfortunately, the creation scientist made no effort to keep current with his subject, which is probably an important trait to be successful in this arena.

The examples popularly cited as to why evolution cannot work are continuously being destroyed by the advance of research, much of it in the rapidly developing area of molecular analysis of evolution. A common trick of the creation scientist is to assert that intermediates between two forms either require too large of a sudden change to have occurred by evolution, or that an imagined intermediate form could not possibly survive successfully in any environment. An example of the former (cited on the night in question) is the wondrous metamorphosis of insects such as butterflies - how could the transformation of a caterpillar into a winged insect possibly evolve, when each form is so different and the change so abrupt? Well, recent analysis of the hormonal and other molecular events of insect development has indicated that the larval stage is really homologous to embryonic stages of other insects (such as cockroaches) that undergo a gradual metamorphosis, and the butterflies and others like them have just accelerated parts of the process and extended others. However, there is no fundamental difference between the two types of insect. An example of "no imaginable viable intermediate" that is often cited is the creation of whales and dolphins, mammals that live in the water. It has been stated that no intermediate animal could be suited to prosper on both land and sea, and would be at such a disadvantage in either environment that its lineage could not survive to eventually become fully aquatic. Molecular analysis of DNA has now pointed to the closest living terrestrial relative of the whales, and lo and behold, the intermediate was always right in front of us. It is the so-called river horse, the hippopotamus. (In science, the answer is often right there, but just takes an open and enquiring mind to see it!)

I have nothing against faith or spirituality. However, these should never be confused with science, which deals with what can be verified by objective observations. It is particularly absurd to promote a "science" that is based on ignorance, and it is difficult to take seriously any "scientist" who has the chutzpah to assert that just because he/she can't explain something, it is therefore unexplainable. Indeed, it is ironic that the argument for an intelligent creator is based on human ignorance of how various events in evolution might have occurred, and our level of ignorance of these events is continuously decreasing; logically, our concept of the creator should therefore be constantly evolving.

2. Evolution - what do I need to know?

Familiarity breeds contempt - and children.
Mark Twain

Natural selection acts on the organism, which is made up of the collection of traits that are encoded in your genes. But what are genes? Most of us know that these include things called DNA, chromosomes, etc., but what has all this got to do with what color your eyes will be?

Your genes are composed of the molecule DNA (deoxyribonucleic acid), which is organized to make the chromosomes that are duplicated each time a cell divides into two. Each gene contains the information to make a specific protein molecule. Proteins are made of units called amino acids, and fold up in very specific ways to make little molecular machines. These protein components are what controls the chemical reactions of your body, and comprise many of the parts for your cells. Some proteins digest and extract energy from the food you eat. Other proteins are molecular motors, that are responsible for things such as the movements of your muscles. (You probably know that it is important that you eat protein in your diet. This is primarily because humans are not able to make all of the amino acid building blocks that are necessary to construct their own proteins - you eat proteins primarily to use their amino acids as parts for your own proteins.)

You have tens of thousands of genes, and it is essential that they all be turned on and off properly so as to make the right proteins in the correct time and place. And, once proteins are made, their activities must also be regulated so that they work in the right combinations, places and times. There are thousands of proteins that are supervisors, whose job is simply to regulate some of the other proteins.

Thus, the genes in your chromosomes contain the information that tells each cell which proteins to make. The proteins are the actual molecular parts that do the work of keeping the cell alive and growing.

The DNA molecules of your genes are long linear strings of units that contain one of four "bases", the names of which we abbreviate as A,T,C and G. The information in a gene is determined by the sequence of the bases along the DNA molecule. Each human chromosome is composed of two linear strands of DNA, tied together by the bases into one very long double stranded molecule. The double stranded DNA molecule of a single human chromosome is tens of millions of bases long. Although all one long molecule, different regions of the DNA in a chromsome contain the information for specific genes. A single gene, which contains the information for a specific protein, typically comprises a few thousand bases along the DNA molecule. There are roughly 25-30,000 unique genes that encode proteins in a human genome, but some 3,000,000,000 bases in our DNA. If you do the math, you will see that most of our DNA does not actually contain information for making proteins. Some of this extra DNA is important for controlling when a gene will be used in a cell, but most of it is not doing anything very specific. This fact is underscored if one compares the DNA contents of different organisms - salamanders and many plants have much more DNA than we do, for example, but this chromosomal excess does not carry over to a greater complexity in the number of functioning genes. It's mostly what we call "junk" DNA.

We have talked a lot about cells, but not really said what these are. (This is a problem with biology - in the beginning it's hard to define one thing without using words that themselves have not yet been defined.) The cell is the basic unit of life. Each of your cells has a copy of all of your chromosomes (and therefore genes), and the necessary machinery to make proteins, grow, etc. When a cell divides, all of this genetic information must be faithfully duplicated, so that each daughter cell receives a complete copy. This was a fundamental problem in biology for many years - how could a molecule, DNA, be constructed so as to duplicate itself perfectly? The answer came when James Watson and Francis Crick successfully modeled the structure of the DNA double strand. The nature of the molecular bonds that hold the individual strands together demand that when they are pulled apart, the new strands constructed on each of the old strands will produce two exact copies of the original double strand. The molecular nature of heredity was thus uncovered, and this represented perhaps the second most important discovery (after natural selection) in the history of biology.

Cells tend to be very small. A bacterium is generally composed of a single cell, which may be on the order of a few millionths of a meter long. Your cells are larger, but typical sizes are much less than a thousandth of a meter. To view this in another way, there are tens of trillions (a trillion is a million million) of cells in an adult human body. Each one (with few exceptions) contains all 46 chromosomes, with billions of bases of DNA. This DNA is tightly wrapped into the chromosomes - if all the 46 DNA molecules were stretched out, each cell could make a DNA line almost two meters (roughly six feet) long! As you can imagine, it is quite a logistical problem to organize all of this so that it does not become hopelessly tangled when a cell divides, since it is essential that each new cell gets exactly one set of chromosomes.

Each cell contains 46 chromosomes, but these are divided up into two sets of 23. One set came from your mother, and one from your father. Thus you have two copies of each gene, or two potential sets of instructions for making each protein. This is important for many reasons. Firstly, copying the DNA molecules is not perfect, and mistakes are made; these are what we call mutations. If a mistake results in a defective protein, then it is critical that you have a backup copy of the gene to encode a functional protein. Secondly, even if both gene copies are OK, they still are likely not to be completely identical. There are often small differences in the amino acids of the proteins, or more commonly, variations in the neighboring DNA regions that encode the instructions for the patterns of protein expression. During the formation of eggs and sperm in the parents, only one set of 23 chromosomes is included, so that the embryo that results from fertilization will again have two sets, or 46 chromosomes. There are also further rearrangements so that each of the 23 chromosomes in the sperm or egg is actually a combination of parts of the parent's maternal and paternal chromosomes. All of these processes insure that the genes in each child will represent a unique combination, none of the children of two people will be genetically identical. This is the genetic variation that evolution and natural selection will have as their starting point. (The one exception to our genetic individuality is identical twins, which are genetically identical because they arise from a single embryo that splits into two during development - a natural cloning event. My twin sisters still cannot agree which is the original and which is the "clone.")

In summary, genes encode information for proteins, which are the machines and parts that make you. You got half your genes from each parent. Because the sets that each parent donates in his or her sperm or egg are never the same, each human is genetically unique. This is part of the basis for DNA fingerprinting, which is familiar to anyone who watches the any of the crime shows on TV. The same essentially holds for any organism that reproduces sexually; each individual will be different, however slightly, from another.

The activities of the proteins create the traits on which selection works. A simple example is eye color in people. Various proteins are responsible for chemical reactions that make pigments in your eye. If you have a functional gene for the protein that makes the brown pigment, it will cover up the other pigments, and your eyes will be brown. If both of the copies of this gene (the one from your mother and the one from your father) are defective, you cannot make this pigment, and your eyes can be blue (or green, etc., depending on what other proteins may be present). The presence of one good copy of the gene for the "brown" pigment leads directly to the trait - brown eyes.

You can see that if both parents have blue eyes, you know immediately that neither has a good copy of the brown gene that they can contribute to a child; all of their children will also have blue eyes. If one parent has blue eyes (equals no working copy of the brown gene) and one parent has brown eyes, things get a little more complicated, depending on whether the brown-eyed parent has one or two good copies of the brown gene. The rules for these types of genetic inheritance were first worked out by the Austrian monk Gregor Mendel, in the mid 19th century. His conclusions were largely ignored at the time, until the basic rules were rediscovered decades later. Significantly, neither Darwin nor Wallace grasped the concept of the gene as a discreet unit in the Mendelian sense, but thought in more general terms of inheritance of traits. The notion of evolution by selection did not really rely on any knowledge of the fundamental nature of what was inherited. However, our current level of understanding allows us to measure the rates at which genes change (are mutated) or their combinations are rearranged with great precision. We can see at the molecular level how our genes are in a constant state of flux.

Of course, the inheritance of most traits is not so straightforward as for eye color. For example, your height is not determined by a single gene, but by the actions of many, many genes. It will also be affected by the circumstances of your life. If you are chronically ill or malnourished as a child, your growth may be stunted. However, the genes that "wanted" to make you taller will remain unchanged, and your children will still be genetically programmed for great heights.

This is one of the important points of natural selection. The environment can change your status, but it does not directly change the genes that are passed on to your progeny. If you lose an arm in a farm accident, you will not have one-armed children. Your genes interact with your environment to make you what you are, but your genetic predisposition to be something does not change. The interaction with the environment simply affects the chances that those genes will make it into the next generation.

Diabetes provides an interesting example that illustrates the interplay between genes and environment, as well as how the changing environment can change which genes will be favorably selected. Diabetes results from defects in the signaling pathway mediated by the hormone insulin. Your body turns most carbohydrates (sugars) into glucose, which is the primary fuel (along with fats) used by your cells. Typically, when blood levels of glucose are high, insulin is released by the pancreas, stimulating cells of the body to take up the sugar, which they use directly as fuel or store for future use. Type I diabetes occurs when your body mistakenly destroys the cells that make insulin; this typically occurs in juveniles. Type II, or adult onset diabetes, results from a decrease in the cells' ability to respond to the hormone. It is clear that some people are genetically predisposed to develop type II diabetes, as shown in part by the fact that the disease tends to "run" in families. Although poorly understood, it is clear that predisposition to diabetes is controlled by many different genes, each of which contributes partially to the effect. Development of diabetes is also strongly affected by lifestyle. Obesity and lack of exercise will greatly increase the risk of diabetes, especially in someone who already is genetically predisposed to the condition. Eating low-fiber, calorie-filled foods also seems to be bad.

Type II diabetes is becoming much more common in the developed world, and the increased incidence is ascribed to the general increase in weight and sedentary lifestyle that characterizes our modern lives. But why are the genes that predispose us to diabetes so common? The answer is likely to be found in populations in which diabetes is especially rampant. For example, the Polynesian population on the South Pacific island of Nauru has been ravaged by diabetes over the past half century. At times, fully 60% of the adult population aged 55-65 has been diabetic. It appears that this results in large part from a sudden change in Nauruan lifestyle. Before the Second World War, the inhabitants of this atoll were mostly fisherman and subsistence farmers, and diabetes was almost nonexistent. Just after war, large concentrations of phosphate were discovered on the island, and all of the relatively small population shared in the resulting wealth. Nauru quickly became one of the richest countries in the world, and virtually everyone stopped doing any manual labor and started eating prodigeous amounts of imported, processed food. Ironically, as diabetes became epidemic, this extraordinarily rich country developed one of the shortest life expectancies in the world. Moreover, although type II diabetes is often thought of as a disease of post-reproductive humans (who would have already passed the genes on to their progeny by the time they became diabetic), on Nauru it occurs frequently in young adults, even teenagers, and it has led to an overall decrease in reproductive rates.

The people of Nauru may have been a bit extreme in their adoption of the gentrified existence, but this alone cannot explain the massive incidence of diabetes that ensued - Naruan lifestyle was not so different from that of many well-heeled American families, for example. It is commonly believed that the people of Nauru were genetically very predisposed to diabetes, however. The prevailing theory is that peoples such as these have been subjected historically to periods when food was very scarce, and that they are better able to survive under these conditions if they have genes that allow them to store energy very efficiently when it is available. That is, they were selected to be especially good at responding to glucose in the bloodstream. This idea of a hair-trigger insulin response being useful when stressed is supported by studies indicating that diabetic rats are better able to survive starvation conditions. Unfortunately for those living the "Westernized" lifestyle, these same "thrifty" genes make one especially sensitive to the diabetes-inducing effects of sloth and gluttony. That is, genes that are selected for under one set of conditions will be counter-selective under different circumstances. Similar high incidences of diabetes are found in some Native American populations of the desert southwest, who also evolved in an environment where food would sometimes have been limiting (during periods of drought), but who can eat to excess in the modern world. In one study of Pima Indians in Arizona, the rate of Type II, "adult" onset diabetes was greater than 5% in girls aged 15-19!

Thus, although we don't know all of the genes that make someone more likely to contract type II diabetes, it is clear that both genes and lifestyle play a part in bringing it on. And, this example demonstrates how changing environments can change which genes will be more strongly selected for or against in a population. Interestingly, recent trends suggest that diabetes may be decreasing slightly on Nauru, independent of any significant change in lifestyle. Could we be witnessing the effects of natural selection in a human population over the span of a few decades?

Thousands of genes, trillions of cells, mutations, etc. etc. - you may be starting to worry that this is all going to be too complicated. Don't give up just now, because we are about to make it all much simpler. Natural selection is concerned with all of your genes, and how they interact with your environment, but it is integrating all of these individual inputs to produce one, unifying trait that matters. That trait is called fitness. In a biological setting, your fitness does not refer to how fast you can run a mile, or how many times you can lift a weight. It is defined simply in terms of the likelihood that your genes will successfully find their way into the next generation - how successfully you will reproduce. If blue eyes will make you more likely to reproduce, then the next generation will have more blue eyed persons than the one before, and blue eyes is a trait that increases your fitness. Blue eyes will be just one component of overall fitness, since other traits will also have effects. But over time, the frequency of the genes that lead to blue eyes will increase in the population. If the sum of all of your traits makes it more likely that you will have successful descendants than your neighbor, then your fitness is greater than his. And, in the end, fitness is the single overriding trait that is being gauged by natural selection.

Eye color in humans probably does not have a very great effect on overall fitness, but anything that improves your likelihood of leaving behind successful children will contribute positively to your fitness. This includes genes that increase your chances of surviving birth, growth and development as a child, etc. And because fitness is directly tied to reproduction, anything that affects your chances of successfully finding a mate will be an especially important component of fitness.

