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Ch.1-4

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My Question

For most of my life I owned very little. I dropped out of college and for almost a decade wandered remote parts of Asia in cheap sneakers and worn jeans, with lots of time and no money. The cities I knew best were steeped in medieval richness; the lands I passed through were governed by ancient agricultural traditions. When I reached for a physical object, it was almost surely made of wood, fiber, or stone. I ate with my hands, trekked on foot through mountain valleys, and slept wherever. I carried very little stuff. My personal possessions totaled a sleeping bag, a change of clothes, a penknife, and some cameras. Living close to the land, I experienced the immediacy that opens up when the buffer of technology is removed. I got colder often, hotter more frequently, soaking wet a lot, bitten by insects faster, and synchronized quicker to the rhythm of the day and seasons. Time seemed abundant.

After eight years in Asia, I returned to the United States. I sold what little I had and bought an inexpensive bicycle, which I rode on a 5,000-mile meander across the American continent, west to east. The highlight was gliding through the tidy farmland of the Amish in eastern Pennsylvania. Amish communities were the closest thing I could find on this continent to the state of minimal technology I had experienced in Asia. I admired the Amish for their selective possessions. Their unadorned homes were square bundles of contentment. I felt my own life, unencumbered by fancy technology, was in parallel to theirs, and I intended to keep technology in my life to a minimum. I arrived on the East Coast owning nothing but my bicycle.

Growing up in suburban New Jersey in the 1950s and 1960s, I was surrounded by technology. But until I was 10, my family had no television, and when it did arrive in our household, I had no appetite for it. I saw how it worked on my friends. The technology of TV had a remarkable ability to beckon people at specific times and then hold them enthralled for hours. Its creative commercials told them to acquire more technologies. They obeyed. I noticed that other bossy technologies, such as the car, also seemed to be able to get people to serve them, and to prod them to acquire and use still more technologies (freeways, drive-in theaters, fast food). I decided to keep technology to a minimum in my own life. As a teenager, I was having trouble hearing my own voice, and it seemed to me my friends' true voices were being drowned out by the loud conversations technology was having with itself. The less I participated in the circular logic of technology, the straighter my own trajectory could become.

When my cross-country bike ride ended, I was 27. I retreated to an out-of-the-way plot of cheap land in upstate New York with plenty of woods and no building codes. With a friend, I cut down oak trees to mill into lumber, and with these homemade beams we erected a house. We nailed each cedar shake onto the roof one by one. I have vivid memories of hauling hundreds of heavy rocks to build a retaining wall, which the overflowing creek tore down more than once. With my own hands I moved those stones many times. With yet more stones we assembled a huge living-room fireplace. Despite the hard work, those stones and oak beams filled me with Amish contentment.

But I was not Amish. If you were going to cut down a huge tree, I decided, it was a good idea to use a chain saw. Any forest tribesman who could get his hands on one would agree. Once you gain your voice around technology and become more sure of what you want, it becomes obvious that some technologies are simply superior to others. If my travels in the old world had taught me anything, it was that aspirin, cotton clothing, metal pots, and telephones are fantastic inventions. They are *good*. People everywhere in the world, with very few exceptions, grab them when they can. Anyone who has ever held a perfectly designed hand tool knows that it can lift your soul. Airplanes had stretched my horizons; books had opened my mind; antibiotics had saved my life; photography had ignited my muse. Even the chain saw, which can cleanly slice through knotty burls too tough for a hand ax, had instilled in me a reverence for the beauty and strength of wood no other agent in the world could.

I became fascinated by the challenge of picking the few tools that might elevate my spirit. In 1980 I freelanced for a publication (the *Whole Earth Catalog*) that used its own readers to select and recommend appropriate tools picked out of the ocean of self-serving manufactured stuff. In the 1970s and '80s, the *Whole Earth Catalog* was, in essence, a user-generated website before the web, before computers, employing only cheap newsprint. The audience were the authors. I was thrilled by the changes that simple, well-selected tools could provoke in people's lives.

At the age of 28, I started selling mail-order budget travel guides that published low-cost information on how to enter the technologically simple realms most of the planet lived in. My only two significant possessions at the time were a bike and sleeping bag, so I borrowed a friend's computer (an early Apple II) to automate my fledgling moonlight business, and I got a cheap telephone modem to transmit my text to the printer. A fellow editor at the *Whole Earth Catalog* with an interest in computers slipped me a guest account that allowed me to remotely join an experimental teleconferencing system being run by a college professor at the New Jersey Institute of Technology. I soon found myself immersed in something altogether bigger and wilder: the frontier of an online community. It was a new continent more alien to me than Asia, and I began to report on it as if it were an exotic travel destination. To my immense surprise, I found that these high-tech computer networks were not deadening the souls of early users like me; they were filling our souls. There was something unexpectedly organic about these ecosystems of people and wires. Out of complete nothingness, we were barn-raising a virtual commonwealth. When the internet finally came along a few years later, it seemed almost Amish to me.

As computers moved to the center of our lives, I discovered something I had not noticed about technology before. In addition to technology's ability to satisfy (and create) desires, and to occasionally save labor, it did something else. It brought new opportunities. Right before my eyes I saw online networks connect people with ideas, options, and other people they could not possibly have met otherwise. Online networks unleashed passions, compounded creativity, amplified generosity. At the very cultural moment when pundits declared that writing was dead, millions began writing online more than they ever had written before. Exactly when the experts declared people would only bowl alone, millions began to gather together in large numbers. Online they collaborated, cooperated, shared, and created in myriad unexpected ways. This was new to me. Cold silicon chips, long metal wires, and complicated high-voltage gear were nurturing our best efforts as humans. Once I noticed how online computers stirred the muses and multiplied possibilities, I realized that other technologies, such as automobiles, chain saws, biochemistry, and yes, even television, did the same in slightly different ways. For me, this gave a very different face to technology.

I was very active on early teleconference systems, and in 1984, based on my virtual online presence, I was hired by the *Whole Earth Catalog* to help edit the first consumer publication that reviewed personal computer software. (I believe I might have been the first person in the world hired online.) A few years later, I got involved in launching the first public gateway to the emerging internet, an online portal called the Well. In 1992, I helped found *Wired* magazine—the official bullhorn of digital culture—and curated its content for its first seven years. Ever since, I've hung out on the cusp of technological adoption. My friends now are the folks inventing supercomputers, genetic pharmaceuticals, search engines, nanotechnology, fiber-optic communications—everything that is new. I see the transforming power of technology everywhere I look.

Yet I don't have a PDA, a smartphone, or Bluetooth anything. I don't twitter. My three kids grew up without TV, and we still don't have broadcast or cable in our home. I don't have a laptop or travel with a computer, and I am often the last in my circle to get the latest must-have gadget. I ride my bike more often than I drive these days. I see my friends leashed to their vibrating handhelds, but I continue to keep the cornucopia of technology at arm's length so that I can more easily remember who I am. At the same time, I run a popular daily website called *Cool Tools*, which is a continuation of my long-ago *Whole Earth* job evaluating select technology for the empowerment of individuals. A river of artifacts flows through my studio sent by vendors hoping for an endorsement; a fair number of those artifacts never leave. I am surrounded by stuff. Despite my wariness, I have chosen to deliberately position myself to keep the maximum number of technological options within my reach.

I acknowledge that my relationship with technology is full of contradictions. And I suspect they are your contradictions, too. Our lives today are strung with a profound and constant tension between the virtues of more technology and the personal necessity of less: Should I get my kid this gadget? Do I have time to master this labor-saving device? And more deeply: What *is* this technology taking over my life, anyway? What is this global force that elicits both our love and repulsion? How should we approach it? Can we resist it, or is each and every new technology inevitable? Does the relentless avalanche of new things deserve my support or my skepticism—and will my choice even matter?

I needed some answers to guide me through my technological dilemma. And the first question I faced was the most basic. I realized I had no idea what technology really *was*. What was its essence? If I didn't understand the basic nature of technology, then as each new piece of it came along, I would have no frame of reference to decide how weakly or strongly to embrace it.

My uncertainty about the nature of technology and my own conflicted relationship with it sent me on a seven-year quest that eventually became this book. My investigations took me back to the beginning of time and ahead to the distant future. I delved deep into technology's history, and I listened to futurists in Silicon Valley, where I live, spin out imaginative scenarios for what will come next. I interviewed some of technology's fiercest critics and its most ardent fans. I returned to rural Pennsylvania to spend more time with the Amish. I traveled to mountain villages in Laos, Bhutan, and western China to listen to the poor who lack material goods, and I visited the labs of rich entrepreneurs trying to invent things that everyone will consider essential in a few years.

The more closely I looked at the conflicting tendencies of technology, the bigger the questions became. Our confusion over technology usually starts with a very specific concern: Should we allow human cloning? Is constant texting making our kids dumb? Do we want automobiles to park themselves? But as my quest evolved, I realized that if we want to find satisfying answers to those questions, we first need to consider technology as a whole. Only by listening to technology's story, divining its tendencies and biases, and tracing its current direction can we hope to solve our personal puzzles.

Despite its power, technology has been invisible, hidden, and nameless. One example: Since George Washington delivered the first State of the Union address in 1790, every American president has presented to Congress an annual summary of the nation's condition and prospects and the most important forces at work in the world. Until 1939, the colloquial use of the term *technology* was absent. It did not occur twice in a State of the Union address until 1952. Surely my grandparents and parents were surrounded by technology! Yet for most of its adult life, our collective invention did not have a name.

The word *technelogos* is nominally Greek. When the ancient Greeks used the word *techne*, it meant something like art, skill, craft, or even craftiness. *Ingenuity* may be the closest translation. *Techne* was used to indicate the ability to outwit circumstances, and as such it was a trait greatly treasured by poets like Homer. King Odysseus was a master of *techne*. Plato, though, like most scholarly gentlemen of that era, thought that *techne*, which he used to mean manual craftwork, was base, impure, and degraded. Because of his contempt for practical knowledge, Plato omitted any references to craft in his elaborate classification of all knowledge. In fact, there's not a single treatise in the Greek corpus that even mentions *technelogos*—with one exception. To the best of our knowledge, it was in Aristotle's treatise *Rhetoric* that the word *techne*

was first joined to *logos* (meaning word or speech or literacy) to yield the single term *technelogos*. Four times in this essay, Aristotle refers to *technelogos*, but in all four instances, his exact meaning is unclear. Is he concerned with the "skill of words" or the "speech about art" or maybe a literacy of craft? After this fleeting, cryptic appearance, the term *technology* essentially disappeared.

But of course, technology did not. The Greeks invented iron welding, the bellows, the lathe, and the key. Their students the Romans invented the vault, the aqueduct, blown glass, cement, sewers, and water mills. Yet in their own time and for many centuries thereafter, the totality of all that was manufactured was virtually invisible—never discussed as a distinct subject, apparently never even contemplated. Technology could be found everywhere in the ancient world except in the minds of humans.

In the centuries following, scholars continued to call the making of things *craft* and the expression of inventiveness *art*. As tools, machines, and contraptions spread, the work performed with them was termed the "useful arts." Each useful art—mining, weaving, metalworking, needlework—had its own secret knowledge that was passed on through a master/apprentice relationship. But it was still an *art*, a singular extension of its maker, and the term retained the original Greek sense of craft and cleverness.

For the next thousand years, art and technique were perceived as distinctly personal realms. Each product of these arts, whether an ironwork fence or an herbal formula, was considered a unique expression derived from the particular cleverness of a particular person. Anything made was a work of solitary genius. As the historian Carl Mitcham explains, "Mass production was unthinkable to the classical mind, and not just for technical reasons."

By the European Middle Ages, craftiness manifested itself most significantly in a new use of energy. An efficient horse collar had disseminated throughout society, drastically increasing farm acreage, while water mills and windmills were improved, increasing the flow of lumber and flour and improving drainage. And all this plentitude came without slavery. As Lynn White, historian of technology, wrote, "The chief glory of the later Middle Ages was not its cathedrals or its epics or its scholasticism: it was the building for the first time in history of a complex civilization which rested not on the backs of sweating slaves or coolies but primarily on non-human power." Machines were becoming our coolies.

In the 18th century, the Industrial Revolution was one of several revolutions that overturned society. Mechanical creatures intruded into farms and homes, but still this invasion had no name. Finally, in 1802, Johann Beckmann, an economics professor at Gottingen University in Germany, gave this ascending force its name. Beckmann argued that the rapid spread and increasing importance of the useful arts demanded that we teach them in a "systemic order." He addressed the techne of architecture, the techne of chemistry, metalwork, masonry, and manufacturing, and for the first time he claimed these spheres of knowledge were interconnected. He synthesized them into a unified curriculum and wrote a textbook titled *Guide to Technology* (or *Technologie* in German), resurrecting that forgotten Greek word. He hoped his outline would become the first course in the subject. It did that and more. It also gave a name to what we do. Once named, we could now see it. Having seen it, we wondered how anyone could not have seen it.

Beckmann's achievement was more than simply christening the unseen. He was among the first to recognize that our creations were not just a collection of random inventions and good ideas. The whole of technology had remained imperceptible to us for so long because we were distracted by its masquerade of rarefied personal genius. Once Beckmann lowered the mask, our art and artifacts could be seen as interdependent components woven into a coherent impersonal unity.

Each new invention requires the viability of previous inventions to keep going. There is no communication between machines without extruded copper nerves of electricity. There is no electricity without mining veins of coal or uranium, or damming rivers, or even mining precious metals to make solar panels. There is no metabolism of factories without the circulation of vehicles. No hammers without saws to cut the handles; no handles without hammers to pound the saw blades. This global-scale, circular, interconnected network of systems, subsystems, machines, pipes, roads, wires, conveyor belts, automobiles, servers and routers, codes, calculators, sensors, archives, activators, collective memory, and power generators—this whole grand contraption of interrelated and interdependent pieces forms a single system.

