A mirror is a strange device. Stand in front of one and what comes back is not the you that you know. Rather, it is you, turned about and shown to you in a crazy literal way. You see the exact reverse of what others see when they look at you. If a photographer hands you a picture (taken in just the right way) of me standing before a mirror, you might have a hard time telling which is the reflection and which is the reality. Mirrors put us off balance by being both literal and subtle at the same time.

When I call our technologies mirrors of ourselves I do not do so lightly. An alien looking at Earth for the first time would certainly seek to know us by gazing upon our reflection in our machines. Indeed, that is what anthropologists do when they examine the alien skeletons of our ancient forebears. Before anthropologists identify a particular primate skull as human, they search the area where they found it for evidence of toolmaking.

The very word technology helps us understand this process. The Greek word τεχνη (or technē) describes art and skill in making things. Τεχνη is the work of a sculptor, a stonemason, a composer, or an engineer. The suffix -logy means the study or the lore of something. Technology is the knowledge of making things. Some people have argued that we should not call our species Homo sapiens, "the wise ones," but rather Homo technologicus, "they who use τεχνη," for that is who we are.
There is more to technology than that. We need our hands by our side and our minds engrossed in work. Our expanded physical capabilities made possible through the use of tools and equipment. We can now navigate through our environment with ease. Our minds are fully engaged in thinking and creating, without the need for physical effort. We must use our tools and equipment wisely. We should not become dependent on them. We must continue to develop our minds and bodies to their fullest potential. We must remember that technology is a tool. It is not a substitute for human intelligence.
It took only a generation or so of planting before the new grain took over. In no time at all, modern wheat dominated the fields. That was both a blessing and a curse. The Natives unwittingly replaced the old wild wheat with a higher-yield crop. But it was a crop that could survive only by their continued intervention. No more lies of the field! From now on we would live better, but we would also be forever bound to this new food by the new technology of agriculture.

And so the technology of farming mirrors the farmer. Humans created farming, and farming made humans into something far different from what they had been. The process was no different than my son's interaction with that primitive computer.

We can see just how deeply this process of mirroring runs through all our technologies (and the sciences that, as we shall see, have been built upon those technologies) if we look at units of measurement. When Protogoras said that "Man is the measure of all things," almost twenty-five hundred years ago, he was closer to literal truth than we might at first think. The gauges and meters we use to measure things usually begin by copying our own senses. All our weights and measures, in some way or another, reflect what we see and feel.

A pound or a kilogram, for example, is roughly the mass of any fairly dense material, like a rock or a piece of metal, that we can hold comfortably in our hand. The inch, foot, yard, and meter all correspond roughly with various body parts. The mile and kilometer also have a meaning that is made clear in parts of rural America where people talk about the distance of a "see." Ask someone in eastern Kentucky how far it is to town and he might say, "Oh, 'bout two sees." He means you should look down the road as far as you can see. Where your vision runs out, you spot, say, an oak tree. You walk to it and look again. There, in the distance, is the town, just two sees away. How far is a see? Of course it varies. But even in flat terrain our ability to make things out usually ends after about a kilometer or, at best, a mile.

We divide thermometers into degrees Fahrenheit or Celsius, and these are roughly the smallest increments of temperature we can feel. We usually know if we have a one-degree fever. We can sense about one volt with our tongue; our ears are sensitive to about one pound per square inch of pressure change; and so on.

The units of a kilowatt or a horsepower represent roughly the power most of us can produce in a short spurt—like running upstairs. By the way, the unit of a horsepower is less than the short-term work of a real horse, but considerably more than a horse can sustain all day long. Not only is the kilowatt or horsepower close to the maximum power you or I can produce in a short burst; it is also the most power we can tangle with without being hurt. They represent about as much energy as the sun pours on us if we lie on the beach at midday, or the rate at which we consume energy when we take a hot shower.

Since we are the basis for most measuring devices, science reflects the world in human terms. But that is not really so bad. Most scientists know perfectly well that science has not yet reached ultimate truth of any sort. The work of science nevertheless yields constructs that make our experiences predictable. Today's science-based engineering obviously has to mirror human needs and human nature. And so does science itself.