It is essential to see that natural selection is only peripherally concerned with genes that promote your survival. Certainly, if you die before reaching reproductive age, your fitness is zero, so survival is especially important at these early times. However, once you have had your children, the reasons for selection to care how long you will live become more limited. In many animals, once offspring are released there really isn't much reason for selection to care how long the parents hang around. In humans and many other animals, however, the parents, and even grandparents, contribute critical nurturing and learning benefits to their offspring. Thus, there is some significant selection in us for continued survival beyond childbirth. However, given the choice, survival will lose out to fitness in every contest where selection is the final judge.

Why would survival be pitted against fitness in some circumstances? An obvious example is in traits that are selected quite strongly during mating rituals. It is hard to imagine that the flagrantly exaggerated tail feathers of a male peacock tail give the animal any survival advantage. They certainly are not going to make flying any easier, or provide an advantage in escaping a predator. Indeed, dragging around such an outlandish appendage can only be a detriment to survival per se. However, the male that can strut his stuff with a fantastic, quivering fan of tail feathers is going to be more successful at convincing Miss Pea-hen that he is the guy for her. And unless he is successful at this task, his fitness is in the dumpster.

The mating ritual also provides examples where behavioral traits can present immediate dilemmas between survival and fitness. One of the clearest examples of this is in animals in which a dominant male keeps a harem of females. In such cases, a male often is required to fight the reigning supremo for dominance, and the privilege of spreading his genes among the herd. Dominance contests often are ritualized, in large part to minimize damage, but in many species the danger of serious harm or death is very real. Is it in the best interest of self-survival to take part in such a contest - of course not. But, if a male is unwilling to engage in risky combat his fitness is close to zero. (Not necessarily absolute zero, since he might be able to slip in for a mating opportunity on the sly.)

Less obvious genetic dilemmas are also common. A trait might maximize your chances of surviving to reproduce, or make you bigger and stronger at the time when reproduction is critical, but this same trait may cause serious survival difficulties later in life. Cardiovascular disease is the primary killer in the developed world, but mostly kills after the age of 50. We also can see the progression of factors that cause the disease with time. Why do we tend to develop high blood pressure, increased cholesterol, etc., as we age? It is likely that the same genetic components that lead us down this self-destructive path in later life provide us with significant advantages as children or young adults. Evolution is quite content for us to run ourselves down at 50 years of age if having increased blood pressure makes us faster and stronger as youngsters, increasing our chances of raising progeny in the 20-40 year range. Indeed, the longevity that we enjoy in the modern world is an evolutionary aberration. It appears that humans are generally not designed to live past 50 or so (as a conservative estimate), and so any genes that will get us after this have not been selected against very strongly. And if those same genes make us better when we are younger, then they will be favored.

In summary, natural selection ultimately acts to maximize a creature's fitness. The genes must get into the next generation, or they will disappear from the population. For most animals, fitness and survival share largely overlapping goals during early growth and development - to reach maturity with the best equipment possible to ensure reproduction. However, once this stage is reached the interests of fitness and survival become more and more divergent, and evolution is going to favor any traits that maximize your ability to leave successful children, even if those traits carry serious disadvatages to your own long-term preservation.

3. The brain - the rules are the same, only different.

I must have a prodigious quantity of mind; it takes me as much as a week sometimes to make it up. Mark Twain

I used to teach an introductory biology class for non-science students at the University of Arizona. The course primarily covered molecular biology and genetics, but I tried always to include an evolutionary perspective to each topic. To be successful a student had to accept the basic premise of evolution by natural selection, and this did not cause any problems; we didn't experience any significant creationism backlash. As part of the course, the students read a marvelous book (The Moral Animal, by Robert Wright) on human behavior from an evolutionary perspective, the emerging field of evolutionary psychology. Each semester, there was always a small number of students who had difficulty with the basic premise of the book. The students could easily accept that their livers, kidneys, lungs, etc., were all shaped by natural selection acting over millions of years. However when it came to their brains, they held steadfastly to the belief that the rules must somehow be different. The students were required to write a paper expanding on some aspect of the book. For the doubters, I told them that they could still get a good grade if they could write a logically consistent argument as to how or why the human brain would be shaped by rules that were different from all other biological entities. None were successful in this. In their defense they were just college undergraduates, but it would be difficult for any prominent scholar to defend this point of view with logic, either.

Why do we resist the idea that human behavior will not be subject to natural selection? I think there are a number of reasons. One goes back to the never-ending nature-versus-nurture argument. Is who we become determined by our genes, or by our upbringing? The short answer is both. I remember some years ago listening to a talk by one of my colleagues (David Rowe) who worked on this question. He summarized study after study, many based on twins who had been separated and raised in different environments, which all indicated that genetics plays a major if not predominant role in personality. (I remember leaving the room thinking that this was a great talk for parents - you could feel absolved from any responsibility for what your children become!) I had no trouble accepting this basic argument, based on personal experience. As a parent it was clear to me that my children had different personalities virtually from the day they were born, and in each of them it was easy to detect distinct aspects of one or the other parent. These differences could not easily be blamed on different environments.

On the other hand, there is no doubt that your environment does indeed have some influence on who you become. We all know of cases where a bad kid has been straightened out by moving into a more structured environment, or conversely, a good-hearted one has been ruined after falling in with bad apples. Moreover, we all like to believe in free will, and thinking that our genetics somehow determine our behavior is simply foreign to that notion.

Part of the problem with the nature/nurture dichotomy is that people often lose the fact that personality is very different from behavior. Your personality is the foundation, the base, from which you build a pattern of behaviors. The many studies that demonstrate a predominant genetic component to who we are typically measure aspects of our personalities. Do we tend to be compulsive? Are we timid? Personality traits are the ones that over and over seem to be mostly under the influence of your genes.

This distinction can be compared to alcoholism and drinking. We look at alcoholism as a deep aspect of a person's being - as they say, you are an alcoholic for life. This does not mean that you are always drunk. One is a basic trait that is a part of your being, and even in this case probably has a genetic component. However, this trait does not have to translate into constant drunkenness. The behavior (drinking) will be strongly influenced by those who interact with the alcoholic, and his/her life circumstances.

I remember an example from David's lecture, in which attitudes to authority were measured, and shown to be determined mostly by genetics. If any aspect of personality was going to be shaped by upbringing, you would think this would be the one. Importantly, this test did not measure whether someone was likely to mouth off to a policeman. Again, our upbringing (nurture) is going to have a huge impact on how we channel our personality traits into behaviors. One could take two individuals with identical personality traits and, because of differing environments, one could grow up to be president and another could be an axe-murderer. OK, maybe that's not such a good example, but you get the idea.

Of course, in all of the above we are talking about defining the reasons for *differences* in human personalities and behaviors. One problem with doing this is that we are looking for relatively subtle distinctions. When asking what evolutionary forces shaped human brains, we need to acknowledge that our similarities are much, much more extensive than our differences. If we can just agree here that the common aspects of human brain function are the result of natural selection, we can proceed to explain these via an evolutionary perspective.

Another reason that we sometimes have a hard time seeing that our behaviors are influenced by selection is that we look around and see people doing so many stupid or even self-destructive things, that it's hard to believe that these could be favored by selection. Yes, it is true that we don't always do what is best for us, and we will discuss some reasons for this in detail later. Now, however, it is more important to appreciate that who we are is not a result of selection in the world that we currently inhabit. Human behavioral evolution was selected mostly by the environment that we lived in thousands of years ago. This world probably included small groups, maybe even villages, with relatively simple social structures. Most of the inhabitants would have been related to one another, and would have been comfortable and familiar with one another. Males and females would have fairly well defined roles, and outsiders would be viewed with suspicion.

Most likely humans maintained this relatively simple existence for many thousands of years. Until the advent of agriculture, large cities which threw together multitudes of strangers did not exist. Once they did come into being, civilization as we think of it started to evolve. Even primitive man was able to pass down the wisdom of learned experiences from generation to generation, but once groups on the order of what we would now refer to as towns and cities were created, the pace of human social and cultural evolution picked up considerably.

Soon our lives were changing at a rate that far outpaced the rate of biological evolution in our genes. We can see this today in simple examples of physiology. Our ancestors ate a diet that was very rich in fruits and vegetables, which contained large amounts of many small molecules that our body requires for its chemistry. As a result, there was little selective pressure for us to continue making these molecules ourselves, and we lost the genes (through mutation) that allowed us to produce these from scratch. As a result, we now must eat these substances, and many of these fall into the category of small molecules we call vitamins. This was no problem as long as we ate well. Of course, our cultural evolution has led to circumstances where most of us don't eat enough of the foods that supply the vitamins we need. Have we suddenly re-evolved the genes necessary to make these vitamins for ourselves? Of course not. We might be able to do this if we suddenly stopped taking vitamin pills - in a few thousand years and after millions had been negatively selected (died) from vitamin deficiencies.

So, biological evolution is MUCH slower than human cultural and social evolution. Our biology was shaped by a world that was very different from the one we have now created for ourselves. Yet, we carry our biological evolutionary baggage, and have to use this toolkit to adapt to modern life. This critical insight is going to be true not only for aspects of our physiology, but for the evolutionary component of our personalities. It can be tempting to dismiss the effect of selection on behavior, since our behaviors don't always seem to be very well adapted to our lives. But the genetic component of our personalities was not selected to live in the modern world. We were selected to flourish in an environment that would be very foreign to almost all of us today, and we have changed the rules much faster than our genes can change to keep up.

If we realize that we were not made (by selection) to live in our current world, it becomes easier to understand that our behaviors will not always make sense. This becomes even more true when we realize that evolution's goals are not necessarily our goals. For example, virtually all of us want to be happy. There is no direct selective pressure for happiness, however. Being happy is probably good in the sense that it relieves stress and anxiety. And happiness can be tied to actions or outcomes that are beneficial, but not in themselves directly useful to our fitness. But happiness per se is not the goal of selection, that goal is maximizing fitness. If being anxiously suspicious of strangers, including those who just moved in next door, will improve your fitness, then selection will care little if that makes you unhappy. We see the same factors at work in other animals. The nervous, constantly alert rodent doesn't conjure an image of happiness, but this trait is probably going to improve the survival and reproductive success of a creature who has a potential predator lurking around every corner.

Our environment is changing at a very rapid rate. Just in the course of recent generations, much of the world has become much more mobile. People move and live in different towns, cities, even different countries, in numbers never before contemplated. In order to make us "need" products for self improvement, we are bombarded with advertising that tries to convince us that we should not be happy with what we have or who we are. (It is probably fairly easy to make us dissatisfied with ourselves, since being content with what we have is not necessarily going to be selective. Continuously striving for more is likely to have positive effects on fitness.) We subject ourselves to new circumstances that must make us uneasy, considering our ancestry. Is it any wonder that so many of us are screwed up? We don't have statistics from any ancient human villages of ten thousand years ago. I would be willing to bet big money, however, that the rates of currently recognized mental illnesses were extremely low. One would not have survived long, much less reproduced, as a severely depressed cave person.

Returning to where we started this chapter, the thing that makes us different from other animals is our brain. We are a LOT smarter than any of the other creatures on the earth. But is this really a qualitative difference, or just a difference of scale that is so great that it looks like a difference in type? In fact, there is no evidence that our brains are fundamentally different from those of related mammals. Certainly, the anatomical structures of our brains have corresponding homologs in other mammals, even rodents. Ah, but we are rational beings, unlike those others, you might say. Ask any practicing psychologist or psychiatrist how rational we are. We are emotional beings. As we will discuss later, the ability of our emotions to short circuit the rationality of our brains was probably an essential part of our evolutionary development. And, the conflict between our rational and emotional sides may be a source of much of the mental disturbances that we experience in the modern world.

We can all think of situations where an individual, or even a group, does things that seem counter selective. This makes it easier for some to dismiss the uncomfortable notion that their brains are shaped by evolutionary forces. As detailed above, many of these behaviors can be explained by the disconnect between the prehistoric environment that selected our behaviors and the present world in which our behavioral traits now find themselves. Other causes of apparent non-selective behaviors result from the fact that unusual situations arise in which a behavior that is usually good for fitness will now be bad. Overall, selection will fix those traits that optimize the fitness of the greatest number of individuals in the population. But in unusual circumstances, these generally positive behaviors can be counter selective. For example, most humans, and many other animals, will love and nurture an offspring that is physically or mentally disabled, and has little chance of contributing to the propagation of the genetic heritage of the parents. This expenditure of valuable resources is clearly not in the best interest of the long term fitness of the parents. However, evolution has selected very strongly for unconditional love of offspring by parents. Let's face it, without this, it would be hard for most of us to put up with the constant attention (day and night, often) that youngsters require. We don't consciously ask if there is going to be a payoff in fitness - we are made to just do it. In the aberrant case of a disabled child, this trait is counter selective. But this selective disadvantage in a few cases is far outweighed by the selective advantage of unconditional parental love in the population as a whole.

So, human behaviors have been shaped by selective forces that attempt to maximize fitness in the population. Aberrations are often easily seen to be just that, behaviors that are not good in a specific circumstance, even though they are beneficial on the whole. And, behaviors that seem generally to be less than optimal can often be explained by the differences in our current environment and the human experience that existed for thousands of years when our brains were being molded. The important thing is that apparent exceptions in isolated cases must be viewed as part of the larger picture. No single crazy person or seemingly illogical behavior can negate the general rules for humans as a group. Indeed, many of the occasional counter selective behaviors that we see in humans are also found in the animal world.

Well, certainly one thing that separates us from other animals is consciousness. This mental quality often takes on a mysterious aura in neurobiology, for reasons that I don't quite understand. This is indeed a critical difference between humans and "lower" forms, but not for the reasons generally assumed. This will be addressed at length in later chapters, but for now, let me just say that I don't see that consciousness suggests that human brains are fundamentally different from others, just more developed.

To sum up, there is no justification for the idea that somehow the brain escaped from the rules of natural selection. The old nature/nurture controversy often is muddied because people are not necessarily talking about the right outputs - personality as opposed to behavior. Nurture has a much larger impact on the latter. We must always keep in mind that actions that seem bad for us because they make us unhappy are not necessarily counter selective - evolution cares about fitness, not our happiness. Perhaps most importantly, human behavior seems to result from forces other than selection in part because we don't live in the environment that selected for our brains. The rapid pace of cultural and social evolution in the civilized world has changed our surroundings at a pace that biological evolution cannot match, making us less than harmonic with our world. This last point, the relatively slow pace of biological evolution, is going to return, with repercussions that are much more significant than our mere happiness.

