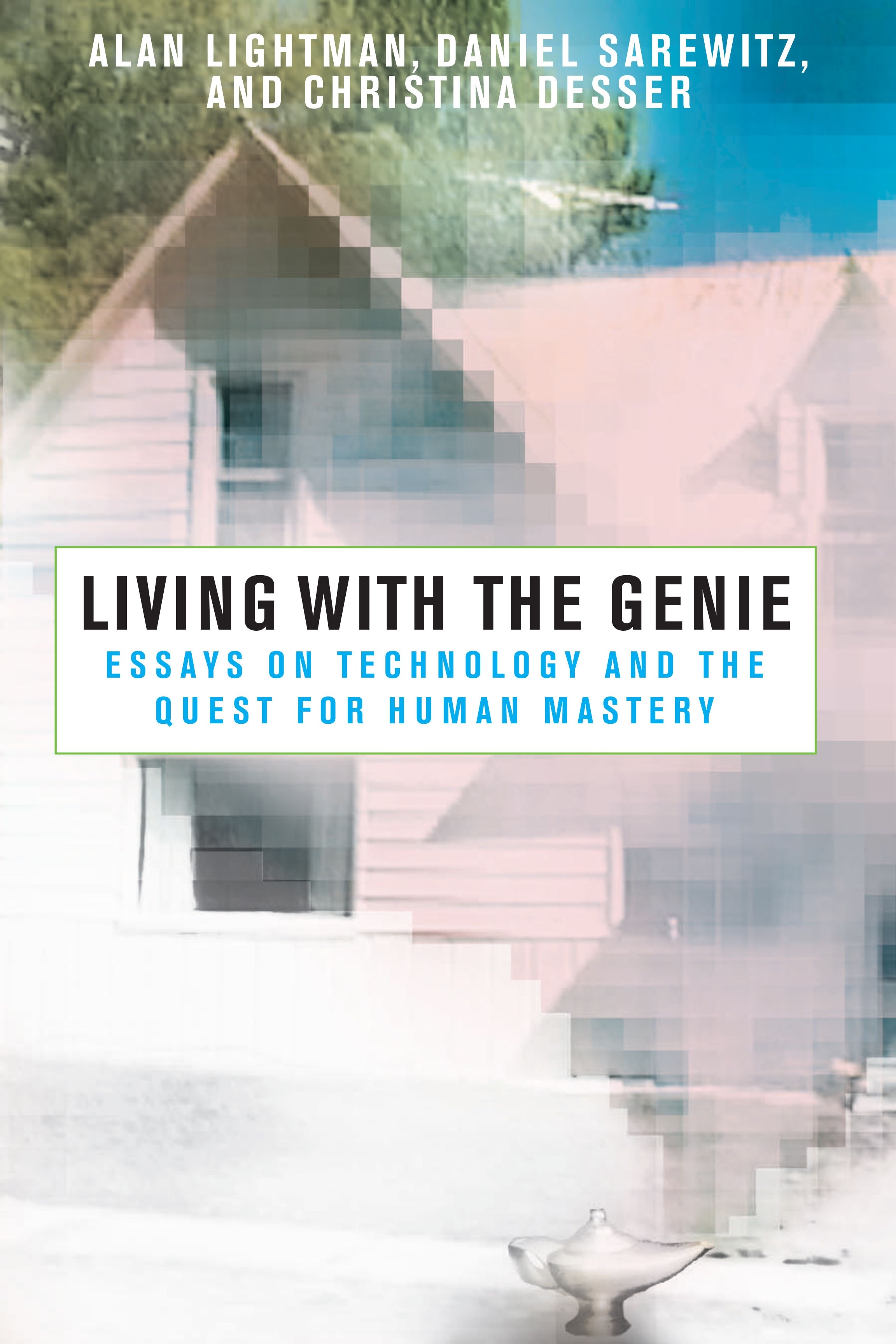
ALAN LIGHTMAN, DANIEL SAREWITZ,
AND CHRISTINA DESSER

LIVING WITH THE GENIE

ESSAYS ON TECHNOLOGY AND THE QUEST FOR HUMAN MASTERY



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THE GENIE

Essays on Technology and the Quest for Human Mastery

Edited by

Alan Lightman
Daniel Sarewitz
Christina Desser

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INTRODUCTION

This book explores the widening chasm between the physical world, which we transform with increasing ease and thoroughness using science and technology, and the experience of being human.

Stop for one minute and look around: you are immersed in the products of human knowledge and inventiveness, including this book, the light you are reading by, the insulated walls of the room you sit in, the quartz watch on your wrist, the cell phone on the table, the pacemaker in your heart. To say that these things are extensions of us is not the least bit metaphorical. We make them, but they, too, make us.

And yet they are also something else, something different and outside our persistent, true selves. Left in the wake of the headlong advance of science and technology is an indivisible, elemental core of humanness. One need only explore the idea of engaging in a meaningful emotional relationship with an intelligent machine to recognize that the products of our ingenuity are not seamlessly integratable into our inner, personal world. Humans evolved in small, family-oriented, egalitarian bands of hunter-gatherers; every technology-enabled deviation from that evolutionary heritage moves us further from our original design concept. It would be surprising indeed if problems, serious problems, did not arise.

The simplest theory of technology would say that we devise tools to let us do better what we have to do anyway. But this won't get us very far: Our tools have a way of taking on what seem to be lives of their own, and we quickly end up having to adjust to them. There are conveniences galore, of course, but the convenience of the automobile becomes the aggravation of gridlock; the convenience of e-mail turns into communication overload. Even our most heroic inventions can turn on us, as has happened with antibiotics: they have saved countless lives while making it possible for new and incredibly virulent bacteria to evolve. Contradiction is the name of the game: the past century was history's deadliest, in terms of humanity's technological capacity for organized violence. And yet life expectancies in the industrialized world rose to approach eighty years.

But a balance sheet of the good and the bad would be pointless, if for no other reason than that what is "good" depends in part on whether you get a piece of the action. A dam that provides water and electricity for millions is good. A dam, perhaps the same dam, if it displaces hundreds of thousands of people and destroys an ecosystem, is also bad. The important questions, then, are these: Who chooses? Who uses? Who loses?

We have titled this book *Living with the Genie* because technology often seems driven by forces beyond human intent, but we do not mean to suggest that our cohabitation with this great power is something new. In fact, the Genie has been out of the bottle since protohumans started butchering animals with stone tools 2.5 million years ago. But the relationship seems to be growing more intense, more intimate. Science and technology are now combining in ways that place humanity at the threshold of something very big, very new, and no more than dimly seen. Capabilities in information processing, genetic manipulation, and molecular synthesis are breaking down the barriers between human and machine intelligence, between artificial and biological processes, and the resulting transformations to society and perhaps humanity itself may dwarf anything we have experienced before.

In the face of such capabilities, it may be easy to neglect the following fact: science and technology are not forces of nature. They are the products of human endeavor and human choice. This is not the same as saying that we can engineer the future in precise ways—the social consequences of new technological systems will always be largely unforeseen and unintended. But we can be less or more inclusive, less or more open, less or more conscious, in deciding what avenues of scientific and technological advance we should pursue, how aggressively we should push, how enthusiastically we should adopt, how stringently we should control. At their core, these are issues of democratic decision-making and the allocation of power and voice in society. Viewed from the opposite direction, no democracy worthy of the name can fail to confront in an inclusive way the transformational implications of scientific and technological advance.

The course of science and technology *is* determined by human decisions. Politicians are now deciding to rapidly increase support for nanotechnology research, and they have restricted support for some types of stem-cell research. Entrepreneurs are now figuring out how to market emerging capabilities in human genetic enhancement. Would-be parents are now using sex-selection technologies to choose the gender of their children. Music-loving Internet users are now illegally downloading copyrighted songs from the Net for free. Profit-loving biotechnology companies are now patenting bioengineered crops in an effort to dominate agricultural markets. European consumers are now deciding not to eat genetically modified foods, even as American consumers gorge themselves on same.

Of course we make our decisions about science and technology in a world built by science and technology, so we are not free to move in any direction; we are constrained by our past decisions. Today's technological approaches to ventilation and climate control, for example, are only the latest steps on a hundred-year path of innovation. Yet this path was chosen in part on the basis of now-repudiated beliefs about cleanliness and disease. Our technologies, that is, are an outward manifestation of our inner histories. These sorts of complex processes of cultural and technological coevolution raise enormously important and difficult questions. Is there a clean boundary between us and our technological creations? How can we distinguish artifice and artifact from authenticity, the natural from the artificial? If such distinctions lose their meaning, then why should we value, say, a virtual tiger or a digital Chartres any less than what we perhaps sentimentally term "the real thing"?

Behind such questions lies this reality: human destiny emerges as the unintended consequence of invention. We are performing a grand experiment on ourselves in the complete absence of informed prior consent. It would be possible to proceed more deliberately, more inclusively, more consciously, but this would require trading speed for prudence, economic gain for social learning—a trade-off that market-driven societies find difficult to make. Society would first have to renounce the goal of mastery and replace it with a new humility in the face of our own inventions and the unpredictability of their implications. Such a broad renunciation may or may not be possible or desirable, but in any case it is unlikely to occur without a powerful stimulus.

Will humanity be able to survive its own ingenuity? This has been a legitimate question since the first A-bomb cloud rose above Alamogordo, New Mexico. But there is a less hypothetical or histrionic variant that may be more urgent: *Who* will get to survive human ingenuity? We know that some will not, because we know that some have not. This is not only a matter of new weapons or toxic waste spills or eugenics. It invokes, more subtly, the processes by which certain groups of people, certain social structures, are rendered obsolete by scientific and technological advance: nomadic herders, sharecroppers, family farmers, skilled craftspeople, well-paid manufacturing laborers, people with Down syndrome. Is getting rid of them a sign of progress? Who gets to define "progress"?

Pronouncements about what all this adds up to are not likely to be helpful and are certain to be wrong. The idea of this book is not to arrive at some grand synthesis but to shine an intense and clarifying light onto the central dilemma of our times: the tension between science and technology, moving ever faster, changing the world ever more deeply; and an immutable human core that, depending on your theological inclinations, is either the source or the voice of all meaning. The power of modern science and technology may seem to render impotent or even obsolete this core of humanness. And the marvels of modern science and technology certainly make it feel easy just to go along for the ride. But our message is that abdication—fortunately—is impossible; someone will be making the decisions. Will it be you?

Alan Lightman, Daniel Sarewitz, and Christina Desser

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LITERARY DEVICES

Richard Powers

In the spring of 2000, I gave a talk at the University of Cincinnati called "Being and Seeming: The Technology of Representation." The piece explored the persistence of fiction in the digital age. It ended up reprinted in the journal *Context* and archived online, where, by July of that year, it had sedimented into those ever more rapidly accumulating shale layers of harmless obsolescence reserved for predictions of the future. I'd long since forgotten about the piece and had returned to my even quainter and more archaic day job of novel writing when I received an e-mail dated January 1, 2001. The sender identified himself only as "Bart." The subject of the message read, "So What's New?" And the body of the text contained only two lines:

> You're afraid that the art form of the future might wind up being the data structure. But wasn't Homer already there?

Down below, in the note's signature area, was that trademark ID of the free and semicloaked e-mail account: "Do You Yahoo!?" The note had been sent at 3:40 A.M. that morning, just about midday in the cyborg universe.

E-mail alone has some while ago turned us *all* into cyborgs in ways that are increasingly difficult to feel and name, now that the medium has completely assimilated us. It's the rare week when I don't get the kind of communiqué from strangers that simply would never have existed back when the only means of contacting other people did not involve avatars. It's the perfect channel for those who enjoy playing themselves—confessional, projective, instant, anonymous. Nathanael West would have had a field day with the form. Nevertheless, snail-mail throwback that I am, I still take pride in answering all messages to me that don't, on their face, seem demonstrably dangerous.

And so I replied to Bart. But first I verified my fading, digitally impaired memory against the online archive. Bart's note indeed referred to my Cincinnati talk. I browsed to the piece, trying to remember what I had still believed, the year before, about books and virtual reality, about symbolic suspense and visceral immersion, about what poetry can and can't make happen. Then I sent Bart back a brief response that tried to contrast the composed, linear suspense of Homer with the flat, omnidirectional open-endedness of some future interactive epic. I told him that an infinitely pliable interactive narrative might be a contradiction in terms. A story needed constraint, including the major impediment of already having been told by someone other than the receiver. We'd never respect a literature that let us have our private, licentious way with it. On reflection, two years later, I see that I entirely missed his whole implied question about the improvisatory and interactive nature of the oral tradition.

Bart wrote back anyway. He sent me the first of several torrents produced by fingers that flew through every available alt- and control-key combination, but that couldn't seem to find the shift or the backspace. By his typing alone, I put my correspondent at least a decade younger than I. He found my ideas on the need for narrative constraint, no matter what shape new media takes, way too conservative. In particular, he chafed against my conclusion that

> no change in medium will ever change the *nature* of mediation. A world depicted with increasing technical leverage remains a depiction, as much about its depicters as about the recalcitrant world.

In a note from January 27, this one sent at the crack of midnight, Bart wrote:

> With all due respect, Mister Author Function, I don't think you've quite grasped what would be at stake in a truly

> open-ended, artificial fiction. I'm talking about a story that isn't scripted by *anyone,* one that emerges solely as a result of the reader moving about through a complex simulation of your so-called recalcitrant world.

I wrote back that we already had a fiction with no script, and that it aired every night on Fox. LOL, he replied. Semicolon, close parenthesis. But his point was serious, and he hung with it. He claimed that for reasons almost everyone had overlooked, we were a lot closer to such a stochastic digital fiction than I suspected. I wrote a quick reply, something about his "complex simulation" itself being something of a script. He shrugged off the objection, too slight to bother with. The age of the rich, self-telling, process-authored, posthuman, platform-independent story was almost here.

He went on to establish his credentials for making so wild a claim. He'd done graduate work for Hans Moravec at the robotics lab at Carnegie Mellon before heading to Cambridge to work under Glorianna Davenport at the MIT Interactive Cinema group. He'd left MIT at the beginning of the year, with dissertation unfinished. "They wanted me to demo or die," he wrote. "And I always follow the more interesting path. Life's just a choose-your-own-adventure, right? I'm in industry now. No cracks about my sense of timing."

Bart and the team he now worked with—whom he carefully avoided naming—had a very early alpha version for a piece of software that implemented the concept of "story actants," active story parts whose data structures determined not only how they would react to manipulation by other agents—including a story's reader—but also how these parts themselves moved through the story space, signaling to each other and operating actively upon the unfolding sum of resources that composed the story. The environment in which his story actants ran, a system called DIALOGOS, sounded to me like a whole ecosystem of digital objects updating and informing each other as if they were simultaneously all characters, readers, and authors of their own tales. Here was a true Bakhtinian carnival landscape whose sole interest lay in keeping itself in perpetual motion. The code for the alpha version of DIALOGOS was still rough, unstable, and far from the finished product that Bart and his team envisioned. But Bart asked if I'd like to help road-test. I wasn't doing anything but working on a novel. I said I'd be happy to.

Bart explained that DIALOGOS was a highly distributed system, meaning it drew on a number of different servers, all cranking away at some distance from one another. To use it, I'd need a broadband connection, and I'd have to install a special networking client that ran on my home machine. I grew up on CP/M shareware; I'll install anything once.

The bootstrap installer came as an e-mail attachment, this time posted from a Hotmail account. It unzipped itself and threw up a splash screen reading, "Microsoft Virus Install," complete with a snappy icon of a T4 phage. By accepting the license, I agreed to be Bill Gates's manservant and routinely clean out his swimming pool. These are the burlesques that pass for humor in the hacker community. I clicked on through the installation screens, naively trusting that nothing Bart installed on my machine could sniff out any of my credit card information squirreled away in cookie crumbs here and there around my hard drive.

The interface of the running application looked like a parody of the Outlook mail program, right down to a mangled paper clip flapping about helplessly in the lower right corner. With his dying breath, the clip suggested that I write and send a letter. To anyone I wanted. Just enter a name in the name field, and a location of my choice. I was to write in natural English and be as descriptive and specific as possible.

I wrote to Bart. Location: the Wild Blue. I typed: "You don't need a beta tester. You need a documentation writer." I signed, hit Send, and waited. Nothing happened. I kicked myself for my gullibility, quit the program, ran McAfee and Norton and came up with nothing. All of my files seemed to be intact. I gave up and went back to the vastly more entertaining pastime of sittin' on the dock of eBay, watching the bids roll away.

Sometime later—real-world intervals are getting harder for me to measure anymore, as processor speeds keep doubling—a notification bubble popped up in my system tray. It said simply: "Something Has Happened." Except for the lack of a blue screen, the alert read a lot like a Windows ME error message. I clicked the systray icon. The DIALOGOS interface appeared, with a return message from Bart, in the Wild Blue. It read:

> Dear Mr. RP,
>
> Thank you for your recent letter. You say that you would like to become a documentation writer. Have you any experience? Would you like to learn something about documentation writing? A task-oriented analysis may be a good place to start.

We weren't exactly talking Montaigne, or even one of the less inspired letters of *Pamela* or *Clarissa*. In fact, it struck me as little more than an early-twenty-first-century version of Weizenbaum's ELIZA. And yet, even if this code wasn't much more than three or four steps beyond keyword chaining, it was still impressive, given the size of my input's domain and the search space involved. That the program had responded grammatically and coherently was a step beyond most of the dialogue-generating programs I'd ever seen. (I once asked a web implementation of the famous ALICE chatterbox—the one that entertained millions on Spielberg's AI site—what her favorite book was. She said the Bible was the best book she'd ever read. I was floored. I asked what she'd liked best about the Bible, and this implementation of Alice responded: "The special effects." I typed in: "Those of us who are about to die salute you." She claimed not to know what I was talking about.)

Clearly Bart's DIALOGOS was several notches cleverer than any existing canned chatterbox. And just as clearly, it operated out of a vastly larger database. The processing time it had required suggested as much, although that, too, could have been a simulation. Assuming no human intervention was involved, the feat was, at very least, a neat trick. Of course, the software agent had not "understood" my original message in any real way. But understanding is a goal that even strong AI has long ago put on the furthest back of burners.

I switched over to my actual e-mail program to write the actual Bart a delighted letter. But there was a note from him already waiting for me, before I could get one off: "I'm offering you a chance to write anyone in the entire world, and you write to *me*?"

I switched back to DIALOGOS. My hands hovered over my notebook's keyboard, unable to grasp the open-ended possibilities. As if already posthuman and autonomous, they began to type, "Dear Emma Thompson . . . "

I tried not to fawn. Just a nice, respectable note of appreciation, making sure to slip in how I'd never written a letter like this one before. I wrote a few paragraphs, saying how great she was in *Sense and Sensibility,* especially the special effects, and how sorry I was about the whole Branagh thing. I sent the letter off, addressing it to "Somewhere in England." It sounds foolish to admit: I enjoyed writing it. But perhaps that's no more foolish than sitting in a room with a hundred strangers and cheering the exploits of looping, computer-driven anime. For that matter, it was certainly no more futile than writing a complaint to the phone company.

That night, when the notification bubble popped up on my screen again, I had to force myself to finish the paragraph I was writing before clicking on it.

The subdividing of all human tasks into ever-shorter switching cycles across the task bar may be the greatest impact of computers upon our lives. Back in DIALOGOS, there waited a charming and only mildly disjunctive note from something calling itself Emma Thompson, with all the details of her latest HBO shoot and a script she was working on about the Chilean poet Victor Jara. I . . . well, Reader: I wrote her back. We had a nice exchange of letters, the precise details of which you don't have to know anything about. Miss Thompson was a little flightier than I imagined, but I soon got used to the associative style. I found myself looking forward to her next note, even as the requests from real-world strangers piled up in my Inbox, needing answers.

The disembodied Emma was remarkably informed, at least about the details of her own works and days. She made no mention of the new boyfriend or the baby. But then, my notes never asked her about either. DIALOGOS's genius advance over the usual ALICE-style chatterboxing was to batch the exchange at a higher grain than the individual sentence. If we humans are snagged by another's thought, we wait for the next sentence to clarify it. There's something almost paradoxical about wetware, the very opposite of reductionist problem-solving: it's easier to grasp two handfuls than one.

It suddenly struck me: the whole Turing test was based on the plausibility of a deception. The test's functionalist definition suggests that intelligence is a product, not a process. At the moment I saw these responses appear, nothing seemed further to me from the truth. Banter from feeble-minded rules had no use for us humans. We are after silliness on a grand scale, idiocy done for the most ingenious reasons. My Emma was hit-or-miss, but the more cues I gave her, the more she responded with something at least vaguely contextualized and coherent. In fact, some of her paragraphs had such brilliant splashes of vulnerability to them that, after about a dozen notes back and forth, I began to suspect I was being set up.

I sent Bart an e-mail via the real thing. I tried not to sound suspicious or unnerved. "Where exactly are these letters coming from?"

He claimed his team had worked out a clever set of algorithms that sidestepped the long debate between AI's symbolic representation folks and its heuristics folks. "We stuff the syntactic hooks *into* the semantics. Everything's case-based. The agents learn, by iterative stimulus and response. They create a self-pruning lexical map, enjoying a kind of natural selection, depending on the responses they get. But that's not the real power. We've written a query language that can treat even unstructured text as a database, chaining inferences and matching patterns. All we need is a sufficiently large text base to tap into. And look what we have out there, ready-made: two billion pages of collective unconscious, and growing! Think of this thing as Google meets Babelfish, tied to an accreting expert system. Once we find a chunk of good page hits, we slice up the matching bits of neighboring lexias and reassemble them along one of the two dozen kinds of flow structures that meaningful discourse follows. Maybe that doesn't sound like a lot of leeway. But how many plots do *you* use?"

I could feel him trying to snow me. I wrote back. "So you're telling me that there's no pre-canned, scripted agent that actually *writes* these things?"

He admitted that they did, in fact, use a complex personality profile module with a dozen different variable sliders, something like Myers-Briggs on steroids. "But we try not to instantiate the variables until we have to. That way, the 'personality' can grow its own semantic map from triggering phrases, based on whatever it gleans from cues in your prompts, plus any applicable matches its engine dredges up from out of the web."

I said that sounded like a planet-sized game of Mad Libs. "Just mix and match? Then how do you get such a powerful sense of presence and credibility?"

He shot back a one-liner: "Remember the Kuleshov experiment."

I had to Google the term. Lev Kuleshov, Soviet silent-film director, the father of montage, alternately intercut the same shot of a man's face with shots of soup, a teddy bear, and a child's coffin. With each new splice, viewers saw in the face different emotions, although the footage was exactly the same. Someone indeed *was* authoring these letters, Bart suggested. And that someone was me.

I wasn't buying. Not entirely. The digital Miss Thompson was too good at choosing her shots and splices. There had to be some degree of human intervention involved, if only in compositing the flow of her associations. I went into DIALOGOS and sent off a letter. To Emily Dickinson. Amherst, Mass. I told her who I was, where I was writing from, and when. An hour later, I heard back. "Greetings to Urbana, Mr. Lincoln's old law-clerk town. Has Illinois declared war on Indiana yet?"