Still, the immediate reflection of our own bodies in the physical measures that we use every day leaves us struggling at each turn to see more objectively—to shake off human limitations. The magnitude of that problem emerges when we pose a deceptively simple question, "Should we regard a certain object as big or small?" To answer, we instinctively refer to the size of our own body. We understand size on the scale we experience it, and we can be surprised by how differently an object will behave when it is much larger or smaller than our bodies.

To see what I mean, you might try this experiment: First find a very large metal sphere and a very small one—say, the big steel ball used in the shot put and a BB. Now drop each from a height of a few feet into a swimming pool. You will see that the shot splash is not at all like a scaled-up BB splash. The large shot sends out a sheet of water that breaks into a fine spray of drops. There are only a few drops in the BB splash. In fact, that's how we know whether the naval battle in a movie is a scale model or footage from a real battle. The splashes look wrong in the scale model.

I once knew a badly crippled construction worker. He had been working on the ledge of a building that was being demolished when he saw a two-ton scoop swinging toward him—very gently, very slowly. He put out his hands to stop it as he might have stopped a child on a swing, and when it reached him, it very gently crushed him. His experience with playground swings had grievously misled him about the behavior of two-ton scoops.
Engineers think a lot about making scale models of big prototypes. We would not get very far if we had to make full-size wind tunnel tests of a Boeing 747. The trick is to set the conditions in a small model so that its behavior is similar to the large prototype. We really want to use a BB experiment to learn what a large shot does when it hits water if we changed two things. The BB would have to move much faster than the shot, and we would have to put just the right amount of detergent in the water to cut its surface tension.

The forces that dominate this process (inertia, gravity, and surface tension) all vary in different ways with size. The theory of modeling tells how to stretch the dimension of the relevant variables into universal values. When we do that, surprising things happen. Suppose, for example, that we want to scale up instead of scaling down. Suppose we want to study the movement of microorganisms in our body fluids using laboratory experiments in the visible world. Modeling theory tells us we can do this if we stretch time and magnify liquid resistance. We can replicate the motions of blood cells or spermatozoa by moving large models of these organisms very slowly through cold honey.

Sir George Cayley, born in 1773 in Yorkshire, came to a remarkable insight about scaling physical phenomena when he was a young man trying to solve the age-old riddle of human flight. Cayley made a number of key discoveries, but none was more surprising than his realization that trout have the ideal, minimum-resistance, body shape for an airplane. Why a trout and not a bird? It is because the flow of water around a fish and the flow of air around a bird of the same size are very different. A century later we had the rules of dynamic similitude. They show that when we scale the interactions of viscous and inertial forces, a small fish in water moves far more like a large machine in the air, than a small bird in the air does. That’s why the design of subsonic airplanes eventually settled on a shape far more like fish than birds. Our machines still mirror our experience, but now that experience is tempered by scientific theory.

So the problem of modeling is one part of a general problem we face whenever we design things. We have to find ways to see what is not obvious to our eyes. We have to find ways to predict complicated behavior before it becomes part of our experience. Our modern systems of weights and measures evolved as scientific instruments gave increasing precision and definition to measurement. However, technology reached high levels of sophistication long before we had any such apparatus.

My grandmother used to tell me that if I burned my finger, I should dip it in a cup of tea. She knew that before doctors knew anything about the healing power of the tannic acid in tea. My grandmother’s finely honed intelligence was in no way lessened by the fact that she’d never studied organic chemistry.

Take the ancient technology of Japanese sword making, which reached an astonishing perfection twelve hundred years ago. A samurai sword is a wonderfully delicate and complex piece of engineering. The steel of the blade is heated, folded, and beaten, over and over, until the blade is formed by 17,768 layers, forge-welded to one another. Each layer is 0.0001 inch thick. All that work was done to very accurate standards of heat treatment. The result was an obidian-hard blade with willowlike flexibility.

The blades represented a perfection of production standards that has yet to be matched by modern quality control. The Japanese craftsmen who made them knew nothing about temperature measurement or the carbon content of steel. How do you suppose they got it right, again and again? The answer is one we are well advised to remember. Sword making was swathed in ceremony and ritual. It was consistent because the ceremony was precise and unvaried. Heat-treating temperatures were controlled by holding the blade to the color of the morning sun. The exact hue was transmitted from master to apprentice through the centuries. Sword making was a part of Japanese art, and it was subsumed into Japanese culture.