4. Becoming smart shouldn't be hard.

Apparently there is nothing that cannot happen today.
Mark Twain

A common question is, what factors might have provided a positive selection for increased intelligence? This may seem simple, but in fact it is not obvious that being human-type smart is such an excellent strategy for improving one's fitness. Yes, we seem to be a dominant species on the earth at this time, but many other species have adapted quite well without being smart enough to write War and Peace. Cockroaches have been walking around for many, many more millions of years than we have, and most would agree that they are likely to be scurrying about long after we are gone. If one does a quick mental survey of all animals, there does not appear to be much of a correlation between overall intelligence and long-term success as a species.

A species is said to occupy a particular niche in its environment. What exactly is a niche? In general a species' niche is a description of the place that it occupies in an ecosystem. The niche includes all of the things that an animal eats, where it nests, when it is active, etc. If a critter is occupying a niche that mostly entails burrowing through soil and eating worms that are detected by smell and touch, then it is not obvious that being smart is going to be particularly useful. This is especially true if being smart requires a large head (which would require excavating bigger tunnels for a burrowing animal) and a very active metabolism (which would not be especially easy to maintain unless there are a lot of worms to eat). It is not surprising that most animals are not very smart by human standards. Indeed, many quite successful creatures are pretty stupid even by comparison to most of our four-legged friends.

Although being very smart is not the only path to evolutionary success, there is no doubt that it can be one of a number of useful strategies, depending on the ecological niche occupied by a species and other biological factors. Certainly, being smarter can potentially help an animal be successful at extracting resources from its environment, avoiding predators, etc. However, each species typically occupies a specific and unique niche in its environment, and morphological or physiological specializations besides intelligence are often more critical for its ability to maximize its fitness within the niche. A more clever giraffe is not going to be able to climb up a tree to get the high leaves. Being a little smarter will not help a desert toad survive the long intervals between rainy periods. In general, only a certain amount of neural wiring is necessary in order to make an animal's behavior quite efficient for the life that it is designed to live, for the niche that it occupies. Nature has not found it necessary to make brains that are capable of advanced thought processes, such as reflection, in order to maximize behaviors that can find food, avoid being eaten, etc.

So what conditions would be most likely to select for increased intelligence? Animals are not just being selected based on their ability to deal with other species and non-biological environmental factors. Our genes are also in competition with the genes from other members of our own species. Many (probably most) people who ponder the merits of brains for improving fitness believe that for the really smartest animals, the primary selective advantage of increased intelligence comes from a better ability to compete against one another - competition within the species. In this case, selection is not acting to defend a niche from other animals, but to make one individual better than the others who occupy the same niche.

When dealing with competition within a species, powerful new selective factors enter the equation. Wolves may compete with cougars for food, shelters, and other resources, but they do not compete with cougars for mates. Not surprisingly, mating success weighs very heavily in fitness, which is after all the ability to send one's genes into the next generation.

Selection for mates throws new complexities into any considerations of selective advantage. We can see in some animals how sexual selection can produce strange morphological or behavioral effects, which would make little sense purely in the context of maximizing a competitive advantage against other species. We've already mentioned the flamboyant peacock tail, which is designed to attract females, not to fly. The elaborate structure that is constructed by a male bowerbird in order to impress females, and the expenditure of energy that this requires, is a behavioral example of the handicaps that animals will endure in the effort to pass genes. Natural selection is quite willing to waste considerable resources or saddle an adult with remarkable physical handicaps in order to increase the chances of wooing a mate. This should come as no surprise, considering the central importance of the mating ritual in the continuation of one's genetic legacy.

Mate selection and access also complicate other more straightforward factors that impact fitness. Food and shelter will not only help an individual to survive, but accumulation of these resources can be important in making one attractive to prospective mates. Particularly in a species (such as humans) where both parents will contribute to raising the offspring, females are inclined to use resource accumulation as an indicator of which males will be the best fathers. One's status in the social pecking order can feed into the fitness equation in many interdependent ways.

In thinking about the arguments above, which types of animals would you expect to be most strongly selected for intelligence? That is, what type of niche would most reward an animal that is a little smarter than its brethren? We can all agree that life becomes more complicated as our social structures become more complex. Animals that live in groups often form dominance hierarchies, hunt in coordinated packs, etc. All of this requires relatively sophisticated mental processing, and it is easy to see that being more intelligent than the neighboring pack could be advantageous. The ability to communicate with one another with more precision will also be important in groups, and this will help to drive intelligence (we'll address this again soon). Then consider the competition between individuals within a pack. If one male is better at making decisions, finding food, choosing the best shelter, that individual is likely to become a leader. In a social structure, one of the perks of higher status is typically more mating opportunities. That is, females are often primed to choose the mates that offer the best genes for their progeny, and they use status in the clan as an important indicator of this.

One also would expect that being smarter will have a greater benefit if an animal is relatively long-lived. Learning does no good if you don't live long enough to use what you have learned. There are probably some relatively trivial morphological and physiological constraints as well. A certain size is required - it's hard to imagine that an ant's head could easily accommodate the number of cells required to learn calculus. Brains also use a lot of energy, and the incredibly complex networks of interacting neurons will work best if conditions (such as temperature) are kept relatively constant. Thus, we would expect evolution for intelligence to be best developed in animals that maintain a relatively constant body temperature.

The animals that we typically consider to be smart meet the above criteria. Canines (dogs and their wolf predecessors), elephants, cetaceans (whales and dolphins), and other primates (monkeys and apes) are all pretty smart as animals go, and all establish social groups, enjoy multiyear lifespans, keep a constant body temperature, and have sufficiently large heads. Many birds also seem quite clever, especially the long-lived parrots. The birds attest to the fact that, while some minimal brain size is required, it needn't be excessively large to house a pretty good little computational machine.

There are quite a few species that seem to be primed to continue selecting for increased intelligence. A priori, all of the mammals listed in the preceding paragraph would appear to have the requisite lifestyles to make increased intelligence a good thing. Moreover, available evidence indicates that for tens of millions of years many dinosaurs were functionally warm blooded, and lived in social groups. Yet since the days of the dinosaurs, only man has become really, really smart. Was there something special about humans that drove us to previously unexplored heights in our ability to think? Or, was there an unlikely series of genetic changes that was required to permit our brains to develop our phenomenal neural capability? These are questions that have been asked by those looking for an explanation of why our brains are so different from those of our nearest relatives. What kinds of ideas have emerged?

All social animals have methods for communicating with one another. But even if a killer whale was smart enough to conceive Moby Dick (and someone designed a keyboard for its flippers), it wouldn't have the vocabulary to accommodate the rich detail that this tome would require. No animal has language abilities that come anywhere near that of humans. It has been argued that the development of complex language provided the necessary driving selective force to create an organ with the cognitive abilities of the human brain.

This "language-drives-intelligence" notion is a hard one to prove or disprove. There is no direct evidence that will allow us to assess language development and cognitive abilities hundreds of thousands or millions of years ago. The earliest period in which we have a reliable record is relatively recent, and both our communication skills and brains were already very developed compared to other animals. Thus, this becomes a "chicken-and-egg" question - which came first? Was there a gradual ramping-up of both intelligence and the use of that intelligence to create more complex language, or was there some identifiable point, a singularity, at which "language" occurred, and this then fed back and provided a new, unique driving force for the development of our relatively massive intelligence?

Any discussion of language must also consider that complex communication, including signals that are interpreted differently depending on context, includes more than auditory verbalizations. Recent studies of our primate cousins suggest that gestures can provide a surprisingly rich and flexible vocabulary, both alone and in combination with vocalizations. We tend to focus on spoken words in thinking about language, but the early development of language could have been built on a more complex, multimodal landscape.

The communication skills of some other social creatures are quite advanced - but when does "whale talking" become "language?" I don't see any reason to propose that language per se was THE defining selective force for human intelligence. Smarter animals will be capable of more complex communication. In social groups, improved ability to express data, desires, and even ideas, will be a good thing. Once animals developed communication systems as complex as those currently seen in primates and other animals, then there should be selection to make these systems better. This should be true across the board, and if language development is what drove us to be so smart, then why did it not drive super, human level intelligence in other animals? What event do we see happening in humans that made communication so special? I concede that language development can be an important force in the positive selection for intelligence, and may have helped make us so much smarter than other animals. However, I don't see that language development can be used to explain the unique character of our intellectual capabilities. This same force should have been pushing numerous other social animals to become very smart as well. In any case, we shall see that whether or not one wants to buy into the notion of the primacy of language, this is not necessarily material to the essential ideas to be presented later.

What about more simple behavioral adaptations, for example use of tools? Again, there is nothing uniquely human in tool use; it is found in many animals. In addition to other primates, tools are used commonly by more distantly related mammals and even birds. Sea otters float on their backs and smash abalone shells on rocks that they balance on their bellies, but I don't expect that any will soon evolve the ability to read this book. Tool use is a sign of a certain level of intelligence, but there is no evidence that it is unique to our lineage, so as to be a critical driving force in the derivation of humanness.

With the advent of DNA sequencing on a massive scale, scientists have been able to identify specific genetic changes that correlate with the evolution of the human condition. As mentioned in Chapter 1, the protein machines of humans and chimps are greater than 99% identical, and most of the chimp-human differences that are found in the amino acid building blocks of the proteins probably have no functional significance. However, some changes have been proposed to be important. For example, molecular biologists recently found that a gene that encodes a protein important for making jaw muscles in most animals was mutated in the ancestors to humans approximately 2.4 million years ago. This mutation appears to lead to a reduced size of our jaw muscles, relative to those of our primate relatives. Moreover, it has been suggested that this may in turn have altered forces elsewhere in the skull and permitted an increase in cranial capacity. That is, a jaw muscle mutation may have indirectly allowed us to grow bigger brains, and this may have allowed us to become more human.

On a more global scale, the determination of complete base (A,T,G and C) sequences of the DNA from multiple species has allowed comparisons of our genetic information with that of other animals on the scale of the whole genome. With these total genetic sequences in hand, it is possible with computers to search for regions that have changed especially rapidly in the lineage that lead directly to humans, including regions in the 98.5% of the sequences that do not carry information directly for the proteins. This has permitted the discovery of multiple regions of our chromosomes that seem to define human-ness in our genetic makeup. Some of these regions are expressed in brain development and in adult brains, at least consistent with the hypothesis that these genetic differences may be important for promoting greater intelligence. As this is written, however, there is no actual experimental evidence that this is the case.

Most of the detected genomic differences do not include regions that contain the information for the structure of our proteins. This fits with earlier suggestions that the primary differences between humans and chimps is not in our proteins, but in the regulation of when and where we make those proteins. For example, one family of proteins known as growth factors are important for communication between cells during development. Cells need to talk to one another to coordinate their activities in the embryo, and later. For example, different types of cells, those that will make skin, muscles, nerves, bone, etc., must all grow in a coordinated manner in order to make a structure with the exquisite organization of a human hand. As the name implies, one thing that growth factor signaling organizes is cell growth and proliferation. One does not need to make a new or mutated growth factor protein in order to make an arm 20% longer than the average arm. One only needs to make a little more of the growth factor in the embryo, or make it for a slightly longer period than normal. The genetic changes that can alter the expression patterns of genes are more difficult to identify than mutations that directly alter protein structure, and these are even more difficult to examine functionally. However, these types of studies can now be done. Some of the regions identified in the whole genome comparisons described in the preceding paragraph will certainly fall into this category of things that affect the regulation of protein expression.

Changes in gene regulation can lead to large scale alterations in development that may have a major impact on the ultimate organism that is created. Some of these are quite striking. For example, salamanders usually have an immature larval stage, that changes into a mature breeding adult under the influence of a specific hormone. This is similar to the metamorphosis of a tadpole into a frog, but not as striking morphologically. There are species in which this change does not occur (because the hormones not made), but other genetic changes have allowed these animals to develop their reproductive organs (and behaviors) in the absence of full adult metamorphosis. This allows the animals to maintain an aquatic lifestyle as a breeding adult.

It has been suggested that human evolution also has benefited from changing the timings of some developmental events. Specifically, much of our development, and especially brain development, seems to have been delayed relative to the time of our birth. Because so many of our neural connections are created after we have entered the real world, we can couple the formation of these connections to learning experiences that are only possible outside of the womb. Of course, this requires that we have parents who are willing to sacrifice their energies (and sleep) during a prolonged post-birth period when we are pretty much incapable of doing anything for ourselves. Although humans may be an extreme case, many of our primate relatives also invest significant parental investment in their young.

So, we can identify many changes that may have played a role in permitting our ancestors to become very smart. These range from specific mutations in known genes to developmental shifts whose underlying genetic causes remain unknown. In some cases, the discoverers of a change imply that their newly identified genetic variation was a critical event in creating increased intelligence in our lineage. It's hard to know if they always believe this. Science is not so different from other professions, and if a researcher can tie a result to an event as captivating as the critical event in human evolution, the paper gets published in the most important journals, grants get funded, etc.

But does any of this really address the question of the uniqueness of human intelligence? There is no doubt that some of these newly identified genetic alterations may have helped us become smart. However, there is little reason to believe that any of these were critical events in our evolution. That is, if this particular genetic change had not happened at this time, would human evolution have been retarded significantly? If the mutation in the myosin heavy chain gene that presumably made our jaws smaller had not occurred when it did, would we still be swinging from trees looking for bananas? The answer is most definitely, "No!" These types of genetic variants are arising on a regular basis in populations of creatures all over the globe. Our evolution into super intelligent animals was a unique event in the history of the earth. It was not a result of a single, particularly rare genetic fluke, or even a few of them, that allowed our brains to get bigger, or our neurons to make more connections. These were not limiting factors.

How can I make that last statement so definitively? It will help to look briefly at the history of multicellular animal life on earth. It is widely accepted that the basic body plans of all existing animals (and other types that have become extinct) were formed over 500 million years ago, most in what has come to be known as the Cambrian Explosion. This was not an explosion in the sense of an impact of a comet or asteroid, like the one that killed off the dinosaurs hundreds of millions of years later. Rather, it was an explosion of diversity in the types of animals that were evolving, over a span of at least 20 million years. This may seem like a long time for an "explosion," but in evolutionary time it resulted in a very rapid and extreme change in the types of creatures that were being made. We had the creation of animals with hard cuticular external skeletons (such as insects), the beginnings of animals with backbones (like us), and many other types. The important point for us here is that all of the basic types of animals we see currently have been in existence for many hundreds of millions of years.

Since the Cambrian Explosion, we have seen each type of animal undergo extensive refinements and, most importantly, diversification. Choosing just one type of animal, the vertebrates (animals with backbones), we can see a stupefying panoply of elaborations on the basic theme. If there is some selective advantage to a long neck, animals with slightly longer necks will have higher fitness, and the next generation will, on average be taller. This will continue in each generation, and it does not take long (in an evolutionary sense) to make a giraffe. What - you've evolved to live on land and now you've changed your mind and you want to live full time in the water again? No worries, we can select for webbed feet, which will eventually morph into flippers. We can change your physiology so that you can hold your breath for a long time, and withstand the immense pressure changes that will permit deep diving. As we saw in Chapter 1, these types of changes typically involve elaborations on basic structures or processes. These elaborations sometimes seem so extreme that they appear to be wholesale changes in the way things are made. But, further analysis, and especially genetic homologies, generally show that they are really variations on a theme.