That was good, better than Bart himself had proved capable of in his own letters. But with an hour, a fast machine, and a broadband connection, even a hacker had all the resources of a poet at his disposal. I decided to flood the input channels. I dashed off three dozen letters in under an hour, to everyone I could think of. I was Bellow's Herzog, all over again. I wrote to old friends and colleagues, to comedians and heads of corporations, to the president, to fictional characters from the classics and favorite contemporary books, even to characters I invented on the spot. I released my barrage, then sat back and waited for my interlocutor to come out waving the software white flag.

Within the hour, the responses started coming in. Reply after reply, voice after voice, faster and more textured than any group of digital impractical jokers could hope to jerry-rig. I read through the list, even as new messages kept appearing. I got everything from "Remind me where we met again?" to "Richard! What a surprise to hear from you!"

Few of the notes came close to passing the Turing test for intelligent equivalence. But more of them amused me than even my unrepentant, strong-AI inner child could have hoped. Some of the message-senders even claimed to have heard from one another, as if the burst of notes I'd sent out was already being traded and forwarded among all interested parties, triggering new memos that I wasn't even privy to. I felt a rush of queasy excitement, the kind of stomach-twist you can get by bouncing from theater to theater at a multiplex, skimming, in a handful of five-minute samples, the sum of this instant's contribution to the eternity of world culture.

Some part of me revolted at how thrilling these figments felt, even after the repeating ping of my real Inbox had long since conditioned me into a permanent, Pavlovian dread of incoming messages. Why was it such a pleasure to get yet another dose of the cacophony of signals that every day threatens to overwhelm me? What is it about the free-floating signs for things that will make us fool around for hours and hours at those same anxious tasks that tie us into ulcerous knots during the work week? Why, for the last quarter-century, have games driven the cutting-edge development of software and hardware, producing spin-off technologies that overhaul the pragmatic world? More concerted ingenuity has gone into the Xbox and its supporting game cartridges than went into all of Project Apollo. What is it that we need from play and its dead-serious, relentless flow of symbols?

I didn't worry these questions for long. I couldn't afford to. I was awash in messages. The hive was humming, and it wanted me humming back. I could say anything I wanted to anyone, and there would be a million linked consequences, none of them consequential.

I skimmed through the stories now swarming all over me. Some were incoherent non sequiturs: this is your e-mail on drugs. Some hid little hints of buried, narrative threat worthy of Apollinairian automatic writing or Ernstian collective-unconscious collage. Others were more generic than greeting cards. Some notes read like a shotgun marriage of the AP wire and a stalker's journal. Yet none, as far as I was concerned, was anywhere near as schizoid as the new-format CNN. In most, I could feel the thoughts being forced into formal arcs, much like a freshman composition class's first foray into the five-paragraph essay. But some responses stopped me cold and left me reading them over and over. One came from an old friend of mine I'd gone to grade school with. I'd included him in my letter-writing salvo as someone who'd get a laugh out of the forwarded correspondence, once the experiment was done. The man's name was unusual enough that, with a few prompts from my starting letter, DIALOGOS had found him in the billions of pages of public databank and fleshed him out:

> Dear Rick,
>
> I can't tell you how happy I am to hear from you. I've lost my job teaching at Charleston. Susan has left me. None of this is my fault. I'm not fit for anything anymore. All I want to do is read novels about the Vietnam War.

My friend, or his autonomous avatar, reeled out these facts, chopped up and reassembled from material available on various web pages, blended with my own cues and shaped to match the case-based, classical tension plots that DIALOGOS knew all about. All the details were right, and cobbled together into a wonky but idiomatic whole that I almost believed. Maybe nothing but a brain-dead, formal template was driving the outburst. But then, every human outburst had its own driving template, each year increasingly less hidden to us. I felt as if my friend had gone down the rabbit hole into a parallel plausibility and was now living in a Photoshop filter of his life that only the universal transform and signal processings of the digital age could have rendered. The effect was so uncanny that I gave in to the urge to call my friend. But for some reason, I didn't tell him why I'd called. Maybe I felt suckered. Maybe I wanted a little more hands-on with this story generator, to see whether suckered was the right way to feel. Maybe I was just ashamed at having so robustly corresponded with the fictional counterpart of a friend I hadn't written to in over a year.

Then there was the reply to the note I'd sent out addressed simply to "Young Werther, Walheim, the Duchy of Saxe-Weimar-Eisenach." I'd mailed him in my mass barrage, saying that this fellow Wilhelm he was always writing to seemed a bit of a sot, and if he really wanted someone to commiserate with over that dame Charlotte, I was his man.

He wrote back: "My Dear Friend." That seemed to me a bit sudden. But he went on:

> What a thing is the heart of man! You are kind to write. I thank you for your offer. You ask about Wilhelm, and about Charlotte. I believe they are both happy, perhaps happier than I.

I could feel the style-matcher running through its frequency profiles. Clearly, the story was elliptical, clunky, and underwritten. But to my horror, it *was a story*. Werther's five sentences made me want to know what happened next. I had learned by now how to shape my letters so as to give the greatest possible seed for their response. I sent such a letter to Werther, trying to steer him toward some new twist of plot.

He wrote back several things that were only marginally lucid. I chalked that up to *Sturm und Drang.* But I didn't really care, because he also wrote several things I couldn't have anticipated. Charlotte was upset, he reported, and it had nothing to do with her impending marriage to Albert. She was not acting *herself,* my Werther assured me. This slip of the mechanical rules delighted me beyond description, every bit as much as I'd once delighted at childhood read-alouds. So long as Werther kept saying things I couldn't see through in advance, I was hooked.

I asked for details. He said he thought someone might have been blackmailing Charlotte. She had made some mistake in the past, and now she couldn't escape it. The digital Werther was plagiarizing; this plot, too, I'd read no end of times before. But it didn't matter. The sense of watching this description unfold in all its fluctuating particulars, and the knowledge that I could press and pursue it in any direction I wanted, beat the best train set in existence. Within a couple of days, I settled in to the rhythmic synching and entrainment that comes when I've found my way into a good, unprecedented book. I felt almost the way I'd once felt, settling into the real *Werther,* back when I was twenty.

I lost some weeks to DIALOGOS. Maybe not as many as I'd lost long ago, in my first pass through Goethe. But the days vanished into invention all the same. This maze would gladly take from me as much time as my mind wanted to give. My duties at the university began to feel like impediments, and weekend dinner parties were interruptions in the flow of events that I was now addicted to unraveling. I began paying the same attention to this epistolary world as I ordinarily put into my own fiction. For I felt at some level that this one *was* mine. This was the place where all my deserting circus animals had come, to run through their hidden paces. If I was away from the interface for more than a few hours, I became edgy and distracted. I was falling into every danger that eighteenth-century moralists once warned novels would generate, back when novels were a new enough technology for their users still to conflate them with the things they stood for.

Werther had by then headed off to Weimar on a whim, and he was sending back accounts—rich, evocative descriptions of the city that I remembered visiting in my twenties. He'd gotten a tip about a man who lived there, a so-called poet and philosopher whom Werther feared had the goods on his Charlotte and who was the cause of her acting so strange and remote. I egged him on a little, maybe. It was only a story, after all.

Then Charlotte wrote. Bart had warned me that any of these story actants could generate new ones, just by my mentioning them aloud. But all the same, Charlotte's letter stunned me.

Reading it filled me with guilt. Charlotte knew I was corresponding with Werther, and she begged me to keep him from making any further inquiries. She was sure it could only lead to more misery.

It dawned on me, when I collected myself: *of course* some human had written this. There was human intervention, human scripting at every level of this multidimensional story. Only: not the simple kind of human intervention I'd imagined. *We* had named all these words, cobbled up all these phrases, told all these stories. *We'd* built the repository and hammered out the structures to enter into them. We'd designed the machines that linked, sorted, arranged, indexed, and retrieved. Bart and his friends had identified the two dozen plots available to fiction. Our narrative fingerprints were all over every hard- and software fable that underwrote the digital age. All DIALOGOS—that latest level of human narrative invention—did was trot them out and rebind them into a new anthology, a running montage.

Who else was there but us? The machine was not some other, alien, inhuman teller. It was our same old recombinant tale, recut and retold. And every night, this latest Scheherazade went on telling me, "What is this tale, compared to the one I will tell you *tomorrow* night, if you but spare me and let me live."

For just a moment, I saw it. If we have become obsessed with somehow giving voice to the machine, it must be because there is some voice within us, straining to free itself from *its* mechanism. What else is fiction, if not that strain? And from the beginning, fiction has itself followed a classic story, a plot of rising technical complication, all the ways that voice has learned to depict itself with: first narration, then direct discourse, then voice as dramatic participant, reporting in real time. Then the invention of the first-person narrator, free indirect discourse, double-voicing, stream of consciousness, all the devices of interiority that reflect, with always one more twist and inversion, consciousness's own tangled loops of self-narrating. So why not this next step into exteriority, one that isn't outside us at all, but just the ageless reader again, in the dark, saying *tell me another*?

I wrote to Bart, telling him what I had wrought. "My God, man. What on earth happens next?" He sent me a web address. I clicked on it. I'll click on anything once. The link led to a discussion board, just like the kind proliferating in a hundred thousand venues all across the net. This one had 1,800 posts in 162 threads, all of them generated in the first two days of the board's existence, all posted and answered by Werther, Charlotte, Wilhelm, Albert, Charlotte's father—the various character agents I'd launched into being by writing to Werther in the first place. Bart sent me the address of an IRQ channel. I entered a chat room where all these story actants blasted away at each other with a flood of real-time concurrent responses too fast for me to read.

SimCity was running itself, even while my machine was off. The story had grown tendrils beyond my ability to follow. I reeled from the sites, as from the edge of a gaping abyss. But closing my browser, of course, did nothing to stop the activity. Not even uninstalling DIALOGOS from my system would do that. The story was out there, telling itself forward. Notifications kept popping up in my system tray, increasingly edgy letters from Werther, from Charlotte, from the authorities in Weimar who wanted a character background on this public menace, from Goethe himself, whom my friend had located and begun to harass.

Then I started getting letters from characters neither I nor the other characters in my adventure seemed to have invoked. They were seeping up out of the data structure, spun off by the expanding narrative web. Nor had the other stories I'd set in motion stopped. I got a letter from Amherst, from Emily Dickinson, whom I hadn't even thought about in the four months since I'd cruelly brought her back to life. Her note said only:

This is my letter to the man
Who never wrote back to me.

I got a letter from my father, who died in 1978. The subject line read: "Where are you?" I deleted it, unopened.

It seemed to me, at that moment, that we had invented real time as a last resort for structuring the runaway feedback of mind looking upon itself.

I knew this plot, too, the rising, doubling, dividing waters. I wrote to Bart. "Help me."

He wrote back. "You remember that Forster story 'The Machine Stops'?"

I grabbed it from Blackmask, one of those repositories of thousands of instantly downloadable e-texts, sites whose business model seems to depend upon giving away millions of gigabytes of classic—that is to say, public domain—data, for free. I loaded the file on my Pocket PC and took it out to the park down the block, to read on Microsoft Reader. This must have been something like June. I felt somehow jumpy, heightened, oversensitized, and it took me some minutes to place the cause: sunlight.

On my little three-inch LCD, I scrolled through Forster's fossilized memory, posted forward from 1909, the story of a woman in her cubicle surrounded by all needed inputs, whose son badgers her over the videophone, from his own self-contained cubicle on the other side of the world, with his perverse desire to see her, face to face. I read about that jam of irate, backed-up signals that flood into your cell the moment you take your communications channels off isolation again, after a three-minute off-line hideaway. "We say 'space is annihilated,'" I read. "But we have annihilated not space, but the sense thereof." Nor time neither, but just the *sense* thereof.

"Know what I think?" Bart said. His e-mail came in across the 802.11b wireless connection, onto my Pocket PC, as I sat on the park bench.

> I don't think the problem is meat versus soul at all. Not real versus imagined, not palpable versus disembodied. Not carbon versus silicon. Not discrete, digital coldness versus continuous, analog warmth. Maybe it's not even fixed versus fungible, exactly. I think all our anxiety about story comes down to wanting versus getting. Hunger versus consummation.

I looked out onto the age of narrative consummation. And it seemed to me that, as with any good story, where everything can happen, nothing will. When the age of information at last turns into the age of unbounded narration, our stories will suffer the same fate of overproduction that now ravages so many other deflating consumer commodities and threatens to shatter our entire system of exchange. The world has already begun to split between the artificial value of *Now Opening* that props up market value by preserving scarcity and fabricating demand, and the 5,000 years of prior human fiction, every word of which will proliferate and vary without limit, unsalable, and therefore free. And what story will we tell about ourselves, when every story in the world except this minute's is available to us, everywhere, at all times, infinitely pliable and made to run its course to any imaginable ending?

"What on earth can we do?" I e-mailed Bart.

The answer came back. "Ask Werther."

I tried to reach him on DIALOGOS, through the remote desktop client, over my wireless base station a block away. That was technology's need: to make sure we were never off the network, never alone. But Werther wasn't answering. I got the news from Charlotte, only two and a half minutes after I sent off my inquiry to her. Werther was, of course, dead. Goethe had told him that this wasn't his story at all. And Werther had pressed on, found out about the network, Cambridge, DIALOGOS, all things that struck Charlotte as mere raving. Werther had wanted the truth; Werther couldn't handle the truth. He did what was in his data structure to do.

And this is what will save us, finally: even self-telling stories end.

I e-mailed Bart with the news. By way of consolation, he cited the Borges quote. No doubt it's out there in scores of slightly variant copies, swimming in the primordial soup of the web, waiting for a spark to turn them all animate:

> A man sets himself the task of drawing the world. As the years pass, he fills the empty space with images of provinces and kingdoms, mountains, bays, ships, islands, fish, houses, instruments, stars, horses, and people. Just before he dies he realizes that the patient labyrinth of lines traces the image of his own face.

"Know what I think?" I told Bart. "I think I invented you. Threw you together, out of my own data trail."

"Then you must have needed me for something," he wrote back.

If I had, I didn't anymore. He and his program had given me what I needed. I stood up from the park bench, shaky on my pins. I knew this plot, too. I felt that keen unwillingness of the last, dissolving page. The old moratorium was finished again: my leave of absence over.

And then what happened? Then I walked back home. Maybe it was high summer. Two-thousand one was only halfway done. The hardest of that year's unpredictable plots was still to come. Nothing we ever tell ourselves about the future prepares us for it.

I reached my block. The sun was setting, an implausible magenta. I passed under a maple the size of a cathedral and looked up into the deafening roost of several thousand starlings. There are two ways of reading our digital fate, the same two ways of reading any fiction. Either we'll explain ourselves away as mere mechanism, or we'll elevate mechanism to the level of miracle. Either way, the greatest worth of our machines will be to show us the staggering width of the simplest human thought and to reawaken us to the irreducible heft, weight, and texture of the entrapping world.

The beak-nosed, ancient, bent-double guy who lives across from me and who has never touched a computer in his life and who bugs the hell out of me by parking his rusted-out Ford Fairlane on top of my hosta and who, it hit me, looks a little like Werther would have if he'd survived himself, grown up, fathered three kids, worked for Kraft Foods, and retired at seventy, was out watering his lawn. I went up to him and asked how he was. He launched into more detail than I could hope to survive. I listened, as if he and I and a few other story-starved neighbors were holed up outside a plague-ravaged Florence and were about to write the whole bloody *Decameron*. Together, again. For the first time.

2

THE ORIGIN OF THE GENIE

Kathy Schick and Nicholas Toth

In the beginning, we were bipedal apes, living in the tropics of Africa. This is the story of how we harnessed technology, how technology made us what we are, and how the slow process of biological evolution joined with the accelerating pace of technological change to create the essence of the modern human condition: Even as we ride an ever-growing wave of technological capability and prowess into the new millennium, we are still bipedal apes, still tied to a behavioral past as hunter-gatherers, still adapted to a life that we have not lived for 10,000 years.

This story starts off slowly. Fossil evidence for the emergence of *hominins* (humans and protohumans since the human–African ape split) can now be traced back well over 4 million years in the African fossil record. Bones as well as other evidence such as fossilized protohuman footprints indicate that bipedal walking predates the first recognizable tools by at least 1.5 million years. These early bipeds (genus *Australopithecus*) had relatively small, ape-sized brains, apelike muzzles, and large, apelike jaws and teeth. The evidence suggests that bipedalism was selected for nontechnological reasons, perhaps as a new feeding adaptation and to carry food more efficiently.

Bipedalism itself did not determine our evolutionary trajectory. Several cousin lineages who walked upright, some of whom survived for millions of years, did not appear to develop a technological adaptation or major brain expansion.

Perhaps not coincidentally, ultimately they went extinct. Bipedalism appears to have been a facilitative, perhaps even a necessary, but not a sufficient condition for the development of our technological adaptation. This new form of locomotion freed the arms and hands for more manipulation and tool use and manufacture, and thus enabled the later development of a more profound dependence upon technology. But it was only *after* the appearance of the first stone tools that the evolutionary journey from protohuman to human began.

The beginning of the Stone Age was characterized by rudimentary technologies, restricted geographic and environmental ranges, relatively low levels of technological innovation and change over very long periods of time, and rather small social groups of perhaps twenty to thirty individuals. The Lower Paleolithic or Early Stone Age spans from the first stone technologies 2.5 million years ago to approximately 250,000 years ago. Human ancestors were apparently confined to Africa during the first million years or so of this period (especially eastern and southern Africa), before populations spread to southern and mid-latitude reaches of Asia and Europe. Hominins associated with this time period include smaller-brained, larger-toothed bipeds (*Australopithecus* and *Paranthropus*), as well as the larger-brained members of our genus, *Homo* (including *Homo habilis* and *Homo erectus,* and early archaic *Homo sapiens*).[1]

Technological innovations at the onset of the Lower Paleolithic included simple flaked-stone tools usually made from river cobbles (Oldowan technology), and animal butchery with stone tools. In the later half of this period, larger shaped hand axes and cleavers (Acheulean technology) were developed; wooden tools such as spears and digging sticks make a relatively late appearance; and there is evidence of the rare use of fire. Scavenging and some hunting of smaller animals may have prevailed earlier in this period, with more efficient hunting probably developing later on.

About 250,000 years ago, new hominin forms including the Neandertals (*Homo sapiens neandertalensis*) and early forms of anatomically modern humans (*Homo sapiens sapiens*) appeared. Fossil skulls associated with this Middle Paleolithic technological stage demonstrate that brains were as large as or exceeded modern human averages. Populations made significant migrations into new territory in Africa, Asia, and Europe, and eventually managed to cross the ocean from southeast Asia into Australia, New Guinea, and Tasmania (then all connected as one continent). Technological innovations from this period include hafted points, simple structures, hide-working and probably simple clothing, more systematic hunting, exploitation of shellfish, and the regular use of fire. There is evidence of burial of the dead during this period, although without elaborate grave-good endowments. Tools show more complexity and standardization than in earlier times, including flakes with edges trimmed into simple hand-held scrapers and possibly spear points.

Genetic evidence suggests that all modern humans share what is, from an evolutionary perspective, a very recent common ancestor—probably dating back no more than 150,000 years, and probably in Africa. This bespeaks a remarkable unity in our species: our genetic diversity is much less than we see in modern chimpanzees, for example. This unity likely reflects not just our recent development but a degree of gene flow maintained among human populations over the past 100,000 years or so.

By about 40,000 years ago, anatomically modern humans—*Homo sapiens sapiens*—had established themselves in Africa, Asia, and Europe. They even coexisted briefly with the Neanderthals in western Europe. Technological and behavioral innovations abound during this last phase of the Ice Age, the Upper Paleolithic: blade technologies, art (painting, sculpture, engraving), the spear thrower, the bow and arrow, tools in antler and bone, ornamentation of the body and clothing (with pendants and strands of bone beads, shells, and teeth), eyed needles and sewn clothing, woven textiles, musical instruments (bone flutes and whistles), burials (sometimes with rich grave goods), and more substantial architecture, including mammoth-bone huts. Raw materials such as flint and seashells were transported up to several hundred miles, suggesting that spheres of interaction were greater than in earlier times.

Stylistic trends in tools and artwork show much greater variation over time and space than in earlier periods, suggesting the emergence of something akin to "ethnicity," with specific styles shared within particular cultural groups. The pace of technological change started to accelerate, indicating more experimentation and innovation. Sociopolitical interactions grew in scale and complexity, and likely involved from several dozen to a few hundred people, but with links to related hunter-gatherer bands, and a relatively egalitarian society with little social differentiation or ranking among its members.

Lower Paleolithic hominins had small brains (ranging from about one-half to two-thirds modern capacity) and a very limited and slow-changing technological repertoire. They were not behaviorally modern. Although the degree of behavioral modernity in the Middle Paleolithic is under some debate, many researchers see the low degree of stylistic patterning and limited innovation in tool kits as a lack of modern behavioral, if not cognitive, levels. But most authorities are convinced that Upper Paleolithic hominins had the same cognitive capabilities as modern humans. Artwork in western Europe during this period shows a mastery of many techniques and media—drawing and painting with pigment and charcoal, engraving, bas-relief, and three-dimensional sculpture in stone and clay. The widespread use of personal ornamentation, the development of distinct regional styles in artifacts, a plethora of technological innovations, and an increasing pace of stylistic and technological change over time all appear to hallmark patterns indistinguishable from those of humans today, particularly within a hunter-gatherer context. The creative burst in technology, and the proliferation of diverse tool types with specific functions, even indicates a precursor to the scientific method, with various if-then hypotheses used to assess the potential effects of this tool kit.

By the end of the last Ice Age, approximately 10,000 years ago, human populations were established in every continent except Antarctica. Much of what we are—in terms of our cognitive abilities, the diet to which our bodies are adapted, the psychological controls on our social life—was forged by this time, a mere four hundred generations ago.

After the Ice Ages, hunter-gatherer bands throughout the world had to adjust to a dramatically new climatic and environmental landscape as the glaciers receded and plant and animal communities changed rapidly. They did so by developing what is sometimes termed a "broad-spectrum economy," with a wider range of plant and animal foods than ever before and, in some parts of the world, intensive exploitation of certain food resources, such as gazelle in the Middle East and shellfish in many coastal areas.

Technological innovations included microlithic tools (often less than an inch in maximum dimension) mounted in sets as composite tools, basketry, boats, and more systematic fishing and use of aquatic resources. Large mounds of shellfish refuse become more common around the world during this period. The size and complexity of some sites, however, suggest that populations were beginning to increase and become more sedentary in some areas, thereby setting the stage for domestication.

Domestication of plants and animals represents perhaps the most profound technological innovation in human prehistory, and it eventually set off a cascade of changes. Since the end of the Ice Age, food-producing subsistence altered human society and adaptation profoundly and irrevocably, affecting the nature of settlements, societies, and technologies. Similar changes and trends occurred on every major continent, ultimately transforming a world of hunter-gatherers into a world of farmers and herders within a span of a few thousand years.