That form of quality control was not unique to the Japanese. It was true of eighteenth-century violin making and it is still true in other older technologies that survive today. Ritual can do much of what we do with weights and measures. Our intelligence, after all, runs deeper than our ability to read gauges. Great technologies arise out of a full range of experience. They come from creativity triggered by more than tables of technical data. Good technology is not independent of culture. The best
doctor knows organic chemistry as well as his grandmother's folklore. The best metallurgist knows about iron-carbon phase diagrams but can see those diagrams in the light of a bright yellow-orange blade emerging from the forge.

Years ago I worked for a seasoned design engineer. One day he looked at a piece of equipment and said, "Look at that heavy gear running on that skinny shaft. Some designer didn't use his eyes." The best engineers know math, physics, and thermodynamics, but they also know the world they live in. The best engineers bring a visceral and human dimension to the exacting math-driven, science-based business of shaping the world around us. The machines they produce therefore mirror themselves.

The easiest place to see the mirror of technology is in the language we use to talk about our technologies. The words science, technology, and engineering take a terrible beating. Who makes a spaceship fly—a scientist, a technologist, or an engineer? Who should shoulder the blame if it fails? These questions are easier to answer if we really understand what the words mean.

The word science comes from the Latin word scientia, which means "knowledge." We apply the word science to ordered or systematic knowledge. A scientist identifies what is known about things and puts that knowledge into some kind of order.

We have noted that the word technology combines the Greek word technē (combined art and skill) with the ending -ology (the lore or the science of something.) In its role as the science of making things, technology stands apart from the actual act of glassblowing or machining. It is the ordered knowledge of these things. It is also its instinct for sharing our knowledge of technique. Our language would be a lot clearer if we could reclaim the old Greek word technē and restrict its use to describing the actual act of making things.

The last of the three words, engineering, comes from the Latin word ingeniōnum. That means "intellectual power." English is full of words related to ingenium: ingenuity, which means "inventiveness," and engine, which can refer to any machine of our devising—any engine of our ingenuity. So an engineer, first and foremost, devises machines. For about three hundred years science and technē have joined forces. We talk more about that in chapter 5. Today's engineers are technologists who are well schooled in science and can make effective use of it when they try to create the engines of their ingenuity.

Which of the three, scientist, technologist, or engineer, deserves the credit for the success, or blame for the failure, of a spaceship? The answer, of course, is that the question is no good. The three functions of technē, science, and invention work together to make a spaceship. Engineers combine these functions. One engineer might behave more like a craftsman—a user of technē—while another might behave more like a scientist, refining background information for designers. But people earn the title engineer when the goal of their labors is the actual creative design process—when they combine a knowledge of technē with science to achieve invention.

Look further at words, at the way we name our machines. A machine normally receives its permanent name only after it has achieved a certain level of maturity—or after it has settled itself into our lives. Take the airplane. A hundred years ago, we had dozens of terms to describe it: aerial velocipede, aerial screw machine, air-o-matic engine, bird machine, and flying machine. Most of these names vanished ten years after the Wright brothers flew. Now we have settled on just two terms, airplane and aircraft.

No one I knew had a refrigerator when I was little. We had an icebox with a rack on top where we put a new fifty-pound block of ice every few days. I still forget, and annoy my sons, by calling our refrigerator an icebox. During the 1900s we tried all kinds of terms for the new machine—Prigodaire, electric icebox, and of course refrigerator.

The words engine and machine show up repeatedly when devices are first named. They are from Latin and Greek roots and broadly refer to devices that carry out functions. The steam engine was first called a fire engine, and it still keeps the engine part of its name. We still say sewing machine, but no one calls a telescope an optical engine anymore (as they did in the seventeenth century). I especially like the name Babbage gave his first programmable computer in the early eighteenth century. He
called it an *analytical engine*. Software packages for checking programs were called *paring engines* long before another engine word attached itself to computers: the now-common term *search engine*.

Foreign names stick to new gadgets for a while, but they tend to fade. Airplane designers have moved away from the French words *empannage*, *fuselage*, and *nacelle* in favor of the English equivalents: *tail*, *body*, and *pod*. The German name *spinnerei* was given to one form of what the French call a *dirigible*. Nowadays we are increasingly inclined to use the English word *airship*. We call a writing desk an *excruciate* only when we want to run up its price. The first names we give new technologies often tie them to older ones. An early name for the first airships was *aerial locomotive*: railway passengers still ride in *coach*, and airplane passengers pay *coach fares*.