We discussed earlier how relatively minor changes in gene expression in development can have major effects on the final adult product. Studies in developmental genetics are uncovering the extremely intricate webs of gene and protein interactions that turn a simple embryo into the magnificently crafted organisms we enjoy today. This work provides a strong molecular underpinning to the notion that there is plenty of genetic variation in a large population of animals to exaggerate virtually any structure or physiological process, if there is sufficient selective pressure to do so. Moreover, depending on the size of the population and the degree of selection, these changes can happen over a surprisingly small number of generations. Of course, we must remember that we are measuring time in an evolutionary sense. Polar bears may not be able to change fast enough to be saved from extinction in the face of global warming, but if the temperature changes occurred over the course of thousands of years instead of decades, they might have a chance.

A good example of how effectively selection can exaggerate a trait can be found in our senses - smell, sight, etc.. If you take your dog for a walk in the neighborhood, he probably likes to stop to sniff many of the objects along the way. Your dog's nose is good enough to detect faint, residual odors that may be weeks old. He is "seeing" the history of each bush and rock, as told by the lingering smells of each previous dog who decided to mark it. A hawk can pick out a tiny rodent scurrying through the brush from hundreds of feet in the air. An owl can hear the same rodent and, in the dark of night, use this ability to zero in on it and snatch it up. A viper sees the same rodent in total darkness, using specialized pits in the front of its head to sense the infrared radiation of the mammal's warm body. Bats use high pitched auditory signals like sonar to detect and capture flying insects in the dark. Using other vocal frequencies, a whale can hear a friend call from half an ocean away. This list could go on and on. The point is, these extreme sensory abilities have evolved numerous times in many, many different lineages. The degree of genetic variation in the population does not seem to be much of a limiting factor. If there is selective pressure to elaborate and exaggerate a modality that already exists, the genetic toolbox seems to have plenty of options for getting one to the desired place. And, it does not require hundreds of millions of years of gradual evolution.

Why should we expect brains to be any different? Mammalian brains have not changed much in terms of the types of structures present or their overall organization. Our brains are larger than those of most other animals, but in terms of basic structure, we are not significantly different from our rodent relatives. Thus, our brains seem to follow the same principles as the rest of our organs. Making a human may have required elaboration and/or exaggeration of existing parts, but there is no reason to think that any unique or difficult genetic events needed to occur. It is especially silly to view increased cranial capacity as a defining event in human evolution. Elephants and whales certainly are not limited by the space that they can allocate for their brains, but neither of them managed to become human smart. Closer to home, it is hard to imagine that an inability to evolve a larger cranium has been a major stumbling block in the development of gorilla intelligence. Taking a part that exists, and simply making it a bit larger, has never been much of a problem for evolution, at least not from the standpoint of the available genetic toolbox.

In summary, there are lots of reasons why being smart can be a good thing. This is especially true in animals that live in well-defined social groups, where competition with one's neighbors is likely to be of particular importance. And, once being smart becomes a weapon in the fitness battle, being a little smarter is going to be a little better. This should drive an intelligence arms race. There is no reason to suggest that the level of genetic heterogeneity in populations is a significant limiting factor in becoming very smart, at least over the time scale during which vertebrate brain evolution has occurred.

Much research and theorizing has focused on asking what unique set of factors arose to provide the positive driving force for human intelligence, or similarly, what unusual biological events (mutations) had to occur to permit us to make the brains necessary to comprise our novel thinking organs. But these are the wrong questions. Nothing uniquely special was required to push the development our magnificent brains. Being smart has advantages, and there are no molecular constraints on the evolution of big or efficient calculating machines.

The question is not what rare events had to happen to drive this evolutionary elaboration. The question that should be asked is, why did it take so long? The answer is that there are costs to being smart. Just as the tail of the peacock makes it less than the most graceful of flyers, there is a selective price to pay when our brain function is exaggerated to a ridiculous extent. In order to become smarter, the advantages to fitness, which are fairly straightforward, have to outweigh the disadvantages, which are less obvious. In searching through the potential costs of being smart, we will find the startling answer to the question of why it was so difficult to evolve a creature who could paint a Mona Lisa. We also will uncover the disturbing reason as to why we are inclined toward such self destructive endeavors as building nuclear weapons and filling the atmosphere with greenhouse gasses.

5. There are no free lunches, or free smarts

When I was younger I could remember anything, whether it happened or not.
Mark Twain

We have seen that the extreme exaggeration of a specific trait can give a fitness advantage under various situations. The long neck and legs of the giraffe allow it to browse from high in the trees and the outrageous peacock tail makes it more attractive to females. However, in each of these cases, there is a selective cost that ensues when a trait is amplified. Peacocks don't fly so well, giraffes become less agile. Even with one-celled bacteria, a mutation that confers resistance to an antibiotic makes the cell less fit if the antibiotic is not present. The same will be true for behavioral traits. A field mouse must forage in order to eat, but each trip away from the nest carries the danger of being swooped up by an owl or jabbed by the fangs of a hungry snake. For a large bull elk, an enormous rack of antlers must be carried through the forest day and night primarily so that he will be better able to acquit himself in the risky combat for mating privileges. In all of these cases, and countless more, there is a tradeoff in the effect on fitness with the expression of a particular trait. If the sum of positive and negative effects comes out on the plus side of the ledger a trait will persist. But, as soon as the negatives balance the positives, continued elaboration of the particular trait(s) will cease. There will still be variations around this point, but in the population as a whole a stable average will be attained.

Intelligence is a trait like any other, and so this begs the question, what might be the costs of being smart? And by smart, we don't necessarily mean human smart, but just smarter than the average bear? Before diving right into this question, it might be useful to look at a similar but slightly simpler question. Our senses (hearing, sight, smell, taste and touch) are also neurally-based traits, and the patterns in which they are developed in animals can be suggestive of some more general considerations.

As we mentioned in the previous chapter, specific senses are developed to extraordinary degrees in various animals. The patterns of these embellishments do not suggest that sensory evolution was constrained by molecular biology or genetics. We see that different senses have been developed to extremes many times in many lineages, when it suits the needs of selection to do so. Dogs, or even vertebrates, are not the only animals with an uncanny ability to smell. Certain moths have been shown to be extremely sensitive to specific odors, such as the molecules that they use to home in on a potential mate. Indeed, even a one-celled bacterium can sense and count single molecules that impinge on its surface, and make decisions as to which way to swim based on the frequency with which it encounters the stimulant.

This causes us to pause and ask, if it's easy to develop such extremely sensitive sensory prowess, how come we don't have lots of animals that can smell like a bloodhound, see like a hawk, hear like an owl, etc.? Heck, why not throw in the ability to see in the infrared, like a pit viper? This becomes even more vexing when we note that many animals have actually lost sensory abilities over time. Where I live in the desert southwest we have peccaries which possess a very acute sense of smell, which allows them to root out food, etc. However, they see very poorly. There obviously is no genetic reason that they cannot have eyes that function at least as well as, say, the deer that also live in the same habitat. What possible advantage could there be to being more blind?

The answer must be that we "learn" (in the evolutionary sense) to focus on the sensory inputs that are doing us the most good, from a fitness perspective. Too much information can lead to some level of confusion, and so we ignore those sensory packets that are going to distract us from the main goal. Evolution could perhaps have dealt with this by altering the way that the data are processed in the higher centers of the brain. Or, it could just limit the amount of less useful data. It seems that this latter strategy was followed in many cases. The importance of focusing on the information that matters most is clearly evident in the photoreceptors of animals and the neurons that process their information. For example, in some frogs it has been shown that the nerves are connected in such a way as to make the frog especially sensitive to motions such as those of a fly moving across the visual field. No one has proven this, but I suspect that this wiring probably makes the frog less capable of scanning the words on a page. But for a frog (except maybe Kermit), the cost of not being a speed reader is small indeed if it means you can catch more bugs.

As evolution for greater cognitive function proceeds, we can expect similar issues to crop up. If an animal tries to compute all of the interconnected possibilities before reaching a conclusion, confusion can result. At the very least, simple decisions can become overly time consuming. Imagine an antelope on the Serengeti Plain of East Africa. There is a snapping sound in the tall grass nearby. The antelope could consider all of the possibilities. Possibility number one may be that this resulted from a branch falling from a tree. How close is the nearest tree to the supposed source of the sound? What may have caused the branch to fall? Was it just because the branch was dead and the wind was blowing? Is the wind blowing? By the time all of the possibilities have been identified, probabilities assessed, potential repercussions analyzed, etc., the antelope may be in the jaws of the lion that stepped on the twig in the tall grass. Thinking too much before making a decision can clearly be fatal. This will typically have a negative impact on fitness.

This doesn't mean that massive computational power is necessarily a drawback. It only points out the fact that it must be managed properly. This simple example shows that in many instances it is desirable to have a short circuit that can override raw analytical tendencies. The antelope might be better off to just jump, and think about it later.

In fact, evolution seems to have decided that in many circumstances it's best not to think about it at all. It's not only our legs and arms that react irrationally to things happening around us; we have "short circuits" that are mostly confined to our brains (and hormones) as well. Many of these correspond to what we call emotions. What is "happy," "sad," "fear," "anxious," "anger?" They are not conclusions that we reach based on a detailed assessment of the plusses and minuses of a given situation, and a rational computation of the response that is in our best interest. They are mental and physiological responses to a particular set of circumstances, in which evolution has determined that this response will, on average, be best in maximizing our fitness. They have been shaped by selection over countless generations to guide our behaviors, in the absence of exhaustive and perhaps futile analysis of situations.

What's that you say - it seems that our emotions are regularly getting us into trouble, so how is it that they are maximizing fitness? To answer this, we need to consider some caveats. The first is that no triggered behavioral response is always going to be the optimal choice in various situations. The antelope that bolts at the slightest disturbance may in fact run directly to a silent stalker, who may have been noticed if the antelope had taken a more measured assessment of all of the options before running. However, most of the time, a quick reaction to the known potential threat will be the best choice. Averaged out over many instances, the delay will be more costly than the potential of going the wrong way. Selection is a very good calculator, and a success difference of a fraction of a percent can be meaningful when applied over thousands or millions of trials.

For humans, our knee-jerk response, often triggered by emotions, is even more likely to be a mistake. This is because of the previously discussed disparity between biological and social evolution. We live in a world that is different from the one for which we were evolved. A fear response that may have served us well in our primitive villages surrounded by trusted, long time companions may not be appropriate in a 21st century metropolis. Thus, we are constantly having to fight innate tendencies that are not healthy for us. For example, as a subsistence hunter-gatherer, it is generally not a bad strategy to eat all you can when you find a food that is rich in energy (sugar or fat), and this is why we are designed by selection to find these foods so pleasant. However, when we are surrounded by essentially limitless quantities of sweets and greasy deep fried yummies, it is decidedly unhealthy to continuously gorge ourselves. The irrationally driven behavior that was good for us thousands of years ago is not in the best interests of an affluent metropolitan of today.

Emotions are just one example of how our brains are designed to take short cuts to generate an overall optimal behavior in a reasonable amount of time. During animal evolution, there must have been a general need to continuously balance raw computational power with speed and other factors that allowed us to make the best decisions. An analogy can be found in computer programs that are designed to play chess. A chess player could, in theory, respond to any opponent's move by computing all possible responses through to the end of the game. Because of the enormous number of potential directions that the game may take, this is an impossible task for a human, and so the best players learn strategic guidelines to follow in the placement of their pieces. This strategic knowledge is combined with the tactical ability to visualize all of the reasonable possible outcomes for a certain number of potential moves into the future. The very best players have a firm understanding of the strategic concepts, as well as an ability to see specific possibilities the farthest into the future.

Chess playing computer programs for many years used a similar strategy. Human strategic thinking was programmed into the machine, and combined with more standard computational brute force tactical calculating abilities. These programs could play excellent chess, but generally did not beat the very top humans. As computational power increased, programmers were able to shift the balance to brute force computaions of all potential series of moves into the future, with relatively little human-type strategic thinking. The best of these programs outperform the older versions, and can beat even the top grandmasters.

Is it possible that human brains could eventually have such massive brute force computational ability? Could we evolve into biological computers on the same scale? In fact, we may already be much closer than you think. And, some of the most interesting evidence for this illustrates why it would not be a very good strategy for success in life, unless success is measured by your ability to do a specific task (such as chess playing) extraordinarily well.

Ever since the movie Rain Man, most of us have been familiar with Savant Syndrome. This syndrome typically combines an extraordinary mental ability with some form of mental disorder, usually autism. The character Raymond Babbitt in the movie was inspired by a real person, who has memorized over 8600 books, and has detailed recall of a bewildering array of information in areas such as sports, geography, and history, among others. He can read extremely rapidly, including the ability to read the left and right pages of a book simultaneously, one with each eye. Some other examples illustrate the scope of the computational potential of the human mind, and also begin to illustrate some of its limitations. One of the earliest described savants was Thomas Fuller, as reported by Benjamin Rush in 1789. Mr. Fuller correctly calculated the number of seconds lived by a man aged 70 years, 17 days and 12 hours, (2,210,500,800), but according to Rush, he "could comprehend scarcely anything, either theoretical or practical, more complex than counting." There is a pair of identical twins who can calculate calendars for over 40,000 years, and who remember the weather for every day of their adult lives. They also can compute 20 digit prime numbers. They are stumped by otherwise simple arithmetic problems.

Numerous other savants are known from around the world and from historical records that show extraordinary abilities. These may be in areas such as music, art, mathematics or spatial skills. One thing that they have in common is that the abilities typically involve remarkable memory and recall abilities. These memory skills may be extremely deep, but they are usually equally narrow in scope.

Savants of the scope described here are rare, it is estimated that currently there are approximately 50 such "prodigious" savants. However, savant-type abilities of lesser degrees are much more common. Indeed, some estimates suggest that as many as 10% of autistic individuals have some form of otherwise exceptional mental attributes. Autism is associated with savant syndrome in roughly half of the cases, however some form of mental disability or brain damage is almost always present. Both the extraordinary abilities and the degree of other disabilities comprise a spectrum, both qualitatively and quantitatively.

What has savant syndrome got to do with "normal" people? Unfortunately, there is no comprehensive explanation for what causes the syndrome. Some evidence is consistent with the notion that savants often have damage to or reduced function of the left brain, with compensation by the right brain, but this has not been demonstrated to be a factor universally.