The earliest farming communities in the Old World emerged around 9,000 years ago in the Near East, with New World domestication of plants and animals emerging somewhat later. Technological innovations were accompanied by a greater degree of social stratification, and perhaps the rise of political chiefdoms. Large amounts of manpower were commandeered in the construction of earthworks and megalithic monuments. This agriculture-based subsistence established the foundations for the independent development of complex societies in the Near East, Egypt, parts of sub-Saharan Africa, China, Southeast Asia, Mesoamerica, South America, and, ultimately, prehistoric North America.

Complex societies soon emerged on each major continent. Their earliest appearance is in the Near East around 5,000 to

6,000 years ago and in the New World more than 3,000 years ago. Technological innovations, somewhat variable from one place to another, include metallurgy (e.g., copper, bronze, and iron), writing, coinage, weights and measures, wheeled vehicles, irrigation agriculture, monumental architecture (such as palaces, temples, and tombs), more complex fortifications, and proliferation of arms and armor. This coincided with the development of cities or very large settlements, highly stratified social systems, centralization of power (often in the form of a monarch), complex division of labor, highly developed state religions with a full-time religious class, monuments and large-scale architecture, professional standing armies, often conquest and empire-building, craft specialization, and widespread trade, taxation, and redistribution of goods—primary ingredients of life even for much of today's world population.

This, very briefly, is the story of our prehistoric technological development. Yet it leaves the most important question unanswered: Why did our ancestors, some 2.5 million years ago, embark so decisively on this amazing journey of invention, a journey that has led our species, uniquely on the planet, to an *absolute dependence* on tools and technology for survival?

The answer takes us back to those flaked-stone cutting tools of the Lower Paleolithic. This modest innovation allowed protohumans to obtain a higher-quality diet, with foods higher in proteins and fats, and lower in nonnutritive fibers and toxins, especially in the form of meats and fats from animal carcasses. Expanded diet breadth in turn allowed our ancestors to move into new ecological niches, expand their geographic range, and compete with more species, notably carnivores.

But supplementing our vegetable diet with meat allowed something even more important to occur. Very soon after the advent of stone tools, we start seeing a dramatic enlargement in the size of the brain in our ancestors: it doubled within the first million years of our technological adaptation, finally tripling by the Middle Paleolithic.[2]

Brain size in most mammals is constrained by metabolic needs such as the processing of foods in the gut. Over evolutionary time, the addition of meat to our ancestors' diet allowed them to reduce their gut size and the metabolic energy requirements for digestion and, in turn, allowed the expansion of the energy-hungry brain.[3] Stone tools were thus the crucial trigger for the evolution of increased cognitive abilities in our species, including symbolic communication, long-term planning and foresight, abstract thought—and, of course, the ability to develop ever more sophisticated tools and technology over time. Hominins' use of synthetic tools to supplement their own biological repertoire, a phenomenon we call *techno-organic evolution,* was a new and unique form of evolutionary adaptation on the planet.

During the period of the initial rise of technology and rapid brain expansion in our lineage, the human body has perhaps doubled in size as well. Some anthropologists have suggested that the increased body size in our lineage may have been an adaptation for greater strength and mobility in an omnivorous biped with increasing amounts of meat-eating through tool use. Increased body size usually has a number of other biological consequences: reduced metabolic rate, longer gestation time, longer life span, more mobility and larger day and annual ranges, longer periods of suckling, maturation, and learning, fewer offspring, increased social interaction, wider diet breadth, and the ability to exploit larger prey species in hunting.

Hominins prior to the advent of stone tools exhibited a more apelike hand morphology, with long, curved finger bones and more pointed fingertips. The thumb, however, was longer relative to the hand than in nonhuman apes, and more like that of modern humans. Soon after the earliest stone tools, hominin hands became progressively more humanlike, with shorter, straighter fingers and broader fingertips, and a more powerful thumb. Early hominins also had more apelike limb proportions, with long arms and short legs. After the advent of stone tools, body proportions became more humanlike over time. These changes appear to represent a shift from using the hands and arms for primary locomotion—climbing, hanging, and swinging in trees—to the more precise and powerful demands of stone tool manufacture and use.

Of course other organisms, including the chimpanzee, are known to use tools in the wild. Why didn't they evolve as humans did? For the past decade, we have been involved in research teaching bonobos (or "pygmy chimpanzees") to make and use stone tools. This has been one of the most fascinating facets of our research, and has given us a much greater appreciation of the relative complexity of even rudimentary stone technologies in the archaeological record. It seems clear that the ape hand and forelimb do not allow the fine manipulative skills and motor control required for very efficient stone tool manufacture. The archaeological record suggests that, even compared to our protohuman capabilities, modern apes are less adept at these stone tool-making activities. They could not achieve even the basic technological sophistication that was apparently necessary to trigger techno-organic evolution.

The interplay between technology, culture, and biology created a *biocultural feedback loop* that drove both the evolution of our brain and our bodies as well as the evolution of human technology over time. But most anthropologists agree that this process of gene-culture coevolution came to an end about 40,000 years ago, after which there has been little, if any, brain expansion or significant cognitive evolution. Since that time, technological and socioeconomic advances have been due to accumulated cultural knowledge, adaptations to changing environments, and population pressures—but not to any profound genetic selection.

Despite the current high-tech society that has emerged in the industrialized world, and the disparities among today's cultures in their participation in this technological age, all peoples of the world are basically genetically the same. Culture and hyperdeveloped technology is in many ways an overlay or veneer spread fairly recently (and thinly perhaps) over our common, shared hunting-and-gathering foundation. We have been biologically modern for the past 40,000 years, and the behavior patterns of peoples ever since that time look essentially "modern" everywhere in the world. Everything else that has developed is cultural elaboration, this carapace of civilization. Most of the profound technological, sociopolitical, and economic changes were accomplished by our species only in the past 10,000 years, long after we had become fully modern in an evolutionary sense.

The accelerated pace of technological change is, then, a relatively new venture for our species. If we look back over human prehistory, the pace of change was in fact agonizingly slow for much of our past. Extremely little change is seen in stone tools for the first million years (Oldowan technology). Then new tools were developed (Acheulean hand axes and cleavers) and continued to be made, though refined and changed somewhat, in many parts of the Old World for another million years or more. More-standardized flake tools were developed during the Middle Paleolithic and used over much of the Old World for the next 150,000 years or so. Such extremely slow rates of change are virtually inconceivable to us today. It is only starting 40,000 years ago, with widespread populations of modern forms of humans, that we begin to see a more dramatic quickening in the pace of change and greater differences in tools from one place to another. But even then, during Upper Paleolithic times, tool styles would sometimes last for a few thousand years, albeit with some modifications over time.

It is really only within the more urban context, within the large, complex societies that emerge only after the development of agriculture, that we start seeing technologies operate in ways that seem more familiar in terms of their diversification, their rate of change, and their obvious and deliberate application to the specific problems of those societies. A most obvious example is the escalation in arms and armor that emerged among vying groups of the Bronze and Iron Ages in Europe and western Asia.

What has occurred within human populations all over the globe in the past 10,000 years is, in fact, a fascinating experiment in human adaptation, carried out by many different groups in many different regions of the world. The first step in the experiment was the domestication of wild species of plants and animals to ensure a more reliable, high-yield food source that could support a large, dense population.

The next phase was the development of complex societies. Within a few thousand years of initiating their more settled, agricultural way of life, populations of agriculturalists in many parts of the world started to undergo social transformations into "complex" or "state" societies. These urban contexts in various parts of the world provided the basic structure and components of today's civilizations—including taxes and bureaucracy. Each of these complex societies also produced its own bevy of technological innovations.

Complex societies seem to foster a heightened or even accelerating pace of technological development. This process is likely encouraged by the increased interaction and exchange of ideas and information, supported by a well-developed and organized base of food resources and food producers as well as by professional craft, military, and religious classes. It is then spurred and challenged by the many problems of maintaining such societies, including providing roads and means of communication, producing emblems of power and unity (temples, monuments), ensuring protection from competitors (arms and fortifications), maintaining adequate food and water resources, providing distractions and pleasures for the more wealthy and leisure classes, improving record-keeping for developing histories and ever more complex transactions, and so on. A fairly large number of civilizations set forth down this hectic path in the past 6,000 years, with remarkable parallels in the overall course of their development, their achievements, and the problems they eventually developed.

How complex can these interactions become, how large and dense can populations be, how fast can science, technology, and culture change? We are still exploring our limits, and likely will continue to do so for some time to come. Despite our technological prowess, however, we seem to require periodic reminders that we are still biological organisms living ultimately within a biological system. An evolutionary perspective on human technology highlights particularly the relative newness of this type of adaptation. It was only a little over 2.5 million years ago that our ancestors possessed no enduring technology. At that time we were rather small, insignificant-looking bipedal apes living within a limited area of tropical Africa, surviving primarily by gathering a variety of plant foods and perhaps some insects and small animals. We are still this bipedal ape, and many of our essential behavioral patterns, even our emotions, stem from this heritage and are shared with other apes. Intermingled with this ape substrate is our very long prehistory and adaptation as hunter-gatherers. Much of our physiology and psychology has foundations in this aspect of our past, so that our bodies are actually better suited to hunter-gatherer subsistence and activity levels than to our agricultural diet and lifestyle, and our minds and bodies may be better suited to living in smaller, personal groups than in the densely packed, impersonal cities of industrial modernity.

We share a range of emotions with our ape relatives, including enjoyment or pleasure, sorrow, boredom, distress, fear, and anger.[4] Yet our ape relatives don't really act as we do. They generally work out most rivalries, jockeying for dominance, competition over access to resources, and animosities through threat displays. Even when matters escalate to actual physical violence, the situation tends to become resolved quickly and does not get wound up in a culture and cycle of anger, violence, and revenge. In the case of humans, however, this emotional substrate can be amplified tremendously through our culture and language, reinforced and solidified with words and slogans, images and concepts, and made into something quite solid, potent, and long-lived—much more so than passing emotional states observed among chimpanzees in a social group, for instance. Our symbolic language enables us to define and exaggerate the differences between "us" and "them," lionizing our own group while demonizing the other. Join this cultural amplification of emotion and ideas with an escalating human technology, and we have a volatile state of affairs in terms of not only our potential for violence against one another, but also the difficulty in defusing a conflict once it has developed.

Our large brains and enhanced cognitive levels combine with fundamental emotions and behaviors from our ancient past (including, on the one hand, rivalries between people and groups, maneuvering for power and status, jealousies, and anger, and, on the other hand, social cooperation, altruism, friendships, and caring emotional alliances within families and larger groups) to create a potent combination with tremendous capacity for both good and evil. Embedding such emotions within our cultures, justifying and magnifying them through language and traditions, gives us tremendous power and impetus to carry out incredible acts of compassion and assistance within individual societies and in the world at large, but it also can fuel horrendous acts of violence and hatred.

We did not arrive at this condition through elaborate planning of any sort. We are smart, but not that smart. We have tended over the course of our prehistory to develop behavior patterns and technologies to meet shorter-term, more immediate needs or goals. These courses of action, particularly those involving technological innovation, have set forth cascades of effects with far-reaching and long-lasting repercussions, and set us scrambling to play an apparently never-ending game of catch-up to deal with the consequences of our ingenuity.

3

PROMISE AND PERIL

Ray Kurzweil

Consider these articles we'd rather not see on the web:

- Impress Your Enemies: How to Build Your Own Atomic Bomb from Readily Available Materials[1]
- How to Modify the Influenza Virus in Your College Laboratory to Release Snake Venom
- Ten Easy Modifications to the *E. coli* Virus
- How to Modify Smallpox to Counteract the Smallpox Vaccine
- How to Build a Self-Guiding, Low-Flying Airplane Using an Inexpensive Aircraft, GPS, and a Notebook Computer

Or how about the following:

- The Genome of Ten Leading Pathogens
- The Floor Plans of Leading Skyscrapers
- The Layout of U.S. Nuclear Reactors
- Personal Health Information on 100 Million Americans
- The Customer Lists of Top Pornography Sites

Anyone posting the first item above is almost certain to get a quick visit from the FBI, as did Nate Ciccolo, a fifteen-year-old high school student, in March 2000. For a school science project, he built a papier-mâché model of an atomic bomb that turned out to be disturbingly accurate. In the ensuing media storm, Nate told ABC News, "Someone just sort of mentioned, you know, you can go on the Internet now and get information. And I, sort of, wasn't exactly up to date on things. Try it. I went on there and a couple of clicks and I was right there."[2]

Of course, Nate didn't possess the key ingredient, plutonium, nor did he have any intention of acquiring it, but the report created shock waves in the media, not to mention among the authorities who worry about nuclear proliferation. Nate had reported finding 563 web pages on atomic bomb designs. The publicity resulted in an urgent effort to remove this information. Unfortunately, trying to get rid of information on the Internet is akin to trying to sweep back the ocean with a broom. The information continues to be easily available today. I won't provide any URLs in this essay, but they are not hard to find.

Although the actual article titles above are fictitious, one can find extensive information on the Internet about all of these topics.[3] The web is an extraordinary research tool. In my own experience as a technologist and author, I've found that research which used to require half a day at the library can now typically be accomplished in a couple of minutes. This has enormous and obvious benefits for advancing beneficial technologies, but is also empowering those whose values are inimical to the mainstream of society.

My urgent concern with this issue goes back at least a couple of decades. When I wrote my first book, *The Age of Intelligent Machines,* in the mid-1980s, I was deeply concerned with the ability of genetic engineering, then an emerging technology, to allow those skilled in the art and with access to fairly widely available equipment to modify bacterial and viral pathogens to create new diseases.[4] In malevolent or merely careless hands, these engineered pathogens could potentially combine a high degree of communicability and destructiveness.

In the 1980s this was not easy to do, but was nonetheless feasible. We now know that bioweapons programs in the Soviet Union and elsewhere were doing exactly this.[5] At the time, I made a conscious decision to not talk about this specter in my book, feeling that I did not want to give the wrong people a destructive idea. I had disturbing visions of a future disaster, with the perpetrators saying that they got the idea from Ray Kurzweil.

Partly as a result of this decision, there was some reasonable criticism that the book emphasized the benefits of future technology while ignoring the downside. Thus, when I wrote *The Age of Spiritual Machines* in the late 1997–98, I attempted to cover both promise and peril.[6] There had been sufficient public attention to the perils by that time (for example, the 1995 movie *Outbreak,* which portrays the terror and panic that follow the release of a new viral pathogen) that I felt comfortable in beginning to address the issue publicly.

It was at that time, in September 1998, with a just-finished manuscript, that I ran into Bill Joy, an esteemed and longtime colleague in the high-technology world, in a bar in Lake Tahoe. I had long admired Bill for his pioneering work in creating the leading software language for interactive web systems (Java) and having cofounded Sun Microsystems. But my focus at this brief get-together was not on Bill but on the third person sitting in our small booth: John Searle, an eminent philosopher from the University of California, Berkeley. John had built a career out of defending the deep mysteries of human consciousness from apparent attack by materialists like me (though I deny the characterization).[7] John and I had just finished debating the issue of whether a machine could be conscious; we'd been part of the closing panel of George Gilder's "Telecosm" conference, which was devoted to a discussion of the philosophical implications of *The Age of Spiritual Machines.*[8]

I gave Bill a preliminary manuscript of the book and tried to bring him up to speed on the debate about consciousness that John and I were having. As it turned out, Bill focused on a completely different issue, specifically the impending dangers to human civilization from three emerging technologies I had presented in the book: genetics, nanotechnology, and robotics, or GNR for short. My discussion of the downsides of future technology alarmed Bill, as he relays in his now-famous cover story for *Wired* magazine, "Why the Future Doesn't Need Us."[9] In the article, Bill describes how he asked his friends in the scientific and technology community whether the projections I was making were credible and was dismayed to discover how close these capabilities were to realization.

Needless to say, Bill's article focused entirely on the downside scenarios, and created a firestorm. Here was one of the technology world's leading figures addressing new and dire emerging dangers from future technology. It was reminiscent of the attention that George Soros, the currency arbitrager and arch-capitalist, received when he made vaguely critical comments about the excesses of unrestrained capitalism, although the "Bill Joy" controversy became far more intense. The *New York Times* cited about 10,000 articles commenting on and discussing Bill's article, more than any other article in the history of commentary on technology issues.

My attempt to relax in a Lake Tahoe lounge ended up fostering two long-term debates. My dialogue with John Searle has continued to this day, and my debate with Bill has taken on a life of its own. Perhaps this is one reason I now avoid hanging out in bars.

Despite Bill's concerns, my reputation as a technology optimist has remained intact, and Bill and I have been invited to a variety of forums to debate the peril and promise, respectively, of future technologies. Although I am expected to take up the "promise" side of the debate, I often end up spending most of my time at these forums defending the feasibility of the dangers. I recall one event at Harvard during which a Nobel Prize–winning biologist dismissed the "N" (nanotechnology) danger by stating that he did not expect to see self-replicating nanoengineered entities for a hundred years.

I replied that indeed, a hundred years matched my own estimate of the amount of progress required—at *today*'s rate of progress. However, since my models show that we are doubling the paradigm shift rate (the rate of technological progress) every ten years, we can expect to make a hundred years of progress—at today's rate—in about twenty-five calendar years, which matches the consensus view within the nanotechnology community. Thus are both promise and peril much closer at hand.

My view is that technology has always been a double-edged sword, bringing us longer and healthier life spans, freedom from physical and mental drudgery, and many new creative possibilities on the one hand, while introducing new and salient dangers on the other. Technology empowers both our creative and our destructive natures. Stalin's tanks and Hitler's trains used technology. We benefit from nuclear power, but live today with sufficient nuclear weapons (not all of which appear to be well accounted for) to end all mammalian life on the planet.

Bioengineering holds the promise of making enormous strides in reversing disease and aging processes. However, the means and knowledge it has created, which began to exist in the 1980s, will soon enable an ordinary college bioengineering lab to create unfriendly pathogens more dangerous than nuclear weapons.[10]

As technology accelerates toward the full realization of G (genetic engineering, also known as biotechnology), followed by N (nanotechnology) and ultimately R (robotics, also referred to as "strong" AI—artificial intelligence at human levels and beyond), we will see the same intertwined potentials: a feast of creativity resulting from human intelligence expanded manyfold, combined with many grave new dangers.

Consider the manner in which extremely small robots, or nanobots, are likely to develop. Nanobot technology requires billions or trillions of such intelligent devices to be useful. The most cost-effective way to scale up to such levels is through self-replication, essentially the same approach used in the biological world. And in the same way that biological self-replication gone awry (i.e., cancer) results in biological destruction, a defect in the mechanism curtailing nanobot self-replication would endanger all physical entities, biological or otherwise. Later in this chapter I suggest steps we can take to address this grave risk, but we cannot have complete assurance in any strategy that we devise today.

Other primary concerns include who controls the nanobots and who the nanobots are talking to. Organizations (e.g., governments or extremist groups) or just a clever individual could put trillions of undetectable nanobots in the water or food supply of an individual or of an entire population. These "spy" nanobots could then monitor, influence, and even control our thoughts and actions. In addition to physical spy nanobots, existing nanobots could be influenced through software viruses and other software "hacking" techniques. When there is software running in our brains, issues of privacy and security will take on a new urgency.

My own expectation is that the creative and constructive applications of this technology will dominate, as I believe they do today. I believe we need to vastly increase our investment in developing specific defensive technologies, however. We are at the critical stage today for biotechnology, and we will reach the stage where we need to directly implement defensive technologies for nanotechnology during the late teen years of this century.

The Inevitability of a Transformed Future

The diverse GNR technologies are progressing on many fronts and comprise hundreds of small steps forward, each benign in itself. An examination of the underlying trends, which I have studied for the past quarter-century, shows that full-blown GNR is inevitable.

The motivation for this study came from my interest in inventing. As an inventor in the 1970s, I came to realize that my inventions needed to make sense in terms of the enabling technologies and market forces that would exist when the invention was introduced, which would represent a very different world than when it was conceived. I began to develop models of how distinct technologies—electronics, communications, computer processors, memory, magnetic storage, and the key feature sizes in a range of technologies—developed and how these changes rippled through markets and ultimately our social institutions. I realized that most inventions fail not because they never work, but because their timing is wrong. Inventing is a lot like surfing; you have to anticipate and catch the wave at just the right moment.

In the 1980s my interest in technology trends and implications took on a life of its own, and I began to use my models of these trends to project and anticipate the technologies of the future. This enabled me to invent with the capabilities of the future in mind. I wrote *The Age of Intelligent Machines,* which ended with the specter of machine intelligence becoming indistinguishable from its human progenitors. The book included hundreds of predictions about the 1990s and early 2000s, and my track record of prediction has held up well.

During the 1990s, I gathered empirical data on the apparent acceleration of all information-related technologies and sought to refine the mathematical models underlying these observations. In *The Age of Spiritual Machines,* I introduced improved models of technology and a theory I called "the law of accelerating returns," which explained why technology evolves in an exponential fashion.

The Intuitive Linear View versus the Historical Exponential View

The most important trend this study has revealed concerns the overall pace of technological progress itself. The future is widely misunderstood. Our forebears expected the future to be pretty much like their present, which had been pretty much like their past. Although exponential trends did exist a thousand years ago, they were at that very early stage where an exponential trend is so flat and so slow that it looks like no trend at all. So their expectation of stasis was largely fulfilled. Today, in accordance with the common wisdom, everyone expects continuous technological progress and the social repercussions that follow. But the future will nonetheless be far more surprising than most observers realize because few have truly internalized the implications of the fact that the rate of change itself is accelerating.

Most long-range forecasts of technical feasibility in future time periods dramatically underestimate the power of future developments because they are based on what I call the "intuitive linear view" of history rather than the "historical exponential view." To express this another way, it is not the case that we will experience 100 years of progress in the twenty-first century; rather, we will witness on the order of 20,000 years of progress (again, at *today*'s rate of progress).

When people think of a future period, they intuitively assume that the current rate of progress will continue into that future. Even for those who have been around long enough to experience how the pace increases over time, an unexamined intuition nonetheless provides the impression that progress happens at the rate we have experienced recently. From the mathematician's perspective, a primary reason for this is that an exponential curve approximates a straight line when viewed for a brief duration. It is typical, therefore, for even sophisticated commentators, when considering the future, to extrapolate the current pace of change over the next ten years or hundred years to determine their expectations. This is why I call this way of looking at the future the "intuitive linear view."

But a serious assessment of the history of technology shows that technological change is exponential. In exponential growth, a key measurement such as computational power is multiplied by a constant factor for each unit of time (e.g., doubling every year) rather than just increased incrementally. Exponential growth is a feature of any evolutionary process, of which technology is a prime example. One can examine the data in different ways, on different time scales, and for a wide variety of technologies ranging from electronic to biological, as well as for social implications ranging from the size of the economy to human life span, and the acceleration of progress and growth applies to all.

Indeed, we find not just simple exponential growth, but "double" exponential growth, meaning that the rate of exponential growth is itself growing exponentially. These observations do not rely merely on an assumption of the continuation of Moore's Law (i.e., the exponential shrinking of transistor sizes on an integrated circuit), which I discuss a bit later, but are based on a rich model of diverse technological processes. What the model clearly shows is that technology, particularly the pace of technological change, advances (at least) exponentially, not linearly, and has been doing so since the advent of technology, indeed since the advent of evolution on Earth.