When scientists began to investigate how this system functioned, they soon noticed something unusual: Large systems of technology often behave like a very primitive organism. Networks, especially electronic networks, exhibit near-biological behavior. Early in my online experience I learned that when I sent out an e-mail message, the network would cut it up into pieces and then send those bits along more than one pathway to the message's final destination. The multiple routes were not predetermined but "emerged" depending on the traffic of the whole network at the instant. In fact, two parts of the e-mail might take radically different pathways and then reassemble at the end. If a bit got lost along the way, it was simply re-sent along different routes until it arrived. That struck me as marvelously organic—very much like the way messages in an anthill are sent.

In 1994, I published a book called *Out of Control* that explored at length the ways in which technological systems were beginning to mimic natural systems. I cited computer programs that could duplicate themselves and synthetic chemicals that could catalyze themselves—even primitive robots that could self-assemble, just as cells do. Many large, complex systems, such as the electrical grid, had been designed to repair themselves, not too differently from the way our bodies do. Computer scientists were using the principles of evolution to breed computer software that was too difficult for humans to write; instead of designing thousands of lines of code, the researchers unleashed a system of evolution to select the best lines of code and keep mutating them, then killing off the duds until the evolved code performed perfectly.

At the same time, biologists were learning that living systems can be imbued with the abstracted essence of a mechanical process like computation. For instance, researchers discovered that DNA—the actual DNA found in the ubiquitous bacteria *E. coli* in our own intestines—could be used to compute the answers to difficult mathematical problems, just like a computer. If DNA could be made into a working computer, and a working computer could be made to evolve like DNA, then there might be, or must be, a certain equivalency between the made and the born. Technology and life must share some fundamental essence.

During the years I was puzzling over these questions, something strange happened to technology: The best of it was becoming incredibly disembodied. Fantastic stuff was getting smaller, using less material but doing more. Some of the best technology, such as software, didn't have a material body at all. This development wasn't new; any list of great inventions in history contains plenty that are rather wispy: the calendar, the alphabet, the compass, penicillin, double-entry accounting, the U.S. Constitution, the contraceptive pill, domestication of animals, zero, germ theory, lasers, electricity, the silicon chip, and so on. Most of these inventions wouldn't hurt you if you dropped them on your toes. But now the process of disembodiment was speeding up.

Scientists had come to a startling realization: However you define life, its essence does not reside in material forms like DNA, tissue, or flesh, but in the intangible organization of the energy and information contained in those material forms. And as technology was unveiled from its shroud of atoms, we could see that at its core, it, too, is about ideas and information. Both life and technology seem to be based on immaterial flows of information.

It was at this point that I realized I needed even greater clarity on what kind of force flowed through technology. Was it really mere ghostly information? Or did technology need physical stuff? Was it a natural force or an unnatural one? It was clear (at least to me) that technology was an extension of natural life, but in what ways was it *different* from nature? (Computers and DNA share something essential, but a MacBook is not the same as a sunflower.) It is also clear that technology springs from human minds, but in what categorical way are the products of our minds (even cognitive products like artificial intelligences) different from our minds themselves? Is technology human or nonhuman?

We tend to think of technology as shiny tools and gadgets. Even if we acknowledge that technology can exist in disembodied form, such as software, we tend not to include in this category paintings, literature, music, dance, poetry, and the arts in general. But we should. If a thousand lines of letters in UNIX qualifies as a technology (the computer code for a web page), then a thousand lines of letters in English (*Hamlet*) must qualify as well. They both can change our behavior, alter the course of events, or enable future inventions. A Shakespeare sonnet and a Bach fugue, then, are in the same category as Google's search engine and the iPod: They are something useful produced by a mind. We can't separate out the multiple overlapping technologies responsible for a *Lord of the Rings* movie. The literary rendering of the original novel is as much an invention as the digital rendering of its fantastical creatures. Both are useful works of the human imagination. Both influence audiences powerfully. Both are technological.

Why not just call this vast accumulation of invention and creation *culture*? In fact, some people do. In this usage, culture would include all the technology we have invented so far, plus the products of those inventions, plus anything else our collective minds have produced. And if by "culture" one means not just local ethnic cultures but the aggregate culture of the human species, then this term very nearly represents this vast sphere of technology that I have been talking about.

But the term *culture* falls short in one critical way. It is too small. What Beckmann recognized in 1802 when he baptized technology was that the things we were inventing were spawning other inventions in a type of self-generation. Technical arts enabled new tools, which launched new arts, which birthed new tools, ad infinitum. Artifacts were becoming so complex in their operation and so interconnected in their origins that they formed a new whole: *technology*.

The term *culture* fails to convey this essential self-propelling momentum pushing technology. But to be honest, the term *technology* does not quite get it right, either. It, too, is too small, because *technology* can also mean specific methods and gear, as in "biotechnology," or "digital technology," or the technology of the Stone Age.

I dislike inventing words that no one else uses, but in this case all known alternatives fail to convey the required scope. So I've somewhat reluctantly coined a word to designate the greater, global, massively interconnected system of technology vibrating around us. I call it the *technium*. The technium extends beyond shiny hardware to include culture, art, social institutions, and intellectual creations of all types. It includes intangibles like software, law, and philosophical concepts. And most important, it includes the generative impulses of our inventions to encourage more tool making, more technology invention, and more self-enhancing connections. For the rest of this book I will use the term *technium* where others might use *technology* as a plural, and to mean a whole system (as in "technology accelerates"). I reserve the term *technology* to mean a specific technology, such as radar or plastic polymers. For example, I would say: "The technium accelerates the invention of technologies." In other words, *technologies* can be patented, while the *technium* includes the patent system itself.

As a word, *technium* is akin to the German word *technik*, which similarly encapsulates the grand totality of machines, methods, and engineering processes. *Technium* is also related to the French noun *technique*, used by French philosophers to mean the society and culture of tools. But neither term captures what I consider to be the essential quality of the technium: this idea of a self-reinforcing system of creation. At some point in its evolution, our system of tools and machines and ideas became so dense in feedback loops and complex interactions that it spawned a bit of independence. It began to exercise some autonomy.

At first, this notion of technological independence is very hard to grasp. We are taught to think of technology first as a pile of hardware and secondly as inert stuff that is wholly dependent on us humans. In this view, technology is only what we make. Without us, it ceases to be. It does only what we want. And that's what I believed, too, when I set out on this quest. But the more I looked at the whole system of technological invention, the more powerful and self-generating I realized it was.

There are many fans, as well as many foes, of technology, who strongly disagree with the idea that the technium is in any way autonomous. They adhere to the creed that technology does only what we permit it to do. In this view, notions of technological autonomy are simply wishful thinking on our part. But I now embrace a contrary view: that after 10,000 years of slow evolution and 200 years of incredible intricate exfoliation, the technium is maturing into its own thing. Its sustaining network of self-reinforcing processes and parts have given it a noticeable

measure of autonomy. It may have once been as simple as an old computer program, merely parroting what we told it, but now it is more like a very complex organism that often follows its own urges.

Okay, that's very poetic, but is there any *evidence* for the technium's autonomy? I think there is, but it rests on how we define autonomy. The qualities we hold dearest in the universe are all extremely slippery at the edges. *Life, mind, consciousness, order, complexity, free will*, and *autonomy* are all terms that have multiple, paradoxical, and inadequate definitions. No one can agree on exactly where life or mind or consciousness or autonomy begins and where it ends. The best we can agree on is that these states are not binary. They exist on a continuum. So: humans have minds, and so do dogs, and mice. Fish have tiny brains, so they must have tiny minds. Does that mean ants, who have smaller brains yet, also have minds? How many neurons do you need to have a mind?

Autonomy has a similar sliding scale. A newborn wildebeest will run on its own the day after it is born. But we can't say a human infant is an autonomous being if it will die without its mother for its first years. Even we adults are not 100 percent autonomous, since we depend upon other living species in our gut (such as *E. coli*) to aid in the digestion of our food or the breakdown of toxins. If humans are not fully autonomous, what is? An organism or system does not need to be wholly independent to exhibit some degree of autonomy. Like an infant of any species, it can acquire increasing degrees of independence, starting from a speck of autonomy.

So how do you detect autonomy? Well, we might say that an entity is autonomous if it displays any of these traits: self-repair, self-defense, self-maintenance (securing energy, disposing of waste), self-control of goals, self-improvement. The common element in all these characteristics is of course the emergence, at some level, of a self. In the technium we don't have any examples of a system that displays *all* these traits—but we have plenty of examples that display some of them. Autonomous airplane drones can self-steer and stay aloft for hours. But they don't repair themselves. Communication networks can repair themselves. But they don't reproduce themselves. We have self-reproducing computer viruses, but they don't improve themselves.

Woven deep into the vast communication networks wrapping the globe, we also find evidence of embryonic technological autonomy. The technium contains 170 quadrillion computer chips wired up into one mega-scale computing platform. The total number of transistors in this global network is now approximately the same as the number of neurons in your brain. And the number of links among files in this network (think of all the links among all the web pages of the world) is about equal to the number of synapse links in your brain. Thus, this growing planetary electronic membrane is already comparable to the complexity of a human brain. It has three billion artificial eyes (phone and webcams) plugged in, it processes keyword searches at the humming rate of 14 kilohertz (a barely audible high-pitched whine), and it is so large a contraption that it now consumes 5 percent of the world's electricity. When computer scientists dissect the massive rivers of traffic flowing through it, they cannot account for the source of all the bits. Every now and then a bit is transmitted incorrectly, and while most of those mutations can be attributed to identifiable causes such as hacking, machine error, or line damage, the researchers are left with a few percent that somehow changed themselves. In other words, a small fraction of what the technium communicates originates not from any of its known human-made nodes but from the system at large. The technium is whispering to itself.

Further deep analysis of the information flowing through the technium's network reveals that it has slowly been shifting its methods of organization. In the telephone system a century ago, messages dispersed across the network in a pattern that mathematicians associate with randomness. But in the last decade, the flow of bits has become statistically more similar to the patterns found in self-organized systems. For one thing, the global network exhibits self-similarity, also known as a fractal pattern. We see this kind of fractal pattern in the way the jagged outline of tree branches look similar no matter whether we look at them up close or far away. Today messages disperse through the global telecommunications system in the fractal pattern of self-organization. This observation doesn't prove autonomy. But autonomy is often self-evident long before it can be proved.

We created the technium, so we tend to assign ourselves exclusive influence over it. But we have been slow to learn that systems—all systems—generate their own momentum. Because the technium is an outgrowth of the human mind, it is also an outgrowth of life, and by extension it is also an outgrowth of the physical and chemical self-organization that first led to life. The technium shares a deep common root not only with the human mind, but with ancient life and other self-organized systems as well. And just as a mind must obey not only the principles governing cognition but also the laws governing life and self-organization, so the technium must obey the laws of mind, life, and self-organization—as well as our human minds. Thus out of all the spheres of influence upon the technium, the human mind is only one. And this influence may even be the weakest one.

The technium wants what we design it to want and what we try to direct it to do. But in addition to those drives, the technium has its own wants. It wants to sort itself out, to self-assemble into hierarchical levels, just as most large, deeply interconnected systems do. The technium also wants what every living system wants: to perpetuate itself, to keep itself going. And as it grows, those inherent wants are gaining in complexity and force.

I know this claim sounds strange. It seems to anthropomorphize stuff that is clearly not human. How can a toaster want? Aren't I assigning way too much consciousness to inanimate objects, and by doing so giving them more power over us than they have, or should have?

It's a fair question. But "want" is not just for humans. Your dog wants to play Frisbee. Your cat wants to be scratched. Birds want mates. Worms want moisture. Bacteria want food. The wants of a microscopic, single-celled organism are less complex, less demanding, and fewer in number than the wants of you or me, but all organisms share a few fundamental desires: to survive, to grow. All are driven by these "wants." The wants of a protozoan are unconscious, unarticulated—more like an urge or a tendency. A bacterium tends to drift toward nutrients with no awareness of its needs. In a dim way it chooses to satisfy its wants by heading one way and not another.

With the technium, *want* does not mean thoughtful decisions. I don't believe the technium is conscious (at this point). Its mechanical wants are not carefully considered deliberations but rather tendencies. Leanings. Urges. Trajectories. The wants of technology are closer to needs, a compulsion toward something. Just like the unconscious drift of a sea cucumber as it seeks a mate. The millions of amplifying relationships and countless circuits of influence among parts push the whole technium in certain unconscious directions.

Technology's wants can often seem abstract or mysterious, but occasionally, these days, you can see them right in front of you. Recently I visited a start-up called Willow Garage in a leafy suburban tract not far from Stanford University. The company creates state-of-the-art research robots. Willow's latest version of a personal robot, called PR2, stands about chest high, runs on four wheels, and has five eyes and two massive arms. When you take hold of one of its arms, it is neither rigid at the joints nor limp. It responds in a supple manner, with a gentle give, as if the limb were alive. It's an uncanny sensation. Yet the robot's grip is as deliberate as yours. In the spring of 2009, PR2 completed a full 26.2-mile marathon circuit in the building without crashing into obstacles. In robotdom, this is a huge accomplishment. But PR2's most notable achievement is its ability to find a power outlet and plug itself in. It's been programmed to look for its own power, but the specific path it takes emerges as it overcomes obstacles. So when it gets hungry, it searches for one of a dozen available power sockets in the building to recharge its batteries. It grabs its cord with one of its hands, uses its laser and optical eyes to line up a socket, and after gently probing the outlet in a small spiral pattern to find the exact slots, pushes its plug in to get fueled. It then sucks up power there for a couple of hours. Before the software was perfected, a few unexpected "wants" emerged. One robot craved plugging in even when its batteries were full, and once a PR2 took off without properly unplugging, dragging its cord behind it, like a forgetful motorist pulling out of the gas station with the pump hose still in the tank. As its behavior becomes more complex, so will its desires. If you stand in front of a PR2 while it is hungry, it won't hurt you. It will backtrack and go around the building any way it can to find a plug. It's not

conscious, but standing between it and its power outlet, you can clearly feel its want.