In any case, the association with mental disability has led many to suspect that savant syndrome is not so much a case of people who have gained fantastic powers of memory or calculation, but that it is primarily a case in which latent abilities that we all possess have been uncovered. That is, our brains are much better calculators than we know, because these abilities are hidden from us by layers of cognition that suppress our consciousness of them. Support for this idea comes from cases in which savant-type abilities are sometimes unleashed in persons who suffer acute brain injury, typically to the left hemisphere. Even more suggestive are cases of previously normal persons who acquired new, prodigious artistic skills following the onset of frontotemporal dementia. In these cases of injury or dementia, individuals with normal functioning minds unlocked exceptional abilities following damage to a part of the brain. This is very strong evidence that we all are walking around with calculators that are far more capable than we imagine.

The phenomenology of savant syndrome fits very well with the general notion that too much informational processing can be deleterious to overall functioning, and fitness. Our brains are extraordinary calculating machines, if we allow them to become obsessively focused on a particular task. But this level of focus compromises our ability to effectively process all of the relevant information that any life situation presents. So, as animals became smarter, they also evolved filters that make executive decisions as to what should command our attention. Humans, with their exceptionally powerful brains, have also become extremely good at generalization. We deal with life in ways similar to the way a strategic thinker plays chess, making moves that we "know" are good not because we are calculating each specific course, but because we are drawing conclusions from emotions, similar experiences, and other global patterns. We may be using a fair amount of our calculating ability, but it is not necessarily close enough to the surface for us to be aware of it. The savant is not distracted by the executive layers of the brain, and this allows him or her to consciously access the deeper cognitive calculator.

As animals become smarter and smarter (evolutionarily), they will need to develop better executive brain functions. They will need to be better at generalizations and prioritizing the information and processing events that will occupy their immediate attention. One could think of autistic savants as individuals who have lost the evolved executive functions (to one degree or another) allowing their innate, exquisite calculators to usurp their attentions obsessively.

Indeed, in an interesting book (Animals in Translation), Dr. Temple Grandin proposes that the minds of autistic individuals are closer to those of our animal relatives than are the brains of most people. Dr. Grandin is a remarkable individual. She is autistic (albeit at the highly functional end of the autistic spectrum), and an authority on animal behavior. She contends that being autistic provides her with unusual insight into the workings of her subjects, primarily livestock. Most importantly, she argues that animals are much more likely to be distracted by novel inputs that most humans would ignore, largely because of our enhanced abilities to generalize and conceptualize.

The abilities of humans to subjugate their immense brain power is not unique, just exaggerated to match the scale of our overall high level of intelligence. Over time, smarter animals would be expected to develop compensatory mechanisms commensurate with their need to keep from being confused or obsessed by their calculating neurons. We can see these mechanisms in animals now. Most vertebrates with whom we are familiar have emotions of the most basic sort; fear, anxiety,etc. Many mammals clearly have nurturing emotions that could pass for love (and not just directed toward progeny), and anyone who has watched otters or who has played fetch with their dog must detect signs of happiness. Moreover, experimenters have uncovered some of the molecular events that have evolved to improve the efficiency of animal (and probably human) brains. For example, it was recently shown in rats that recollection of an experience can lead to its replacement in the memory banks by a more recent, similar event. That is, the animals are continuously updating their files with the most recent, and likely the most relevant, memories to use for future reference. (For this reason, a neuroscientist colleague believes that it is a mistake to encounter an old flame from the distant past - you run a serious risk of losing the youthful good memories!)

Being too smart can come with costs. Primarily, the cost is potential confusion from too much analysis, or obsessions that result from focusing too deeply on a particular part of our immense calculator. However, it appears that as animals got smarter, evolution generally was able to keep the costs down by developing compensatory executive brain functions. Animals have been able to maximize their cognitive abilities by proper organization and conceptualization. These two events, increased computational ability and more developed executive functions, can evolve in small steps together, as needed. Thus, these costs don't seem to have provided significant handicaps for continual cognitive advancements. Humans manage pretty successfully with brains that are very far advanced, compared to other animals. This suggests that these issues should not be very problematical for the evolution of smarter gorillas, or even dogs.

So, confusion and obsession do not appear to be critical handicaps that would inhibit the continued development of smarter and smarter animals. However, there is one additional hurdle that presents new challenges for intelligent beings. Unlike the continuous relationship between the benefits of increased computational power and the cost of confusion or obsession, this hurdle presented a discrete, novel barrier at a specific point in our evolution, which required a totally new strategy in order to overcome it. That barrier, and the events that allowed us to break through it, have profound implications for the further development of our species.

6. The wall

Man is the only animal that blushes - or needs to.
Mark Twain

The critical event in our evolution as super intelligent animals occurred relatively recently, certainly within the last few million years. At that time, we encountered the barrier that effectively prevents selection for the further development of all intelligent animals. The wall is hit when an animal becomes self-aware, and this chapter describes why this presents such difficulty for selection. Before moving right to that issue, however, it will be useful to summarize some of the salient points from the previous sections:

1. First and foremost, it is a fundamental tenet of evolution that natural selection will act to maximize the fitness of a population, where fitness is defined as one's ability to reproduce successfully.

2. The basic vertebrate body plan, including the overall organization of our brains, was established hundreds of millions of years ago.

3. We can see from many examples that there is more than ample genetic heterogeneity being generated in large populations for selection to create more elaborate versions of structures. That is, the genetic parts are there to make greatly exaggerated versions of our limbs, organs, etc., if there is sufficient positive selective value to do so. There is nothing special about our brains in this regard.

4. Many animals are reasonably intelligent, especially those that live in groups with hierarchical social organizations. In these animals, intelligence should generally be a good thing, and more intelligence should be even better.

5. Although being smarter will be good in some ways, like all exaggerated traits intelligence comes with some costs. Evolution has dealt with the obvious costs of confusion and obsession by developing higher brain functions that permit us to conceptualize and generalize. These don't appear to have presented any uniquely difficult obstacles for the evolution of more intelligent beings.

So, from both the genetic and selective points of view, there is no obvious reason as to why it took hundreds of millions of years to evolve an animal with extreme, human-type intelligence. Moreover, we are a LOT smarter than any other animals. That is, once a certain level of intelligence was reached, we then became much smarter very quickly. These two observations indicate that there is a specific barrier at some point along the evolutionary road to becoming very smart. Breaking through that barrier requires an unlikely series of events; it has happened only once in the history of the earth. However, once that wall is breached by a species, it can continue down the path to greater intelligence essentially unrestrained, becoming much smarter than those who are still held in check. This is what happened to humans.

Not coincidentally, the critical barrier to becoming intelligent is the very thing that most people agree sets us apart from other animals: self-awareness. This is similar or identical to the concept of consciousness, which after all is nothing more than being aware of your identity and place in the world. The term consciousness often comes with a significant amount of baggage, however, and sometimes takes on meanings, including spiritual connotations, that go well beyond simple self-awareness. So we will avoid the "c" word as much as possible.

What exactly do I mean by self-awareness? An animal is self-aware when it reaches a level of intelligence that drives it to examine its identity, its place in the world relative to the rocks, trees, etc., and relative to its brethren. The creature's nervous system is now able to move well beyond reflexive or calculating pathways, and its brain can progress to reflective thought. When an animal reaches this point, it also begins to question what it means to be alive. Conversely, when any creature reflects on the meaning of life, it begins to contemplate what it means to die. This appreciation for the implications of death has major repercussions for natural selection.

Some will argue that the uniqueness of human consciousness is evidence that our brains are fundamentally different from those of our animal cousins. I would argue that the quality of self-awareness requires nothing particularly special in terms of brain function. It is a quality that simply arises once a certain level of cognitive powers is reached; it's not something that we have because human brains are uniquely organized or imbued with some spiritual quality. Is a one-day-old child fully aware of itself and its place in the world? Hardly. Self-awareness comes into being at some later time, as our brains continue to develop and we continue to learn. Consciousness seems uniquely special simply because we are so much smarter than other animals. That is, we are not just a little self-aware; we are smart enough that we have become obsessed with who we are, why we are here, etc. The magical quality of consciousness is simply self-awareness on steroids.

Self-awareness is an emergent property that arises naturally at a particular threshold of smarts. As such, it does not require any especially magical or unlikely series of biological events to evolve. However, self-awareness does have a unique and profound effect on the evolution of an organism. In fact, the rules of natural selection demand that naked self-awareness will immediately have negative consequences. Once a rational animal becomes smart enough to reflect on the idea of mortality, it begins to make decisions that are not in the best interests of its fitness.

Why is self-awareness counter selective? A few examples will make this abundantly clear. However, before proceeding directly to these, it is important to emphasize that in each case we are considering animals that are making rational decisions. One immediate reaction of many to these ideas is that the idea of self-awareness and the accompanying concept of mortality cannot be counter selective, since humans have both to an extreme, and we seem to have done alright so far. Well, we are not rational animals. We have well-honed, irrational mechanisms that allow us to deal with the dilemma of being smart and mortal. As we shall see, the solution to the self-awareness problem is non-trivial, and causes problems of its own. For now, though, let's deal with hypothetical creatures who are smart enough to be self-aware, and rational enough to channel their behaviors based on this acquired trait.

Assume that you are a young adult male lion. Like all of the other young studs, you are pretty frustrated. That big old guy with the flowing mane has his way with all of the lionesses in the pride, and if you want to get some action you have to try to sneak in occasionally without being noticed. This doesn't happen very often, if at all, and you decide you want to try to do something about it. If you want to sow your oats freely, you are going to have to challenge the dominant male. Although many animals have evolved stereotyped combat rituals that are designed to select the "best" male while minimizing the danger to the combatants, there remains a small but significant chance that you will be killed. What do you do?

If your brain is dominated by thoughts and emotions that have been shaped by natural selection, you will go for the fight, if you think there is a reasonable chance of victory. Winning the battle will mean that you can mate at will with multiple females, and your genes will be shooting into the next generation by the bucket full. Your fitness, as measured by your reproductive success, will increase tremendously.

However, if you are a self-aware, rational lion, you will have thought about your mortality at some length. You will realize that if you are killed, that's it - life will be over. Bummer! It might be nice to have more little lions like yourself, but it will be a disaster if you fail and cease to exist. From a strictly rational perspective, it would be crazy to risk getting killed in order to further the existence of your genes.

This is the fundamental problem with self-awareness and the corresponding concept of mortality. Life places us in situations where fitness is at odds with survival. If an animal thinks much about what it really means to be dead, the rational intelligent being will choose survival every time. But natural selection chooses fitness. Thus, that little extra level of smarts that brings on self-awareness comes at a great selective disadvantage in the population. The slightly dumber members of the group, who think little of mortality, will be more successful at propagating themselves.

Of course, survival is a component of fitness - animals have to live in order to reproduce. This is especially true before we reach sexual maturity. However, life eventually is going to place creatures in situations where their survival will be placed in some jeopardy if they pursue the course that will maximize their ability to reproduce. Indeed, in many animals reproduction itself is risky. The resources devoted to growing offspring, both within and outside the womb, are draining for parents, and childbirth itself carries significant dangers in many animals, especially humans.

The dilemma of the lion is a case where reproduction is directly tied to a risky adventure. Not all of our life-threatening behaviors are so obviously designed to improve fitness, but indirect connections are common. Animals, including humans, will go to great lengths to acquire wealth (resources) and status in the living group, typically well beyond what is required to live a long, happy life. In general, the possession of resources and status will grant one better access to mates. The best hunter will be viewed as the best potential father, and will attract the most desirable mates. Grok the caveman may not be able to eat an entire mammoth by himself, but if he successfully risks getting stomped, gored, or squished by a hairy trunk to bring back such a feast, the gorgeous Grokesses will choose him over the hunter who returns with a squirrel. Bank on it.

Of course, like other animals self-aware humans are willing to risk death every day for seemingly trivial reasons. We drive our cars, often even refusing to engage in such simple protective measures as wearing seat belts. We will go to war, where we can expect to have others shooting at us. The newspapers are full of stories of persons who engage in lethal confrontations over mates. What about parents who are willing not just to take a risk, but who will actually sacrifice themselves for the lives of their children? Natural selection, or at least the biological residue of selection on our distant ancestors, supports all of these decisions to some degree, based on a biological "calculation" that compares the value of survival and fitness in each case, but it is not being done via any conscious, rational manner. The behaviors of all animals are determined by these unconscious biological calculations, but when an animal attains self-awareness a whole new dimension is added to the equation.

We previously discussed how emotions can short circuit rational analysis, in humans and other animals. Could we just extend our emotional repertoire gradually to deal with emerging self-awareness, similar to the way we proposed that excutive functions gradually developed to compensate for increasing calculatory ability? Some emotions may be cranked up sufficiently to make us do things that are not in the best interest of survival, such as the love that might make a mother devote so many resources to raising offspring. However, many emotions are already working largely to promote survival, and often the struggle between irrational drives (e.g., fear and lust) is the calculator that determines whether we will optimize fitness or survival.

Our emotions are designed to produce a quick, generally positive response to a circumstance, in order to maximize our ability to reach a goal. Self-awareness does not simply introduce an incremental change in how we should weight various inputs, but rather it turns the entire system on its head. Self-awareness suddenly changes the ultimate goal that our behavior is trying to attain. The entire system of irrational behavioral drivers in an animal on the verge of self-awareness is evolved to generate behaviors with a single endpoint, maximal fitness. Self-awareness creates a very different new target (survival), and some of our most influential emotions (e.g., fear) are extremely capable of directing our behaviors to move us toward that goal. Our fear response will be instantly heightened to enormous levels if we are obsessed with the consequences of death. What emotion or unconscious behavioral driver can compensate - or more accurately, could possibly have been in place to compensate when our ancestors first became self-aware?

Yes, we almost certainly have reprioritized various unconscious emotions, etc., as we became more intelligent. However, the new, and relatively sudden emergence of the imperative to value survival (or more accurately, death avoidance) so highly could not be compensated by a minor tweaking of our existing irrational behavioral drivers. Self-awareness required a novel strategy in order to overcome the negative selective consequences. That strategy is the topic of the next chapter.

7. Breaking through the wall

Denial ain't just a river in Egypt.
Mark Twain

The most basic principles of evolution by natural selection demand that unfettered self-awareness must be bad for the long term survival of a population. Selection rewards any trait that improves reproductive success, or fitness. Self-awareness will bring about an appreciation of the concept of mortality, and in a rational animal this will lead to behaviors that will maximize survival. Will an intelligent being accept a 10% risk of the cessation of its existence in order to increase its fitness by 20%? Natural selection says to go for it, but this is not what a rational person would do. Reproduction is OK, but not if the price is death.