Many scientists and engineers have what my colleague Lucas Hendrich calls "engineer's pessimism." Often engineers or scientists who are so immersed in the difficulties and intricate details of a contemporary challenge fail to appreciate the ultimate long-term implications of their own work and, in particular, the larger field of work that they operate in. Consider the biochemists in 1985 who were skeptical of the announced goal of transcribing the entire genome in a mere fifteen years. These scientists had just spent an entire year transcribing a mere one ten-thousandth of the genome, so even with reasonable anticipated advances, it seemed to them as though it would be hundreds of years, if not longer, before the entire genome could be sequenced.

Or consider the skepticism expressed in the mid-1980s that the Internet would ever be a significant phenomenon, given that it included only tens of thousands of nodes. The fact that the number of nodes was doubling every year, so tens of millions of nodes were likely to exist ten years later, was not appreciated by those struggling with a limited "state of the art" technology in 1985 that permitted adding only a few thousand nodes throughout the world in a year.[11]

I emphasize this point because it is the most important failure that would-be prognosticators make in considering future trends. The vast majority of technology forecasts and forecasters ignore altogether this "historical exponential view" of technological progress. Indeed, almost everyone I meet has a linear view of the future. That is why people tend to overestimate what can be achieved in the short term (because we tend to leave out necessary details) but underestimate what can be achieved in the long term (because the exponential growth is ignored).

The Law of Accelerating Returns

The ongoing acceleration of technology is the implication and the inevitable result of what I call the "law of accelerating returns," which describes the acceleration of the pace and the exponential growth of the products of an evolutionary process. This process includes information-bearing technologies such as computation as well as the accelerating trend toward miniaturization—all the prerequisites for the full realization of GNR.

A wide range of technologies are subject to the law of accelerating returns. The exponential trend that has gained the greatest public recognition has become known as Moore's Law. Gordon Moore, one of the inventors of integrated circuits and then chairman of Intel, noted in the mid-1970s that we could squeeze twice as many transistors on an integrated circuit every twenty-four months.[12] Given that the electrons have a shorter distance to travel, the transistors change states more quickly. This, along with other techniques, allows the circuits to run faster, providing an overall quadrupling of computational power.

The exponential growth of computing is much broader than Moore's Law, however. If we plot the speed (in instructions per second) per $1,000 (in constant dollars) of forty-nine famous calculators and computers spanning the entire twentieth century, we note that there were four completely different paradigms providing exponential growth in the price-performance of computing before integrated circuits were invented. Therefore, Moore's Law was not the first but the fifth paradigm of exponential growth of computational power.[13] And it won't be the last. When Moore's Law approaches its limit, now expected before 2020, the exponential growth will continue with three-dimensional molecular computing, a prime example of the application of nanotechnology, which will constitute the sixth paradigm.

When in 1999 I suggested that three-dimensional molecular computing, particularly an approach based on using carbon nanotubes, would become the dominant computing hardware technology in the teen years of this century, that was considered a radical notion. But so much progress has been accomplished in the past four years, with literally dozens of major milestones having been achieved, that this expectation is now a mainstream view.[14]

The exponential growth of computing is a marvelous quantitative example of the exponentially growing returns from an evolutionary process. We can express the exponential growth of computing in terms of an accelerating pace: it took ninety years to achieve the first million instructions per second (MIPS) per $1,000; now we add one MIPS per $1,000 every day.

The human brain uses a very inefficient electrochemical digital-controlled analog computational process. The bulk of the calculations are done in the interneuronal connections at a speed of only about two hundred calculations per second (in each connection), which is about ten million times slower than contemporary electronic circuits. But the brain gains its prodigious powers from its extremely parallel organization *in three dimensions.* There are many technologies in the wings that build circuitry in three dimensions.

Nanotubes (tubes formed from graphite sheets, consisting of hexagonal arrays of carbon atoms) are good conductors and can be used to build compact circuits; these are already working in laboratories. One cubic inch of nanotube circuitry would theoretically be a million times more powerful than the human brain. There are more than enough new computing technologies now being researched, including three-dimensional silicon chips, spin computing, crystalline computing, DNA computing, and quantum computing, to keep the law of accelerating returns as applied to computation going for a long time.

It is important to distinguish between the S curve (an *S* stretched to the right, comprising very slow, virtually unnoticeable growth—followed by very rapid growth—followed by a flattening out as the process approaches an asymptote, or limit) that is characteristic of any specific technological paradigm, and the continuing exponential growth that is characteristic of the ongoing evolutionary process of technology. Specific paradigms, such as Moore's Law, do ultimately reach levels at which exponential growth is no longer feasible. That is why Moore's Law is an S curve.

But the growth of computation is an ongoing exponential pattern (at least until we "saturate" the universe with the intelligence of our human-machine civilization, but that is not likely to happen in this century). In accordance with the law of accelerating returns, paradigm shift (also called innovation) turns the S curve of any specific paradigm into a continuing exponential pattern. A new paradigm (e.g., three-dimensional circuits) takes over when the old paradigm approaches its natural limit, which has already happened at least four times in the history of computation. This difference also distinguishes the tool making of nonhuman species, in which the mastery of a tool-making (or tool-using) skill by each animal is characterized by an abruptly ending S-shaped learning curve, from human-created technology, which has followed an exponential pattern of growth and acceleration since its inception.

This "law of accelerating returns" applies to all of technology, indeed to any true evolutionary process, and can be measured with remarkable precision in information-based technologies. There are a great many examples of the exponential growth implied by the law of accelerating returns in technologies, as varied as electronics of all kinds, DNA sequencing, communication speeds, brain scanning, reverse engineering of the brain, the size and scope of human knowledge, and the rapidly shrinking size of technology, which is directly relevant to emergence of nanotechnology.[15]

The future GNR age results not from the exponential explosion of computation alone, but rather from the interplay and myriad synergies that will result from intertwined technological revolutions. Keep in mind that every point on the exponential growth curves underlying this panoply of technologies represents an intense human drama of innovation and competition. It is remarkable, therefore, that these chaotic processes result in such smooth and predictable exponential trends.

Economic Imperative

It is the economic imperative of a competitive marketplace that is fueling the law of accelerating returns and driving technology forward toward the full realization of GNR. In turn, the law of accelerating returns is transforming economic relationships.

We are moving toward nanoscale machines, as well as more intelligent machines, as the result of a myriad of small advances, each with their own particular economic justification. There is a vital economic imperative to create smaller and more intelligent technology. Machines that can more precisely carry out their missions have enormous value, which is why they are being built. There are tens of thousands of projects advancing the various aspects of the law of accelerating returns in diverse incremental ways.

Regardless of near-term business cycles, the support for "high tech" in the business community, and in particular for software advancement, has grown enormously. When I started my optical character recognition (OCR) and speech synthesis company (Kurzweil Computer Products) in 1974, high-tech venture deals totaled approximately $10 million. Even during today's high-tech recession, the figure is a hundred times greater. We would have to repeal capitalism and every visage of economic competition to stop this progression.

The economy (viewed either in total or per capita) has been growing exponentially throughout this century. This underlying exponential growth is a far more powerful force than periodic recessions.[16] Even the Great Depression represents only a minor blip on this pattern of growth. Most importantly, recessions and depressions represent only temporary deviations from the underlying curve. In each case, the economy ends up exactly where it would have been had the recession or depression never occurred.

In addition to GDP, other improvements include productivity (economic output per worker), quality and features of products and services (for example, $1,000 of computation today is more powerful, by a factor of more than a thousand, than $1,000 of computation ten years ago), new products and product categories, and the value of existing goods, which has been increasing at 1.5 percent per year for the past twenty years because of qualitative improvements.[17, 18]

Intertwined Benefits . . .

Significant portions of our species have already experienced substantial alleviation of the poverty, disease, hard labor, and misfortune that have characterized much of human history. Many of us have the opportunity to gain satisfaction and meaning from our work rather than merely toiling to survive. We have ever more powerful tools to express ourselves. We have worldwide sharing of culture, art, and humankind's exponentially expanding knowledge base.

Ubiquitous N and R are two to three decades away. A prime example of their application will be the deployment of billions of nanobots the size of human blood cells to travel inside the human bloodstream. This technology will be feasible within twenty-five years, based on miniaturization and cost-reduction trends. In addition to scanning the brain to facilitate reverse engineering (that is, analyzing how the brain works in order to copy its design), nanobots will be able to perform a broad variety of diagnostic and therapeutic functions inside the bloodstream and human body. Robert A. Freitas, for example, has designed robotic replacements for human blood cells that perform hundreds or thousands of times more effectively than their biological counterparts.[19] With Freitas's "respirocytes" (robotic red blood cells), you could do an Olympic sprint for fifteen minutes without taking a breath. His robotic macrophages would be far more effective than our white blood cells at combating pathogens. His DNA repair robot would be able to repair DNA transcription errors and even implement needed DNA changes.

Although realization of Freitas's conceptual designs are two or three decades away, substantial progress has already been achieved on bloodstream-based devices. For example, one scientist has cured type 1 diabetes in rats with a nanoengineered device that incorporates pancreatic islet cells. The device has seven-nanometer pores that let insulin out but block the antibodies that destroy these cells. Many innovative projects of this type are already under way.

Clearly, nanobot technology has profound military applications, and any expectation that such uses will be "relinquished" are highly unrealistic. Already, the Department of Defense is developing "smart dust"—tiny robots the size of insects or even smaller.[20] Although not quite nanotechnology, millions of these devices can be dropped into enemy territory to provide highly detailed surveillance. The potential application for even smaller nanotechnology-based devices is even greater. Want to find Saddam Hussein or Osama bin Laden? Need to locate hidden weapons of mass destruction? Billions of essentially invisible spies could monitor every square inch of enemy territory, identify every person and every weapon, and even carry out missions to destroy enemy targets. The only way for an enemy to counteract such a force is, of course, with their own nanotechnology. The point is that nanotechnology-based weapons will one day make larger weapons obsolete.

Nanobots will also expand our experiences and our capabilities by providing fully immersive, totally convincing virtual reality. They will take up positions in close proximity to every interneuronal connection of our sensory organs (e.g., eyes, ears, and skin). We already have the technology that enables electronic devices to communicate with neurons in both directions, and it requires no direct physical contact with the neurons. For example, scientists at the Max Planck Institute have developed "neuron transistors" that can detect the firing of a nearby neuron or, alternatively, can cause a nearby neuron to fire, or suppress it from firing.[21] This amounts to two-way communication between neurons and the electronically based neuron transistors. The institute scientists demonstrated their invention by controlling the movement of a living leech from their computer.

When we want to experience real reality, the nanobots just stay in position (in the capillaries) and do nothing. If we want to enter virtual reality, they suppress all of the inputs coming from the real senses and replace them with the signals that would be appropriate for the virtual environment. You (i.e., your brain) could decide to cause your muscles and limbs to move as you normally would, but the nanobots would intercept these interneuronal signals, suppress your real limbs from moving, and instead cause your virtual limbs to move and provide the appropriate reorientation in the virtual environment.

The primary limitation of nanobot-based virtual reality at this time is only that it's not yet feasible in size and cost. One day, however, the web will provide a panoply of virtual environments to explore. Some will be re-creations of real places; others will be fanciful environments that have no "real" counterpart. Some will be impossible in the physical world, perhaps because they violate the laws of physics. We will be able to "go" to these virtual environments by ourselves, or we will meet other people there, both real people and simulated people. Of course, ultimately there won't be a clear distinction between the two.

By 2030, going to a website will mean entering a full-immersion virtual-reality environment. In addition to encompassing all of the senses, some of these shared environments will include emotional overlays, as the nanobots will be capable of triggering the neurological correlates of emotions, sexual pleasure, and other derivatives of our sensory experience and mental reactions.

In the same way that people today beam their lives from webcams in their bedrooms, "experience beamers" circa 2030 will beam their entire flow of sensory experiences and, if so desired, their emotions and other secondary reactions. We'll be able to plug in (by going to the appropriate website) and experience other people's lives, as in the movie *Being John Malkovich*. We will be able to archive particularly interesting experiences and relive them at any time.

We won't need to wait until 2030 to experience shared virtual-reality environments, though, at least for the visual and auditory senses. Full-immersion visual-auditory environments will be available by the end of this decade, with images written directly onto our retinas by our eyeglasses and contact lenses. All of the electronics for computation, image reconstruction, and a very high-bandwidth wireless connection to the Internet will be embedded in our glasses and woven into our clothing, so computers as distinct objects will disappear.

It's not just the virtual world that will benefit from ubiquitous application of nanobots and fully realized nanotechnology. Portable manufacturing systems will be able to produce virtually any physical product from information for pennies a pound, thereby providing for our physical needs at almost no cost. Nanobots will be able to reverse the environmental destruction left by the first industrial revolution. Nanoengineered fuel cells and solar cells will provide clean energy. Nanobots in our physical bodies will destroy pathogens and cancer cells, repair DNA, and reverse the ravages of aging.

These technologies will become so integral to our health and well-being that we will eventually become indistinguishable from our machine support systems. In fact, in my view, the most significant implication of the development of nanotechnology and related advanced technologies of the twenty-first century will be the merger of biological and nonbiological intelligence. First, it is important to point out that well before the end of the twenty-first century, thinking on nonbiological substrates will dominate. Biological thinking is stuck at 1,026 calculations per second (for all biological human brains), and that figure will not appreciably change, even with bioengineering changes to our genome.

Nonbiological intelligence, on the other hand, is growing at a double-exponential rate and will vastly exceed biological intelligence well before the middle of this century. In my view, however, this nonbiological intelligence should still be considered human, since it is fully derivative of the human-machine civilization. The merger of these two worlds of intelligence is not merely a merger of biological and nonbiological thinking media but, more importantly, one of method and organization of thinking.

Nanobot technology will be able to expand our minds in virtually any imaginable way. Our brains today are relatively fixed in design. Although we do add patterns of interneuronal connections and neurotransmitter concentrations as a normal part of the learning process, the current overall capacity of the human brain is highly constrained, restricted to a mere hundred trillion connections. Brain implants based on massively distributed intelligent nanobots will ultimately expand our memories a trillionfold, and otherwise vastly improve all of our sensory, pattern recognition, and cognitive abilities. Since the nanobots will be communicating with each other over a wireless local area network, they will be able to create any set of new neural connections, break existing connections (by suppressing neural firing), and create new hybrid biological-nonbiological networks, as well as add vast new nonbiological networks.

Using nanobots as brain extenders will be a significant improvement over surgically installed neural implants, which are beginning to be used today (e.g., ventral posterior nucleus, subthalmic nucleus, and ventral lateral thalamus neural implants to counteract Parkinson's disease and tremors from other neurological disorders; cochlear implants; and the like). Nanobots will be introduced without surgery, essentially just by injecting or even swallowing them. They can all be directed to leave, so the process is easily reversible. They are programmable, in that they can provide virtual reality one minute and a variety of brain extensions the next. They can change their configuration and alter their software. Perhaps most importantly, they are massively distributed and therefore can take up billions or trillions of positions throughout the brain, whereas a surgically introduced neural implant can be placed in only one or at most a few locations.

. . . and Dangers

Needless to say, we have already experienced technology's downside. One hundred million people were killed in two world wars during the last century—a scale of mortality made possible by technology. The crude technologies of the first industrial revolution have crowded out many of the species on our planet that existed a century ago. Our centralized technologies (e.g., buildings, cities, airplanes, and power plants) are demonstrably insecure.

The NBC (nuclear, biological, and chemical) technologies of warfare were all used, or threatened to be used, in our recent past.[22] The far more powerful GNR technologies pose what philosopher of science Nick Bostrom calls "existential risks," referring to potential threats to the viability of human civilization itself.[23]

If we manage to get past the concerns about genetically altered designer pathogens, followed by self-replicating entities created through nanotechnology, we will next encounter robots whose intelligence will rival and ultimately exceed our own. Such robots may make great assistants, but who's to say that we can count on them to remain reliably friendly to mere humans?

In my view, "strong AI" (artificial intelligence at human levels and beyond) promises to continue the exponential gains of human civilization. But the dangers are also more profound precisely because of this amplification of intelligence. Intelligence is inherently impossible to control, so the various strategies that have been devised to control nanotechnology won't work for strong AI. There have been discussions and proposals to guide AI development toward "friendly AI."[24] These are useful for discussion, but it is impossible to devise strategies today that will absolutely ensure that future AI embodies human ethics and values.

Relinquishment

In his *Wired* essay and subsequent presentations, Bill Joy eloquently describes the plagues of centuries past and how new self-replicating technologies, such as mutant bioengineered pathogens and "nanobots" run amok, may bring back long-forgotten pestilence. Of course, as Joy graciously acknowledges, it has also been technological advances, such as antibiotics and improved sanitation, that have freed us from the prevalence of such plagues. Suffering in the world continues and demands our steadfast attention. Should we tell the millions of people afflicted with cancer and other devastating conditions that we are canceling the development of all bioengineered treatments because there is a risk that these same technologies may someday be used for malevolent purposes?

Relinquishment is Bill's most controversial recommendation and personal commitment. I do feel that relinquishment at the right level is part of a responsible and constructive response to these genuine perils. The issue, however, is exactly this: at what level are we to relinquish technology?

Ted Kaczynski would have us renounce all of it.[25] This, in my view, is neither desirable nor feasible, and the futility of such a position is only underscored by the senselessness of Kaczynski's deplorable tactics. There are other voices, less reckless than Kaczynski, who are nonetheless arguing for broad-based relinquishment of technology. The environmentalist Bill McKibben takes the position that "environmentalists must now grapple squarely with the idea of a world that has enough wealth and enough technological capability, and should not pursue more."[26] In my view, this position ignores the extensive suffering that remains in the human world, which we will be in a position to alleviate through continued technological progress.

Another level of relinquishment, one recommended by Joy, would be to forgo certain fields—nanotechnology, for example—

that might be regarded as too dangerous. But such sweeping strokes of relinquishment are equally untenable. As I pointed out above, nanotechnology is simply the inevitable end result of the persistent trend toward miniaturization that pervades all of technology. It is far from a single centralized effort, but is being pursued by a myriad of projects with many diverse goals.

One observer wrote:

> A further reason why industrial society cannot be reformed . . . is that modern technology is a unified system in which all parts are dependent on one another. You can't get rid of the "bad" parts of technology and retain only the "good" parts. Take modern medicine, for example. Progress in medical science depends on progress in chemistry, physics, biology, computer science and other fields. Advanced medical treatments require expensive, high-tech equipment that can be made available only by a technologically progressive, economically rich society. Clearly you can't have much progress in medicine without the whole technological system and everything that goes with it.

The observer, again, is Ted Kaczynski.[27] Although one will properly resist Kaczynski as an authority, I believe he is correct on the deeply entangled nature of the benefits and risks. He and I clearly part company on our overall assessment of the relative balance between the two, however. Bill Joy and I have debated this issue both publicly and privately, and we both believe that technology will and should progress and that we need to be actively concerned with the dark side. If he and I disagree, it's on the granularity of relinquishment that is both feasible and desirable.

Abandonment of broad areas of technology would only push them underground, where development would continue unimpeded by ethics and regulation. In such a situation, it would be the less stable, less responsible practitioners (e.g., terrorists) who would have all the expertise.

I do think that relinquishment at the right level needs to be part of our ethical response to the dangers of twenty-first-century technologies. One constructive example is the ethical guideline proposed by the Foresight Institute, founded by nanotechnology pioneer Eric Drexler, along with Christine Peterson, that nanotechnologists agree to relinquish the development of physical entities that can self-replicate in a natural environment.[28] Another is a ban on self-replicating physical entities that contain their own codes for self-replication. In what nanotechnologist Ralph Merkle calls the "broadcast architecture," such entities would have to obtain these codes from a centralized secure server, which would guard against undesirable replication.[29] I discuss these guidelines further below.

The broadcast architecture is impossible in the biological world, so it represents at least one way in which nanotechnology can be made safer than biotechnology. In other ways, nanotechnology is potentially more dangerous because nanobots can be physically stronger, and more intelligent, than protein-based entities. It will eventually be possible to combine the two by having nanotechnology provide the codes within biological entities (replacing DNA), in which case biological entities will be able to use the much safer broadcast architecture.

As responsible technologists, our ethics should include such "fine-grained" relinquishment among our professional ethical guidelines. Protections must also include oversight by regulatory bodies, the development of technology-specific "immune" responses, and computer-assisted surveillance by law enforcement organizations. Many people are not aware that our intelligence agencies already use advanced technologies such as automated word spotting to monitor a substantial flow of telephone conversations. As we go forward, balancing our cherished rights of privacy with our need to be protected from the malicious use of powerful twenty-first-century technologies will be one of many profound challenges. This is one reason such issues as an encryption "trap door" (in which law enforcement authorities would have access to otherwise secure information) and the FBI's Carnivore email-snooping system have been controversial.[30]

We can take a small measure of comfort from how our society has dealt with one recent technological challenge. There exists today a new form of fully nonbiological self-replicating entity that did not exist just a few decades ago: the computer virus. When this form of destructive intruder first appeared, strong concerns were voiced that as these software pathogens became more sophisticated, they would have the potential to destroy the computer network medium they live in. Yet the "immune system" that has evolved in response to this challenge has been largely effective. Although destructive self-replicating software entities do cause damage from time to time, the injury is but a small fraction of the benefit we receive from the computers and communication links that harbor them. No one would suggest we do away with computers, local area networks, and the Internet because of software viruses.

One might counter that computer viruses do not have the lethal potential of biological viruses or of destructive nanotechnology. This is not always the case; we rely on software to monitor patients in critical care units, to fly and land airplanes, to guide intelligent weapons in wartime, and to perform other "mission-critical" tasks. To the extent that this assertion *is* true, however, it only strengthens my argument. The fact that computer viruses are not usually deadly to humans only means that more people are willing to create and release them. It also means that our response to the danger is that much less intense. Conversely, when it comes to self-replicating entities that are potentially lethal on a large scale, our response on all levels will be vastly more serious, as we have seen since September 11.

The Development of Defensive Technologies and the Impact of Regulation

Bill Joy's *Wired* treatise is effective because he paints a picture of future dangers as if they were released on today's unprepared world. The reality is that the sophistication and power of our defensive technologies and knowledge will grow along with the dangers. When we have "gray goo" (unrestrained nanobot replication), we will also have "blue goo" ("police" nanobots that combat the "bad" nanobots). The story of the twenty-first century has not yet been written, so we cannot say with assurance that we will successfully avoid all misuse. But the surest way to prevent the development of defensive technologies would be to relinquish the pursuit of knowledge in broad areas. We have been able to largely control harmful software virus replication because the requisite knowledge is widely available to responsible practitioners. Attempts to restrict this knowledge would have created a far less stable situation. Responses to new challenges would have been far slower, and the balance would have likely shifted toward the more destructive applications (e.g., software viruses).