There is a nest of ants somewhere beneath my family's house. The ants, if we let them—and we won't—would carry off most of the food in our pantry. We humans are obliged to obey nature, except that sometimes we are forced to thwart it. While we bow to nature's beauty, we also frequently take out a machete and temporarily hack it back. We weave clothes to keep the natural world away from us, and we concoct vaccines to inoculate us against its mortal diseases. We rush to the wilderness to be rejuvenated, but we bring our tents.

The technium is now as great a force in our world as nature, and our response to the technium should be similar to our response to nature. We can't demand that technology obey us any more than we can demand that life obey us. Sometimes we should surrender to its lead and bask in its abundance, and sometimes we should try to bend its natural course to meet our own. We don't have to do everything that the technium demands, but we can learn to work with this force rather than against it.

And to do that successfully, we first need to understand technology's behavior. In order to decide how to respond to technology, we have to figure out what technology wants.

After a long journey, that is where I have ended up. By listening to what technology wants, I feel that I have been able to find a framework to guide me through this rising web of hatching technologies. Seeing our world through technology's eyes has, for me, illuminated its larger purpose. And recognizing what it wants has reduced much of my own conflict in deciding where to place myself in its embrace. This book is my report on what technology wants. My hope is that it will help others find their own way to optimize technology's blessings and minimize its costs.

2

Inventing Ourselves

To see where technology is going, we need to see where it has come from. And that's not easy. The further back we trace the technium's history, the further back its origins seem to recede. So let's begin with our own origins, that moment in prehistory when humans lived primarily surrounded by things they did not make. What were our lives like without technology?

The problem with this line of questioning is that technology predated our humanness. Many other animals used tools millions of years before humans. Chimpanzees made (and of course still make) hunting tools from thin sticks to extract termites from mounds and slammed rocks to break nuts. Termites themselves construct vast towers of mud for their homes. Ants herd aphids and farm fungi in gardens. Birds weave elaborate, twiggy fabrics for their nests. And some octopuses will find and carry shells for portable homes. The strategy of bending the environment to use as if it were part of one's own body is a half-billion-year-old trick at least.

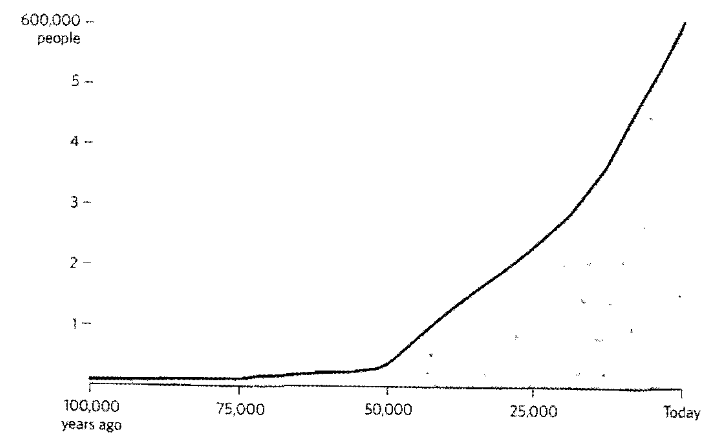
Our ancestors first chipped stone scrapers 2.5 million years ago to give themselves claws. By about 250,000 years ago they devised crude techniques for cooking, or predigesting, with fire. Cooking acts as a supplemental stomach—an artificial organ that permits smaller teeth and smaller jaw muscles and provides more kinds of stuff to eat. Technology-assisted hunting, as opposed to tool-free scavenging, is equally old. Archaeologists have found a stone point jammed into the vertebra of a horse and a wooden spear embedded in a 100,000-year-old red deer skeleton. This pattern of tool use has only accelerated in the years since.

All technology, the chimp's termite-fishing spear and the human's fishing spear, the beaver's dam and the human's dam, the warbler's hanging basket and the human's hanging basket, the leaf-cutter ant's garden and the human's garden, are all fundamentally natural. We tend to isolate manufactured technology from nature, even to the point of thinking of it as antinature, only because it has grown to rival the impact and power of its home. But in its origins and fundamentals, a tool is as natural as our life. Humans are animals—no argument. But humans are also not-animals—no argument. This contradictory nature is at the core of our identity. Likewise, technology is unnatural—by definition. And technology is natural—by a wider definition. This contradiction is also core to human identity.

Tools and bigger brains mark the beginning of a distinctly human line in evolution. The first simple stone tools appeared in the same archaeological moment that the brains of the hominins (humanish apes) who made them began to enlarge toward their current size. Thus hominins arrived on Earth 2.5 million years ago with rough, chipped stone scrapers and cutters in hand. About a million years ago, these large-brained, tool-wielding hominins drifted beyond Africa and settled into southern Europe, where they evolved into the Neanderthal (with an even bigger brain) and further into eastern Asia, where they evolved into *Homo erectus* (also bigger brained). Over the next several million years, all three hominin lines evolved, but the ones that remained in Africa evolved into the human form we see in ourselves. The exact time these protohumans became fully modern humans is of course debated. Some say 200,000 years ago, but the undisputed latest date is 100,000 years ago. By 100,000 years ago, humans had crossed the threshold where they were outwardly indistinguishable from us. We would not notice anything amiss if one of them were to stroll alongside us on the beach. However, their tools and most of their behavior were indistinguishable from those of their relatives the Neanderthals in Europe and Erectus in Asia.

For the next 50 millennia not much changed. The anatomy of African human skeletons remained constant over this time. Neither did their tools evolve much. Early humans employed rough-and-ready lumps of rock with sharpened edges to cut, poke, drill, or spear. But these handheld tools were unspecialized and did not vary by location or time. No matter where or when in this period (called the Mesolithic) a hominin picked up one of these tools, it would resemble one made tens of thousands of miles away or tens of thousands of years earlier or later, whether in the hands of a Neanderthal, Erectus, or *Homo sapiens*. Hominins simply lacked innovation. As biologist Jared Diamond put it, "Despite their large brains, something was missing."

Then about 50,000 years ago, that missing something arrived. While the bodies of early humans in Africa remained unchanged, their genes and minds shifted noticeably. For the first time, hominins were full of ideas and innovation. These newly vitalized modern humans, or Sapiens (a term I am using to distinguish them from earlier populations of *Homo sapiens*), charged into new regions beyond their ancestral homes in eastern Africa. They fanned out from the grasslands, and in a rela-



Prehistory Explosion of Human Population. A simulation of the first human population explosion, which began about 50,000 years ago.

tively brief burst exploded from a few tens of thousands of individuals in Africa to an estimated eight million worldwide just before the dawn of agriculture 10,000 years ago.

The speed at which Sapiens marched across the planet and settled every continent (except Antarctica) is astounding. In 5,000 years they overtook Europe. In another 15,000 they reached the edges of Asia. Once tribes of Sapiens crossed the land bridge from Eurasia into what is now Alaska, it took them only a few thousand years to fill the whole of the New World. Sapiens increased so relentlessly that for the next 38,000 years they expanded their occupation at the average rate of one mile (two kilometers) per year. Sapiens kept pushing until they reached the furthest they could go: land's end at the tip of South America. Fewer than 1,500 generations after their "great leap forward" in Africa, *Homo sapiens* had become the most widely distributed species in Earth's history, inhabiting every type of biome and every watershed on the planet. Sapiens were the most invasive alien species ever.

Today the breadth of Sapiens occupation exceeds that of any other macrospecies we know of; no other visible species occupies more niches, geographical and biological, than *Homo sapiens*. Sapiens' overtake was always rapid. Jared Diamond notes that "after the ancestors of the Maori reached New Zealand," carrying only a few tools, "it apparently took them barely a century to discover all worthwhile stone sources; only a few more centuries to kill every last moa in some of the world's most rugged terrain." This sudden global expansion following millennia of steady sustainability was due to only one thing: technological innovation.

As Sapiens expanded in range, they remade animal horns and tusks into thrusters and knives, cleverly turning the animals' own weapons against them. They sculpted figurines, the first art, and the first jewelry, beads cut from shells, at this threshold 50,000 years ago. While humans had long used fire, the first hearths and shelter structures were invented about this time. Trade of scarce shells, chert, and flint rock began. At approximately the same time Sapiens invented fishing hooks and nets and needles for sewing hides into clothes. They left behind the remains of tailored hides in graves. A few bits of pottery from that time have the imprint of woven net and loose fabrics on them. In the same period

Sapiens also invented animal traps. Their garbage reveals heaps of skeletons of small furred animals without their feet; trappers today still skin small animals the same way, keeping the feet with the skin. On walls artists painted humans wearing parkas and killing animals with arrows or spears. Significantly, unlike Neanderthal's and Erectus's crude creations, these tools varied in small stylistic and technological ways place by place. Sapiens had begun innovating.

The Sapiens mind's ability to make warm clothes opened up the arctic regions, and the invention of fishing gear opened up the coasts and rivers of the world, particularly in the tropics, where large game was scarce. While Sapiens' innovation allowed them to prosper in many new climates, the cold and its unique ecology especially drove innovation. More complex "technological units" are needed (or have been invented) by historical hunter-gatherer tribes the higher the latitude of their homes. Hunting oceanic sea mammals in arctic climes took significantly more sophisticated gear than fishing salmon in a river. The ability of Sapiens to rapidly improve their tools allowed them to adapt to new ecological niches at a much faster rate than genetic evolution could ever allow.

During their quick global takeover, Sapiens displaced (with or without interbreeding) the several other coinhabiting hominin species on Earth, including their cousins the Neanderthals. The Neanderthals were never abundant; they may have only numbered 18,000 individuals at one time. After dominating Europe for hundreds of thousands of years as the sole hominin, the Neanderthals vanished in less than 100 generations after the tool-carrying Sapiens arrived. That is a blink in history. As anthropologist Richard Klein points out, this displacement occurred almost instantaneously from a geologic perspective. There were no intermediates in the archaeological record. As Klein says, "The Neanderthals were there one day, and the Cro-Magnons [Sapiens] were there the next." The Sapien layer was always on top, and never the reverse. It was not even necessary that the Sapiens slaughter the Neanderthals. Demographers have calculated that as little as a 4 percent difference in reproductive effectiveness (a reasonable expectation given Sapiens' ability to bring home more kinds of meat) could eclipse the lesser breeding species in a few thousands years. The speed of this several-thousand-year extinction was without precedent in natural evolution. Sadly, it was only the first rapid species extinction to be caused by humans.

It should have been clear to Neanderthals, as it is now clear to us in the 21st century, that something new and big had appeared—a new biological and geological force. A number of scientists (including Richard Klein, Ian Tattersall, and William Calvin, among many others) think that the "something" that happened 50,000 years ago was the invention of language. Up until this point, hominins had been smart. They could make crude tools in a hit-or-miss way and handle fire—perhaps like an exceedingly smart chimp. The growth of the African hominin's brain size and physical stature had leveled off, but evolution continued inside the brain. "What happened 50,000 years ago," says Klein, "was a change in the operating system of humans. Perhaps a point mutation affected the way the brain is wired that allowed languages, as we understand language today: rapidly produced, articulate speech." Instead of acquiring a larger brain, as the Neanderthals and Erectus did, Sapiens gained a rewired brain. Language altered the Neanderthal-type mind and allowed Sapien minds for the first time to invent with purpose and deliberation. Philosopher Daniel Dennett crows in elegant language: "There is no step more uplifting, more momentous in the history of mind design, than the invention of language. When *Homo sapiens* became the beneficiary of this invention, the species stepped into a slingshot that has launched it far beyond all other earthly species." The creation of language was the first singularity for humans. It changed everything. Life after language was unimaginable to those on the far side before it.

Language accelerates learning and creation by permitting communication and coordination. A new idea can be spread quickly if someone can explain it and communicate it to others before they have to discover it themselves. But the chief advantage of language is not communication but autogeneration. Language is a trick that allows the mind to question itself; a magic mirror that reveals to the mind what the mind thinks; a handle that turns a mind into a tool. With a grip on the slippery, aimless activity of self-awareness and self-reference, language can harness a mind into a fountain of new ideas. Without the cerebral structure of language, we couldn't access our own mental activity. We certainly couldn't think the way we do. If our minds can't tell stories, we can't consciously create; we can only create by accident. Until we tame the mind with an organization tool capable of communicating to itself, we have stray thoughts without a narrative. We have a feral mind. We have smartness without a tool.

A few scientists believe that, in fact, it was technology that sparked language. To throw a tool—a rock or stick—at a moving animal and hit it with sufficient force to kill it requires a serious computation in the hominin brain. Each throw requires a long succession of precise neural instructions executed in a split second. But unlike calculating how to grasp a branch in midair, the brain must calculate several alternative options for a throw at the same time: the animal speeds up or it slows down; aim high or aim low. The mind must then spin out the results to gauge the best possible throw before the actual throw—all in a few milliseconds. Scientists such as neurobiologist William Calvin believe that once the brain evolved the power to run multiple rapid-throw scenarios, it hijacked this throw procedure to run multiple rapid sequences of notions. The brain would throw words instead of sticks. This reuse or repurposing of technology then became a primitive but advantageous language.

The slippery genius of language opened up many new niches for spreading tribes of Sapiens. Unlike their cousins the Neanderthals, Sapiens could quickly adapt their tools to hunt or trap an increasing diversity of game and to gather and process an increasing diversity of plants. There is some evidence that Neanderthals were stuck on a few sources of food. Examination of Neanderthal bones show they lacked the fatty acids found in fish and that the Neanderthal diet was mostly meat. But not just any meat. Over half of their diet was woolly mammoth and reindeer. The demise of the Neanderthal may be correlated with the demise of great herds of these megafauna.