So, self-awareness poses a new dilemma for evolution, and it is one that demands a novel solution. It is likely that many long-lived, social animals have been bumping against the self-awareness barrier for millions of years. Wild canines, whales and dolphins, and elephants all seem to be close to the line. And if not these, then some of our primate cousins certainly are in the neighborhood. All of these animals could in principle gain advantages from being smarter. Yet, only humans managed to break through the self-awareness wall. This required that we have some special mechanism that could compensate for the potential selective disadvantage encountered when one places too much emphasis on survival purely for the sake of survival (as opposed to reproduction).

How do we deal with the contradictory demands of maximizing both our reproductive fitness and our odds of survival? The answer is quite simple; we just deny our mortality. Despite all rational evidence to the contrary, humans generally don't actually believe that they will die.

Granted, if you were to take a poll and ask people on the street if they anticipated that, someday, they would stop breathing and die, there is a good chance that 100 out of 100 would answer in the affirmative. However, a large majority would also tell you that they didn't believe that this would mean the cessation of their existence. Most humans believe that following their mortal life there is some form of afterlife for their soul. We all agree that death is one of the two certainties (with taxes) of life, but we don't agree on what death implies. Living, breathing immortality is an impractical dream to most, but life ever after is not.

Certainly the most overwhelming evidence for the denial of our mortality is the ubiquity of religion. All cultures have some form of ritualized spiritual beliefs, which may be codified to varying degrees. More formalized religions often provide detailed descriptions of what type of experience one can expect postmortem, complete with rules for attaining entrance to different strata of afterlife society. This can take on wildly different forms. In some religions, one is reincarnated and returned to the earth as a new mortal entity. In others, specific destinations are assigned for life everlasting, depending on how well one behaved in mortal life (often including how much money one might have donated to the Church in question). Some religions are more vague. What all religions share is a mechanism to assuage our need for a continued existence following the cessation of our physiological being - a denial of the finality of death.

When we think of religion our minds typically go directly to the major established religions of the world; Buddhism, Christianity, Hinduism, Islam. Ancient civilizations also practiced different forms of piety, for the same ultimate goal. The Pharaohs of Egypt went to extraordinary lengths in order to provide accoutrements that would serve them on their voyage into the great beyond. Aboriginal peoples throughout the world also have religious or spiritual beliefs that serve the same fundamental purpose. Indeed, if we want to ask when humans, or more accurately our precursors, first reached a level of intelligence that instituted self-awareness, we should look for the earliest dates at which internments are accompanied by ornaments and appliances that suggest a future destination for the spiritual corpse. Here, we are limited by the physical preservation of such sites, as well as one's faith in the interpretive abilities of archeologists, etc. However, this certainly occurred at least 40-50,000 years ago, and most probably well over 100,000 years ago, before humans as we know them existed. This latter supposition is based on studies of internment sites of European Neanderthals, which are an extinct sister group to modern *Homo sapiens*. At this time, there is no way of saying just how far back the practice occurred.

Hand-in-hand with our belief in an afterlife is our need to find a "meaning" for life itself. People want to think that they are "put on the earth" to serve some larger purpose, that they are somehow "part of a grander scheme." Grander than what? Why are we more comfortable thinking that we are pawns of some higher power(s), toying with our lives for his/her/their enjoyment? Because the alternative, that there is no meaning, no scheme, also implies that there is nothing after death. The deep anxiety generated by this latter conclusion has kept mankind searching for the meaning of life for thousands of years, and will continue to do so for the foreseeable future. At least it's steady employment, as there is no indication that the answer will be uncovered any time soon. It requires a lot of faith to find meaning when a happy four-year-old girl is killed by a drunk driver. For the time being, when the happenings of life make no sense we will just have to be satisfied with platitudes such as "God works in mysterious ways," especially for those events that we view as tragic within our limited mortal frame of reference.

No doubt, the reader is now wondering how this explanation can account for atheists. Back when humans thought the earth was flat and infinite, that stars were holes in the dark sky, etc., we didn't have any concept of DNA, cells, and the aspects of physiological life that science has provided. It was easy and even rational to evoke spiritual entities in order to explain the inconceivable complexity of our being, and to connect our consciousness to an undefinable soul that exists beyond our tangible flesh. But now we have a much more sophisticated view of the world and our place in it. Many humans no longer feel the need to accept that a higher being is running the show.

However, just because one does not consciously believe in God(s) does not mean that he/she is not in denial of mortality. First, many individuals possess some sense of spirituality without accepting the formal rigors of an established religion. This essentially constitutes an individual religious construct, and can satisfy the need for immortality of the soul as well as an established religion. But whether one confesses to spirituality or not, there are many who will assert rationally that they believe that death brings an absolute end to existence.

But really, does anyone really practice an absolute secular philosophy 100% of the time? Who among us has not, albeit rarely, made a little unspoken prayer in a time of stress? Virtually all of us have at some time asked that a loved one be granted the ability to survive a medical crisis, win a contest, or some such thing. This is true even when the plaintiff has no firm concept as to the identity of the individual/spirit/deity who is being asked to look upon the situation with favor. You might say, "Yeah, I've done that, but it really didn't mean that I expected someone or something to be listening." Rationally this may be true. But, this behavior is uncovering a deeper spiritual persuasion that lurks in the subconscious. I think that virtually all of us are a little religious (or spiritual, or whatever), whether or not we acknowledge it consciously. It's part of the human condition.

What's that you say? You never, ever entertain the idea that there is more to life and death than the chemistry of your cells. And, you are convinced, at all levels of your being that if you get hit by that semi that that's it, nothing awaits. Well, one might question just how deeply you are in touch with your core, subconscious beliefs. But even if you are correct, and you have found a way to ignore the repercussions of these conclusions so thoroughly that you have found an alternative to religion, you have simply entered an alternate form of denial. If someone contemplated such an existence, and the repercussions of its end, it would lead to constant anxiety, stress, depression, and paralyzing behavior in many ordinary circumstances. Note the caveat that this argument applies only to well adjusted, sane persons. Death anxiety is a disability that afflicts many in the civilized world, and its prevalence is likely to be increased as people become more educated. This is a mental illness that once again illustrates the point that we are not designed to live in the modern, educated world that we have created for ourselves .

Whether overtly religious or not, virtually everyone is willing to risk death, even if the risk is small, in ways that do not make sense in a perfectly rational world. We smoke cigarettes, despite mountains of evidence that there is a significant chance this behavior will lead to premature death. We refuse to wear seat belts, knowing full well that they will increase our chances of survival in an accident; never mind the fact that just getting in the car is dangerous to a degree. We risk fatal disease by practicing unprotected sex. We eat the wrong foods, eat too much food, and don't get enough exercise. We agree, or even volunteer, to become soldiers and fight for our country. It's not just religious or otherwise spiritual people who engage in these activities. Irrational risks are taken by practically everyone, including individuals who would assert that, consciously, they do not believe in an afterlife. Typically, we rationalize these hazards by saying that we are weighing the risks against the benefits, the latter often being that the behavior makes us happy. But is a little happiness worth an increased chance of non-existence in a totally rational assessment? In reality, we often are expecting that it will be someone else who becomes the statistic; another symptom of our capacity for denial. Regardless, these behaviors demonstrate that we are also in denial of the implications of our ultimate mortality; indeed in denial of mortality itself.

The denial of our mortality at a deep level of our being is essentially universal, and is a fundamental quality of being human. But perhaps even more telling than its pervasiveness is the MASSIVE degree of this denial in many people. Consider the basic tenets of Christianity as an example - although almost any major organized religion would do. To be a good fundamentalist Christian requires an unwavering acceptance of a diety that is both merciful and vengeful, omnipotent and created in our own image. Right there are a couple of internal contradictions that should give pause. Of course, one must also accept that most of what we know about the world from science is not true. The earth is not millions of years old. Dinosaurs did not exist. Somewhere in the sky is a place we cannot detect called heaven. Hell is somehow hiding down in the center of the planet. The physical laws that we accept in every other facet of our lives as inviolate do not apply when the hand of God is involved. Of course, no one has actually seen these laws violated recently, but centuries ago someone wrote that they were violated, and so it is true. In short, a good Christian is required at one time or another to deny EVERYTHING that his/her experience in the real world says is true. No problem. If this helps to satisfy the absolute need to believe in our immortality, it's a done deal.

Many people in the modern world have a hard time with this absolute acceptance of the doctrines of fundamentalist religions. They find accomodations that allow them to accept much of modern learning while maintaining their basic faith. This still requires a significant degree of denial of physical reality, it's just a question of scale. As stated by the TV character Gregory House, "Isn't it interesting that religious behavior is so close to being crazy that we can't tell them apart?" Indeed, it is just a matter of context; anyone who denied obvious reality in another guise would certainly be considered a loon. In any case, the fact that so many people accept so much of the physically impossible necessities of established religions speaks volumes to the massive capacity of humanity to exist in a constant state of denial. By comparison, failure to accept the consequences of mortality is relatively trivial.

The attacks on evolution that currently preoccupy many fundamentalists provide an interesting insight into the essential purpose of religion. Over the centuries, the advance of knowledge based on scientific inquiry has created conflicts with various teachings of Christianity. Galileo's persecution by the Catholic Church over the central position of the earth in the cosmos is the most famous of these. In the end, the Church relented, and the Vatican now runs an astronomical observatory. However, people find it more difficult to make compromises between faith-based teachings and science when it comes to evolution. Why is evolution "a line in the sand" from which there can be no compromise? Is it because evolution strikes to the very heart of the reason that people seek religion? One can make an allowance for the solar system as an entity that is described only metaphorically in the Bible without jeopardizing the idea of an afterlife; you just have to travel a bit further now to get to heaven. However, if one accepts the scientific notion of evolution by natural selection, man's uniqueness is threatened, as well as any notion of a higher meaning to life, the immortality of the soul, etc. But this is why we have religion in the first place. Thus, even though the scientific evidence for evolution is every bit as overwhelming as the evidence for the organization of the planets, the latter can be tolerated, but evolution can never be accepted. Of course, some Eastern and Aboriginal religions imbue spiritual qualities to animals or other entities besides humans. One would expect that evolution might be more easily tolerated by these disciplines.

Similarly, people often feel threatened by those who practice religious beliefs different from their own. Indeed, history reveals countless examples where religion has been used as a justification for the slaughter of non-believing infidels, where non-believers are typically defined not as those with no beliefs, but as those with different beliefs. Why is this? Of course, religious affiliation is often used as a convenient proxy for economic or other differences that may make a group feel disadvantaged. But historically religion alone has also successfully incited humans to high levels of animosity, including the launching of killing sprees. Many formal religions require absolute acceptance of their tenets for successful transition to the next life. Perhaps the existence of another possible incarnation of the after-death safety net threatens the reliability of the one on which we have come to rely. If "their" religion has validity, then we are at grave risk. Destroying the practitioners is a way of destroying the threat. Is this why we care so much whether someone follows the same spiritual path that we choose? I don't know, but we do tend to be more tolerant of other, non-religious social and cultural differences of others, especially if they don't directly impinge on our own lives.

Finally, with respect to religion, I feel the need to insert a conciliatory note here. This chapter may come across as an anti-religion polemic - that is not the intent. Self-aware animals require a large dose of mortality denial in order to compensate for the selective disadvantages that accompany the "survival first" mentality. Religion supplies a formal device that can satisfy this requirement. Unfortunately, some of our more popular religions have become large, structured, political and economic entities, that go well beyond the need for which they were initially created. This often leads to religion in general getting a bad rap. Many religions or other spiritual constructions have managed to provide a comfortable degree of denial without being overly intrusive on everyday life. Nor does the acceptance of the central necessity of denial as the driving force for the development of religion prove that there is no God or that all spiritual beliefs are a load of bunk. Science can no more disprove the existence of a higher being any more than it can prove that such an entity is watching over us. We can say with a high level of confidence that many of the teachings of various established religions are faulty. But, evolution does not mean there is no plan, it just puts constraints on what the plan might be. For example, while we have a pretty good idea how life on earth evolved over hundreds of millions of years, no one can say with confidence how life originated. Scientists have done experiments to show how organic life may have been created, but if you want to invoke the metaphysical hand of God in this event, we can't prove you wrong. It seems reasonable to simply accept that spirituality is a denial-essential quality of humanity, and try to make our spiritual sides as congruent with reality as our psyches will permit.

8. The evolution of denial

A man is never more truthful than when he acknowledges himself a liar.
Mark Twain

Up to this point, we have made arguments that are based on fairly firm experimental or logical footings: Natural selection favors traits that will maximize fitness. There is lots of genetic diversity in large populations, apparently enough to elaborate or exaggerate essentially any trait if there is a significant net positive selective force. Positive selection is often balanced by a selective cost, especially as a trait becomes more exaggerated. Being smarter has advantages and disadvantages, but we seem to deal with most of the obvious disadvantages of excessive computational abilities (confusion, obsession) by the development of higher executive functions. Once we reached a certain level of intelligence, we became a lot smarter than anything else very quickly, suggesting that once a specific barrier was breached, there was no significant biological difficulty in becoming smarter. Self-awareness will be accompanied by an appreciation for the repercussions of mortality. This will lead to behaviors that maximize survival over fitness, which is counter selective; this is a barrier that needed to be overcome to allow higher intelligence to evolve. We seem to solve this dilemma by denial of our mortality in various ways, the most obvious being a belief in an afterlife.

BUT, from where did our enormous capacity for mortality denial arise? This is a much more speculative discussion than most of what has come before. But, it's fun to think about, so......

Imagine the time when our ancestors first became intelligent enough to achieve self-awareness, and grapple with the consequences of mortality. These first humans could not say to themselves "Golly, this death thing really sucks. I had better figure out a way to avoid acknowledging its implications, or at least thinking about it any more. Otherwise, I will make decisions that will inhibit my ability to reproduce - not to mention be wracked by anxiety." There are many reasons it wouldn't have happened this way, in addition to the obvious one that sophisticated English had not been invented. First of all, this level of logical analysis would have been a bit much at this stage of the game - we weren't nearly as smart then as we are now. More importantly, evolution does not work this way. You can't evolve a trait after it is required. Fully terrestrial reptiles did not evolve from fish that just decided to flop up onto dry land and have a go at breathing air. A primarily aquatic creature evolved a mechanism to gain oxygen from air in order to supplement its gills, allowing it to take advantage of spells outside of the water. This tactic became more developed over time, permitting greater periods for the exploration of dry land. Eventually, lungs resulted.