Finally, a game we all might play: Over the next decade, track the changing computer-related names. Watch as we run through words such as *screen*, *CRT*, and *monitor*, or *Internet* and *Web*. Watch us select among names like *microcomputer*, *PC*, *workstation*, or simply the *machine*. Watch as those systems become metaphors for who we are. When we finally settle on names, what we shall really be doing is taking the machine fully into our lives.

Thus far, I have described the mirror of our technology in fairly objective terms, but technology lies too close to the human heart to be dealt with in such a straightforward way. The mirror reflects aspects of our nature that are not immediately obvious to ourselves. I can clarify my meaning here by asking yet another question: What is the oldest human technology?

Farming developed late in human history. Before farming, settled herdsmen and gatherers made clothing, knives, tents, and spears, but so did nomads before them. Go back farther: Archaeologists show us that pictures and music were among the Stone Age technologies. Magnificent cave paintings have survived since the beginning of the Upper Paleolithic period—at least twenty-five thousand years ago. Along with them we found evidence of rattles, drums, pipes, and shell trumpets. Even the Bible, the chronology of the Hebrew tribes, identifies the making of musical instruments as one of three technologies that arose in the seventh and eighth generations after Adam.

Music is clearly as old as any technology we can date. Couple that with the sure knowledge that whales were composing complex songs long before we walked this earth—that the animal urge to make music precedes technology—and I offer music making as my candidate for the oldest technology.

The societies with the least technology still make sophisticated music. Song, dance, musical instruments, and poetry are central to ancient Australian Aborigine culture. Music is the most accessible art and, at the same time, the most elusive. In almost any age or any society, music making is every bit as complex as other technologies. But our own experience tells us as much as archaeology does. Experience tells us that music is primal. It is not just a simple pleasure. Jessica says to Lorenzo in Shakespeare's *Merchant of Venice*: "I am never merry when I hear sweet music." Lorenzo replies,

The reason is your spirits are attentive,

The man that hath no music in himself,

Is fit for treasons,",

And we know what he means! If we cannot respond to art, to music, then something is missing and we are fit for treasons. Music helps us understand the human lot. Music is as functional as any worthwhile technology. Its function is to put reality in terms that make sense. That means dramatizing what we see—transmuting it into something more than is obvious. Poet Wallace Stevens wrote:

They said, "You have a blue guitar,

You do not play things as they are."

The man replied "Things as they are

Are changed upon the blue guitar."

The blue guitar—music, or any art—does change reality. It turns the human dilemma around until we see it in perspective. Sometimes it takes us through grief and pain to do that, disturbing us at the same time it comforts us. But it serves fundamental human need. So it is no coincidence that the technologies for creating art, and music in particular, preceded all else.

Those subjective factors are always at work, shaping technologies to serve us best—shaping them to serve more elemental needs than are evident. The reason technology is impossible to predict is that our pre-
Hearst's Lighthouse: built on a stilted frame of these former ships. The ship's handsome, wooden masts were replaced with steel. The building was divided into a living quarters for the lighthouse keepers and a lookout tower. The tower was reached by a spiral staircase inside a cylindrical steel framework.

The lighthouse was lit by a large, iron lantern that contained a phosphorescent substance that glowed for hours after the kerosene fuel was extinguished. This allowed the tower to be seen from a great distance, even on hazy days. The tower was lifted from the ground by a crane and then raised into place, a testament to the engineering skills of the time.

The lighthouse was operational by 1874, and it remained a vital navigational aid for ships for over a century. It was finally deposed in 1975, when a new, automated system was installed.

The lighthouse's legacy continues to this day. The tower and the associated buildings are now part of a historic site, visited by thousands of tourists each year. The lighthouse itself has been restored and is open to the public, allowing visitors to climb the tower and experience the same views that were enjoyed by ships' captains hundreds of years ago.

As early as the 19th century, lighthouses were being built in the United States. The first lighthouse in the country was completed in 1737 on Cape Henlopen, Delaware. The lighthouse was built by a local shipowner and was used to guide ships around the swampy area.