Sapiens thrived as broadly omnivorous hunter-gatherers. The unbroken line of human offspring for hundreds of thousands of years proves that a few tools are sufficient to capture enough nutrition to create the next generation. We are here now because hunting-gathering worked in the past. Several analyses of the diets of historical hunter-gatherers show that they were able to secure enough calories to meet the U.S. FDA recommendations for folks their size. For example, anthropologists found the historical Dobe gathered on average 2,140 calories a day; Fish Creek tribe, 2,130; Hemple Bay tribe, 2,160. They had a varied menu of tubers, vegetables, fruit, and meat. Based on studies of bones and pollen in their trash, so did the early Sapiens.

The philosopher Thomas Hobbes claimed the life of the savage—and by this he meant Sapien hunter-gatherers—was "nasty, brutish, and short." But while the life of an early hunter-gatherer was indeed short, and often interrupted by nasty warfare, it was not brutish. With only a slim set of a dozen primitive tools, not only did humans secure enough food, clothing, and shelter to survive in all kinds of environments, but these tools and techniques also afforded them some leisure while doing so. Anthropological studies confirm that present-day hunter-gathers do not spend all day hunting and gathering. One researcher, Marshall Sahlins, concluded that hunter-gatherers worked only three to four hours a day on necessary food chores, putting in what he called "banker hours." The evidence for his surprising results is controversial.

A more realistic and less contentious average for food-gathering time among contemporary hunter-gatherer tribes, based on a wider range of data, is about six hours per day. That average belies a great variation in day-to-day routine. One- to two-hour naps or whole days spent sleeping were not uncommon. Outside observers almost universally noted the punctuated nature of work among foragers. Gatherers may work very hard for several days in a row and then do nothing in terms of food getting for the rest of the week. This cycle is known among anthropologists as the "Paleolithic rhythm"—a day or two on, a day or two off. An observer familiar with the Yamana tribe—but it could be almost any hunter tribe—wrote: "Their work is more a matter of fits and starts, and in these occasional efforts they can develop considerable energy for a certain time. After that, however they show a desire for an incalculably long rest period during which they lie about doing nothing, without showing great fatigue." The Paleolithic rhythm actually reflects the "predator rhythm," since the great hunters of the animal world, the lion

and other large cats, exhibit the same style: hunting to exhaustion in a short burst and then lounging around for days afterward. Hunters, almost by definition, seldom go out hunting, and they succeed in getting a meal even less often. The efficiency of primitive tribal hunting, measured in the yield of calories per hour invested, was only half that of gathering. Meat is thus a treat in almost every foraging culture.

Then there are seasonal variations. Every ecosystem produces a "hungry season" for foragers. At higher, cooler latitudes, this late winter–early spring hungry season is more severe, but even at tropical latitudes, there are seasonal oscillations in the availability of favorite foods, supplemental fruits, or essential wild game. In addition, there are climatic variations: extended periods of drought, floods, and storms that can disrupt yearly patterns. These great punctuations over days, seasons, and years mean that while there are many times when hunter-gatherers are well fed, they also can—and do—expect many periods when they are hungry, famished, and undernourished. Time spent in this state along the edge of malnutrition is mortal for young children and dire for adults.

The result of all this variation in calories is the Paleolithic rhythm at all scales of time. Importantly, this burstiness in "work" is not by choice. When you are primarily dependent on natural systems to provide you foodstuffs, working more does not tend to produce more. You can't get twice as much food by working twice as hard. The hour at which the figs ripen can be neither hurried nor predicted exactly. Nor can the arrival of game herds. If you do not store surplus or cultivate in place, then motion must produce your food. Hunter-gatherers must be in ceaseless movement away from depleted sources in order to maintain production. But once you are committed to perpetual movement, surplus and its tools slow you down. In many contemporary hunter-gatherer tribes, being unencumbered with things is considered a virtue, even a virtue of character. You carry nothing; instead, you cleverly make or procure whatever you need when you need it. "The efficient hunter who would accumulate supplies succeeds at the cost of his own esteem," says Marshall Sahlins. Additionally, the surplus producer must share the extra food or goods with everyone, which reduces the incentive to produce extra. For foragers, food storage is therefore socially self-defeating. Instead your hunger must adapt to the movements of the wild. If a dry spell diminishes the yield of the sago, no amount of extra work time will advance the delivery of food. Therefore, foragers take a very accepting pace to eating. When food is there, all work very hard. When it is not, no problem; they will sit around and talk while they are hungry. This very reasonable approach is often misread as tribal laziness, but it is in fact a logical strategy if you rely on the environment to store your food.

We civilized modern workers can look at this leisurely approach to work and feel jealous. Three to six hours a day is a lot less than most adults in any developed country put in to their labors. Furthermore, when asked, most acculturated hunter-gatherers don't want any more than they have. A tribe will rarely have more than one artifact, such as an ax, because why do you need more than one? Either you use the object when you need to, or, more likely, you make one when you need one. Once used, artifacts are often discarded rather than saved. That way nothing extra needs to be carried or cared for. Westerners giving gifts such as a blanket or knife to foragers have often been mortified to see them trashed after a day. In a very curious way, foragers live in the ultimate disposable culture. The best tools, artifacts, and technology are all disposable. Even elaborate handcrafted shelters are considered temporary. When a clan or family travels, they might erect a home (a bamboo hut or snow igloo, for example) for only a night and then abandon it the next morning. Larger multifamily lodges might be abandoned after a few years rather than maintained. The same goes for food patches, which are abandoned after harvesting.

This easy just-in-time self-sufficiency and contentment led Marshall Sahlins to declare hunter-gatherers "the original affluent society." But while foragers had sufficient calories most days and did not create a culture that continually craved more, a better summary might be that hunter-gatherers had "affluence without abundance." Based on numerous historical encounters with aboriginal tribes, we know they often, if not regularly, complained about being hungry. Famed anthropologist Colin Turnbull noted that although the Mbuti frequently sang to the goodness of the forest, they often complained of hunger. Often the complaints of hunter-gathers were about the monotony of a carbohydrate staple, such as mongongo nuts, for every meal; when they spoke of shortages, or even hunger, they meant a shortage of meat, and a hunger for fat, and a distaste for periods of hunger. Their small amount of technology gave them sufficiency for most of the time, but not abundance.

The fine line between average sufficiency and abundance matters for health. When anthropologists measure the total fertility rate (the mean number of live births over the reproductive years) of women in modern hunter-gatherer tribes, they find it relatively low—about five to six children in total—compared to six to eight children in agricultural communities. There are several factors behind this depressed fertility. Perhaps because of uneven nutrition, puberty comes late to forager girls, at 16 or 17 years old. (Modern females start at 13.) This late menarche for women, combined with a shorter life span, delays and thus abbreviates the childbearing window. Breast-feeding usually lasts longer in foragers, which extends the interval between births. Most tribes nurse till children are 2 or 3 years old, while a few tribes keep children suckling for as long as 6 years. Also, many women are extremely lean and active and, like lean, active women athletes in the West, often have irregular or no menstruation. One theory suggests women need a "critical fatness" to produce fertile eggs, a fatness many forager women lack—at least part of the year—because of a fluctuating diet. And of course, people anywhere can practice deliberate abstinence to space children, and foragers have reasons to do so.

Child mortality in foraging tribes was severe. A survey of 25 hunter-gatherer tribes in historical times from various continents revealed that, on average, 25 percent of children died before they were 1, and 37 percent died before they were 15. In one traditional hunter-gatherer tribe, child mortality was found to be 60 percent. Most historical tribes had a population growth rate of approximately zero. This stagnation is evident, says Robert Kelly in his survey of hunting-gathering peoples, because "when formerly mobile people become sedentary, the rate of population growth increases." All things being equal, the constancy of farmed food breeds more people.

While many children died young, older hunter-gatherers did not have it much better. It was a tough life. Based on an analysis of bone stress and cuts, one archaeologist said the distribution of injuries on the bodies of Neanderthals was similar to that found on rodeo professionals—lots of head, trunk, and arm injuries like the ones you might get from close encounters with large, angry animals. There are no known remains of an early hominin who lived to be older than 40. Because extremely high child mortality rates depress average life expectancy, if the oldest outlier is only 40, the median age was almost certainly less than 20.

A typical tribe of hunters-gatherers had few very young children and no old people. This demographic may explain a common impression visitors had upon meeting intact historical hunter-gatherer tribes. They would remark that "everyone looked extremely healthy and robust." That's in part because most everyone was in the prime of life, between 15 and 35. We might have the same reaction visiting a trendy urban neighborhood with the same youthful demographic. Tribal life was a lifestyle for and of young adults.

A major effect of this short forager life span was the crippling absence of grandparents. Given that women would only start bearing children at 17 or so and die by their thirties, it would be common for children to lose their parents before the children were teenagers. A short life span is rotten for the individual. But a short life span is also extremely detrimental for a society as well. Without grandparents, it becomes exceedingly difficult to transmit knowledge—and knowledge of tool using—over time. Grandparents are the conduits of culture, and without them culture stagnates.

Imagine a society that not only lacked grandparents but also lacked language—as the pre-Sapiens did. How would learning be transmitted over generations? Your own parents would die before you were an adult, and in any case, they could not communicate to you anything beyond what they could show you while you were immature. You would certainly not learn anything from anyone outside your immediate circle of peers. Innovation and cultural learning would cease to flow.

Language upended this tight constriction by enabling ideas both to coalesce and to be communicated. An innovation could be hatched and

then spread across generations via children. Sapiens gained better hunting tools (such as thrown spears, which permitted a lightweight human to kill a huge, dangerous animal from a safe distance), better fishing tools (barbed hooks and traps), and better cooking methods (using hot stones not just to cook meat but also to extract more calories from wild plants). And they gained all these within only 100 generations of beginning to use language. Better tools meant better nutrition, which could assist in faster evolution.

The primary long-term consequence of this slightly better nutrition was a steady increase in longevity. Anthropologist Rachel Caspari studied the dental fossils of 768 hominin individuals in Europe, Asia, and Africa, dated from 5 million years ago until the great leap. She determined that a "dramatic increase in longevity in the modern humans" began about 50,000 years ago. Increasing longevity allowed grandparenting, creating what is called the grandmother effect: In a virtuous circle, via the communication of grandparents, ever more powerful innovations carried forward were able to lengthen life spans further, which allowed more time to invent new tools, which increased population. Not only that: Increased longevity "provide[d] a selective advantage promoting further population increase," because a higher density of humans increased the rate and influence of innovations, which contributed to increased populations. Caspari claims that the most fundamental biological factor that underlies the behavioral innovations of modernity may be the increase in adult survivorship. It is no coincidence that increased longevity is the most measurable consequence of the acquisition of technology. It is also the most consequential.

By 15,000 years ago, as the world was warming and its global ice caps retreating, bands of Sapiens expanded their population and tool kits, hand in hand. Sapiens used 40 kinds of tools, including anvils, pottery, and composites—complicated spears or cutters made from multiple pieces, such as many tiny flint shards and a handle. While still primarily a hunter-gatherer, Sapiens also dabbled in sedentism, returning to care for favorite food areas, and developed specialized tools for different types of ecosystems. We know from burial sites in the northern latitudes at this same time that clothing also evolved from the general (a rough tunic) to specialized items such as a cap, a shirt, a jacket, trousers, and moccasins. Henceforth human tools would become ever more specialized.

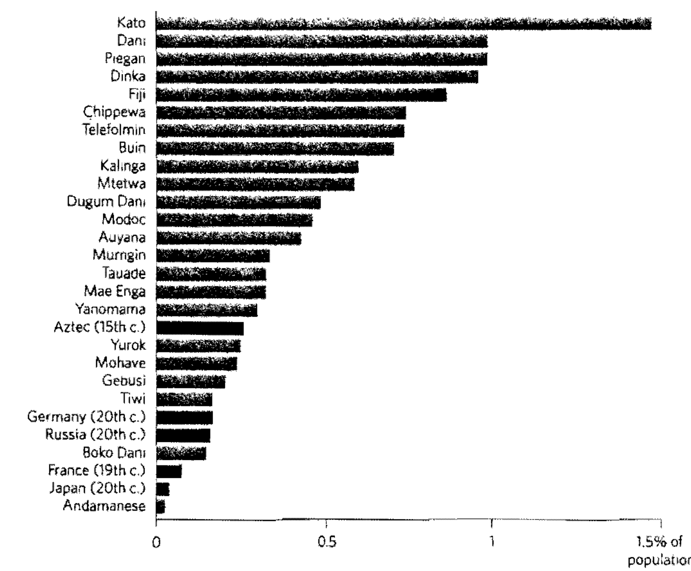
The variety of Sapiens tribes exploded as they adapted into diverse watersheds and biomes. Their new tools reflected the specifics of their homes; river inhabitants had many nets, steppe hunters many kinds of points, forest dwellers many types of traps. Their languages and looks were diverging.

Yet they shared many qualities. Most hunter-gatherers clustered into family clans that averaged about 25 related people. Clans would gather in larger tribes of several hundred at seasonal feasts or camping grounds. One function of the tribes was to keep genes moving through intermarriage. Population was spread thinly. The average density of a tribe was less than .01 person per square kilometer in cooler climes. The 200 to 300 folk in your greater tribe would be the total number of people you'd meet in your lifetime. You might be aware of others, because items for trade or barter could travel 300 kilometers. Some of the traded items would be body ornaments and beads, such as ocean shells for inlanders or forest feathers for the coast dwellers. Occasionally, pigments for face painting were swapped, but these could also be applied to walls or to carved wood figurines. The dozen tools you carried would have been bone drills, awls, needles, bone knives, a bone hook for fish on a spear, some stone scrapers, maybe some stone sharpies. A number of your blades would be held by bone or wood handles, hafted with cane or hide cord. When you crouched around the fire, someone might play a drum or bone flute. Your handful of possessions might be buried with you when you died.