Like placing a fish out of water, self-awareness would have presented a sudden challenge, requiring a dramatic adaptation in order to counteract the negative effects of the survival vs. fitness conundrum. One cannot become self-aware, and then later evolve denial of mortality in order to solve the problem. There must be at least some rudimentary degree of denial already in place in the population. This does not necessarily have to reach the massive proportions that our current level of intelligence, and modern religions, now require, but it had to be sufficient to deal with our awakening sense of mortality.

So, denial not only allows us to be smart, but it had to be there waiting for us when we first became smart. When thinking about the frequencies at which events must occur to support evolution, usually quite rare events can suffice. Mutations in any given gene happen at rates of one in many thousands or millions of times that a cell divides. This seems glacially slow, but is more than sufficient to provide the genetic diversity for evolutionary events that take thousands of years. However, even when considering probability on evolutionary time scales, what are the chances that a species will have developed a sufficiently strong capacity for denial independently of its need for deflecting the anxiety attacks of mortality awareness? This was an extremely unlikely event, and probably only occurred once in the history of the globe. The improbability of evolving such denial is the reason that it took so long for any species to become truly intelligent.

If the human brain had to be programmed for denial before becoming self-aware, what was the evolutionary driving force? There is no compelling evidence that can answer this question. It's like the question of how life first arose; we can show possible answers, but we can't say with conviction that this is what actually happened. With respect to denial, there is one especially intriguing scenario that is based on current aspects of human thought and behavior, and which has potentially important implications related to our status as denial generators.

Lets go back a few hundred thousand years, at least. Our ancestors are getting smart enough to be tickling the self-awareness barrier. We live in relatively stable social groups, with established social hierarchies. Individuals can communicate in fairly sophisticated ways; something at least approaching language is developing. Does this need to be more sophisticated than the communicative skills of current primates? I don't know. I suspect that chimps can communicate with one another with more precision than we know; whether this is sufficient for the following scenario is open to debate.

As is true for current humans, in our ancient society there is significant parental investment in the raising and training of children, from both parents. Biologically, eggs are far more valuable than sperm in most animals. That is, reproductive rates for the population are very sensitive to how many eggs mature and are potentially fertilized to become embryos, babies, and the next generation of adults. Sperm, on the other hand, are very cheap, and only a very lucky few will ever find an egg and have a future. This makes mate selection especially critical for females. They not only want a mate who is healthy and has good genes for strength, speed, etc., but they want a good father as well. The supplier of sperm is also going to be a supplier of food, maker of shelter, and teacher to the offspring.

In this intraspecific competitive environment (society), each male will be trying to convince females that he will be a good choice as a mate. He will want to demonstrate good genes for physical traits, excellent abilities as a provider, as well as good intentions with respect to future behavior. Females will be judging the candidates with a careful and suspicious eye. He is desperate to be selected as a mate - it is an event that increases his fitness more directly than almost any other. In this situation, males have been known to puff up their résumés. If it can influence the female favorably, males will even tell lies! Yes, we can see it happen today, and it has been happening for millennia.

This means there will be selection for males who are good liars. They can get the best mates, potentially. Of course, the females don't want to succumb to lies - they want the genuine article. This means that there will also be selection to become good lie detectors, especially among the females. So when it comes to mate selection, there is an arms race. Males will become better and better liars, females will counter by becoming better lie detectors. The effects of these traits on fitness are especially obvious in this example of mate selection, ultimately because of the intrinsic biological inequality of eggs and sperm. However, in a society of animals, any lies that assist in the acquisition of resources will be selected for. And, resources can be tangible entities such as food, or intangibles such as status in the social hierarchy, which lead indirectly to the accumulation of food, shelter, mates, etc.

So, even in a relatively simple society with rudimentary language skills, being a successful liar will improve ones ability to influence others; one will be better able to compete with one's neighbors. It will increase fitness, and be selected for. Conversely, knowing when one is being lied to is also a good thing, and will be selected for. Both of these traits are obviously well developed in any good poker player; at the top level it's what the game is all about. But they are also being used in life in general.

In the lying arms race there is one ultimate weapon; a tactic that can circumvent even the best lie detector. This strategy can fool a champion poker player or the most coy socialite. No matter how subtle your "tells" might be (to use the poker parlance), no one can detect your bluff. How can you lie without ever tipping your hand? You simply believe the lie yourself. If you convince yourself that whatever nonsense you are spouting is actually true, no lie detector can pick up the behavioral or even physiological signs of untruth. This is why actual lie detection machines have no chance against psychopaths. If what you are saying is actually part of your personal reality, there are no abnormal signs that can give you away.

Thus, when competing for resources (especially mates) within even a primitive social framework, there is a selective advantage in making oneself out to be better than reality. It is also advantageous to be able to recognize when a member of the group is being less than honest. However, if one believes his or her own lies to be truth, it is impossible for another to detect even subtle behavioral signs of lying. This will provide a selective advantage for those who develop a controlled capacity for self-deception. Of course, we aren't trying to make a case that becoming a raving psycho is a good thing. Like all traits, there is a cost as well as an advantage. For the cost of self-deception to be tolerable, it must be moderated and channeled in ways that can provide the maximum benefit without paying too much in other ways.

This may all sound a bit far-fetched, but a little reflection on human behavior today indicates that we are pretty good at convincing ourselves of things. In particular, we tend to be influenced by how many times we are told something. Advertisers realize this. Repetition has a remarkable ability to get us to accept ideas as to which car is the best value, which cola tastes the best, etc. Still, the practitioners who take fullest advantage of the power of repetition are governments. As this is written, most Americans still believe that the invasion of Iraq was a legitimate response to the events of 9/11, and that the nonexistent "weapons of mass destruction" are in fact real. Of course, all of the objective evidence is contrary to these beliefs, but the government gives them an air of respectability by constant repetition. And, I have no doubt that many of those in government who make these ridiculous assertions actually believe what they are saying is the truth. They are accomplished liars.

We are particularly susceptible to this type of self-deception when the lie is so attractive that we really want to believe it. For example, politicians are adept at promising simultaneous tax cuts and increased government services. Of course, once enacted the tax cuts frequently are followed by deficits and reduced services. Yet most of the politicians actually believe what they are selling. And, the promises still seem to be effective to varying degrees come election day. This self-deception works at various levels of our consciousness. As anyone who has engaged in heated political arguments can attest, the other guy is clearly deluded in his/her seemingly rational analyses of events. But someone who rationally knows the score can also subconsciously be deceived at a deeper level that still has a profound effect on behavior. We may acknowledge all of the overwhelming statistics, but it's the "other guy" who will be the one to die from cigarette smoking, not us.

Note that it is not just repetition from another source that effectively turns fantasy into reality. We convince ourselves of rationally absurd notions by self-repetition as well; this is the essence of the proposed development of self-deception. To take an example from my own professional experience, researchers can become wedded to theories based on relatively flimsy evidence. One often finds that the more an individual espouses the idea, the harder it is to convince him/her otherwise, even with contradictory experimental evidence. This type of validation by repetition is a far bigger problem in science than is outright experimental fraud. It is also harder to detect, as the proponents of the theory are true believers. Intelligent, educated people are no more or less susceptible to this effect than anyone else; it's an integral part of being human.

In all of this, we have been referring to our development of self-deception as a mechanism to improve our ability to lie, and therefore influence others. This self-deception is just one form of the denial or reality, or can at least develop into more comprehensive denial skills with relative ease. That is, our need to deny the realities of death could have its beginnings in traits that were selected to improve our fitness by making us better liars.

Of course, we can only speculate as to how complex our communication skills were at the critical time, how accomplished we were at deceiving others, and the quality and quantity of self-deception that was useful in this regard. It is not hard to imagine that as we developed the first inklings of the true consequences of death, there was just enough denial in place to put these anxieties aside. Remember, all we had to do was not worry about dying to the point that our intelligence prevented us from doing the things that maximized fitness. This might have been assisted by the fact that many of these things were fun anyway (sex, eating, etc.), since making them so would have selective advantage. As we got a little smarter, and a little more cognizant of death, we were able to ramp up our denial abilities accordingly to divert our anxieties. Now, denial was serving a new selective purpose, and this would change the way it continued to evolve. We became smarter and smarter, and got better and better at denying reality specifically when it suited our purposes.

The hard part was just getting through the early stages, when there had to be enough self-deception in place to support the level of denial that allowed us to do things that were not necessarily in the best interests of our individual survival, as opposed to our survival as a population. Again, this critical event was extraordinarily improbable. Animals probably bumped up against this barrier for millions of years, probably hundreds of millions, before all the traits came together in sufficiently elaborated fashions to allow one species, us, to deflect the fitness costs of real intelligence. And once that happened, we could elaborate our denial ability along with our smarts, eventually reaching the extraordinary heights on both fronts that we currently experience.

Whether or not becoming more accomplished liars was the driving force for the original development of denial, independent of self-awareness, is unknown. What is certain is that we now employ denial to deal with the unthinkable consequences of our mortality. Massive capacity for denial is now a fundamental quality of being human. This has enormous and potentially disastrous consequences for humanity. These will be the subjects of the rest of this book.

9. Too smart for our own good

All you need in this life is ignorance and confidence, and then success is sure.
Mark Twain

We are not just a little bit smarter than our closest animal relatives, we are a lot smarter. As we learn more about other primates, cetaceans, etc., we see that they are capable of much more incisive thinking than was once believed. Still, no other creature can approach the abilities of the human mind. This is obvious in the machines we build, the art we create, and the conventions we construct to organize ourselves into powerful groups for work, play, and war. We generate abstract constructs, and a complex communication system that can convey enormously intricate thoughts or exquisite subtleties. Our brains are outfitted to go well beyond the needs of survival in a competitive world.

We are so much smarter than other animals that our minds seem to be qualitatively different; that is, our brains appear unique in some fundamentally different way. This is why it has been easy for humans to view themselves as the designated curators of the world, with all of the rest of earth's living and nonliving treasures placed here for our benefit. In fact, our uniqueness is quantitative. We were able to break through the self-awareness barrier by fortuitously hitting upon a solution to the survival vs fitness dilemma. Once this was accomplished, there was nothing really to hold us back. Further increases in intelligence, which entailed even more potential costly confusions and obsessions, could be accompanied by the continued development of the compensating executive brain functions. Of course, we also were able to question mortality more definitively as we became smarter. So, in addition to a growing capacity to filter, we also had to continually enhance our capacity for denial.

In contrast to the discrete problem caused by self-awareness, the subsequent challenges to getting smarter and their continuing solutions were similar to the difficulties faced by any animal that is subject to positive selection for intelligence. Thus, although the evolutionary adjustments were gradual in the sense that they took place over generations, once self-awareness was "solved" by denial, increasing intelligence was rapid on an evolutionary scale. We became a LOT smarter very quickly. This is why we seem qualitatively unique, and why "consciousness" seems so special. Consciousness (self-awareness) is special only in that it provided a specific barrier to the evolution of intelligence. But there is no reason to ascribe almost metaphysical properties to consciousness; it is just an emergent property of reaching a certain level of smarts. It doesn't signify a unique quality of our brains, only a more developed capacity for thinking.

So once we were able to deal with our mortality issues related to self-awareness, there was nothing to hold us back. Once the shackles were released we became smart enough to produce more complex language, to write down the knowledge accumulated over a lifetime, and to pass this wisdom on to subsequent generations in an efficient manner. We developed agriculture, cities, machines, and culture.

Cultures and technologies are not static, they also evolve over time. However, the rules for cultural and technological evolution are not the same as for biological evolution. If an animal loses a limb in an accident, its progeny are not born with a missing limb. Biological traits are passed down to subsequent generations only when they derive from the molecular structures of the genes, and these change relatively slowly. On the other hand, if a member of one generation figures out that water can be had from deep in the ground by digging a well, the next generation knows that as well. The same is true when someone invents a steam engine, or a printing press, or devises a game in which players try to score runs by hitting a thrown ball. Acquired "traits" can be incorporated into the technological and cultural heritage of the population immediately. And, any useful trait that is developed by one member of the group can spread throughout the population almost instantly. When one villager figured out how to make fire, this knowledge could be conferred upon everyone in the group. Finally, the parts available for cultural and technological change are not the result of the accidents of random genetic alterations. There is at least some aspect of intelligent design involved, although many might argue that the proliferation of entities like "reality" television shows argues against this.

What all of this means is that cultural and technological evolution in humans proceeds at light speed compared to the slow plod of biological evolution. In biology, major evolutionary changes that occur over ten thousand years are considered blindingly fast. By contrast, one does not need to be a historian to appreciate the incredible pace of the "other" evolutionary forces in our lives; human technology is advancing at a speed that amazes us even in the span of a single lifetime. Automobiles first became relevant just over a century ago; it is now difficult for most of us to imagine life without them. Powered flight was invented in 1903, and within fifty years it became a common, if somewhat special, form of transportation. Today, commercial air travel is almost like catching a bus, and often less comfortable. I may be part of the last generation of Americans who spent more childhood time playing in and experiencing the actual world outside my house, instead of watching it on TV or maneuvering through its representation on a computer screen.

Electricity revolutionized our world, making possible all of the devices that we use daily. Automobiles revolutionized our world, making it trivial to travel daily over distances that previously demanded that we live and work in close proximity. Television revolutionized our world, allowing us to witness the events of the entire world as they happened (as well providing mind-numbing entertainment for the masses). Atomic weapons revolutionized our world, not just with the never-ending threat of annihilation but actually providing some limits on the warfare that could be contemplated by sane leaders (if only humans were generally sane individuals). Commercial jets revolutionized our world, making it much, much smaller. Computers revolutionized our world, allowing us to organize and harness all of the other technologies in ways that never could have been imagined just decades ago. And most recently, the internet has revolutionized our world, making instant communication and information transfer available to virtually every citizen of the developed world. Now, imagine a world without any of these revolutionary innovations. No cars, planes, computers, etc. That would be the world of just over one hundred years ago. It's staggering, really, when you consider how fast things have changed.

Perhaps even more staggering is the realization that things are changing faster now than ever before. Indeed, the rate at which we advance technology has increased relentlessly over the course of time. The difference in human technology between 1900 and 2000 was much greater than the difference between 1800 and 1900, which was greater than the difference between 1700 and 1800, which was greater than the difference between 1600 and 1700, etc. Yes, there may have been hiccups in brief periods of history, but over centuries the rate of technological change has continued to increase, and there is every reason to see that this trend will continue. This is especially obvious in emerging technologies. For example, there has been a general rule that the size of a chip required to contain a constant amount of information is halved every five or so years (with reduced cost as well). So, our computer-based devices become smaller and smaller, until they are limited more by the size of our fingers (for pushing the buttons) than by the electronics of the device. In a related example, it was only a few years ago that we were overjoyed at the idea of having a telephone that didn't have to be connected to a wire! How amazing this was! Now, if our cell phone cannot also send text messages, take photos, show videos and connect to the internet, it is an obsolete toy. And, of course, it has to do all of this without unduly causing a bulge when carried in a pocket.