Over the years, lighthouses became symbols of national pride and technological advancement. They were built in all parts of the country, from the East Coast to the West Coast, and were a source of fascination and wonder to those who saw them. Today, lighthouses continue to be an important part of American history and culture.
A confusion of design schools was compounded with each other in the study of architecture. It was a time of great excitement and a time when the world was being rebuilt after World War II. The International Style was the dominant architectural style of the time, and it was characterized by simplicity, functionalism, and a focus on form and function. The International Style was influenced by the work of Le Corbusier, who was known for his influential theories on modern architecture. His ideas were widely adopted and became the foundation for many of the buildings that were constructed during this period.

The International Style was not without its critics, however. Some argued that it was too focused on form and function at the expense of beauty and craftsmanship. Others believed that it was too focused on the needs of the machine and not enough on the needs of the people. Despite these criticisms, the International Style had a profound impact on the development of modern architecture and continues to influence design to this day.
thing itself. These were not just artist's creations. Torrance had written the rules of nature and then let the computer obey those rules. In a sense, he had told the computer how to re-create the actual living of nature.

Of course, it is not easy to parse reality into the language of computers. Yet when we do, the results are not just stunning, they are disorienting as well. Students of fluid flow struggle to make their computers tell them how fluids move over airfoils, through tubes, past turbine blades. As computers replicate the tortuous swirls of water and air in slow-motion, on a computer screen, we sometimes wonder whether we are seeing reality or the imaginings of a lunatic.

By now, the science of computer graphics has moved far ahead and we see stunning machine-generated realities on movie screens or even on our computer monitors. Today's scientists can do many experiments more accurately within the computer than in the laboratory. Yet some computer modeling is terribly deceptive. Its seeming accuracy can miss features that would have been revealed in the laboratory. In either case, as the computer's role expands, we users adopt the language of people dealing with real things. We speak of doing "numerical experiments" when we isolate processes on the machine instead of in the laboratory. We can be disarmingly casual about separating computer and laboratory data. The computer takes a larger and larger role as a partner in human decision making.

We no longer can be sure who created the picture we are looking at: an artist, a camera, or a computer. The computer can replicate the sound of a concert grand piano and fool me into thinking that I hear a live person playing a real instrument. As the computer speaks to our senses as well as to our intellects, we start to have trouble finding the line between realities of the machine and realities outside it.

Machines mirror our lives. Our lives mirror our machines. We've seen how devices change us. Machines extend our reach and take us where our legs cannot. They amplify our voices. They even give us wings.

I talk about machines extending our bodies because that is the way they touch us so powerfully. But replacing our legs with an automobile, or our backs with a forklift, is nothing compared to what computers do. They sit right beside our brains and assume a kind of partnership practically inside our heads. Our relations with machines have always been personal, but with our computers they are terrifyingly so. Just how personal has come home to me in a very real way in recent years.

Between 1983 and 1988 I wrote everything on my first word processor—papers, talks, letters, and two books, well over a million words of finished copy and several times that in discarded drafts. Imagine, if you can, my intimacy with that machine when, after five years, it became clear that it had grown obsolete. By then it held my thoughts and was giving them back to me. But time had now passed it by.

I had no choice but to buy a flashy new computer. Once I did, it worked diligently to further change me. It had ten times the memory of the old machine, two hundred times the storage capacity. It had a colorful new screen. It thought with blinding speed. Now it played chess and Othello with me. It handled several manuscripts at the same time, corrected my spelling, indexed my texts, and tended my files and addresses. It suggested better words for me to use. By the time I was done with the second computer and moved on to a third one with ten or a hundred times more capacity, the second one still held countless surprises I had yet to discover.

By now I had realized that each of those new computers knew all the tricks of behavior modification. If I said the wrong thing, the machine stopped talking to me and feigned ignorance. It confided its secrets to me only if I said just the right words to it. During the first month each new computer has kept me on the rack, rewarding me now and then by tossing me a new bone.

After a month, the transition begins to complete itself. The new machine is not yet the comfortable old shoe that the one before it had become. But it gets there, and its way of getting there is by changing me. It is in the transition from one machine to another that we come to appreciate their power in our lives. Do you remember your first bike or the first car you drove? Think back for a moment. That bike was like a flying carpet. It changed you, irrevocably.

People often ask, "Do these transitions occur for good or ill?" But that's not very helpful, because machine making is an inseparable part of us. We are mirrored by our machines, and the corollary is also inseparable. We mirror our machines. The question is not whether we should let them change us, but whether we are to be lifted up or dragged down in the process. That issue hovers over the rest of what follows as we talk about technology and its place in our lives.