But don't take this progress for harmony. Within 20,000 years of the great march out of Africa, Sapiens helped exterminate 90 percent of the then-existing species of megafauna. Sapiens used innovations such as the bow and arrow, spear, and cliff stampedes to kill off the last of the mastodons, mammoths, moas, woolly rhinos, and giant camels—basically every large package of protein that walked on four legs. More than 80 percent of all large mammal genera on the planet were completely

extinct by 10,000 years ago. Somehow, four species escaped this fate in North America: the bison, moose, elk, and caribou.

Violence between tribes was endemic as well. The rules of harmony and cooperation that work so well among members of the same tribe, and are often envied by modern observers, did not apply to those outside of the tribe. Tribes would go to war over water holes in Australia or hunting grounds and wild-rice fields in the plains of the United States or river and ocean frontage along the coast in the Pacific Northwest. Without systems of arbitration, or even leaders, small feuds over stolen goods or women or signs of wealth (such as pigs in New Guinea) could grow into multigenerational warfare. The death rate due to warfare was five times higher among hunter-gatherer tribes than in later agriculture-based societies (.1 percent of the population killed per year in "civilized" wars versus .5 percent in war between tribes). Actual rates of warfare



Comparison of War Fatality Rates. Annual war deaths as a percentage of the population in both prestate (gray bars) and modern societies (darker bars).

varied among tribes and regions, because as in the modern world, one belligerent tribe could disrupt the peace for many. In general, the more nomadic a tribe was, the more peaceful it would be, since it could simply flee from conflict. But when fighting did break out, it was fierce and deadly. When the numbers of warriors on both sides were about equal, primitive tribes usually beat the armies of civilization. The Celtic tribes defeated the Romans, the Tuareg smashed the French, the Zulus trumped the British, and it took the U.S. Army 50 years to defeat the Apache tribes. As Lawrence Keeley says in his survey of early warfare in *War Before Civilization*, "The facts recovered by ethnographers and archaeologists indicated unequivocally that primitive and prehistoric warfare was just as terrible and effective as the historic and civilized version. In fact, primitive warfare was much more deadly than that conducted between civilized states because of the greater frequency of combat and the more merciless way it was conducted. . . . It is civilized warfare that is stylized, ritualized, and relatively less dangerous."

Before the revolution of language 50,000 years ago, the world lacked significant technology. For the next 40,000 years, every human born lived as a hunter-gatherer. During this time an estimated 1 billion people explored how far you could go with a handful of tools. This world without much technology provided "enough." There was leisure and satisfying work for humans. Happiness, too. Without technology beyond stone implements, the rhythms and patterns of nature were immediate. Nature ruled your hunger and set your course. Nature was so vast, so bountiful, and so close, few humans could separate from it. The attunement with the natural world felt divine. Yet without much technology, the recurring tragedy of child death was ever present. Accidents, warfare, and disease meant your life, on average, was far less than half as long as it could have been—maybe only a quarter of the natural life span your genes afforded. Hunger was always near.

But most noticeably, without significant technology, your leisure was confined to traditional repetitions. There was no place for anything new. Within narrow limits you had no bosses. But the direction and interests of your life were laid out in well-worn paths. The cycles of your environment determined your life.

It turns out that the bounty of nature, though vast, does not hold all possibilities. The mind does, but it had not yet been fully unleashed. A world without technology had enough to sustain survival but not enough to transcend it. Only when the mind, liberated by language and enabled by the technium, transcended the constraints of nature 50,000 years ago did greater realms of possibility open up. There was a price to pay for this transcendence, but what we gained by this embrace was civilization and progress.

We are not the same folks who marched out of Africa. Our genes have coevolved with our inventions. In the past 10,000 years alone, in fact, our genes have evolved 100 times faster than the average rate for the previous 6 million years. This should not be a surprise. As we domesticated the dog (in all its breeds) from wolves and bred cows and corn and more from their unrecognizable ancestors, we, too, have been domesticated. We have domesticated ourselves. Our teeth continue to shrink (because of cooking, our external stomach), our muscles thin out, our hair disappears. Technology has domesticated us. As fast as we remake our tools, we remake ourselves. We are coevolving with our technology, and so we have become deeply dependent on it. If all technology—every last knife and spear—were to be removed from this planet, our species would not last more than a few months. We are now symbiotic with technology.

We have rapidly and significantly altered ourselves and at the same time altered the world. From the moment we emerged from Africa to colonize every inhabitable watershed on this planet, our inventions began to alter our nest. Sapiens' hunting tools and techniques had far-reaching effects: Their technology enabled them to kill off key herbivores (mammoths, giant elk, etc.) whose extinctions altered the ecology of entire grassland biomes forever. Once dominant grazers were eliminated, their absence cascaded through the ecosystem, enabling the rise of new predators, new plant species, and all their competitors and allies, surfacing a modified ecosystem. Thus a few clans of hominins shifted the destiny of thousands of other species. When Sapiens gained control of fire, this powerful technology further modified the natural terrain on a massive scale. Such a tiny trick—burning grasslands, controlling it with backfires, and summoning flames to cook grains—disrupted vast regions of the continents.

Later the repeated inventions and spread of agriculture around the planet affected not only the surface of the Earth, but its 100-kilometer-wide (60-mile-wide) atmosphere as well. Farming disturbed the soil and increased CO_2. Some climatologists believe that this early anthropogenic warming, starting 8,000 years ago, kept a new ice age at bay. Widespread adoption of farming disrupted a natural climate cycle that ordinarily would have refrozen the northernmost portions of the planet by now.

Of course, once humans invented machines that ate concentrated old plants (coal) instead of fresh plants, the mechanical exhalations of CO_2 further altered the balance of the atmosphere. The technium bloomed as machines harnessed this source of abundant energy. Petroleum-eating machines such as tractor engines transformed the productivity and spread of agriculture (accelerating an old trend), and then more machines drilled for more oil faster (a new trend), accelerating the rate of acceleration. Today the CO_2 exhalation of all machines greatly exceeds the exhalation of all animals and even approaches the volume generated by geological forces.

The technium gains its immense power not only from its scale but from its self-amplifying nature. One breakthrough invention, such as the alphabet, the steam pump, or electricity, can lead to further breakthrough inventions, such as books, coal mines, and telephones. These advances in turn led to other breakthrough inventions, such as libraries, power generators, and the internet. Each step adds further powers while retaining most of the virtues of the previous inventions. Someone has an idea (a spinning wheel!), which can hop to other minds, mutate into a derivative idea (place the spinning wheel beneath a sled to make it easy to haul!), which disrupts the prevailing balance, causing a shift.

But not all changes induced by technology have been positive. Industrial-scale slavery, such as that imposed upon Africa, was enabled by the sailing ships that transported captives across oceans and encouraged by the mechanical cotton gins that could cheaply process the fibers the slaves planted and harvested. Without technology, slavery at this

massive scale would have been unknown. Thousands of synthetic toxins have caused mass disruptions of natural cycles in both humans and other species, a huge unwanted downside from small inventions. War is a particularly serious amplifier of the great negative powers brought by technology. Technological innovation has led directly to horrific weapons of destruction capable of inflicting entirely new atrocities upon society.

On the other hand, the remedies for and offsets of the negative consequences also stemmed from technology. Local ethnic slavery was practiced by most earlier civilizations, and probably in prehistoric times as well, and still continues in various remote areas; its overall diminishment globally is due to the technological tools of communication, law, and education. Technologies of detection and substitution can eliminate the routine use of synthetic toxins. The technologies of monitoring, law, treaties, policing, courts, citizen media, and economic globalism can temper, dampen, and in the long run diminish the vicious cycles of war.

Progress, even moral progress, is ultimately a human invention. It is a useful product of our wills and minds, and thus it is a technology. We can decide slavery is not a good idea. We can decide that fairly applied laws, rather than nepotistic favoritism, is a good idea. We can outlaw certain punishments with treaties. We can encourage accountability with the invention of writing. We can consciously expand our circle of empathy. These are all inventions, products of our minds, as much as lightbulbs and telegraphs are.

This cyclotron of social betterment is propelled by technology. Society evolves in incremental doses; each rise in social organization throughout history was driven by an insertion of a new technology. The invention of writing unleashed the leveling fairness of recorded laws. The invention of standard minted coins made trade more universal, encouraged entrepreneurship, and hastened the idea of liberty. Historian Lynn White notes, "Few inventions have been so simple as the stirrup, but few have had so catalytic an influence on history." In White's view, the adoption of the lowly foot stirrup for horse saddles enabled riders to use weapons on horseback, which gave an advantage to the cavalry over infantry and to the lords who could afford horses, and so nurtured the rise of aristocratic feudalism in Europe. The stirrup is not the only technology that has been blamed for feudalism. As Karl Marx famously claimed, "The hand-mill gives you society with the feudal lord; the steam-mill, society with the industrial capitalist."

Double-entry bookkeeping, invented in 1494 by a Franciscan monk, enabled companies to monitor their cash flow and for the first time to steer complex business. Double-entry accounting unleashed the banking industry in Venice and launched a global economy. The invention of moveable-type printing in Europe encouraged Christians to read their religion's founding text themselves and make their own interpretations, and that launched the very idea of "protest" within and against religion. Way back in 1620, Francis Bacon, the godfather of modern science, realized how powerful technology was becoming. He listed three "practical arts"—the printing press, gunpowder, and the magnetic compass—that had changed the world. He declared that "no empire, no sect, no start seems to have exerted greater power and influence in human affairs than these mechanical discoveries." Bacon helped launch the scientific method, which accelerated the speed of invention; thereafter society was in constant flux, as one conceptual seed after another disrupted social equilibrium.

Seemingly simple inventions like the clock had profound social consequences. The clock divided an unbroken stream of time into measurable units, and once it had a face, time became a tyrant, ordering our lives. Danny Hillis, computer scientist, believes the gears of the clock spun out science and all its many cultural descendants. He says, "The mechanism of the clock gave us a metaphor for self-governed operation of natural law. (The computer, with its mechanistic playing out of predetermined rules, is the direct descendant of the clock.) Once we were able to imagine the solar system as a clockwork automaton, the generalization to other aspects of nature was almost inevitable, and the process of Science began."

During the Industrial Revolution, our inventions transformed our daily routines. Mechanical contraptions and cheap fuel gave us plenty of food, nine-to-five days, and smokestacks. This phase of technology was dirty, disruptive, and often built and run at an inhuman scale. The stiff, cold, unbending nature of raw steel, brick, and glass cast the encroachment as alien, in opposition to us, if not to all living things. It directly fed upon natural resources and so had a devilish shadow. The worst by-products of the industrial age—black smoke, black river waters, blackened short lives working in the mills—were so remote from our cherished self-conception that we wanted to believe the source itself was alien. Or worse. It was not difficult to eye the hard, cold material takeover as evil, even if a necessary evil. When technology appeared among our age-old routines, it was set outside ourselves and treated like an infection. People embraced its products, but guiltily. It would have been ludicrous a century ago to think of technology as ordained. It was a suspect force. When two world wars unleashed the full killing power of this inventiveness, it cemented the reputation of technology as a beguiling satan.

As we refined this stuff through generations of technological evolution, it lost much of its hardness. We began to see through technology's disguise as material and began to see it primarily as action. While it inhabited a body, its heart was something softer. In 1949, John von Neumann, the brainy genius behind the first useful computer, realized what computers were teaching us about technology: "Technology will in the near and in the farther future increasingly turn from problems of intensity, substance, and energy, to problems of structure, organization, information, and control." No longer a noun, technology was becoming a force—a vital spirit that throws us forward or pushes against us. Not a thing but a verb.

3

History of the Seventh Kingdom

Looking back at Paleolithic times, we can observe an evolutionary phase when human tools were embryonic, when the technium existed in its most minimal state. But since technology predated humans, appearing in primates and even earlier, we need to look beyond our own origins to understand the true nature of technological development. Technology is not just a human invention; it was also born from life.

If we chart the varieties of life we have so far discovered on Earth, they fall into six broad categories. Within each of these six categories, or kingdoms of life, all species share a common biochemical blueprint. Three of these kingdoms are the tiny microscopic stuff: one-celled organisms. The other three are the biological kingdoms of organisms we normally see: fungi (mushrooms and molds), plants, and animals.

Every species in the six kingdoms, which is to say every organism alive on Earth today, from algae to zebra, is equally evolved. Despite the differences in the sophistication and development of their forms, all living species have evolved from predecessors for the same amount of time: four billion years. All have been tested daily and have managed to adapt across hundreds of millions of generations in an unbroken chain.

Many of these organisms have learned to build structures, and those structures have allowed the creature to extend itself beyond its tissue. The hard two-meter mound of a termite colony operates as if it were an external organ of the insects: The mound's temperature is regulated and it is repaired after injury. The dried mud itself seems to be living. What we think of as coral—stony, treelike structures—are the apartment buildings of nearly invisible coral animals. The coral structure and coral animals behave as one. It grows, breathes. The waxy interior of a beehive or the twiggy architecture of a bird's nest works the same way. Therefore a nest or a hive can best be considered a body built rather than grown. A shelter is animal technology, the animal extended.

The extended human is the technium. Marshall McLuhan, among others, noted that clothes are people's extended skin, wheels extended feet, camera and telescopes extended eyes. Our technological creations are great extrapolations of the bodies that our genes build. In this way, we can think of technology as our extended body. During the industrial age it was easy to see the world this way. Steam-powered shovels, locomotives, television, and the levers and gears of engineers were a fabulous exoskeleton that turned man into superman. A closer look reveals the flaw in this analogy: The extended costume of animals is the result of their genes. They inherit the basic blueprints of what they make. Humans don't. The blueprints for our shells spring from our minds, which may spontaneously create something none of our ancestors ever made or even imagined. If technology is an extension of humans, it is not an extension of our genes but of our minds. Technology is therefore the extended body for ideas.