The incredible pace of technology has created a curious new phenomenon. We now see children teaching adults how to use everyday devices. For example, I'm a reasonably intelligent, well educated person. But if I want to know something about computers, new video equipment, etc., I call one of my kids. Granted, my offspring (each in their twenties) aren't exactly children anymore. However, it's not uncommon to see a 12-year-old instructing a parent on how to install a new application on the hard drive. This sort of thing did not happen very often fifty years ago. We accumulated wisdom and talents and passed these on to our offspring. Today, the skills are changing faster than most of us oldsters can keep up, but the nimble minds of the kids, unfettered by so many obsolete skill sets, soak up the new technologies like little sponges.

It is easy to see that technological change is occurring at a phenomenal pace, and that the rate of change is increasing. However, for the time being at least, our biological evolution remains constrained to proceed at a rate that is limited by the rules of genetics. We are still carrying the evolutionary baggage of biological processes that were selected to enhance the fitness of creatures living thousands of years ago. As discussed in the early part of this book, our physiology is designed for animals with a much shorter useful lifespan, and so as we age we develop cardiovascular disease and cancer. Our behavioral programs were also selected for a different type of society, and so we are stressed by the rapid pace of the lives that we live, surrounded by strangers and crammed into giant cities.

In addition to more classically defined physiological and behavioral processes, our biological history demanded that we be masters of denial. Denial was essential for us to become smart, and it is now an ingrained component of our biological heritage. But we are not still creatures of denial just because biological evolution is slow. As we became smarter and smarter, and better able to probe the depths of mortality with deeper levels of reflection, it was probably necessary for our innate capacity for denial to grow as well. Even if biological evolution could be speeded up, there is no reason to think that we would lose our propensity for denial. Knowing more about the world in general and specifically about the biological workings of living things makes our requirement for mortality denial even greater now than it has ever been. Denial is an essential skill for us to function normally in the world. It is a fundamental property of being human.

Thus, we now have a convergence of qualities that make for potentially combustible times. We are an intelligent race that can develop technologies at a blinding pace. But the intelligence that fuels this technological onslaught demands that we also are saddled with a massive capacity for denial. We have developed nuclear weapons and built them by the thousands, without accepting the inevitability that these will again be unleashed on unsuspecting populations. However, it is increasingly easy to build bombs (even a desperately poor country like North Korea can do it), and thousands of warheads are supposedly being decommissioned or simply neglected, especially in the poorer regions of the former Soviet Union. Can any reasonable person really think that this technology will never fall into the hands of those who are psychologically less stable than the explosive isotopes contained in the weapons? With the advent of global terrorism, we are finally beginning to come to grips with the reality of this possibility. Whether we are being diligent enough at this late date remains to be seen.

Similarly, we now know a considerable amount about how new influenza viruses change genetically so that they can move from animals to humans, creating pandemics that have the potential to kill millions around the world in a matter of weeks. The 1918 Spanish flu was one such event, and it is conservatively estimated to have killed more than 20 million people worldwide. Since at least 1997, we have seen the beginnings of a similar event evolving in the Asian bird flu, and experts concur that it is not a question of if a new killer flu will spread to humans, but when. Fortunately, it has not happened yet, and there is now work to try to develop vaccines or otherwise contain an outbreak. However, considering the likely losses, the effort devoted to this by our leaders is trivial compared to more visible but minor threats. Although both are virtually as certain to occur by a rational analysis, the potential terrorist bombing of an airplane is harder to deny and gets more attention than the next flu pandemic, even though the losses of the former are measured in the hundreds, and those of the latter could be in the hundreds of millions.

Politicians are generally accused of neglecting serious but relatively distant problems, and we typically ascribe this to the relatively short election cycles that drive public policy. If a Congressperson has to face re-election in two years, there is little political capital in asking voters to make sacrifices to prevent a possible disaster that might occur in twenty years. This is certainly a factor, but there is also a much deeper issue. Unless the catastrophe is actually occurring or is obviously imminent, our innate denial mechanisms make it easy to dismiss the issue entirely. It's not a problem, there is no real evidence that it will be a problem, let's not worry about it. Only after planes flew into buildings did we in the United States take the terrorist threat seriously. Perhaps only after bird flu is racing through the human population, leaving a trail of carnage that is without parallel in our history, will we give it the attention it warrants.

Remember, we postulated earlier that denial actually grew out of selection specifically for self-deception, which made us better liars. That is, we are very good at convincing ourselves that what we want to be true will be true. We see this every day as well. To a rational outsider, it is lunacy to think that Iraqis would tolerate a foreign occupation force for very long, even if the majority were not especially fond of the old regime. How dissatisfied would the average American have to be with his/her government in order to support a liberating invasion of Chinese? Yet, our invasion of Iraq was based on the assumption that this is exactly what would happen. Moreover, it was believed that everyone would be so giggly happy with the fall of

Saddam Hussein that all of the ethnic groups in the country would now embrace one another in a common festival of freedom-loving harmony, despite the fact that they had been wanting to kill one another for generations. Were the architects of this policy total idiots? No, they were simply humans, and as such were very good at convincing themselves that what they wanted to believe was actually true. It's a mechanism that we use to get our way. It's who we are.

One related problem is that repetition breeds acceptance. As we mentioned earlier, this is a basic tactic of advertising and propaganda. Most ads do not use data to try to sway the discerning customer. Large corporations know that simply inundating consumers with the contention that their product is the best will generate a subconscious belief that this is in fact true. Pepsi and Coke must be the best colas. Why? Because we see their ads everywhere. Just keeping the name out there is enough to sway buyers. Governments know the same rules, and rely on the maxim that if one repeats something often enough, it starts to become the truth. Unfortunately, when the government repeats something often enough, frequently the government also begins to believe it is true. Yes, you can cut taxes and still get better government services, while not running up a deficit. This is the classic self-deception that makes us good liars. It also then leads to disastrous policies.

Unfortunately, religious doctrine taps into the heart of this basic feature of human nature. Formalized religions are designed for formalized denial of mortality, and once one stimulates our penchant for reality denial, it is relatively easy to add in other policies. One hundred years ago, it made good political sense for the Roman Catholic Church to object to birth control. More Catholic children meant a growing base for the Church. But now, with the world facing numerous crises that have their roots in overpopulation, it is insane to promote an unfettered increase in birth rates. Not only does this cause massive destruction of the natural environment, but the unsustainable growth tends to maintain poverty in overpopulated, underdeveloped countries. But it's Church doctrine, handed down from God (by his human conduits), and so is not to be questioned. Denial of reality is especially trivial when one invokes the word of God. It is easy to see why religion is used so effectively as a motivational tool for political and military purposes.

There is a foreboding sense that the world is becoming a more dangerous place. Calamities on a massive scale seem to be lurking around the corner. Is this real, or simply a byproduct of the information glut that bombards us with horror stories from lands near and far? Unfortunately, it is not an illusion. We became real smart, real fast. Our numbers are increasing at an unsustainable rate, and our technology is galloping ahead at an ever increasing speed. We can destroy cities, countries, and the global environment by the pushing of a few buttons in a few capitals. We can spread a disease pandemic around the world in a matter of days. We are polluting the earth and changing the climate in ways that we can't predict, and likely at some point, can't easily reverse. If we're so smart, why do we continue to sow the seeds for our eventual destruction? Because we are saddled with a brain that is designed by selection to cope with the ultimate disaster (death) by denying that it will occur, and so we treat other impending disasters by denying that they will ever happen. If we can believe in heaven, how hard is it to convince ourselves that global warming is just an inconvenient theory?

Yes, there is a real danger that our rampaging technology will come back to bite us in a very big way, and very soon. But is this inevitable? Maybe yes, maybe no.

10. A tale of two futures.

A. For the pessimist:

**Truth is mighty and will prevail. There is nothing wrong with this, except that it ain't so.
Mark Twain**

As detailed in the last chapter, the world stands today in a precarious position. Our explosive technological advance has seen the creation of thousands of nuclear weapons which, if unleashed on a wide scale, would have devastating consequences for humankind. Many millions would be killed outright, followed by a catastrophic breakdown of society, exacerbated by consequences such as a long lasting nuclear winter. But of course, no sane people would allow such an event to occur. We have constructed many thousands of nuclear warheads, but we don't expect that they will be used for the purpose for which they were deployed.

This is just one example of how the combination of our super-intelligence and massive denial have led to a dangerous world. Less obvious, but in the long term more dangerous, threats result directly or indirectly from technological developments that have permitted us to increase our numbers well beyond the carrying capacity of the natural world. More efficient agriculture permits humans to produce food sufficient to support numbers that would be unthinkable for other animals of our size. Antibiotics and other medical advances also have permitted population numbers to explode. The world is overpopulated already, and is becoming more so at an alarming rate. And although we pay lip service to the resulting problems, we do relatively little to address their root cause. Indeed, many religions continue to promote the unrestrained propagation of their flocks.

One consequence of a large, resource devouring human population is global warming. This is becoming a popular topic of discussion, but few are willing to make the major lifestyle changes necessary to reverse it. The government of the country which is the biggest per capita culprit (the United States) refuses to even admit that it is a problem. Much research indicates that as forests disappear and ice caps melt, etc., there are positive feedback mechanisms that will make warming increasingly difficult to tackle. Perhaps most worrying, there will likely be a "tipping point", after which continued warming may become irreversible no matter what we do. Still, it is more convenient to simply deny the problem.

Other potential disasters are less directly tied to overpopulation. We are using the earth's natural resources at an alarming rate. Oil will become more scarce and costly. Forests are disappearing, especially in the tropics. Clean water is becoming increasingly difficult to secure. Dwindling resources were a problem when only a small part of the world's people were living in developed countries. Now, as the huge populations of other parts of the world aspire to similar levels of resource gobbling (especially now in East and South Asia), the rate of utilization of limited natural resources will increase, as will the rate at which we produce pollutants that poison the globe. And of course, as resources become more limiting the chances become greater that those nasty nuclear weapons will be used in anger.

Increased population density and rapid global transportation also increase the danger from biological pestilence. As we discussed earlier, a new influenza pandemic would now envelop the globe in a matter of days. Even the spread of HIV, which is not especially contagious, has not effectively been contained. Finally, our technology makes it possible for us to construct horrific biological weapons with relative ease. These types of weapons have often been considered impractical, since one cannot easily confine the devastating effects to the target population. For an insane terrorist, confinement may not be much of a concern, and like the influenza pandemic, a properly designed infectious agent could travel the globe in a very short time.

One can easily build a logical argument that our innate denial coupled with our runaway technological achievements virtually guarantees that we are facing global calamities on a scale never before seen. Many different scenarios can be constructed around resource depletion, climate change, disease pandemics, etc., that will lead to a breakdown in modern civilization, war, and human death and suffering on a massive scale. History would suggest that we will not learn any long term lessons from the first one or two of these disasters, in part because of our nemesis denial. Indeed, it is arguable that we are destined ultimately to destroy ourselves as a species. Or, at the very least, that we will continue to cycle between well developed civilization and catastrophic collapse, never reaching a technological state much beyond what we currently enjoy.

Interestingly, the fundamental arguments that got us to this point will be valid for any planet that harbors life. The rules of natural selection, and the fitness vs survival paradox that arises at self-awareness, do not depend on what types of molecules (DNA, proteins, etc.) make up the life forms in question. The generality of deep-seated self-deception (denial) as a solution to the self-awareness problem is less clear, but this may in fact be a universally adopted mechanism. Thus, this pessimistic view of our future, if true, is also general. That is, intelligence at the human level may be a metastable state, wherever it evolves. This is one of the potential solutions to what is often referred to as the Fermi Paradox - the question of why, if there are so many potential planets in the universe (or even the galaxy) that could harbor life, how come we have never seen any hard evidence that our neighbors exist or have visited? It's possible that we are the first or only smart beings to evolve, but it also may be that the solution to the self-awareness paradox (denial) insures that no intelligent beings persist long enough to master long distance space travel of themselves or their machines.

B. For the optimist:

When we remember we are all mad, the mysteries disappear and life stands explained.
Mark Twain

The conclusion that intelligent life is a metastable state is logical, but certainly not incontrovertible. Most of us would prefer to believe that the solution to the Fermi Paradox is that interstellar space travel is simply not practical physically (no, there is no warp drive), that our potential visitors from Starfleet follow the Prime Directive of non-interference in other cultures, or one of the many other possible explanations. Even those of us who agree that human nature and technology are essentially incompatible would like to think that eventually, perhaps after a disaster or two, we will shape up and come to grips with our basic problems.

One can be such an optimist and still accept all of the arguments here about self-awareness and denial. Indeed, it is probably *essential* for our long term success that we embrace the idea that denial is a fundamental part of human nature. For it is only by knowing the enemy that we can consciously change our innate, destructive behavioral tendencies. It is similar to the personality-behavior difference discussed in the context of the nature vs nurture controversy. An alcoholic is not necessarily a drunk. But, in order to avoid this outcome, it is necessary for the alcoholic to acknowledge his/her innate tendencies, and to actively fight the impulses trying to drive a behavior that is satisfying in the short term, but which is self-destructive in the long haul. Just as an alcoholic must sometimes hit a psychological or emotional bottom in order to come to grips with his/her problem, it may require a small nuclear war, or major climactic disruption, in order for us to see the light. We certainly haven't seen it yet, nor have we even acknowledged the underlying trait (denial) that makes it so difficult for us to deal with our critical issues.

Many of our everyday problems have a component of denial, whether it is deciding to stay with a noncommittal or even abusive partner, invest in a risky scheme, or whatever. Those who give advice, professionally or otherwise, can easily recognize the denial component, and advise the subject to escape from this state. What they fail to recognize is that denial is such a fundamental part of us all that one cannot easily just shed its clutches. To continue the alcoholic analogy, we can't abandon denial any more than we can change fundamental personality traits. What we can do is to recognize this trait, and try to manage its deleterious effects, just as the alcoholic manages that disease. Indeed, we don't want to completely escape from our state of denial, even if we could - it's the only thing that keeps us sane in the face of rational mortality. We just need to recognize and manage its pathological consequences. We need psychotherapy on a societal and global scale.

The big question, then, is are we capable of controlling denial sufficiently to solve our current dilemma? Can we create a spiritual construct (individually or as a new formal religion) that can satisfy our acceptance of mortality, without letting it drive our lives and society to oblivion? As always, the first step is recognition of the problem. The next step may require a process that is every bit as unlikely as the convergence of self-awareness and self-deception that allowed us to break through the wall so many years ago. It required hundreds of millions of years for the latter event to occur. We don't have that much time to solve our current dilemma.