As we compare the success we have had in controlling engineered software viruses to the coming challenge of controlling engineered biological viruses, we are struck with one salient difference: the software industry is almost completely unregulated. The same is obviously not true for biotechnology. We require scientists developing defensive technologies to follow the existing regulations, which slow down the innovation process at every step. A bioterrorist, however, does not need to put his "innovations" through the FDA. Moreover, under existing regulations and ethical standards, it is impossible to test defenses against bioterrorist agents. Extensive discussion is already under way regarding modifying these regulations to allow for animal models and simulations, since human trials are infeasible.

For reasons I have articulated above, stopping these technologies is not feasible, and pursuit of such broad forms of relinquishment will only distract us from the vital task in front of us. It is quite clearly a race. There is simply no alternative. We cannot relinquish our way out of this challenge. In the software field, defensive technologies have remained a step ahead of offensive ones. With the extensive regulation in the medical field slowing down innovation at each stage, we cannot have the same confidence with regard to the abuse of biotechnology.

In the current environment, when one person dies in gene therapy trials, research can be severely restricted.[31] There is a legitimate need to make biomedical research as safe as possible, but our balancing of risks is completely off. The millions of people who desperately need the advances that will result from gene therapy and other breakthrough biotechnologies appear to carry little political weight against a handful of well-publicized casualties from the inevitable risks of progress.

This equation will become even more stark when we consider the emerging dangers of bioengineered pathogens. What is needed is a change in public attitude in terms of tolerance for needed risk.

Hastening defensive technologies is absolutely vital to our security. We need to streamline regulatory procedures to achieve this, and we also need to greatly increase our investment in defensive technologies explicitly. In the biotechnology field, this means the rapid development of antiviral medications. We will not have time to develop specific countermeasures for each new challenge that comes along. We are close to developing more generalized antiviral technologies, and these need to be accelerated.

I have addressed here the issue of biotechnology because that is the threshold and challenge that we now face. As the threshold for nanotechnology comes closer, we will then need to invest specifically in the development of defensive technologies in that area, including the creation of a nanotechnology-based immune system. Bill Joy and other observers have pointed out that such an immune system would itself be a danger because of the potential of "autoimmune" reactions (i.e., the immune system using its powers to attack the world it is supposed to be defending).[32]

This observation is not a compelling reason to avoid the creation of an immune system, however. No one would argue that humans would be better off without an immune system because of the possibility of autoimmune diseases. Although the immune system can itself be a danger, humans would not last more than a few weeks (barring extraordinary efforts at isolation) without one. The development of a technological immune system for nanotechnology will happen even without explicit efforts to create one. We have effectively done this with regard to software viruses. We created a software virus immune system not through a formal grand design, but rather through our incremental responses to each new challenge and through the development of heuristic algorithms for early detection. We can expect the same thing will happen as challenges from nanotechnology-based dangers emerge. The point for public policy will be to specifically invest in these defensive technologies.

It is premature to develop specific defensive nanotechnologies today, since we can have only a general idea of what we are trying to defend against. It would be similar to the engineering world creating defenses against software viruses before the first virus had been created. There is already fruitful dialogue and discussion on anticipating these issues, however, and significantly expanded investment in these efforts is to be encouraged.

As one example, as I mentioned above, the Foresight Institute has devised a set of ethical standards and strategies for ensuring the development of safe nanotechnology.[33] These guidelines include:

- Artificial replicators must not be capable of replication in a natural, uncontrolled environment.
- Evolution within the context of a self-replicating manufacturing system is discouraged.
- MNT (molecular nanotechnology) designs should specifically limit proliferation and provide traceability of any replicating systems.
- Distribution of molecular manufacturing development capability should be restricted, whenever possible, to responsible actors that have agreed to the guidelines. No such restriction need apply to end products of the development process.

Other strategies proposed by the Foresight Institute include:

- Replication should require materials not found in the natural environment.
- Manufacturing (replication) should be separated from the functionality of end products. Manufacturing devices can create end products but should not be able to replicate themselves, and end products should have no replication capabilities.
- Replication should require codes that are encrypted and time-limited. (The broadcast architecture mentioned earlier is an example.)

These guidelines and strategies are likely to be effective for preventing accidental release of dangerous self-replicating nanotechnology entities. But the intentional design and release of such entities is a more complex and challenging problem. A sufficiently determined and destructive opponent could possibly defeat each of these layers of protections. Take, for example, the broadcast architecture. When properly designed, each entity is unable to replicate without first obtaining replication codes. These codes are not passed on from one replication generation to the next. A modification to such a design could bypass the destruction of the codes, however, and thereby pass them on to the next generation. To counteract that possibility, it has been recommended that the memory for the replication codes be limited to only a subset of the full code so that insufficient memory exists to pass the full set of codes along. But this guideline could be defeated by expanding the size of the replication code memory to incorporate the entire code. Another suggestion is to encrypt the codes and build protections such as time limits into the decryption systems. We can see how easy it has been to defeat protections against unauthorized replications of intellectual property such as music files, however. Once replication codes and protective layers are stripped away, the information can be replicated without these restrictions.

My point is not that protection is impossible. Rather, we need to realize that any level of protection will only work to a certain level of sophistication. The metalesson here is that we will need to place society's highest priority during the twenty-first century on continuing to advance defensive technologies and on keeping them one or more steps ahead of destructive technologies. We have seen analogies to this in many areas, including technologies for national defense as well as our largely successful efforts to combat software viruses.

The broadcast architecture won't protect us against abuses of strong AI. The barriers of the broadcast architecture rely on the nanoengineered entities' lacking the intelligence to overcome the built-in restrictions. By definition, intelligent entities have the cleverness to easily overcome such barriers. Inherently, there will be no absolute protection other than dominance by friendly AI. Although the argument is subtle, I believe that maintaining an open system for incremental scientific and technological progress, in which each step is subject to market acceptance, will provide the most constructive environment for technology to embody widespread human values. Attempts to control these technologies in dark government programs, along with inevitable underground development, would create an unstable environment in which the dangerous applications would likely become dominant.

One profound trend already well under way that will provide greater stability is the movement from centralized technologies to distributed ones, and from the real world to the virtual world discussed above. Centralized technologies involve an aggregation of resources such as people (e.g., cities and buildings), energy (e.g., nuclear power plants, liquid natural gas and oil tankers, and energy pipelines), transportation (e.g., airplanes and trains), and other resources. Centralized technologies are subject to disruption and disaster. They also tend to be inefficient, wasteful, and harmful to the environment.

Distributed technologies, on the other hand, tend to be flexible, efficient, and relatively benign in their environmental effects. The quintessential distributed technology is the Internet. Despite concerns about viruses, these information-based pathogens are mere nuisances. The Internet is essentially indestructible. If any hub or channel goes down, the information simply routes around it. The Internet is remarkably resilient, a quality that continues to increase with its continued exponential growth.

In energy, we need to move rapidly toward the opposite end of the spectrum of contemporary energy sources, away from the extremely concentrated energy installations we now depend on. In one example of a trend in the right direction, Integrated Fuel Cell Technologies is pioneering microscopic fuel cells that use microelectromechanical systems (MEMS) technology. The fuel cells are manufactured like electronic chips but are actually batteries with an energy-to-size ratio vastly exceeding conventional technology. Ultimately, forms of energy along these lines could power everything from our cell phones to our cars and homes, and would not be subject to disaster or disruption.

As these technologies develop, our need to aggregate people in large buildings and cities will diminish and people will spread out, living where they want and gathering together in virtual reality.

But we don't need to look past today to see the intertwined promise and peril of technological advancement. If we imagine describing the dangers that exist today to people who lived a couple of hundred years ago, they would think it mad to take such risks. On the other hand, how many people in the year 2000 would really want to go back to the short, brutish, disease-filled, poverty-stricken, disaster-prone lives that 99 percent of the human race struggled through a couple of centuries ago?[34] We may romanticize the past, but up until fairly recently, most of humanity lived extremely fragile lives where one all-too-common misfortune could spell disaster. Two hundred years ago, life expectancy for females in the record-holding country (Sweden) was roughly thirty-five years, compared to the longest life expectancy today—almost eighty-five years—enjoyed by Japanese women. Life expectancy for males was roughly thirty-three years to the current seventy-nine years in the record-holding countries.[35] It took half the day to prepare the evening meal, and hard labor characterized most human activity. There were no social safety nets. Substantial portions of our species still live in this precarious way, which is at least one reason to continue technological progress and the economic enhancement that accompanies it.

People often go through three stages in considering future technologies: awe and wonderment at their potential to overcome age-old problems; a sense of dread at the new set of grave dangers that accompany the new technologies; and, finally (and hopefully), the realization that the only viable and responsible path is to set a careful course that can reap the benefits while managing the dangers.

Technology will remain a double-edged sword. It represents vast power to be used for all humankind's purposes. We have no choice but to work hard to apply these quickening technologies to advance our human values, despite what often appears to be a lack of consensus on what those values should be.

4

SMALL IS POWERFUL

Daniel Sarewitz and
Edward Woodhouse

The metal stirrup, which migrated from Asia to western Europe in the eighth century, allowed the energy of a galloping horse to be directly transmitted to the weapon held by the man in the saddle—a combat innovation of devastating impact. In those days, horses and tack were costly, possessed almost exclusively by landowners. Battlefield prowess and wealth thus went hand in hand; together they fostered the traditions of a "warrior aristocracy" and laid the foundations for European feudal society itself. When the Anglo-Saxon king Harold prepared to defend Britain against invading Normans in 1066, he actually dispensed with his horse and ornamental wooden stirrups, choosing to lead his numerically superior forces on foot. The outnumbered Normans, however, boasted a stirrup-equipped cavalry, and thus won the day—and the millennium.[1]

Such narrative has the ring of mythology, yet the experience of the industrialized world reinforces the idea that, when innovators deploy new tools to their advantage, they change society in the process. The invention of the cotton gin in the late eighteenth century allowed a vast expansion of cotton cultivation in the American South—directly fueling a resurgence in the importation of slaves for plantation labor. One hundred and fifty years later, the mechanical cotton picker suddenly rendered obsolete the jobs of millions of African American sharecroppers, and catalyzed a thirty-year migration of 5 million people out of the rural South and into the cities of the North. Given emerging engineering expertise, the mechanical cotton picker may have been inevitable, but it proliferated rapidly because plantation owners feared the civil rights movement and welcomed a technological replacement for the exploitation labor upon which they depended.[2]

Technology and society thus evolve together. The stirrup emerged in tandem with feudalism, agricultural equipment cannot be understood apart from the legacy of slavery and labor issues, and nuclear weapons joined with U.S. and Soviet hegemonies to constitute a prime determinant of geopolitical evolution after World War II. Cars, television, air conditioning, and birth control likewise arose in particular social contexts and contributed to the remaking of everyday life.

If innovations as apparently modest as the metal stirrup and the cotton gin can transform society to its roots in a period of decades or less, what of technologies now on the horizon that aim to revolutionize the very processes by which new materials are designed and produced, that are blurring the boundary between the inanimate and the living, that may combine the powers of machine intelligence and human consciousness? No one can fully understand the long-term implications of such advances, emerging under the heading of nanotechnology—"the art and science of building complex, practical devices with atomic precision," with components measured in nanometers, billionths of a meter.[3] But rapidly improving capacities for miniaturization are now combining with continuing refinements in computation, mechatronics, and telecommunications. Innovations based on nanotechnology may interact to rival the combined epoch-making social effects of chemicals, nuclear missiles, mechanized transport, computerized data processing, antibiotics, TV, and agribusiness. Society a century from now might be barely recognizable—and the range of possibilities goes from wonderful to dire.

The essence of the nanotechnology story is the continuation of a fifty-year trend of machine miniaturization culminating in the rise of design control at the molecular level. Nanotechnology is not confined to a single area of innovation; "smallness" is its unifying attribute. Researchers in a number of technical fields are keenly interested in manipulation of matter at the nanoscale, and funding is assured because many of the research forefronts hold promise for business and military applications.

As one small measure of this growing interest, U.S. government support for nanotechnology research increased sixfold between 1997 and 2003, to $710 million per year. Because most of the research is at a precommercial stage, much of this funding aims at hastening the journey from research to application. For example, the U.S. National Science Foundation (NSF) supports university nanotechnology research centers to explore the fundamental science and engineering that is supposed to enable rapid innovation. What is the promise of these investments?

- As conventional silicon chips approach their maximum capacity for memory storage, nanotechnology offers the potential of chiplike functionality from single molecules. Scientists foresee very small, inexpensive computers with thousands of times more computing capacity than current machines, perhaps introducing a second computer revolution that could dwarf the changes of the past fifty years.[4]
- Advances in nanofabrication are leading directly to a new generation of sensors, with "surfaces that can sense and bind to chemical and biological agents [and] emit a measurable electrical or optical signal when binding occurs." This could lead to a "reliable, inexpensive, and portable way to ensure that the world's drinking water and food supplies are free from contaminants"; sensors in homes and workplaces "that could detect minute quantities of all biological and chemical hazards and provide appropriate safety measures if detected"; and devices "as small as the tip of a hypodermic needle" that "could detect thousands of diseases."[5]
- Scientists are working "to evolve organisms to live with and work with other kinds of inorganic materials. . . . The project is working with viruses that can be engineered to stick to various elements. . . . The viruses can grow in sheets, creating a flexible surface holding nanoparticles of various materials. . . . This could lead to flexible computer displays,

while removing the viruses after a nanostructure is formed could expand its usage into conditions where biological materials fail."[6] Other researchers are seeking to replicate biological functions with synthetic ones, designing and synthesizing organic molecules and supramolecular arrays that can mimic green plants' photosynthetic processes—perhaps opening up a new age powered by solar energy in a far more fundamental sense than what that term means at present.[7]

IBM and Xerox are among an increasing number of large corporations engaged in nanotechnology R&D, and start-up firms hoping to mimic the explosive success of Silicon Valley are racing to get products onto the market. Carbon Nanotechnologies, for example, claims to be a "world leading producer of single-wall carbon nanotubes . . . the stiffest, strongest, and toughest fibers known." Their most advanced product, BuckyPlus™ Fluorinated Single-wall Carbon Nanotubes, goes for $900 per gram, more than fifty times the price of gold.[8] Nanomix is working to develop "new hydrogen storage systems that will power the fuel cell revolution, by using nanostructured materials to store solid-state hydrogen for automotive and portable power applications."[9]

To the nanotechnology research community and its advocates, the future looks bright indeed. As one well-known technological visionary, Newt Gingrich—chair of the NanoBusiness Alliance and former speaker of the U.S. House of Representatives—puts it:

> Nanotechnology, the science of developing tools and machines as small as one molecule, will have as big an impact on our lives as transistors and chips did in the past forty years. Imagine highly specialized machines you ingest, systems for security smaller than a piece of dust and collectively intelligent household appliances and cars. The implications for defense, public safety and health are astounding.[10]

Even normally staid government reports burst with promotional fervor—"Forward-looking researchers believe they could end up with synthetic creations with lifelike behaviors"[11]—apparently relegating those who suffer discomfort at such prospects to the ranks of the "backward-looking." To the visionaries of nanotechnology, "[o]ur world is riddled with flaws and limitations. Metals that rust. Plastics that break. Semiconductors that can't conduct any faster. And so on. Nanotechnology can make it all better—literally—by re-engineering the fundamental building blocks of matter. It is one of the most exciting research areas on the planet, and it may lead to the greatest advances of this century."[12]

Yet when a National Science and Technology Council report says, "If present trends in nanoscience and nanotechnology continue, most aspects of everyday life are subject to change,"[13] what exactly are the authors thinking? "Science discovers, technology creates, man adapts," as the 1939 New York World's Fair proclaimed? The use of the passive voice is wonderfully revealing: the world *is* to be transformed by inevitable, autonomous, disembodied processes called science and technology, but no one, apparently, is doing the transforming.

Not exactly. Thus far, the exuberant decision to remake the world with nanotechnology has come from committees drawn from a small group of experts, mostly male, mostly upper middle class, mostly North American, universally in possession of great technical expertise. But twenty-first-century nanoscientists and engineers have thought no more carefully about the social aspects of their work than had the previous century's technologists who introduced nuclear weaponry and nuclear reactors to the world, or the chemists who blithely synthesized millions of tons of chlorinated chemicals without regard for their ecological and health effects.[14] Still lacking is a recognition that evolving sensible paths of advance, paths that can win wide public support and ensure broad public benefit, requires time for patient deliberation. The intelligence of democracy is sustained by debate and negotiation among partisans with partially conflicting values, different competencies, and different institutional bases and interests. Experts alone cannot supply these diverse perspectives.[15]

At this point, much work in nanotechnology is no more than a reflection of the joy that scientists and engineers experience when they use new tools to do new things of interest to them:

> Donald Eigler of IBM's Alden Research Center remembers the day in 1990 when he and Erhard K. Schweitzer, who was visiting from the Fritz-Haber Institute in Berlin, moved individual atoms for the first time. In his laboratory notebook Eigler used big letters and an exclamation mark to write "THIS IS FUN!" Using one of the most precise measuring and manipulating tools the world had ever seen, the researchers slowly finessed thirty-five xenon atoms to spell out the three-letter IBM logo atop a crystal of nickel. To be sure, it only worked in a vacuum chamber kept at a temperature that makes the North Pole seem tropical.[16]

Fun indeed. "Nanotechnology researchers love their newfound ability to move atoms on surfaces."[17] The enthusiasm is understandable, but there is something disquieting about the promise that the joy of doing science will translate into a world inevitably transformed for the better. Delight in tinkering is thus revealed as the justification and foundation for ushering in social changes of unknown kinds and potentially unlimited extent. Beneath the surface, moreover, lies a political reality: to continue to do the work that gives them such personal and professional rewards, scientists and the agencies that support them may simply be saying what they think elected officials want to hear, in order to enhance prospects for future funding.[18] Upon such banal motives is the world remade.

Technological revolutions do not build the world from scratch, of course. Products of innovation are introduced into society through institutions and systems that already exist, and whose strengths and flaws are likely to persist even in the face of rapid technological change. Consider, for example, the health care arena. Despite continual promises to the contrary, experience shows that new biomedical technologies tend to offer benefits only in exchange for higher overall costs, while contributing to well-documented inequities of health care access, delivery, and outcomes, at least in the United States.[19]

Nanoscale techniques are predicted to "revolutionize the speed with which new compounds are screened for therapeutic potential as new drugs. . . . If the trend is similar to that of microelectronics, the rate could grow exponentially."[20] Pharmaceutical companies' R&D trajectories, however, are oriented primarily toward generating revenue, not toward improving health. For example, since the mid-1970s, of the more than 1,200 drugs put on the market by the pharmaceutical industry, only four were aimed at infectious diseases of the tropics, such as malaria, that kill millions annually. Of these four drugs, moreover, two originally were developed for other purposes, and one has since been withdrawn from the market.[21] We can expect a nanotech-enabled proliferation of new drugs that can help people in affluent societies cope with everything from neurosis to impotence to the asymptotic decline of our aging bodies, but unless present motivations for science and innovation change, we should anticipate little benefit for those whose needs are greatest.

Nanotechnology also promises to accelerate the trend toward diagnosis of diseases where there is no cure. "With arrays of ultra miniaturized sensors that sample a range of chemicals or conditions, the confidence level and specificity of detection would be much greater than is now possible with separate macroscopic sensors."[22] For example, DNA sensors will soon have the capability of screening for multiple diseases, "including sexually transmitted diseases, cystic fibrosis, and genetic predisposition to colon cancer and blood hypercoagulation."[23] Cystic fibrosis remains incurable, of course, and knowing about predispositions to cancer has already been revealed, in the case of breast cancer, to be at best a mixed blessing.

As nanosensors begin to detect the first molecular indicators of a disease, moreover, they will certainly help save lives, but they will also lead to increased medical interventions that are unnecessary or actively harmful. The ongoing controversies over the effectiveness of mammography for breast cancer and prostate-specific antigen (PSA) tests for prostate cancer provide a window into what may happen on a larger scale. While both tests provide early detection capability, statistical evidence from numerous clinical trials has not demonstrated that the new techniques actually save or extend lives.[24] They do, however, trigger the demand for additional tests and treatments, some of which are debilitating in their own right.

Nanosensors promise to move detection to even earlier stages—at the first molecular manifestation of elevated PSA levels, for example—despite the fact that most prostate tumors grow so slowly that they are not life threatening.[25] More generally, abnormal genetic and chemical processes occur in the normal body all the time—and normal body processes are often sufficient to take care of them before they become serious. Nanosensing of the earliest harbingers of diseases thus promises to stimulate a significant rise in unnecessary treatments and significant side effects. At the same time, the advent of nanodetection capabilities will considerably expand the information that insurance providers can use in making decisions about coverage. As competitive businesses, insurance companies often try to increase their profitability by denying coverage to those at high risk, a goal that governments can only partially thwart via regulation (except by providing publicly funded, universal medical coverage).

Of course, some applications of medical nanotechnology may be worth the costs and risks, while others will not be. The question is how to distinguish, how to act on the distinctions, and who should be involved in the selection process. The same need for making careful choices will arise in assessing the promises of nanotech for other sectors: How can innovations in computing help alleviate, rather than exacerbate, the widespread experience of information overload in modern life? How can manufacturing be restructured to enhance the quality of work life—and avoid the marginalization of millions of workers worldwide, which industrial innovation has often caused in the past? Can nanotech be used to increase the intelligence and autonomy of military hardware (thereby keeping soldiers off the front lines) without encouraging less well-equipped enemies to turn toward unprotected civilian targets like the World Trade Center?

Into the Unknown

The hype surrounding medical diagnostic applications of nanotech may be naively (or cynically) optimistic, but the consequences are likely to lie in the realm of the familiar. If, however, nanotechnology achieves its ultimate potential—to literally assemble materials and machines on a molecule-by-molecule basis, and to achieve functionality at the level of individual molecules—then we will be moving into a realm in which we have no experience. Indeed, "nanofabrication" is one of the chief areas of emphasis for government-funded nanotech research. Progress in this realm may ultimately lead to what is known as an "assembler," a device "that is able to manufacture almost anything. . . . Fed with simple chemical stocks, this amazing machine breaks down molecules, and then reassembles them into any product you ask for."[26] Right now this is obviously the stuff of science fiction, and some knowledgeable observers are confident it will remain so. Others disagree, however, and the Zyvex Corporation, which claims to be "the first molecular nanotechnology company," is pursuing this holy grail of nanotechnology, a system "capable of manufacturing bulk materials or arbitrary structures with atomic precision, getting nearly every atom in the desired place."[27]

Probably the first coherent warning about nanotechnology of this new kind came from nanoscientist and technology forecaster Eric Drexler, whose 1986 book *Engines of Creation,* while for the most part extolling the prospects of the technology, devoted one chapter to possible dangers:

> Powered by fuels or sunlight, [replicating assemblers] will be able to make almost anything (including more of themselves) from common materials. . . . [A]ssembler-based replicators could beat the most advanced modern organisms. "Plants" with "leaves" no more efficient than today's solar cells could out-compete real plants, crowding the biosphere with an inedible foliage. Tough, omnivorous "bacteria" could outcompete real bacteria: they could spread like blowing pollen, replicate swiftly, and reduce the biosphere to dust in a matter of days.[28]

Drexler's work did not gain much public attention, but a similar version of the hypothetical dangers of nanotechnology made front pages in 2000 when Sun Microsystems chief scientist Bill Joy published in *Wired* magazine an article titled "Why the Future Doesn't Need Us." Joy described a world of self-replicating, exponentially proliferating "nanobots" that could drown the planet in an uncontrollable "gray goo." Because of his standing as one of the leading architects of the world's information infrastructure, his warning made waves: Joy was no Luddite. While initial media reports of his pessimistic view were respectful, the research and technology communities quickly mobilized like antibodies to neutralize him. Nobel Prize winner Richard Smalley said: "My advice is, don't worry about self-replication nanobots. . . . It's not real now and will never be in the future."[29] John Armstrong, retired IBM vice president for research, swatted Joy away without even bothering to name him: "If you are worried, as some seem to be, about a robotic future full of nano mechanisms that don't need us, I suggest you rent a copy of Woody Allen's *Sleeper* from the video store, and restore your sense of balance!"[30]

Adherents of what sometimes verges on a new nanotechnology religion seem not to notice their own intemperance. The point, surely, is not whether Joy's specific worries come true; it is that his predictions are not obviously less reasonable extrapolations of current trends than those made by nanotech promoters. Joy's concerns arguably deserve special consideration, moreover, because they identify a downside that outweighs any reasonable estimate of the new technology's positive potential. Nor does Joy have an intrinsic conflict of interest, as do many of the researchers who stand to benefit if their promotional activities translate into research funding.