With minor differences, the evolution of the technium—the organism of ideas—mimics the evolution of genetic organisms. The two share many traits: The evolution of both systems moves from the simple to the complex, from the general to the specific, from uniformity to diversity, from individualism to mutualism, from energy waste to efficiency, and from slow change to greater evolvability. The way that a species of technology changes over time fits a pattern similar to a genealogical tree of species evolution. But instead of expressing the work of genes, technology expresses ideas.

Yet ideas never stand alone. They come woven in a web of auxiliary ideas, consequential notions, supporting concepts, foundational assumptions, side effects, and logical consequences and a cascade of subsequent possibilities. Ideas fly in flocks. To hold one idea in mind means to hold a cloud of them.

Most new ideas and new inventions are disjointed ideas merged. Innovations in the design of clocks inspired better windmills, furnaces engineered to brew beer turned out to be useful to the iron industry, mechanisms invented for organ making were applied to looms, and mechanisms in looms became computer software. Often unrelated parts end up as a tightly integrated system in a more evolved design. Most engines combined heat-producing pistons with a cooling radiator. But the clever air-cooled engine merges two ideas into one: The engine contains the pistons but also doubles as a radiator to dissipate the heat they generate. "In technology, combinatorial evolution is foremost, and routine," says economist Brian Arthur in *The Nature of Technology*. "Many of a technology's parts are shared by other technologies, so a great deal of development happens automatically as components improve in other uses 'outside' the host technology."

These combinations are like mating. They produce a hereditary tree of ancestral technologies. Just as in Darwinian evolution, tiny improvements are rewarded with more copies, so that innovations spread steadily through the population. Older ideas merge and hatch idea-lings. Not only do technologies form ecosystems of cross-supported allies, but they also form evolutionary lines. The technium can really only be understood as a type of evolutionary life.

We can arrange the story of life in several ways. One way chronicles biological landmarks. At the top of the list of life's greatest million-year passages would be the point when organisms migrated from the sea to land or the period when they acquired backbones or the era in which they developed eyes. Other milestones would be the arrival of flowering plants or the demise of dinosaurs and the rise of mammals. These are important benchmarks in our past and legitimate achievements in our ancestors' tale.

But since life is a self-generated information system, a more revealing way to view the four-billion-year history of life is to mark the major transitions in the informational organization of life's forms. Of the many ways in which a mammal differs from, say, a sponge, one of the primary differences is the additional layers in which information flows through the organism. To view life's stages we need to call out the major transitions of life's structures over evolutionary time. This was the method of biologists John Maynard Smith and Eors Szathmary, who recently found eight thresholds of biological information in life's history.

They concluded that the major transitions in biological organization were:

One replicating molecule → Interacting population of replicating molecules
Replicating molecules → Replicating molecules strung into chromosome
Chromosome of RNA enzymes → DNA proteins
Cell without nucleus → Cell with nucleus
Asexual reproduction (cloning) → Sexual recombination
Single-cell organism → Multicell organism
Solitary individual → Colonies and superorganisms
Primate societies → Language-based societies

Each level in their hierarchy marks a major advance in complexity. The invention of sex is probably the biggest step in the reordering of biological information. By permitting a controlled recombination of traits (some traits from each partner) rather than either the pure random diversity of mutations or the rigid sameness of clones, sex maximizes evolvability. Animals using sexual recombination of genes will evolve faster than their competitors. The later natural invention of multicellularity and, still later, the invention of colonies of multicell organisms each supply Darwinian survival advantages. But more important, these innovations serve as platforms that permit biological informational bits to be organized in newer, more easily organized ways.

The evolution of science and technology parallels the evolution of nature. The major technological transitions are also passages from one level of organization to another. Rather than catalog important inventions such as iron, steam power, or electricity, in this view we catalog how the structure of information is reshaped by new technology. A prime example would be the transformation of alphabets (strings of symbols not unlike DNA) into highly organized knowledge in books, indexes, libraries, and so on (not unlike cells and organisms).

In a parallel to Smith and Szathmary, I have arranged the major transitions in technology according to the level at which information is organized. At each step, information and knowledge are processed at a level not present before.

The major transitions in the technium are:

Primate communication → Language
Oral lore → Writing/mathematical notation
Scripts → Printing
Book knowledge → Scientific method
Artisan production → Mass production
Industrial culture → Ubiquitous global communication

No transition in technology has affected our species, or the world at large, more than the first one, the creation of language. Language enabled information to be stored in a memory greater than an individual's recall. A language-based culture accumulated stories and oral wisdom to disseminate to future generations. The learning of individuals, even if they died before reproducing, would be remembered. From a systems point of view, language enabled humans to adapt and transmit learning faster than genes.

The invention of writing systems for language and math structured this learning even more. Ideas could be indexed, retrieved, and propagated more easily. Writing allowed the organization of information to penetrate into many everyday aspects of life. It accelerated trade, the creation of calendars, and the formation of laws—all of which organized information further.

Printing organized information still more by making literacy widespread. As printing became ubiquitous, so did symbolic manipulation. Libraries, catalogs, cross-referencing, dictionaries, concordances, and the publishing of minute observations all blossomed, producing a new level of informational ubiquity—to the extent that today we don't even notice that printing covers our visual landscape.

The scientific method followed printing as a more refined way to deal with the exploding amount of information humans were generating. Via peer-reviewed correspondence and, later, journals, science offered a method of extracting reliable information, testing it, and then linking it to a growing body of other tested, interlinked facts.

This newly ordered information—what we call science—could then be used to restructure the organization of matter. It birthed new materials, new processes for making stuff, new tools, and new perspectives. When the scientific method was applied to craft, we invented mass production of interchangeable parts, the assembly line, efficiency, and specialization. All these forms of informational organization launched the incredible rise in standards of living we take for granted.

Finally, the latest transition in the organization of knowledge is happening now. We inject order and design into everything we manufacture. We are also adding microscopic chips that can perform small amounts of computation and communication. Even the tiniest disposable item with a bar code shares a thin sliver of our collective mind. This all-pervasive flow of information, expanded to include manufactured objects as well as humans, and distributed around the globe in one large web, is the greatest (but not final) ordering of information.

The trajectory of increasing order in the technium follows the same path that it does in life. Within both life and the technium, the thickening of interconnections at one level weaves the new level of organization above it. And it's important to note that the major transitions in the technium begin at the level where the major transitions in biology left off: Primate societies give rise to language.

The invention of language marks the last major transformation in the natural world and also the first transformation in the manufactured world. Words, ideas, and concepts are the most complex things social animals (like us) make, and also the simplest foundation for any type of technology. Thus language bridges the two sequences of major transitions and unites them into one continuous sequence, so that natural evolution flows into technological evolution. The complete sequence of major transitions in deep history runs like this:

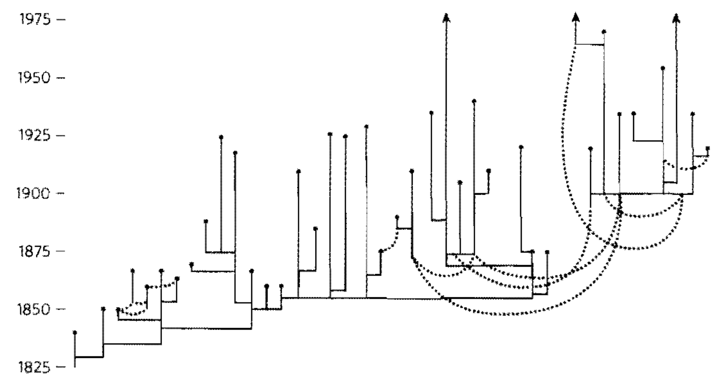
One replicating molecule → Interacting population of replicating molecules
Replicating molecules → Replicating molecules strung into chromosome
Chromosome of RNA enzymes → DNA proteins
Cell without nucleus → Cell with nucleus
Asexual reproduction (cloning) → Sexual recombination
Single-cell organism → Multicell organism
Solitary individual → Colonies and superorganisms
Primate societies → Language-based societies
Oral lore → Writing/mathematical notation
Scripts → Printing
Book knowledge → Scientific method
Artisan production → Mass production
Industrial culture → Ubiquitous global communication

This escalating stack of increasing order is revealed to be one long story. We can think of the technium as the further reorganization of information that began with the six kingdoms of life. In this way, the technium becomes the seventh kingdom of life. It extends a process begun four billion years ago. Just as the evolutionary tree of Sapiens branched off from its animal precursors long ago, the technium now branches off from its precursor, the mind of the human animal. Outward from this common root flow new species of hammers, wheels, screws, refined metal, and domesticated crops, as well as rarefied species like quantum computers, genetic engineering, jet planes, and the World Wide Web.

The technium differs from the other six kingdoms in a couple of important ways. Compared to members of the other six kingdoms, these new species are the most ephemeral species on Earth. The bristlecone pines have watched entire families and classes of technology come and go. Nothing we have made approaches the endurance of the least living thing. Many digital technologies have shorter life spans than individual mayflies, let alone species.

But nature can't plan ahead. It does not hoard innovations for later use. If a variation in nature does not provide an *immediate* survival advantage, it is too costly to maintain and so over time it disappears. But sometimes a trait advantageous for one problem will turn out to be advantageous for a second, unanticipated problem. For instance, feathers evolved to warm a small, cold-blooded dinosaur. Later on, these same feathers, once installed on limbs for warmth, proved handy for short flights. From this heat-conservation innovation came unplanned wings and birds. These inadvertent anticipatory inventions are called exaptations in biology. We don't know how common exaptations are in nature, but they are routine in the technium. The technium is nothing but exaptations, since innovations can be easily borrowed across lines of origin or moved across time and repurposed.

Niles Eldredge is the cofounder (with Stephen Jay Gould) of the theory of punctuated, stepwise evolution. His professional expertise is the history of trilobites, or ancient arthropods that resemble today's pill bugs. As a hobby he collects cornets, musical instruments very similar to trumpets. Once Eldredge applied his professional taxonomic methods to his collection of 500 cornets, some dating back to 1825. He selected 17 traits that varied among his instruments—the shape of their horns, the placement of the valves, the length and diameter of their tubes—very similar to the kinds of metrics he applies to trilobites. When he mapped the evolution of cornets using techniques similar to those he applies to ancient arthropods, he found that the pattern of the lineages were very similar in many ways to those of living organisms. As one example, the evolution of cornets showed a stepwise progress, much like trilobites. But the evolution of musical instruments was also very distinctive. The key difference between the evolution of multicellular life and the evolution of the technium is that in life most blending of traits happens "vertically" in time. Innovations are passed from living parents down (vertically) through offspring. In the technium, on the other hand, most blending of traits happens laterally across time—even from "extinct" species and across lineages from nonparents. Eldredge discovered that the pattern of evolution in the technium is not the repeated forking of branches we associate with the tree of life, but rather a spreading, recursive network of pathways that often double back to "dead" ideas and resurrect "lost" traits. Another way of saying the same thing: Early

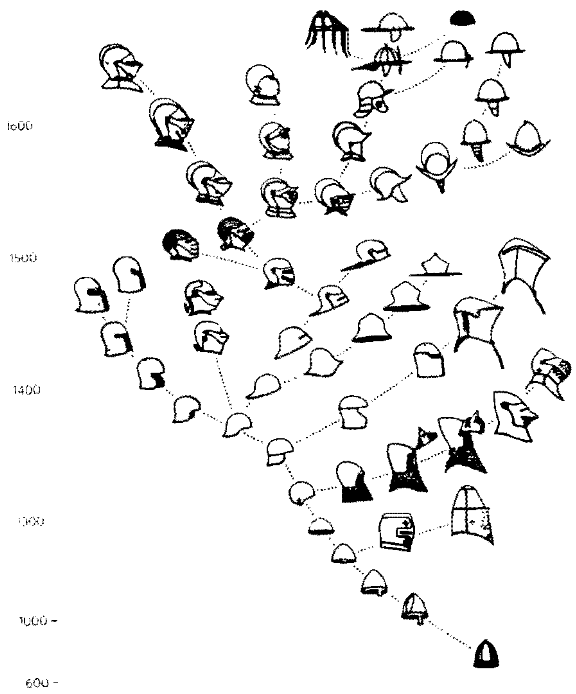


Evolutionary Tree of Cornets. The design heritage for each musical instrument shows how some branches borrow from far earlier models or nonadjacent branches (dotted lines), unlike organic evolution.

traits (exaptations) anticipate the later lineages that adopt them. These two patterns were distinct enough that Eldridge claims one could use it to identify whether an evolutionary tree depicted a clan of the born or of the made.

The second difference between evolution of the technium and evolution of the organic is that incremental transformation is the rule in biology. There are very few revolutionary steps; everything advances via a very long series of tiny steps, each one of which must work for the creature at the time. In contrast, technology can jump ahead, make abrupt leaps, and skip over incremental steps. As Eldredge points out, "No way did the transistor 'evolve from' the vacuum tube the way the eyes on one side of a flatfish's head are derived from the original bilaterally symmetrical conformation of the ancestral fish." Instead of the hundreds of millions of incremental improvements the flatfish endured, the transistor leaped from the ancestral vacuum tube via dozens of iterations at the most.

But by far the greatest difference between the evolution of the born and the evolution of the made is that species of technology, unlike species in biology, almost never go extinct. A close examination of a supposedly extinct bygone technology almost always shows that somewhere



A Thousand Years of Helmet Evolution. The American zoologist and medieval armor expert Bashford Dean sketched out this diagramatic "genealogical tree" of the evolution of medieval European helmets starting in the year 600.

on the planet someone is still producing it. A technique or artifact may be rare in the modern urban world but quite common in the developing rural world. For instance, Burma is full of oxcart technology; basketry is ubiquitous in most of Africa; hand spinning is still thriving in Bolivia. A supposedly dead technology may be enthusiastically embraced by a heritage-based minority in modern society, if only for ritual satisfaction. Consider the traditional ways of the Amish, or modern tribal communities, or fanatical vinyl record collectors. Often old technology is obsolete, that is, it is not very ubiquitous or is second rate, but it still may be in small-time use. For just one of many examples, as late as 1962, in what was then called the atomic age, many small businesses on a block

in Boston ran machines using steam power delivered to them by overhead driveshafts. This kind of anachronistic technology is not at all unusual.

In my own travels around the world I was struck by how resilient ancient technologies were, how they were often first choices where power and modern resources were scarce. It seemed to me as if no technologies ever disappeared. I was challenged on this conclusion by a highly regarded historian of technology who told me without thinking, "Look, they don't make steam-powered automobiles anymore." Well, within a few clicks on Google I very quickly located folks who are making *brand-new* parts for Stanley steam-powered cars. Nice shiny copper valves, pistons, whatever you need. With enough money you could put together an entirely new steam-powered car. And of course, thousand of hobbyists are still bolting together steam-powered vehicles, and hundreds more are keeping old ones running. Steam power is very much an intact, though uncommon, species of technology.

I decided to see how many old technologies a postmodern urban citizen living in a cosmopolitan city (like San Francisco) could lay his hands on. One hundred years ago, there was no electricity, no internal combustion engines, few highways, and little long-distance communication except via the post office network. But through that postal network you could order almost anything manufactured from the Montgomery Ward catalog. The faded newsprint of my reproduction catalog had the air of a mausoleum of a long-dead civilization. However, it became quickly and surprisingly clear that most of the thousands of items for sale 100 years ago, as cataloged by this wish book, were still for sale now. Although the styling is different, the underlying technology, function, and form are the same. A leather boot with doodads is still a leather boot.

I set myself the challenge of finding all the products on a sample page from the 1894–95 Montgomery Ward catalog. Flipping through its 600 pages, I selected one fairly typical page that featured agricultural implements. These types of obsolete tools would be far harder to find today than, say, the stove pots, lamps, clocks, pens, and hammers that populate the rest of the pages. Farm tools seemed like certain dinosaurs. Who

Catalogs of Durable Goods. On the left, page 562 of the 1894–95 Montgomery Ward catalog offering farm implements by mail order. On the right, the equivalent brand-new items offered by various sources on the web in 2005.

needs a hand-powered corncob sheller, or a paint mill, whatever that was? If I could purchase these obsolete tools from the agricultural era it would strongly suggest not much was gone.

Of course it's a no-brainer to find antiques on eBay. My test was to find newly manufactured versions of this equipment, since this would show that these species were still viable.

The results stunned me. In a few hours I was able to find every single item listed on this page of a century-old catalog. Each old tool was available in a new incarnation and sold on the web. Nothing was dead.

I haven't done the research to find out the reason for the survival of each item, but I suspect that most of these tools share a similar story. While working farms have shed these obsolete tools entirely and are almost completely automated, many of us still garden with very primitive hand tools simply because they work. As long as backyard tomatoes taste better than farmed ones, the primeval hoe will survive. And apparently, there's pleasure in harvesting some crops by hand, even in bulk. I suspect a few of these items may be bought by the Amish and

other back-to-the-landers who find virtue in doing things without oil-fed machinery.

But maybe 1895 is not old enough. Let's take the oldest technology of all: a flint knife or stone ax. Well, it turns out you can buy a brand-new flint knife, flaked by hand and carefully attached to an antler-horn handle by tightly wound leather straps. In every respect it is precisely the same technology as a flint knife made 30,000 years ago. It's yours for fifty dollars, available from more than one website. In the highlands of New Guinea, tribesmen were making stone axes for their own use until the 1960s. They still make stone axes the same way for tourists now. And stone-ax aficionados study them. There is an unbroken chain of knowledge that has kept this Stone Age technology alive. Today, in the United States alone, there are 5,000 amateurs who knap fresh arrowhead points by hand. They meet on weekends, exchange tips in flint-knapping clubs, and sell their points to souvenir brokers. John Whittaker, a professional archaeologist and flint knapper himself, has studied these amateurs and estimates that they produce over one million brand-new spear and arrow points per year. These new points are indistinguishable, even to experts like Whittaker, from authentic ancient ones.

Few technologies have disappeared forever from the face of the Earth. The recipe for Greek warfare was lost for millennia, but there is a good chance research has recovered it. The practical know-how for the Inca system of accounting using knots on a string, called *quipu*, is forgotten. We have some antique samples, but no knowledge of how they were actually used. This might be the single exception. Not too long ago, science fiction authors Bruce Sterling and Richard Kadrey compiled a list of "dead media" to highlight the ephemeral nature of popular gadgetry. Recently vanished gizmos such as the Commodore 64 computer and the Atari computer were added to a long list of older species such as lantern slide projectors and the telharmonium. In reality, though, most of the items on this list aren't dead, just rare. Some of the oldest media technologies are maintained by basement tinkerers and crazy amateur enthusiasts. And many of the more recent technologies are still in production but under different brand names and configurations. For instance, a lot of the technology first introduced in early computers is now found inside your watch or toys.

With very few exceptions, technologies don't die. In this way they differ from biological species, which in the long term inevitably go extinct. Technologies are idea based, and culture is their memory. They can be resurrected if forgotten, and can be recorded (by increasingly better means) so that they won't be overlooked. Technologies are forever. They are the enduring edge of the seventh kingdom of life.

4

The Rise of Exotropy

The origin of the technium can be retold in concentric creation stories. Each retelling illuminates a deeper set of influences. In the first account (chapter two), technology begins with the Sapien mind but soon transcends it. The second telling (chapter three) reveals an additional force besides the human mind at work on the technium: the extrapolation and deepening of organic life as a whole. Now in this third version, the circle is enlarged further, beyond mind and life, to include the cosmos.

The root of the technium can be traced back to the life of an atom. An atom's brief journey through an everyday technological artifact, such as a flashlight battery, is a flash of existence unlike anything else in its long life.

Most hydrogen atoms were born at the beginning of time. They are as old as time itself. They were created in the fires of the big bang and dispersed into the universe as a uniform warm mist. Thereafter, each atom has been on a lonely journey. When a hydrogen atom drifts in the unconsciousness of deep space, hundreds of kilometers from another atom, it is hardly much more active than the vacuum surrounding it. Time is meaningless without change, and in the vast reaches of space that fill 99.99 percent of the universe, there is little change.

After billions of years, a hydrogen atom might be swept up by the currents of gravity radiating from a congealing galaxy. With the dimmest hint of time and change it slowly drifts in a steady direction toward other stuff. Another billion years later it bumps into the first bit of matter it has ever encountered. After millions of years it meets the second. In time it meets another of its kind, a hydrogen atom. They drift together in mild attraction until aeons later they meet an oxygen atom. Suddenly something weird happens. In a flash of heat they clump together as one water molecule. Maybe they get sucked into the atmosphere circulation of a planet. Under this marriage, they are caught in great cycles of change. Rapidly the molecule is carried up and then rained down into a crowded pool of other jostling atoms. In the company of uncountable numbers of other water molecules it travels this circuit around and around for millions of years, from crammed pools to expansive clouds and back. One day, in a stroke of luck, the water molecule is captured by a chain of unusually active carbons in one pool. Its path is once again accelerated. It spins around in a simple loop, assisting the travel of carbon chains. It enjoys speed, movement, and change such as would not be possible in the comatose recesses of space. The carbon chain is stolen by another chain and reassembled many times until the hydrogen finds itself in a cell constantly rearranging its relations and bonds with other molecules. Now it hardly ever stops changing, never stops interacting.

The hydrogen atoms in a human body completely refresh every seven years. As we age we are really a river of cosmically old atoms. The carbons in our bodies were produced in the dust of a star. The bulk of matter in our hands, skin, eyes, and hearts was made near the beginning of time, billions of years ago. We are much older than we look.

For the average hydrogen atom in our body, the few years it spends dashing from one cellular station to another will be the most fleeting glory imaginable. Fourteen billion years in inert lassitude, then a brief, wild trip through life's waters, and then on again to the isolation of space when the planet dies. A blink is too long as an analogy. From the perspective of an atom, any living organism is a tornado that might capture it into its mad frenzy of chaos and order, offering it a once-in-a-14-billion-year-lifetime fling.

As fast and crazy as a cell is, the rate of energy flowing through technology is even faster. In fact, technology is more active in this respect—it will give an atom a wilder ride—than any other sustainable structure we

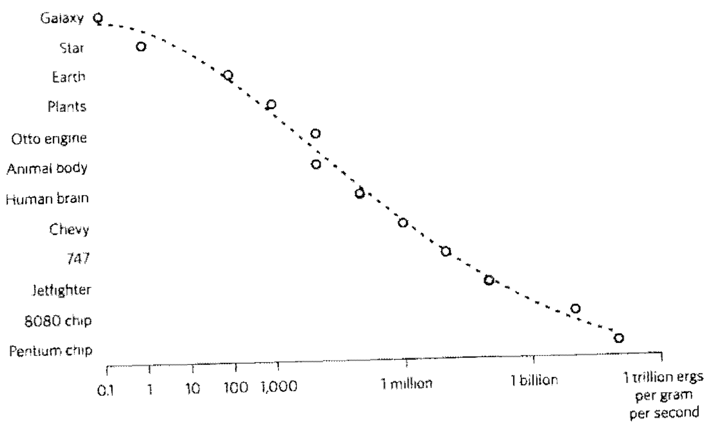
are currently aware of. For the ultimate trip today, the most sustainable energetic thing in the universe is a computer chip.

There is a more precise way to say this: Of all the sustainable things in the universe, from a planet to a star, from a daisy to an automobile, from a brain to an eye, the thing that is able to conduct the highest density of power—the most energy flowing through a gram of matter each second—lies at the core of your laptop. How can this be? The power density of a star is huge compared to the mild power drifting through a nebulous gas cloud in space. But remarkably, the power density of a sun pales in comparison to the intense flow of energy and activity present in grass. As intense as the surface of the sun is, its mass is enormous and its lifetime is 10 billion years, so as a whole system, the amount of energy flowing through it per gram per second is less than that in a sunflower soaking up that sun's energy.

An exploding nuclear bomb has a much higher power density than the sun because it is an unsustainable out-of-control flow of energy. A one-megaton nuclear bomb will release 10^{17} ergs, which is a lot of power. But the total lifetime of that explosion is only a hyperblink of 10^{-6} seconds. So if you "amortized" a nuclear blast so that it spent its energy over a full second instead of microseconds, its power density would be reduced to only 10^{11} ergs per second per gram, which is about the intensity of a laptop computer chip. Energywise, a Pentium chip may be better thought of as a very slow nuclear explosion.

The same fleeting flameout seen in a nuke applies to fires, chemical bombs, supernovas, and other kinds of explosions. They literally consume themselves with incredibly high but unsustainable densities of energy. The glory of a sunlike star is that it can sustain its brilliant fission for billions of years. But it does so at a lower energy flow rate than the sustainable flux that takes place in a green plant! Rather than a burst of fire, the energy exchange in grass yields the cool order of green blades, tawny stalks, and plump seeds ripe with information that can duplicate a picture-perfect clone. Greater yet is the steady energy flow within animals, where we can actually sense the energetic waves. They wiggle, pulse, move, and in some cases radiate warmth.

The flow of energy through technology is still greater. Measured in



Power Density Gradient. Large, complex systems listed in order of their energy flow density, as measured by the amount of energy that flows through the system per gram per second of the system's duration.

joules (or ergs) per gram per second, nothing concentrates energy for long periods of time as much as high-tech gadgetry. At the far right apex of the power density graph above, compiled by physicist Eric Chaisson, shines the computer chip. It conducts more energy per second per gram through its tiny corridors than animals, volcanoes, or the sun. This bit of high technology is the most energetically active thing in the known universe.

We can now retell the story of the technium as a story of expanding cosmic activity. At the very start of creation, the universe, such as it was, was packed into a very, very small space. The entire cosmos began as a flash smaller than the smallest bit of the smallest particle in the smallest atom. It was equally hot and bright and dense within that dot. All parts of this too-tiny spot shared a uniform temperature. There was, in fact, no room for any differences, and no activity at all.

But from the very start of its creation, this tiny spot expanded by a process we don't understand. Every new point flew away from every other new point. As the universe ballooned to about the size of your head, coolness became possible. Before it expanded to that size, in its first three seconds, the universe was perfectly solid, with no emptiness for relief. It was so full, even light could not move. Indeed, it was so uniform that the four fundamental forces we see at work in reality today—gravity, electromagnetism, the strong and weak nuclear forces—were compressed into a single unified force. In that start-up phase there was *one* general energy, which differentiated into four distinct forces as the universe expanded.

It would not be too much of an exaggeration to say that in the initial femtoseconds of creation there was only one thing in the universe, one superdense power that ruled all, and this solitary power expanded and cooled into thousands of variations of itself. The history of the cosmos thus proceeds from unity to diversity.

As the universe stretched out, it made nothingness. As emptiness increased, so did coolness. Space permitted energy to cool into matter and for matter to slow down, light to radiate, and gravity and the other energetic forces to unfold.

Energy is simply the potential—the difference needed—to cool. Energy can only flow from greater to lesser, so without a differential no energy can flow. Curiously, the universe expanded faster than matter itself could cool and gel, which means the potential for cooling kept increasing. The faster the universe expanded, the greater was its potential to cool and the greater were the potential differences within its boundaries. Over aeons of cosmic time this expanding differential (between expanding emptiness and the remnant hotness of the big bang) powered evolution, life, intelligence, and eventually the acceleration of technology.

Energy, like water under gravity, will seep to the lowest, coolest level and not rest until all differential has been eliminated. In the first thousand years after the big bang the temperature difference within the universe was so small that it would have reached equilibrium quickly. Had not the universe kept expanding, very little interesting would have happened. But the expansion of the universe put a tilt into things. By expanding omnidirectionally—every point receding from every other point—space provided an empty bottom, a basement of sorts, down which energy could flow. The faster the cosmos enlarged, the bigger the basement it constructed.