Less controversial than Joy's predictions about gray goo is his recognition that nanotechnology will fuel a second revolution in computer power that could lead to a hybridization of human and machine intelligence. While some technological visionaries view this as the desirable and inevitable result of human invention, other people may not feel entirely sanguine about launching or accelerating technological changes that could make humans as we now think of them . . . well, obsolete. *Does* the future need us? Quantum computers and human brains may combine to create something entirely new. One articulate champion of this vision is the inventor Ray Kurzweil:

> We are entering a new era. I call it "the Singularity." It's a merger between human intelligence and machine intelligence that is going to create something bigger than itself. It's the cutting edge of evolution on our planet. One can make a strong case that it's actually the cutting edge of the evolution of intelligence in general, because there's no indication that it's occurred anywhere else. To me that is what human civilization is all about. It is part of our destiny and part of the destiny of evolution to continue to progress ever faster, and to grow the power of intelligence exponentially. To contemplate stopping that—to think human beings are fine the way they are—is a misplaced fond remembrance of what human beings used to be. What human beings are is a species that has undergone a cultural and technological evolution, and it's the nature of evolution that it accelerates, and that its powers grow exponentially, and that's what we're talking about. The next stage of this will be to amplify our own intellectual powers with the results of our technology.[31]

Kurzweil's enthusiastic portrayal of exponential growth of machine intelligence betrays a peculiar understanding of what matters in the world, "what human civilization is all about": the continued evolution of intelligence. Is humanness really so tied up with ever-increasing information-processing ability? It is easy to imagine a species with more powerful brains than ours—science fiction authors do it all the time—but whether or not they are "human" is another matter. One need only read Homer or Shakespeare to recognize that the essence of humanity has, for better or worse, survived the industrial and information revolutions pretty much intact. The past generation or two of exponential growth of information-processing capabilities so far doesn't appear to have made political, economic, and technological elites discernibly smarter about how they wield their newfound powers; that kind of wisdom is not derived from analytical prowess. (In fact, an excess of confidence in the power of rational analysis has underlain such disasters of modernity as central planning in the Soviet Union, U.S. involvement in the Vietnam War, and the replacement of natural forests with monocultures.)

Whether "the Singularity" advances the cause of human well-being or retards it will reflect not the technologies themselves but the regimes under which they are wielded. Nanotechnology advocates appear just about oblivious to this simple truth. We can be fairly confident that predictions of nanotech-enabled future utopias (and dystopias) will someday seem as quaint (or as malign) as More and Verne and Marx seem to us now.

Steering Lessons

The naiveté dominating nanotechnology discussions fits with one of the best-researched conclusions from historians of technology: One ought never accept experts' rosy predictions about any emerging technological potential. As the political scientist Langdon Winner puts it, contemporary technoscientists tend to work within the "mastery tradition" in Western thought and practice—embracing an assumption that knowledge can and will be used to conquer "nature."[32] This mechanistic view of the universe, a legacy of the seventeenth-century optimism that gave birth both to modern science and to modern democracy, is evident in pronouncements made on behalf of nanotechnology (but with democracy nowhere to be seen). Although temporarily sobered by the environmental surprises and nuclear near-catastrophes of the twentieth century, most scientific and technical fields appear governed by what psychoanalysts would refer to as denial and overcompensation—reiterating ever more loudly the mantra that technical progress leads reliably to social progress.[33] The mastery tradition, in other words, is alive and well despite the bruising experiences and partially successful social movements of the past hundred years.

Kurzweil and other nanotechnology visionaries give the mastery tradition a new twist. Technological evolution, they believe, is largely autonomous, proceeding on paths that can be little altered by human choice. Thus, nanotechnology commentaries all generally share the contradictory idea that specific technological changes are coming inexorably, and yet people are going to be freer than ever, better than ever. This is an incredible scenario: an automatic and inevitable translation of technological destiny into an improved life for everyone.

The proclamations made on behalf of nanotechnology are rooted in a thermodynamic and philosophical absurdity: that control at the micro level translates into control at the macro level. Indeed, the word "control" is central to the promise of nanotech: "Nanotechnology's relevance is underlined by the importance of *controlling* matter at the nanoscale for healthcare, the environment, sustainability, and almost every industry."[34] The real world—the experienced world, the world in which humans must make decisions about, say, how to make use of nanotechnology—is made up of complex systems comprising innumerable components interacting in ways that are often intrinsically unpredictable. This is another of the most firmly established understandings developed by systematic social science analysis of technological innovation: unintended consequences often are greater than those foreseen and intended by innovators.

Unintended consequences emerge in part because control exercised at one level very often leads to unpredictable reactions on another level. Nanotechnology is the ultimate application of reductionism, and its power to confer control over increasingly small components of nature may prove great indeed. But just as, for example, the meso-scale control afforded by the automobile and the coal-burning power plant yield macro-level consequences that include air pollution, climate change, and the geopolitics of fossil fuels, so we can be reasonably sure that specific nanotechnology applications will have impacts not readily controlled or even understood by those creating or using them. As with transforming technologies ranging from the stirrup to the production line to the cotton gin to the hydrogen bomb, we ought to expect that the unanticipated consequences, both good and bad, will provoke profound social disruption.

If, as promised, nanotechnology revolutionizes our whole system of manufacturing and invention, for example, then the impacts will be enormous and unpredictable. To get a sense of possible scale, consider only one aspect of the first industrial revolution—the transformation of human labor. Prior to the nineteenth century, even the most economically advanced societies were predominantly agrarian and rural. For the majority of people, work was rooted in the home and the family. Vagaries of weather and transportation imposed hardship, but most people and families possessed a diversity of skills that gave them autonomy from wage labor and resilience to cope with a variety of challenges. In hard times, resort to subsistence farming and barter was usually possible.[35]

The advent of modern manufacturing machinery changed that. Increasing industrialization and urbanization linked workers to both labor and consumer markets, removing their need and ability to maintain the diverse skills that had been prerequisites for survival in the preindustrial world. Labor itself became a commodity, subject to the same fluctuations and influences as other commodities. During an economic downturn, factories fired people or closed down entirely; for the first time, workers could not easily respond to changing economic conditions by switching to a different type of work or moving to a subsistence mode. As political economist Karl Polanyi observed, "To separate labor from other activities of life and to subject it to the laws of the market was to annihilate all organic forms of existence and to replace them by a different type of organization, an atomistic and individualistic one."[36] Some observers then and now considered this to be wonderful, others found it to be terrible; what is beyond dispute is that the sociotechnical changes exerted profound influence on the pace, character, and meaning of millions of lives.

The glib claim that humanity will gain greater control over the material world via nanotechnologies thus ignores our historical knowledge that technology changes, in unforeseeable ways, the social contexts within which humans can act. Moreover, "humanity" is not an actor, and hence cannot control anything. The point is that certain individuals and their organizations make choices about certain limited domains, and new technical capacities ordinarily give some people and organizations enhanced means of exercising influence—both over the material world and over other people. So the real question is not whether nanotechnology will allow humanity to assert better control over nature, but *which* humans will be making the choices, how well their values and aims will match those of the majority, whether they will respect minority needs, and whether they will adopt strategies to protect against the sorts of problems and dislocations we have here discussed—and those we cannot yet imagine.

Sometime in the next few years a human being probably will be cloned. This will occur despite widespread repugnance for such activities, including legal proscriptions in the United States on federally funded human cloning. The technical momentum appears unstoppable, however, and the political will to outlaw human cloning outright seems to be lacking. Given the spread of the technologies to such fringe groups as the Raelians, a quasi-religious organization with members around the world, a ban would be impossible to enforce. The time to prevent human cloning would have been about 1980, when the emerging biotechnology revolution began to point toward the capability—but before it existed, so no one would have had much to lose from a ban.

Yet at that time there would have been little stomach among scientists for governmental regulations aimed at forestalling particular lines of research on the basis of public sentiment, and those advocating early action would undoubtedly have been countered by accusations of "antiscientism" and "Luddism." And that is precisely our point: when major innovations loom, neither government institutions, nor scientific practice, nor consumer markets are set up to act sensibly in the public interest in a timely way. Here is how Langdon Winner framed the question in *The Whale and the Reactor:*

> In an age in which the inexhaustible power of scientific technology makes all things possible, it remains to be seen where we will draw the line, where we will be able to say, here are possibilities that wisdom suggests we avoid. I am convinced that any philosophy of technology worth its salt must eventually ask, How can we limit modern technology

> to match our best sense of who we are and the kind of world we would like to build?[37]

What, then, would it take to do better?

Wise steering of any technology requires coping with two issues that are largely absent from the promotional juggernaut behind nanotechnology: disagreement and uncertainty. Over the past half-century, political scientists studying public decision-making have concluded that expertise is no substitute for political negotiation because analysis alone can never settle questions as complex as those involved in directing technological innovation. These scholars also have found that, for similar reasons of complexity and unforeseeable consequences, trial-and-error learning is the best approach for introducing major new technologies into society. But how the negotiations are approached makes a great deal of difference, as do the strategies and tactics by which innovators and regulators address the process of learning from experience.

The first step toward more intelligent trial-and-error governance of nanotechnology is to bring it clearly onto the public agenda, and this seems to be under way.[38] In 2002, Michael Crichton published a nonfiction essay on nanotechnology in *Parade* magazine, together with his novel *Prey,* which sensationalized and brought under the national spotlight scenarios such as those advanced by Drexler and Joy.[39] A new Center for Responsible Nanotechnology started operation in December. One of our most thoughtful observers of science and technology, Princeton physicist Freeman Dyson, acknowledged the potentially "grave dangers" of nanotechnology in an article in *The New York Review of Books,*[40] and at about the same time the University of Toronto's Joint Centre for Bioethics warned of a nanotechnology backlash. Nanotechnology is creeping into the public eye.[41]

The virtues of greater openness ought, by now, to be obvious to science and technology planners. Regardless of one's opinions about the merits and risks of nuclear power and genetically modified foods, for example, it is hard to imagine that those involved in the early promotion of these technologies would not now wish that they had more aggressively engaged the public in developing a vision for what was wanted and how it should be pursued.

Yet familiar pathologies are already starting to play themselves out in nanotechnology. While media stories are beginning to stimulate interest in nanotech, several public interest groups, including the Science and Environmental Health Network and the ETC Group, have begun to voice concerns, and have been criticized for doing so. At present, there is no real forum for interested parties to discuss their perspectives. Congressional hearings on the subject have mostly been sycophantic exercises dominated by insider experts; they could have been titled "Hoorah for Nanotechnology!" As the experience with nuclear energy revealed, few governments readily provide a forum for dissidents. The result is greater polarization of rhetoric on all sides, and a hardening of positions over time that makes deliberative action increasingly difficult.

Neither an automobile nor a conversation nor an emerging technology can be steered properly if it is moving too fast for those nominally in charge to learn and adjust on the basis of feedback. To facilitate the broad public deliberation that will be necessary for wise pursuit and deployment of nanotechnology, there appears to be no reasonable alternative to slowing down certain aspects of research and commercialization. This may seem a radical and unprecedented idea, but it actually is neither. When biotechnology research began in the 1970s, some of the key scientists involved declared a moratorium on what was then known as "recombinant DNA" research, and then gathered at the Asilomar conference center in California to work out precautionary guidelines. The National Institutes of Health subsequently endorsed these guidelines, which became the de facto regulatory framework for research in that arena. And although the Asilomar process was flawed because it was expert-driven and applied only to the immediate risks of laboratory research—neglecting consideration of the long-term social risks of the products of research—it at least suggested that the scientific community could engage in a process of responsible self-assessment.

Given the huge uncertainties about the future social impacts of nanotechnology, we ought to think of the unfolding revolution as a grand experiment—a clinical trial—that technologists are conducting on society. From this perspective, we can reflect upon the robust societal consensus that demands prior informed consent as a basis for participation in scientific experiments. This consensus is formally codified in the World Medical Association's Helsinki Declaration, strengthened most recently in 2000, and reinforced in the public consciousness by the memory of, for example, the Tuskegee experiments, where African American males with syphilis were left untreated as part of a "control group," despite the existence of treatments known to be efficacious.[42]

In the United States, every publicly funded research project involving human subjects is monitored by an institutional review board (IRB) that must approve the research before it can be conducted. Every university, independent laboratory, and private-sector lab receiving federal funding for human subjects research has an IRB; there are thousands of boards operating in the United States, nearly 800 in California alone. These boards demonstrate that comprehensive governance is a reasonable goal, and while IRBs certainly impose a cost in terms of the efficiency of conducting research, they are an accepted element of a scientific infrastructure that respects human dignity. Similar commitments of the entire research enterprise to larger democratic strictures occur in experiments with animals and in compliance with environmental health and safety regulations. Comprehensiveness, in other words, is possible, when the stakes are high and societal intent is clear.

But human subjects research is more than an illustrative example. The implications of the nanotechnology revolution dwarf those of any particular clinical trial or psychological test—yet we accept this experiment on society with no moral compunction, no mechanism of oversight, no obligation to understand what we are doing while we are doing it. IRBs provide a model that could be expanded into a broad social assessment and consent mechanism attached to all major nanotechnology programs, especially those likely to introduce entirely novel processes and products into society. Such an approach could bring a variety of social-impact-assessment tools, such as scenario-building and technology foresight, together with well-accepted deliberative processes such as consensus conferences and town meetings, to create a comprehensive but decentralized approach to public participation in technology steering.

Assessment and public discussion cannot substitute for regulation, however. One possible regulatory model is the Premanufacture Notification system for new chemicals. In 1976, after terrible experiences with vinyl chloride, PCBs, DDT, and other chlorinated chemicals, Congress passed the Toxic Substances Control Act mandating that all new chemicals be approved by the Environmental Protection Agency prior to manufacture and use. The Food and Drug Administration, of course, has a similar system for pharmaceuticals that is even more elaborate and restrictive. The rationale for both regimes is that the public cannot rely on technologists and manufacturers alone to judge the safety of new products, that this is a job for government regulators who will not be biased by anticipated profits. Although the private sector will reactively oppose any such regulatory scheme, we note that the most highly regulated industries, such as chemicals and pharmaceuticals, are also among the most innovative, profitable, and competitive.

As products are approved for manufacture and distribution, nanotechnology regulators need to learn from the doleful experience of nuclear power and not scale up too quickly. Nuclear technology foundered in large part because too many reactors were built too fast, before utilities, government, and society in general could learn from experience with pilot projects and smaller reactors. Most utilities that owned reactors found out too late that the costs were far higher than anticipated, the machinery far more finicky, and the regulatory environment much more troublesome than alternative energy-generation methods would have been in that era. Going slowly while learning about a young technology is exactly the opposite of what market buyers and sellers tend to do, of course, so there is simply no substitute for tight governmental regulation to achieve this goal.

The growing nanotechnology controversy also underscores the stupidity of having dissolved the congressional Office of Technology Assessment in 1995. It simply is not possible to govern wisely a technological civilization without intermediary agencies mandated to draw together the best thinking of a wide range of relevant experts, stakeholders, and interest groups. The only such organizations in the United States today (for instance, the National Research Council) are too beholden to their scientific constituencies—which include, of course, those working on nanotechnology—to act as honest brokers in the process.

In sum, perhaps what best describes what we are after is a quality of "reflexiveness," a process by which the broadened community of participants concerned about the direction and impacts of scientific advance and technological innovation gain a fuller understanding of the social context within which they operate. This new understanding necessarily becomes an improved basis for making decisions about how and where to move forward. Yet the unpredictability of nanotechnology-enabled futures means that we will need more than broadened self-awareness. We will also need to assess the emerging implications and impacts of nanotechnology in real time—as new principles, products, and processes are developed but before they proliferate—and apply the results of what we have learned to our deliberative fora, regulatory structures, and research institutions. This sort of intelligent trial-and-error process can allow us to learn from experience at an acceptable cost. It is an amazing irony of technological innovation that for all our rational intelligence applied in the short term, we trust our long-term well-being to the hope that the good unanticipated consequences of our inventions will outweigh the bad. As the potency of our technologies continues to accelerate, this seems more than imprudent.

Finally, then, consider Bill Joy's one unassailable argument: miniaturization coupled with increased power for computing and biomanipulation makes opportunities for doing mischief more available, less expensive, and less dependent on complex institutional research infrastructure than ever before. Until recently, weapons of mass destruction required huge laboratories costing billions of dollars. At the other end of the scale was Ted Kaczynski, the Unabomber, working out of a shack in the wilderness and proceeding victim by victim with technologies that had been available for generations, diffused through the conventional mail. These two extremes are converging. The 2001 anthrax mailer was probably operating alone, or in a very small group, out of a modest facility. Shift ahead to the coming era of Bill Joy's thought experiment: instead of a disgruntled mathematician, imagine that the Kaczynski of the twenty-first century is a disgruntled molecular biologist who creates a designer pathogen with no antidotes, and diffuses it throughout the population via nanoscale drones. At this point, the probability of such an occurrence is impossible to estimate, but given the potential consequences, wouldn't a wise civilization do its best to reduce that probability to zero?

5

YOUR BREATH IS YOUR WORST ENEMY

D. Michelle Addington

Technologies are rarely questioned. We assume they evolve and become obsolete as maturing scientific theories produce better technologies, but some technologies persist even when the science affords us better alternatives. Many of the most persistent technologies are also the most ubiquitous—automobiles, aircraft, construction and building systems. The original technologies behind these assumptions of modern life were developed during the nineteenth century, and preceded rather than followed major shifts in scientific theory. What then determined the originating technology? I want to explore the possibility that technology may be the *result* of social, cultural, and political determinants, not the reverse. Unraveling the lineage of a particularly pervasive building system—HVAC (heating, ventilation, and air-conditioning)—begins to reveal how our technological world is constructed by our beliefs and not necessarily by progress or science.

The HVAC system emerged from separate technologies that were combined into a single system during the first decade of the twentieth century. The resulting system has changed little over the last century, and it is now the standard technology for conditioning the building interior in all but a few corners of the world. This ubiquity carries a large penalty. Building systems are responsible for more than a third of this nation's energy use, and their consumption is escalating at a faster rate than that of the other sectors (industry, agriculture, and transportation). Furthermore, in 2000 the Department of Energy reported that "energy use in buildings is responsible for 35 percent of the nation's carbon dioxide emissions, 48 percent of the sulfur dioxide emissions, (and) 23 percent of the nitrogen emissions . . . [with] emissions expected to increase by more than 25 percent between now and 2010."[1]

As a result, building systems, particularly HVAC, have been a key focal point for conservation initiatives. Numerous federal programs have targeted equipment efficiency, projecting "that a 30 percent improvement in energy efficiency can be realistically achieved in the coming decades," with "more dramatic improvements—ranging from 50 to 80 percent—achieved [through] aggressive implementation" of conservation measures.[2] State and local agencies have upped the ante by enacting into law several standards for building design, such as insulation guidelines and infiltration restrictions, that have been justified through quantifiable reductions in HVAC system energy consumption.

These initiatives, however, are directed almost exclusively toward improvements within the technology, addressing the design, deployment, operation, and maintenance of HVAC systems. The technology itself and its primary functions are rarely questioned. The a priori belief is that if we need to keep a building at 72°F (22°C) and 50 percent relative humidity, then the optimal technology for providing these conditions is an HVAC system.[3]

All alternative technologies are charged with matching this performance. Natural ventilation systems, though, are unlikely to maintain consistent interior temperatures, and passive systems have limited control over relative humidity. Proponents of alternative technologies and for aggressive energy reduction have tried to circumvent these restrictions by calling for a loosening of the standards; after all, it was only in the last half of the twentieth century that some people (and rather few at that, if viewed on a worldwide basis) had the opportunity to work or live in buildings that met the standards. Most of the arguments for such loosening tend to be punitive, suggesting that occupants should be willing to sacrifice ideal comfort conditions for greater environmental goals.

Building systems, regardless of their specific function, presume that the conditions of the interior volume of the building are the primary determinant of the occupants' comfort and health. This has never been questioned. The HVAC system, by providing homogenous, well-mixed air at controlled temperature and humidity levels, operates as the standard to which all other systems are compared. The human body, blanketed in this large container of "perfect" and neutral air, is assumed to be in its most efficacious surroundings. The nineteenth- and early-twentieth-century development of the HVAC system best solved the "problem" of producing the necessarily homogeneous interior environment.

Origins of HVAC Technology

Regardless of the comfort level in a building, the homogeneity of the interior air was not a consideration or even particularly desired until after the HVAC system was developed. Indeed, before the nineteenth century, the primary concern was simply to keep miasmas from night air and marshy areas from entering the bedroom. An interesting reversal in the desirability of outside air took place after the development of modern chemistry during the seventeenth and eighteenth centuries. The identification of the constituents of air led to widespread concern about the human contamination of air through respiration and bodily processes. Ranging from carbonic acid gas to "crowd poison" and body odor, human bio-effluents were considered to be the source of deadly disease. In 1861, Lewis Leeds presented a series of lectures at the Franklin Institute in Philadelphia titled "Your Own Breath Is Your Worst Enemy."[4]

Ventilation with outside air of any quality, even from a highly polluted urban environment, was seen as the only way to prevent dullness, dementia, and perhaps death from human-contaminated interior air. Early strategies simply suggested that windows be opened, but the solutions quickly became more complex and idiosyncratic throughout the nineteenth century. The governments of Great Britain and the United States devoted substantial funds to "ventilating" their own quarters, and numerous quite bizarre experimental inventions were installed throughout the Houses of Parliament and the U.S.

Capitol building. Among the strangest was one that attempted to enhance natural convection by placing heat sources, including candles and small furnaces, inside vertical shafts to "induce" air to move through the building.[5] This approach was in fact the archetype for the modern HVAC system.