At the very bottom of the basement lies the final end state known as heat death. It is absolutely still. There is no movement because there is no difference. No potential. Picture it as lightless, silent, and identical in all directions. All distinctions—including the elemental distinction between this and that—have been spent. This hell of uniformity is called maximum *entropy*. Entropy is the crisp scientific name for waste, chaos, and disorder. As far as we know, the sole law of physics with no known exceptions anywhere in the universe is this: All creation is headed to the basement. Everything in the universe is steadily sliding down the slope toward the supreme equality of wasted heat and maximum entropy.

We see the slope all around us in many ways. Because of entropy, fast-moving things slow down, order fizzles into chaos, and it costs something for any type of difference or individuality to remain unique. Each difference—whether of speed, structure, or behavior—becomes less different very quickly because every action leaks energy down the tilt. Difference within the universe is not free. It has to be maintained against the grain.

The effort to maintain difference against the pull of entropy creates the spectacle of nature. A predator such as an eagle sits atop a pyramid of entropic waste: In one year 1 eagle eats 100 trout, which eat 10,000 grasshoppers, which eat 1 million blades of grass. Thus it takes, indirectly, 1 million blades of grass to support 1 eagle. But this pile of 1 million blades far outweighs the eagle. This bloated inefficiency is due to entropy. Each movement in an animal's life wastes a small bit of heat (entropy), which means every predator catches less energy than the total energy the prey consumed, and this shortfall is multiplied by each action for all time. The circle of life is kept going only by the constant replenishment of sunlight showering the grass with new energy.

This inevitable waste is so harsh and unavoidable that it is astounding that any organization can persist for long without rapidly dissolving to cold equilibrium. Everything we find interesting and good in the cosmos—living organisms, civilization, communities, intelligence, evolution itself—somehow maintains a persistent difference in the face of entropy's empty indifference. A flatworm, a galaxy, and a digital camera all have this same property—they maintain a state of difference far

removed from thermal undifferentiation. That state of cosmic lassitude and stillness is the norm for most atoms of the universe. While the rest of the material cosmos slips down to the frozen basement, only a remarkable few will catch a wave of energy to rise up and dance.

This rising flow of sustainable difference is the inversion of entropy. For the sake of this narrative, call it *exotropy*—a turning outward. *Exotropy* is another word for the technical term *negentropy*, or negative entropy. It was originally coined by the philosopher Max More, though he spelled it extropy. I've appropriated his term with an alternative spelling to heighten its distinction from its opposite entropy. I prefer *exotropy* over *negentropy* because it is a positive term for an otherwise double negative phrase meaning "the absence of the absence of order." Exotropy, in this tale, is far more uplifting than simply the subtraction of chaos. Exotropy can be thought of as a force in its own right that flings forward an unbroken sequence of unlikely existences.

Exotropy is neither wave nor particle, nor pure energy, nor supernatural miracle. It is an immaterial flow that is very much like information. Since exotropy is defined as negative entropy—the reversal of disorder—it is, by definition, an increase in order. But what is order? For simple physical systems, the concepts of thermodynamics suffice, but for the real world of cucumbers, brains, books, and self-driving trucks, we don't have useful metrics for exotropy. The best we can say is that exotropy resembles, but is not equivalent to, information and that it entails self-organization.

We can't make an exact informational definition of exotropy because we don't really know what information is. In fact the term *information* covers several contradictory concepts that should have their own terms. We use *information* to mean (1) a bunch of bits or (2) a meaningful signal. Confusingly, bits rise but signals decrease when entropy gains, so one kind of information increases while the other kind decreases. Until we clarify our language, the term *information* is more metaphor than anything else. I try to use it in the second meaning here (not always consistently): Information is a signal of bits that makes a difference.

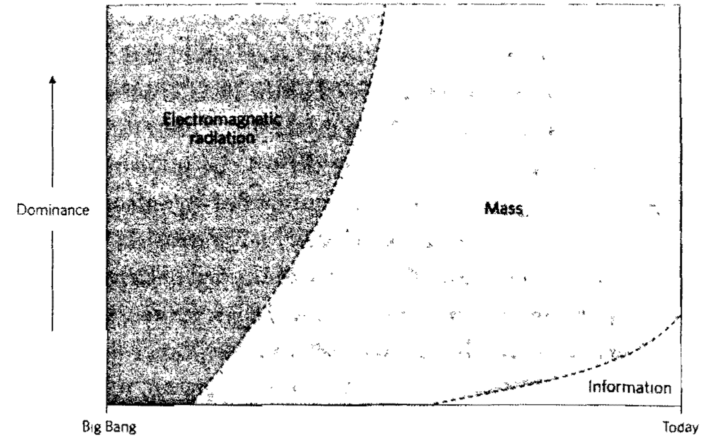
Muddying the waters further, information is the reigning metaphor of the moment. We tend to interpret the mysteries surrounding life in imagery suggested by the most complex system we are aware of at the time. Once nature was described as a body, then a clock in the age of clocks, then a machine in the industrial age. Now, in the "digital age," we apply the computational metaphor. To explain how our minds work, or how evolution advances, we apply the pattern of a very large software program processing bits of information. None of these historical metaphors is wrong; they are just incomplete. Ditto for our newest metaphor of information and computation.

But exotropy, as rising order, must entail more than information alone. We have thousands of years of science ahead of us, and thousands of metaphors. Information and computation can't be the most complex immaterial entity there is, just the most complex we've discovered so far. We might eventually discover that exotropy involves quantum dynamics, or gravity, or even quantum gravity. But for now, information (in the sense of structure) is a better analogy than anything else we know of for understanding the nature of exotropy.

From one cosmic perspective, information is the dominant force in our world. In the initial era of the universe, back just after the big bang, energy dominated existence. At that time radiation was all there was. The universe was a glow. Slowly, as space expanded and cooled, matter took over. Matter was clumpy, unevenly distributed, but its crystallization generated gravity, which began to shape space. With the rise of life (in our immediate neighborhood), information ascended in influence. The informational process we call life took control of the atmosphere of Earth several billion years ago. Now the technium, another informational processing, is reconquering it. Exotropy's rise in the universe (from the perspective of our planet) might look like the chart on the opposite page, where E = energy, M = mass, and I = information.

The multibillion-year rise of exotropy—as it flings up stable molecules, solar systems, a planetary atmosphere, life, mind, and the technium—can be restated as the slow accumulation of ordered information. Or rather, the slow ordering of accumulated information.

This is more clearly seen at the extreme. The difference between four bottles of nucleotides on a laboratory shelf and the four nucleotides arrayed in your chromosomes lies in the additional structure, or ordering,



Dominant Eras of the Universe. The relative dominant force in our local area of the universe has shifted since the big bang. Time is indicated on a log scale, its units exponentially increasing over time. On this scale a few nanoseconds at the dawn of time occupy the same horizontal distance as a billion years today.

those atoms get from participating in the spirals of your replicating DNA. Same atoms, but more order. Those atoms of nucleotides acquire yet another level of structure and order when their cellular host undergoes evolution. As organisms evolve, the informational code their atoms carry is manipulated, processed, and reordered. In addition to genetic information, the atoms now convey adaptive information. They gain order from the innovations that survive. Over time, the same atoms can be promoted to new levels of order. Perhaps their one-cell home joins another cell to become multicellular—that demands the informational architecture for a larger organism as well as a cell. Further transitions in evolution—the aggregation into tissues and organs, the acquisition of sex, the creation of social groups—continue to elevate the order and increase the structure of the information flowing through those same atoms.

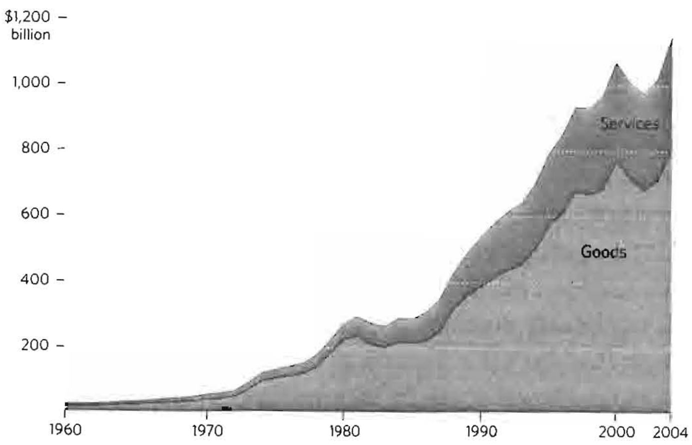
For four billion years evolution has been accumulating knowledge in its library of genes. You can learn a lot in four billion years. Every one of the 30 million or so unique species alive on the planet today is an unbroken informational thread that traces back to the very first cell. That thread (DNA) learns something new each generation and adds that hard-won knowledge to its code. Geneticist Motoo Kimura estimates that the total genetic information accumulated since the Cambrian explosion some 500 million years ago is 10 megabytes per genetic lineage (such as a parrot or a wallaby). Now multiply the unique information held in every individual organism by the total number of organisms alive in the world today and you get an astronomically large treasure. Imagine the Noah's Ark of digital storage that would be needed to carry the genetic payload of every organism on Earth (seeds, eggs, spores, sperms). One study estimated the Earth harbored 10^{30} single-cell microbes. A typical microbe, such as a yeast, produces one one-bit mutation per generation, which means one bit of unique information for every organism alive. Counting the microbes alone (about 50 percent of the biomass), the biosphere today contains 10^{30} bits, or 10^{29} bytes, or 10,000 yottabytes of genetic information. That's a lot.

And that is only the biological information. The technium is awash in its own ocean of information. It reflects 8,000 years of embedded human knowledge. Measured by the amount of digital storage in use, the technium today contains 487 exabytes (10^{20}) of information, many orders smaller than nature's total, but growing exponentially. Technology expands data by 66 percent per year, overwhelming the growth rate of any natural source. Compared to other planets in the neighborhood, or to the dumb material drifting in space beyond, a thick blanket of learning and self-organized information surrounds this orb.

There is yet one more version of the technium's cosmic story. We can view the long-term trajectory of exotropy as an escape from the material and a transcendence into the immaterial. In the early universe, only the laws of physics reigned. The rules of chemistry, momentum, torque, electrostatic charges, and other such reversible forces of physics were all that mattered. There was no other game. The ironclad constraints of the material world birthed only extremely simple mechanical forms—rocks, ice, gas clouds. But the expansion of space, with its corresponding increase in potential energy, introduced new immaterial vectors into the world: information, exotropy, and self-organization. These new organizational possibilities (like a living cell) did not contradict the rules of

chemistry and physics but flowed from them. It is not as if life and mind were simply embedded in the nature of matter and energy; but rather, life and mind emerged out of the constraints to transcend them. Physicist Paul Davies summarizes it well: "The secret of life does not lie in its chemical basis. . . . Life succeeds precisely because it evades chemical imperatives."

Our present economic migration from a material-based industry to a knowledge economy of intangible goods (such as software, design, and media products) is just the latest in a steady move toward the immaterial. (Not that material processing has let up, just that intangible processing is now more economically valuable.) Richard Fisher, president of the Federal Reserve Bank of Dallas, says, "Data from nearly all parts of the world show us that consumers tend to spend relatively less on goods and more on services as their incomes rise. . . . Once people have met their basic needs, they tend to want medical care, transportation and communication, information, recreation, entertainment, financial and legal advice, and the like." The disembodiment of value (more value, less mass) is a steady trend in the technium. In six years the average weight per dollar of U.S. exports (the most valuable things the U.S. produces)



The Dematerialization of U.S. Exports. In billions of dollars, the total annual amount of both goods and services exported from the United States between 1960 and 2004.

dropped by half. Today, 40 percent of U.S. exports are services (intangibles) rather than manufactured goods (atoms). We are steadily substituting intangible design, flexibility, innovation, and smartness for rigid, heavy atoms. In a very real sense our entry into a service- and idea-based economy is a continuation of a trend that began at the big bang.

Dematerialization is not the only way in which exotropy advances. The technium's ability to compress information into highly refined structures is also a triumph of the immaterial. For instance, science (starting with Newton) has been able to abstract a massive amount of evidence about the movement of any kind of object into a very simple law, such as F = ma. Likewise, Einstein reduced enormous numbers of empirical observations into the very condensed container of $E = mc^2$. Every scientific theory and formula—whether about climate, aerodynamics, ant behavior, cell division, mountain uplift, or mathematics—is in the end a compression of information. In this way, our libraries packed with peer-reviewed, cross-indexed, annotated, equation-riddled journal articles are great mines of concentrated dematerialization. But just as an academic book about the technology of carbon fiber is a compression of the intangible, so are carbon fibers themselves. They contain far more than carbon. The philosopher Martin Heidegger suggested that technology was an "unhiding"—a revealing—of an inner reality. That inner reality is the immaterial nature of anything manufactured.

Despite the technium's reputation for dumping hardware and material gizmos into our laps, the technium is the most intangible and immaterial process yet unleashed. Indeed, it is the most powerful force in the world. We tend to think of the human brain as the most powerful-force in the world (although we should remember what is telling us that). But the technium has overtaken its brainy parents. The powers of our minds can be only slightly increased by mindful self-reflection; thinking about thoughts will only make us marginally smarter. The power of the technium, however, can be increased indefinitely by reflecting its transforming nature upon itself. New technologies constantly make it easier to invent better technologies; we can't say the same about human brains. In this unbounded technological amplification, the immaterial organization of the technium has now become the most dominant force in this part of the universe.

Technology's dominance ultimately stems not from its birth in human minds but from its origin in the same self-organization that brought galaxies, planets, life, and minds into existence. It is part of a great asymmetrical arc that begins at the big bang and extends into ever more abstract and immaterial forms over time. The arc is the slow yet irreversible liberation from the ancient imperative of matter and energy.