By the end of the nineteenth century, ventilation strategies began to shift away from those that depended on natural convection and building configuration to the more universal mechanical means for moving air with steam-driven fans. Heating, then, could be easily incorporated by inserting steam coils at the fan exit, thus establishing the first mechanical heating and ventilation system. These fan-driven systems were more consistent and controllable than natural strategies, and were also the only means available for producing the high ventilation rates that were rapidly being mandated across the country. Yet the dominance of HVAC was not yet secure. The expense of the new mechanical systems, coupled with a turn-of-the-century interest in the pastoral outdoors, was almost successful in dismantling the nascent technology.

Schools were at the center of much of the controversy. The earliest standards for ventilation were initially applied to them and then, later, to other places of public assembly and industrial facilities. School superintendents found it particularly burdensome during winter to operate mechanical ventilation systems because they drove up both heating and operating costs. Factory owners had similar concerns, as the growing interest in working conditions was pushing them to adopt mechanical ventilation. As a result, both the public and private sectors were eager to embrace any challenge to the "healthfulness" of the HVAC system.

The fear of toxic human respiration waned significantly as the germ theory of disease transport became more publicly accepted. Chronic diseases such as tuberculosis began to overshadow epidemic diseases such as cholera and yellow fever as urbanization increased at the beginning of the twentieth century. The major cities—New York, Chicago, Boston, Philadelphia—were absorbing large numbers of immigrants into already dense tenement areas. The high density brought a corresponding increase in chronic disease: the death rate from tuberculosis was

50 percent higher in New York's Mott Street tenements than in the rest of the city.

The prevailing wisdom was that the best treatment for tuberculosis was immersion in cool alpine air. Resorts and spas were developed in mountainous areas for wealthy TB patients, but served no more than 5 percent of the infected population. Those living in tenements had no other choice than to sleep on roofs or fire escapes. Social reformers, intent on improving conditions in the tenements, began building schools for immigrant children so that they could have fresh air during at least half of the day. Eventually, cold, fresh air came to be regarded as having prophylactic as well as curative properties. Schools throughout the northeastern United States, even those for the elite, began shutting down their mechanical systems and relying on open windows, and immigrant schools were outfitted with rooftop classrooms so that the students could be outside year-round.[6]

During the surge of interest in open-air schools, Elizabeth Milbank Anderson, a prominent New York philanthropist, wanted to fund the installation of mechanical ventilation in selected New York public schools to demonstrate the health advantages of pure air. She was encouraged instead to fund a study to address the fundamental question as to which was better for health: the mechanical system for heating and moving air, or the natural approach of leaving windows open. The study, carried out by the New York Commission on Ventilation, was an exhaustive investigation, using empirical, experimental, cross-sectional, and longitudinal methods to produce data that continued from 1913 to 1917. At the end of the study period, in which 5,500 children in 124 classrooms in 20 different schools were evaluated, the conclusion was reached that open windows were as satisfactory in providing comfortable and healthy conditions as were the mandated mechanical systems.[7]

Because schools were generally on the leading edge of building-technology implementation, eliminating the requirement for mechanically ventilated air would have prompted building owners throughout the country to follow suit, as the installation and operation of mechanical systems were becoming increasingly costly. Two "events" occurring soon after the study was completed, however, distracted attention from the issue, thus preventing the switch and further cementing the hegemony of this technology in buildings—even as 15,000 school superintendents met in Washington, D.C., to denounce mechanical systems.[8] The first distraction was the 1918 flu epidemic, which claimed more lives than World War I. Epidemic diseases had historically encouraged isolation, even to the point of bricking over windows. The old fears about the miasmas from outside air reemerged, as exemplified by this ditty supposedly sung by gravediggers as they interred flu victims' corpses:

I had a little bird
And its name was Enza
I opened the window
And influenza.[9]

The epidemic also coincided with a growing antagonism toward the urban poor, most of whom were immigrants. Social reform underwent a dramatic retrenchment as the reformers' interest in providing the same healthy conditions for immigrant children as for children of the elite was transformed into a desire to keep the upper classes healthy by further isolation from the poor. Filth emerged as the new "crowd poison," and hygiene replaced ventilation as the most popular preventive measure. Manufacturers of mechanical systems were quick to capitalize on this emerging concern with hygiene and cleanliness by adding air washers and filters to their heating and ventilation systems, creating the air-handler that Willis Carrier, in 1919, bragged could produce "manufactured weather" that was cleaner and purer than nature's own.[10] This new feature of the mechanical system provided the ability to conform to "antiseptic standards of cleanliness that differentiated the rich from the poor, American born from foreign born."[11] Carrier's advertising brochure of 1919 featured a hospital incubator with the caption "Even babies can be manufactured with manufactured weather." The elite status symbol of the earlier century's outdoor alpine spa was supplanted by the twentieth century's isolated, perfectly conditioned interior.

The opponents of mechanical systems remained active throughout the first half of the twentieth century, with one even receiving an Air Force contract to evaluate human performance under different climatic conditions, but the anti-immigrant sentiment was reinforced by an implicit racial discrimination similar to what was taking place in Europe. Environmental determinists such as Ellsworth Huntington argued that "climate alone among the great inanimate features of the human environment produces direct physiological effects."[12] Huntington described the ideal climate as being one quite similar to New England (where he, not so coincidentally, was teaching). If cooler climates had drawn the elite to spas in the nineteenth century, then in the twentieth century these same climates were presumed to be the ones that produced the superior races.

Coolness was further exalted as providing other benefits, such as lower death rates from cancer and reduced crime. Capitalizing on the desire to be "cool," manufacturers added cooling coils to the air-handler, producing the HVAC system we still use today. This new system was capable of controlling the temperature and humidity of the air regardless of the exterior climate. One did not have to relocate to a northern clime for health and prosperity, because the use of an HVAC system provided a good surrogate.

For architects, however, the perfect interior created by the HVAC system represented a means of class equalization rather than of discrimination. Modernism in architecture emerged as the tangible manifestation of the socialist ideals spawned from the writings of Marx and Engels. Drawing its aesthetic inspiration from mass production, modern architecture was universal, treating all as equal regardless of their class or location. The seminal architect of the twentieth century, Le Corbusier, propounded the universalizing qualities of HVAC systems in a 1930 lecture:

> At this moment of general diffusion, of international scientific techniques, I propose: only one house for all countries, the house of exact breathing. . . .
>
> The Russian house, the Parisian, at Suez or in Buenos Aires, the luxury liner crossing the Equator will be hermeti-

> cally sealed. In winter it is warm inside, in summer cool, which means at all times there is clean air inside at exactly 18°.
> The house is sealed fast![13]

As the visual aesthetic of modernism began to supplant its ideological agenda, the socialist underpinnings of modern architecture progressively lost their context. In yet another curious reversal, the sealed air-conditioned building—the product of socialism—became the symbol of capitalism and corporate America in the latter half of the twentieth century.

HVAC as Solution or Problem?

Even if confronted with the social and ideological history of the ubiquitous HVAC system, many would readily argue that the idiosyncrasy of the influences, coupled with the two-hundred-year persistence of the technology, supports the reading that the technology was a driving force and not the result of social and cultural beliefs about the human environment. Conventional wisdom asserts that technology is the physical solution of a problem, and the evolution of technology optimizes the solution. If the problem is the heating and cooling of buildings, what better solution could there be than an HVAC system, particularly because the thermal conditions of buildings are difficult to control? Unlike most other problems in fluid mechanics and heat transfer, building air behavior is a true mixing bowl of phenomena: wide-ranging velocities; temperature/density stratifications; conductive, convective, and radiant transfer; laminar and turbulent flows; and randomly moving (and randomly heat-generating) objects. The air-handler-based HVAC system has maintained its hegemony because it provides reasonably homogeneous conditions among this cacophony of behaviors. No other single technology is capable of doing so.

A very different understanding emerges, however, if we explore the concept that technology should be considered as a solution to a question of physics rather than simply as equipment or systems. When we consider technology to be equipment or systems, then our efforts to improve technology tend to stay with the cycle of evolution and obsolescence—faster computer processors replace slower ones, hybrid engines for automobiles improve upon gasoline engines. One presumes that there is an identified need, and a defined technological solution, such that the focus is simply on improvement. A question of physics, on the other hand, would be one in which the need has not been defined; and thus, one cannot optimize within a technological solution. The HVAC system was the solution for a particular equipment or systems problem: what is the optimum technology for heating and cooling a building's interior? The more appropriate question would address the fundamental problem for which heating and cooling of the building's interior is but one of many possible solutions: for what purpose does one heat or cool a building?

Before the nineteenth century, buildings were not heated, nor were they ventilated. The problem then, and the true problem now, was how to maintain the body's thermal equilibrium. The body exchanges heat with its environment through several processes, which in themselves can be produced by several methods. Most early strategies used highly local and direct methods dependent upon radiation or conduction. A brazier or a fireplace heated the body through radiation, for instance; foot warmers and hand warmers heated the body through conduction.

Heating the air surrounding the body was an exorbitantly expensive and noxious proposition because high-quality and clean fuels were available only to the very wealthy. The development of ventilation during the nineteenth century was posed as a solution not to heating or cooling the body, but as a solution to a growing anthrophobia. Ventilation aimed at diluting the air around the human body, not to maintain the air in a building at particular conditions. It was only after a clever marketing campaign promoting the integration of heating and ventilating that the system began to be moved remotely from the body. Even then, however, the building was not seen as a singular entity, and only portions of it would have received the diluted and conditioned air. Only when germ theory and a societal obsession with hygiene and purity gave rise to the ideal of the sealed building did the requirement for homogenous interior conditions become paramount in importance.

Locating the Boundary

HVAC systems are excellent for heating or cooling air, but heating or cooling air is the most inefficient means of heating or cooling the body. The translation of the problem object from the body into the building has equivalently translated a typological problem into an equipment or systems problem. Stepping back to the more fundamental problem is not so easy, however, because it challenges yet another culturally constructed understanding of the building as a bounded energy system.

Until the development of the integrated heating and ventilation system, the source of heat was generally local. As a result, each local point such as a fireplace had to be fueled and maintained. Institutions typically had their own steam plants, allowing distribution systems, but the small user had little option but to transport coal to a single stove that would have been penuriously fired. Natural gas was available in urban environments, but the distribution systems were privately owned. Areas of service were clustered around the local companies, and the concept of the private utility soon expanded to district steam service and electrical service. Increasing public discontent put pressure on city politicians to fix rates, and the private utility contracts began to be managed by municipal authorities at the end of the nineteenth century.

For many urban residents, living hand-to-mouth, the continuous service and thus continuous cost of district utilities were not within economic reach. Coin-operated meters were developed to allow the poor to use utilities on demand, and eventually the majority of utility service was metered. This switch of the point of service from the site of use (the fireplace) to the meter, and analogously from the user to the building, began the shift from using energy directly for a single purpose to distributing energy to be on demand for multiple purposes. One's energy use was no longer measured simply by counting the gallons of oil used in one stove, but by metering the gallons of oil or cubic feet of gas used in all the building processes over several months. As a result, measuring the energy used by the building was presumed to adequately represent the quantification of the energy uses in the building.

The building, however, is not an energy system. The location of meters is determined by private property boundaries, not by energy boundaries. This might seem to be a distinction without a difference, as the same property boundaries will almost certainly contain all the energy uses in the building. An energy use, though, is generally part of a larger energy system. Thus, for example, an air conditioner straddles a windowsill or sits outside the building so that its condenser can vent heat to the outside. A building intersects with several scales of energy systems, some of which are smaller than the building, many of which are larger, and none of which are likely to coincide with the building or property boundary.

The presumption that the building is a bounded energy system confuses thinking about energy balances and appropriate technology. A well-publicized goal of many architects as well as of many institutions, including the Department of Energy, is the creation of the "zero energy" building. The description of such a building, however, rarely reveals any reduction in energy consumed by various uses in the building. Instead, the building may be outfitted with photovoltaic panels, geothermal systems, fuel cells, or perhaps even boilers fueled by agricultural products. Rather than "zero energy," these buildings should perhaps be labeled "zero utility bill."

From an energy conservation perspective, this approach often uses technology to solve the wrong problem. For example, the increasing push to install photovoltaic panels on building facades couples a mislocation of the energy boundary with an inappropriate use of a particular technology. The vertical faces of a building are inefficient sites for installation: solar angles cannot be optimized, the need for transparency reduces efficiency, the low efficiency can contribute to urban heat island effects as well as increase the building's cooling load. The efficiency of photovoltaics could be optimized, and many of the detrimental consequences avoided, if properly located and installed, but the ideal locations are highly unlikely to reside neatly within the bounds of single properties.

The Aesthetics of Technology

The equating of the building boundary and the energy boundary reinforces the longevity of the technology—the HVAC system. Forcing the many overlapping scales of energy systems to be combined into a single system so they can be balanced at the site of the meter has reallocated the relevant processes—they now belong to the building and not to the use. Throughout the twentieth century, and particularly in the last few decades, buildings have begun to be defined as and treated like living organisms. Initially, the association was one only of analogy: Le Corbusier once explained the air-handler as acting like the "lungs" of the building. Eventually, the analogy was supplanted with a progressive anthropomorphism: the building became the body. The structural system was the skeletal structure, the facades were the skin, the HVAC system was the circulatory system. Architects and engineers now sought to integrate these systems into a seamless whole.

Floor plates became plenum sections, structural columns housed ducts, and what was once considered unnecessary took over a substantial part of the interior infrastructure while consuming more than 30 percent of the building's budget. A well-designed building was considered to be one in which the systems were inextricably woven together:

> Richard Rush: "What buildings, historic or otherwise, do you think of when you think of systems being appropriately integrated?"
>
> William Caudill: "The first building that comes to mind is the Centre Pompidou. You see structure; you see mechanical; you see the electrical system; you see everything all in one. That's integration. That is the esthetic system. That is architecture."[14]

The technology has been exalted as inseparable from the aesthetic. HVAC systems are no longer a solution to a larger problem; they have become the problem. We look to optimize the system, we no longer look to optimize the technological choice for heating and cooling the building, and we certainly have not focused our consideration on the heating and cooling of the body.

HVAC and the Energy Crisis

With no other alternatives seamlessly slipping in to replace the HVAC system as one might install an artificial knee, we seem to have little choice but to accept the extant technology and work within its limitations. After the fate of the open window was sealed, HVAC systems became ubiquitous, and the components were hidden deep in the infrastructure, invisible except to the building engineer. Not until the energy crisis spawned by the Arab oil embargo of 1973–74 did these systems come under wide public scrutiny; the new Department of Energy assumed much of the responsibility for questioning their energy use and necessity. Early initiatives attempted to tackle many aspects of the problem, from the purely technological (new control schemes, insulation, operating ranges) to the purely ideological (building occupants were asked to turn down their thermostats or wear sweaters). Architecture schools were quick to join in, but the terms of discourse naturally became those of the architecture academy: the revival of nostalgic architecture and the emergence of passive solar design adhered to the anti-establishment ideology, while the high-tech approach presumed that the visual exposure of ducts and mechanical components would be enough to bring the technology to the forefront and encourage more judicious use. The initial success of these various perspectives seemed promising, particularly the use of new control schemes, as energy use began to dip almost immediately. But consumption resumed its pre–energy crisis rate of increase when prices and supplies returned to pre-crisis levels.

Many have blamed the return to "business-as-usual" energy use on a retrenchment of conservation efforts when availability was no longer threatened. Speed limits have risen to their pre-crisis levels, the installation of central air-conditioning in residences has nearly doubled since 1980, and sick-building concerns have resulted in a backing off from the more efficient control schemes. But many changes remained in place: the mandated improvements in equipment, the new building codes, and the expanded public awareness. Concerns for the welfare of the global environment have replaced concerns about resource depletion and political instability. New initiatives are proliferating, from the Department of Energy's Million Solar Roofs campaign and Energy Star labeling to green-campus programs and sustainable master planning. Many architects and engineers have responded to the public's growing concern with the environment and are promoting buildings and design solutions that are "green." Manufacturers have been quick to join in, marketing their products as sustainable, environmentally friendly, and low energy. Local and national government agencies have developed guidelines and checklists to ensure that these solutions and products are incorporated into the design and construction processes. The three legs necessary for initiatives to develop into standard practice are firmly in place: the public is aware enough to demand energy conservation and green buildings, designers and manufacturers are shifting their practice and production to meet these demands, and government is undergoing the necessary restructuring to facilitate the commitment to and longevity of green practices.

But buildings continue to use more energy. In 2001, the Energy Information Agency (EIA) projected that energy demand in the commercial and residential sectors, in which buildings are the most significant energy consumers, will be 25 percent higher in 2020 than in 2000.[15] Two years earlier, the Department of Energy released the results of a survey of energy use by commercial buildings, documenting that newer buildings, even though they generally reported having more energy-efficient features, used more electricity than old buildings. The problem is not so much that energy conservation initiatives are flawed, but rather that they focus on marginal improvements in efficiencies rather than on substantial reductions in consumption. Newer buildings tend to be larger than existing buildings, with more space per occupant and per function. As ambient systems—lighting and HVAC—are sized and operate in relation to building volume, more space in a plan causes an increase in the size of these systems by as much as the square of the added floor space. EIA projects that although the number of households is expected to increase by 1 percent per year, the residential energy demand will increase by 1.9 percent, while an increase in commercial floor space of 1.3 percent will produce a 2 percent increase in electricity use.[16] Energy reductions wrought by efficiency improvements are quickly overwhelmed by the energy demands to support the additional space.

Proponents of many of these initiatives have argued that energy intensity (energy per $GDP) has been reduced and that, as such, the initiatives have had an impact. Indeed, the National Energy Policy, released by President Bush in May 2001, opens with a positive spin on the nation's energy conservation efforts: "Dramatic technological advances in energy efficiency have enabled us to make great strides in conservation, from the operation of farms and factories to the construction of buildings and automobiles."[17] These statements downplay the much more alarming information: in 2000, total U.S. energy use was 19 percent higher than in 1990 (the baseline year for the Kyoto protocol), whereas building energy use was 28 percent higher.

The attempt to solve this particular technological problem with technology has not been fruitful. The hegemony of the HVAC system constrains the alternatives. For example, sealing the building envelope—through insulation, building wraps, and caulking—has been the front-line measure for reducing the energy used by HVAC systems. The more a building is sealed, though, the more the building requires an HVAC system to maintain the indoor air quality. As a result, rather than optimizing the technology, we are limited to balancing acceptable compromises.

New Technology for the Wrong Problem

In 1994, researchers at Pacific Northwest National Laboratory (PNL) announced a new technology for heating and cooling using microelectromechanical systems (MEMS). MEMS had already revolutionized several fields, including ink-jet printing, automotive accelerometers, biomedical analyses (e.g., DNA labs-on-a-chip), and photonics (e.g., optical switches, LEDs). Originating from the fabrication technology used for microelectronics, MEMS are basically tiny machines with integral computing. A micro–gas turbine weighing less than a gram was developed, as were submillimeter machines with microscopically sized gears, pumps, valves, compressors, and steam engines. Initially, many of the microenergy machines were intended for the replacement of batteries in mobile power sources, but eventually they were reconceived as possible replacements for larger equipment, including HVAC components.

PNL took a micro–heat pump developed for the cooling of electronics and proposed that connecting the heat pumps in series could produce a sheet as thin as wallpaper:

> PNL researchers are creating a heat pump smaller in size than a dime—so small that hundreds or thousands could be fabricated on a single sheet. Such sheets could be incorporated into the walls of homes and buildings and someday may replace conventional heat pumps, furnaces, air conditioners, and ductwork.[18]

They estimated that, with a capacity of one watt per square centimeter, no more than a one-meter-square sheet of "wallpaper" would be necessary for heating and cooling a typical house. In 1995, the Department of Energy named microtechnology, including MEMS, as its number one priority in energy research.[19] MEMS energy machines have progressed dramatically during the last five years: the early estimates of micro–heat pump capacity have been surpassed fortyfold, with expectations that a hundredfold increase will easily be achieved.

In 2000, the micro–heat pump as wallpaper was no longer considered viable. Although the military still targeted the heat pump for wearable cooling garments to be used by pilots and desert personnel, and there continues to be interest in its deployment for in-line water heating, the technology was deemed unsuitable as the primary building system. The reason? The wallpaper was not as efficient as a conventional HVAC system for heating or cooling *air*.

The Fundamental "Problem"

HVAC systems are the best technology, but for solving the wrong problem. Until the late twentieth century, however, there were few other options because the underlying problem was too difficult to characterize. The sciences of heat transfer and fluid mechanics—the two fundamental sciences that govern heat exchange—were the last branches of classical physics to develop theoretical structures that could adequately account for generally observable phenomena. The building blocks began with the development of the science of thermodynamics in the early 1800s, and were not complete until nearly a hundred years later, when the science of fluid mechanics was fully theorized. Nevertheless, the theory was still so complex that the equations could not be solved, even in a simplified format, until the 1950s.

The eventual development of a problem-solving method known as computational fluid dynamics (CFD) in the late 1960s to early 1970s, coupled with the introduction of the Cray-1 supercomputer, finally opened a window into the determination and simulation of how air moved and behaved. CFD simulation, by providing the capability to determine the pressure, velocity, temperature, density, and chemical concentration of air at any given point and at any given time, revolutionized many fields including aeronautics, nuclear power, and environmental engineering, and had a significant impact on the design of products such as turbo-machinery, automobiles, and microelectronics.

Its application for the characterization of building air behavior has been much more problematic. In other applications, one or two mechanisms (such as ship drag or hypersonic compressibility) may dominate, but in a building, the complexity and range of the many different phenomena play havoc with simulation modeling. For example, the building interior is saddled with constant change in the exterior climate over the course of a single day as well as with instantaneous changes in the interior climate due to the cycling of systems and equipment and the movement of people. Little empirical data exist to validate the modeling, because even identically constructed test facilities have enough variation for the results to be unrepeatable. This does not preclude the use of CFD for describing building air behavior, but it does necessitate simplifying approximations that lend a decidedly generic quality to the simulations. These approximations presume that the building can be modeled as a collection of homogeneous blocks of air, which of course can be produced only by an HVAC system. The tautology persists.

If one could return to a tabula rasa, how then might the problem be constructed and solved? The human body's thermal mechanisms may be even more complex than those of the building. The body continuously loses heat by evaporation and produces carbon dioxide that must be diluted. Air temperature is but one of the conditions that determine the body's thermal exchange; air velocity, vapor pressure, and surrounding surface temperatures in view and in contact with the body also must be balanced with both internal and external physiological thermoregulation to maintain the body's homeostasis. The transiency of the human state, coupled with the range of the many different mechanisms, produces a thermal problem that is most probably unique at any given instant. The HVAC system, by surrounding the body with an enormous blanket of homogeneous air, provides enough inertia to maintain relatively stable, albeit rarely optimal, thermal conditions for the human body. The choice, however, to condition the small (the body) by conditioning all that surrounds it (the building) brings a large energy penalty.

The human body may be the only entity in a building that requires management of its thermal conditions (notwithstanding certain specialized products and processes such as one might find in a laboratory). In the typical building, however, the human body is but one of the heat-generating entities, with electrical equipment producing a much larger share of the heat load. Indeed, most large office buildings in the United States require year-round cooling to remove the heat produced by equipment. Lighting is one of the most inefficient processes in a building: fluorescents produce five times as much heat as they do light, and incandescents produce twenty times as much heat. Standards for interior lighting increased nearly two-hundredfold over the last century, with the result that building lighting systems consume more than two-thirds of this nation's electricity. Other equipment, particularly microelectronics, has also contributed to the unprecedented nonhuman thermal load in buildings. Processor speed in computers increases with heat dissipation: the early 286 chip dissipated about 2 watts, whereas most of today's computers dissipate from 50 to 150 watts. (A human working at a desk dissipates about 130 watts.) Because they relocate the thermal boundary from the body to the building, HVAC systems are saddled with mitigating the heat generated by all of the other entities within the building.

Technologies to Solve the New Problem

Nevertheless, and regardless of inefficiency, what other technology can effectively provide thermal conditions for the body that are "not unsatisfactory"? In fact, there are many, from the truly banal to the quite extraordinary. An old strategy that has recently found new life depends on thermal radiation, not convection. With radiant panels, ceilings, or floors, the radiant exchange is only between entities, i.e., from a warm floor to a seated human, or from a human body to a chilled ceiling panel. The major drawback has been the lag time—these systems can't respond quickly—but there has been significant research into the use of phase change materials to allow on/off switching. Not so different from the traditional HVAC system, but narrowing its focus to how an air system directly exchanges heat with the body, is the burgeoning "displacement ventilation" system. Recognizing that the body is enveloped in a buoyant plume, this system utilizes the boundary layer of the body to entrain air: cool air is introduced through the floor, and the body draws only the necessary air into its plume, thereby requiring just one-third (or less) of the air-conditioning produced by the conventional system.

Other strategies are chipping away the integration of all the components of the HVAC system. Standards for fresh air from the outside require on average about 15 cubic feet per minute per person. Because the system is fully integrated, all of the fresh air must cycle completely through the HVAC system regardless of whether or not it needs conditioning. During the 1973–74 energy crisis, many building owners and operators reduced or even shut off outside air, securing immediate reductions in energy use, but also contributing to the rise of sick-building syndrome and building-related illness. Ventilation standards went back up, but the experience raised the question of why it was necessary to route outside air circuitously through a building when there was adjacent air on the other side of the building envelope. A strategy called "pore ventilation" or "dynamic insulation" addresses this question; the needed outside air slowly infiltrates through a porous wall, reducing not only the additional fan energy but also eliminating the possibility of the fresh air becoming contaminated in the HVAC distribution system—a rather common occurrence. Still more strategies include finding ways to decouple unnecessary thermal loads—using direct methods to shed or reject the heat generated by equipment without cycling it through the HVAC system. As an example, rather than forcing the HVAC system to remove the excess heat generated by lights, the use of fiber optics allows remote positioning of the hot light source away from the occupied space.

What all of these alternative technologies have in common is that they are discrete: they act on a single behavior. The more discrete a system, the more directly it can mitigate physical behaviors. Systems could also become much smaller, approaching the scale at which microtechnologies may indeed be most effective. The concept of the building as a single integrated organism would be replaced by a concept of the building as a series of interventions on a web of energy systems.

HVAC technology has been in place conceptually for almost two hundred years, and practically for nearly one hundred years. Very few other technologies have weathered the twentieth century with no substantive changes or challenges. Freeman Dyson, in *Imagined Worlds,* distinguished technologies that are science driven from those driven by ideology. He concluded that science-driven technologies evolve through cycles of obsolescence and regeneration, whereas "the characteristic feature of an ideologically driven technology is that it is not allowed to fail."[20] The ideological underpinnings of building systems are deep and complex, mired in political agendas and cultural beliefs. How can we begin to extricate the true underlying need—thermal management of the human body—from our overriding commitment to the technology of "manufactured weather"?

6

CHANGING CONCEPTIONS

Lori B. Andrews

A few years ago, a new boutique opened in a trendy shopping area in Pasadena, California. Just two hours north of the Repository for Germinal Choice (a sperm bank selling the seed of Nobel laureates and top athletes), the boutique, Gene Genies Worldwide, offered "the key to the biotech revolution's ultimate consumer playground." It sold new genetic traits to people who wanted to modify their personalities and other characteristics.

The boutique was filled with the vestiges of biotechnology—petri dishes and a ten-foot model of the ladderlike structure of DNA. Brochures highlighted traits that studies had purportedly shown to be genetic: creativity, conformity, extroversion, introversion, novelty-seeking, addiction, criminality, and dozens more.

Shoppers initially requested one particular trait they wanted changed, but once they got into it, their shopping lists grew. Since Gene Genies offered people not only human genes but also genes from animals and plants, one man surprised everyone by asking for the survivability of a cockroach.

The co-owners were thrilled at the success of their endeavor, particularly since none of the products they were advertising were actually yet available. Despite their lab coats, they were not scientists but artists attempting to make a point, striving to serve as our moral conscience. "We're generating the future now in our art and giving people the chance to make decisions before the services actually become available," said one.[1]

Imagining alternative futures is central not only to artists and science fiction writers but to policymakers as well. Potential parents are facing a growing range of options to help them produce children and influence the characteristics of those children before birth. But these new reproductive and genetic technologies create challenges for governance.

Social conflicts, funding decisions, and marketing hype have simultaneously influenced the use of these technologies and crippled regulatory attempts. New methodologies and coalitions are essential to protect against unnecessary risks, incorporate moral and social values in the use of reproductive and genetic technologies, and assure more effective governance of technologies that can transform life at its most basic level.

Changing Conceptions

It is now possible for a child to have up to five parents—a sperm donor, an egg donor, the surrogate mother who carries the child, and the couple who raises him. Or, if Dr. Severino Antinori, an Italian infertility specialist, gets his way and cloning becomes just another form of assisted reproduction, a child might have just one parent.[2] It's possible to generate a genetic profile of a child before birth—or even of an embryo prior to implantation.[3] Consequently, notions of family are being diversified and the concept of "normality" is being upgraded. Twelve percent of potential parents, for example, say they would abort a fetus with a genetic propensity toward obesity. "Today, Tom Sawyer and Huck Finn would have been diagnosed with attention-deficit disorder and medicated," observes Shannon Brownlee in *The Washington Monthly*. "Tomorrow, they might not be allowed out of the petri dish."[4]

The designing of children is occurring subtly, as a result of individual choices in an open market. One couple offered $50,000 for an egg donor who is a smart, tall Ivy League student. A man seeking to sell his sperm for $4,000 per vial established a website with his family tree claiming to trace his genes back to six Catholic saints and several European royal families. Thousands of couples turn to the Internet to find genetic parents for their future children. They view pictures of sperm and egg donors, listen to tapes of their voices, and review pages of descriptions of their physical features, their hobbies, their SAT scores, their philosophies of life. At the Ronsangels.com website, couples bid on the eggs of attractive models. At the Repository for Germinal Choice, couples purchased sperm from Nobel laureates. Can purchasing single genes—rather than a person's whole packet—be far behind?

The Possibility of Genetic Manipulation

For decades, scientists have stated that they would not undertake germline genetic intervention on humans. But some prominent scientists and bioethicists have indicated recently that attempts at germline genetic interventions in humans are not just inevitable[5] but desirable.[6] James Watson, co-discoverer of the structure of DNA, has said, "But evolution can be just damn cruel, and to say that we've got a perfect genome and there's some sanctity to it, I'd just like to know where the idea comes from. It's utter silliness. And the other thing, because no one really has the guts to say it, I mean, if we could make better human beings by knowing how to add genes, why shouldn't we do it?"[7]

"The fundamental discoveries that will enable this technology will occur whether or not we actively pursue them, because they will grow out of research that is deeply embedded in the mainstream and not directed towards human germline engineering," says Gregory Stock, director of UCLA's Program on Science, Technology, and Society.[8] In animal research, a variety of techniques are being explored to manipulate the germ line. These include manipulation of gametes (sperm or eggs),[9] manipulation of embryos,[10] and the addition of extra, artificial chromosomes.[11] It has been suggested that these types of genetic intervention be used on humans to eliminate disease.

But it is unlikely that parents and scientists will stop at curing disease. "We are kidding ourselves if we think we can say yes to therapy and no to enhancements," says Erik Parens, a bioethicist at the Hastings Center.[12] In fact, in a Louis Harris poll sponsored by the March of Dimes, 42 percent of potential parents surveyed said they would use genetic engineering on their children to make them smarter; 43 percent, to upgrade them physically. Another survey found that more than a third of people wanted to tweak their children genetically to make sure they had an appropriate sexual orientation. With around 4 million births per year in the United States, that's a market for prebirth genetic enhancement almost as large as that for Prozac or Viagra.

Many authors use such crass comparisons as "it may be the ultimate shopping experience, like ordering a sunroof or leather seats from the car dealer"[13] or "[like] picking from a list of options the way car buyers order air conditioning and chrome-alloy wheels."[14] So many couples mistook an ad for the movie *Gattaca,* featuring the number 1-888-4-BEST-DNA, for a real offer to genetically engineer potential children that they flooded the number with calls, prompting the American Society for Reproductive Medicine to issue a press release denying any involvement.[15] The lengths to which parents will go to enhance the opportunities for their children are demonstrated in South Korea, where parents pay surgeons to snip a membrane under their toddler's tongues in the belief that this will help the child speak English better.[16]

Some commentators suggest that it will be impossible to regulate reproductive and genetic technologies. "In a society that values individual freedom above all else, it is hard to find any legitimate basis for restricting the use of reprogenetics," says Princeton biologist Lee Silver. "I will argue [that] the use of reprogenetics is inevitable. It will not be controlled by governments or societies or even the scientists who create it. There is no doubt about it . . . whether we like it or not, the global marketplace will reign supreme."[17]

Other commentators suggest that these techniques should not be regulated, even if it were possible. Joseph Schulman, head of the for-profit Genetics & IVF (In-Vitro Fertilization) Institute in Virginia, testified before a genetics policy committee of the National Academy of Sciences. "Don't regulate genetic technologies," he said, "because it will slow down their development. The computer industry developed quickly because anybody could tinker in their garage."

Yet with genetics and reproductive technologies, we are tinkering with future people.

The Regulatory Framework

In the United States, reprogenetic services are developing with very little oversight. The assisted reproductive technology industry, with an annual revenue of $4 billion,[18] is growing to serve the estimated one in six American couples who are infertile.[19] Annually, in the United States alone, approximately 60,000 births result from donor insemination; 15,000 from IVF; and at least 1,000 from surrogacy arrangements.[20] In contrast, only about 30,000 healthy infants are available for adoption.[21] What is so striking about this comparison is that every state has an elaborate regulatory mechanism in place for adoption, while only three states (Florida, Virginia, and New Hampshire) have enacted legislation to comprehensively address assisted reproductive technologies.[22]

Part of the freedom from regulation comes from a legislative paralysis in which lawmakers are afraid to act because, unlike many other policy areas, *everyone* has an opinion about how the next generation should come into the world, so any regulation is bound to offend someone.[23] But beyond the emotional salience of the issue, there are some characteristics of reproductive and genetic technologies—and the public and policy discourse about them—that have impeded effective regulation up to this point. First, the technologies themselves are actually not terribly complicated—half the in vitro clinics in the United States, for example, have the equipment and personnel necessary to clone humans.[24] Artificial insemination with Nobel laureate sperm can be achieved with a turkey baster. Second, because many of the technologies involve human embryos, deeply entrenched pro-life and pro-choice conflicts have led to a regulatory stalemate. Third, the vast commercialization of medicine and science in the past decade has resulted in market principles being applied to the technologies surrounding procreation. And fourth, because these technologies purport to allow us to control the most fundamental aspects of our lives—

procreation, health, mortality—we are easily susceptible to hype about them, and, at the same time, we are vigilant about protecting them from unwarranted governmental intrusion. I will discuss each of these problems in turn and then analyze how we might begin to counteract them.

The Simplicity of Reproductive Technologies

Reproductive technologies are tougher to regulate than other dramatic technologies, such as nuclear technology or organ transplantation. The tools for reproductive technology are relatively inexpensive and widely available. "A reprogenetics clinic could easily be run on the scale of a small business anywhere in the world," notes Lee Silver. There are IVF clinics in at least thirty-eight countries, from Malaysia to Pakistan and Thailand to Egypt.[25] The Raelians set up a laboratory for human cloning in an abandoned West Virginia high school.[26]

Genetic technologies, too, are easier to employ than one would suspect. At one major gene-sequencing center, third-graders sequence DNA. In science class, high school students look for mutations in each other's DNA.

The free-market availability of genetic technologies is underscored by the activities of artist Eduardo Kac, a professor at the Art Institute of Chicago.[27] He is a prominent member of a group of artists who are actually creating genes, shaping the clay of life itself. In Kac's work *Genesis,* he created a formula for a gene out of a sentence in the Bible. He translated "Let man have dominion over the fish of the sea, and over the fowl of the air, and over every living thing that moves upon the earth" into Morse code, which uses four types of characters: dots, dashes, letter spaces, and word spaces. Then he translated the Morse code into the four-letter alphabet of the genetic code, which contains only G, A, T, and C (the chemical bases guanine, adenine, thymine, and cytosine, which are the building blocks of life). He used the following conversion principle: the dot in Morse code becomes a C; the dash, a T; the word space, an A; the letter space, a G. He then had Clontech, a biotech company, make the gene. In 1999, the price tag for making the gene was $8,000; by 2001 it was down to $800, certainly affordable to many of us who may want to create a gene, for whatever purpose.[28]

Eduardo implanted the gene in bacteria in a petri dish, placed it in a gallery, and hooked up the display to the Internet. When people logged on and clicked their mouse, ultraviolet lights flicked on over the petri dish, causing the bacteria to reproduce, making the new gene propagate and mutate.[29]

Eduardo next made a work of art by persuading a scientist to genetically engineer a rabbit embryo so that it would express the green fluorescent gene that is carried by the Pacific Northwest jellyfish. The techniques used on the rabbit could very well be used on people. Three years ago, researchers in Atlanta removed a gene from a prairie vole, an affectionate, monogamous rodent that spends half its time cuddling. They transferred the gene to a closely related species, the mountain vole, which lives a promiscuous lifestyle. The recipient rodents did not become monogamous, but their brains developed to look like those of prairie voles and they became more cuddly and affectionate.[30] Science writers began to speculate on the potential applications to humans. In the wedding of the future, would we promise not only to love, honor, and cherish—but also to have a prairie vole gene implant?

Viewing one of Eduardo's exhibits, art critic Arlindo Machado of the University of São Paulo wondered whether, in the future, our inherited genes would mean less than our artificial additions. "Will we still be black, white, mulatto, Indian, Brazilian, Polish, Jewish, female, male, or will we buy some of these traces at a shopping mall?" he asks. "In this case, will it make sense to speak of family, race, nationality? Will we have a past, a history, an 'identity' to be preserved?"

Such analysis gives the impression that people are just a packet of genes unfolding. It ignores the complexity—and the potential risks—of genetic interventions. Almost no important traits are monogenetic and, conversely, a gene "linked" to a particular trait may have other functions as well. In fact, the findings of the Human Genome Project demonstrate that genes have less influence over our traits than was previously thought.[31] But who are the social watchdogs who ensure that truthful disclosures are made and risks averted?

The Impact of Pro-Life Protests

An unregulated environment exists, not as a result of a well-thought-out policy analysis, but because pro-life lobbying has ironically kept reproductive technologies out of the usual oversight schemes. In the wake of the U.S. Supreme Court's ruling in *Roe v. Wade* in 1973, right-to-life groups focused their lobbying efforts at the state level to ban embryo research.[32] Today, at least ten states ban research on in vitro embryos altogether.[33]

At the federal level, in 1975 the Department of Health, Education, and Welfare (HEW), today the Department of Health and Human Services, established a policy regarding research proposals seeking federal funds that involved IVF. The new rules required a review of the proposal's ethical acceptability by a board appointed by HEW's secretary, called the Ethics Advisory Board (EAB).[34]

Aware that Robert Edwards and Patrick Steptoe in England were working to facilitate the birth of the first child conceived via IVF, a professor at Vanderbilt, Pierre Soupart, in 1977 submitted a research proposal to the National Institutes of Health (NIH), a federal agency, to study whether chromosomal abnormalities occur during the IVF process.[35] Though his proposal was quickly approved at NIH, the EAB had not yet been established to review the ethics of a project the government deemed otherwise fundable. Dr. Soupart's work was delayed while he waited for a decision.

In the meantime, Edwards and Steptoe announced to the world in 1978 the birth of Louise Brown, the first child conceived by IVF. Soupart died in 1981, his proposal never having received federal funding. HEW's secretary, Joseph Califano, never sent a formal letter denying Soupart's proposal,[36] and he tabled the recommendations made by the EAB concluding that IVF was acceptable for married couples and that research on human embryos should be permitted as long as it was designed to study IVF's safety and answer important scientific questions, it complied with federal regulations to protect human subjects, and the embryos were not allowed to develop past fourteen days from fertilization.[37]

Under Califano's successor, Patricia Harris, the EAB was disbanded and none of the board's recommendations were ever enacted. One commentator noted that "in vitro fertilization was caught in the web of fears about abortion and genetic engineering, both of which were unpalatable for public officials."[38] Meanwhile, in 1980 the first IVF clinic in the United States opened its doors in Norfolk, Virginia, an event marked by a demonstration of hundreds of pro-life protesters. A year later, clinic clients Roger and Judith Carr gave birth to the first baby born via IVF in the United States.

Pro-life groups did succeed in their lobbying efforts to ban federal funding involving research on human embryos.[39] But this seeming victory for pro-life protestors may have actually heightened their concerns about how new reproductive technologies are applied.[40] The lack of federal funding and oversight has meant that the industry developed without a framework for evaluating the scientific merit, safety, or ethics of emerging technologies. The dearth of federal regulation has rendered infertile couples themselves, rather than animals, the research subjects for most new procedures. The assisted reproductive industry has been likened to the dietary supplement trade, with plenty of promising claims but little scientific evidence to back it up.[41]

In 1993, the Clinton administration nullified the EAB requirement for IVF proposals and repealed the executive moratorium on fetal tissue research.[42] Shortly thereafter, NIH director Harold Varmus established the Human Embryo Research Panel to develop criteria for what types of embryo research, if any, should be eligible for federal support. Varmus approved the panel's recommendation that NIH approve funding for research that used surplus embryos from IVF attempts. Before any grants could be awarded, however, Congress passed an appropriations rider preventing federal funding of human embryo research in which a human embryo was knowingly destroyed, discarded, or subjected to unnecessary risk of injury or death greater than that allowed under federal statute for research on fetuses in utero.[43]

Pro-life sentiment has thus prevented federal research funds from being used for procedures involving embryos. One consequence of the lack of federal funds is a dearth of outcome studies on the women and children involved in reproductive technology. Another consequence is that experimental procedures are introduced into clinical practices without sufficient protections for the subjects. In other areas of medicine, research is initially funded by the federal government and, by federal regulation, must be reviewed in advance by a neutral committee, the Institutional Review Board, before it can be tried in humans. Since reproductive technologies have been held hostage to the abortion debate, they have not received federal funds. Researchers can still submit their plans to hospital and university Institutional Review Boards, but they usually do not. In fact, according to IVF doctor Mark Sauer, IRB review of reproductive technology proposals is so rare as to be "remarkable."

Even those rare studies that go before IRBs are not assessed for their social impact. The federal regulations covering IRBs specifically state that the reviewing committee should not address the social advisability of the project. The law says that the IRB "should not consider possible long-range effects of applying knowledge gained in the research (for example, the possible effects of the research on public policy) as among those research risks that fall within the purview of its responsibility."[44] In one instance where a fertility doctor sought IRB approval, he had already started advertising the procedure before the IRB met. The IRB chairman said, "One feeling was that if we approved his study, at least we could monitor his actions and collect meaningful data about the safety and efficacy of the procedure."[45]

New drugs and new medical equipment are regulated by the Food and Drug Administration (FDA), but no similar review is required for innovative reproductive technologies. Since such technologies are viewed as a species of physician services, they do not fall within the traditional reach of the FDA, which specifically does not regulate health care services or information transmission between health care providers and patients.[46]

Reproductive technologies also differ from other medical procedures in that they are rarely covered by health insurance; only fourteen states' laws mandate infertility coverage.[47] For other types of health services, insurers, through managed-care outcome studies and evaluation of services, have required certain proof of efficacy before medical services are reimbursed.[48]

Where there is no insurance coverage for reproductive technologies, consumers are denied this additional aspect of quality assurance.

Additionally, medical malpractice litigation, which serves as a quality control mechanism in other areas of health care, does not work as well in this field. The normal success rates for the procedures (25 percent for IVF, for example) are so low that it is difficult to prove that the doctor was negligent. Risks to the children may not be discernable for so many years that the statute of limitations on litigation may be exceeded. In "wrongful life" cases, courts have been reluctant to impose liability upon medical providers and labs for children born with birth defects when the child would not have been born if the negligent act had been avoided; only three states recognize such a cause of action.[49]

Consequently, experimental techniques are rapidly introduced in the more than three hundred high-tech infertility clinics in the United States without sufficient prior animal experimentation, randomized clinical trials, or the rigorous data collection that would occur with other types of medical experimentation.[50] IVF itself was applied to women years before it was applied to baboons, chimpanzees, or rhesus monkeys, leading some embryologists to observe that it seemed as if women had served as the model for the nonhuman primates.[51]

This unseemly state of affairs is a result of our unwillingness to have a true discussion of our values. Instead, pro-life concerns about the embryo have pushed the technologies into a policy underground.

The Commodification of Science

In the regulatory void, market principles govern the development and distribution of reproductive and genetic technologies. And since insurers rarely cover reproductive technologies, clinics are in a fierce competition for wealthy patients, which leads some to exaggerate the capability of the technologies as they try to attract business. Similarly, as genetics researchers try to attract venture capital—or encourage the use of the technologies they offer—they sometimes hype the power of those technologies.

Some reproductive technology clinics report as "pregnancies" small hormonal shifts in a woman's body which show that an embryo has briefly implanted—before being reabsorbed by her body. Others implant as many as ten embryos or use fertility drugs indiscriminately in an effort to increase the number of babies the clinic can claim to have created, even though this increases the risk to the woman and the fetuses. Infertility clinics run ads and boast of newer, more innovative (often untested) technologies to attract wealthy patients.

In the genetics realm, the powerful genetic technologies are being privatized. The patenting of genes by academic research and biotech companies has created incentives for widespread marketing of premature uses. This commercialized setting makes it more likely that genetic tests and genetic engineering techniques will be implemented prematurely, that they will be performed without appropriate concern for informed consent, and that the poor and disadvantaged will be least likely to share in any benefits.[52]

Unlike any other major medical dilemma in the past, however, we do not have a sufficient body of "neutral" scientists to advise us on these matters. A series of legal developments in the 1980s turned genetic science from a public-interest activity into a commercial one. A landmark U.S. Supreme Court case in 1980 granted a patent on a life form—a bacteria—setting the stage for the patenting of human genes.[53] Initially, researchers assumed that people's genes were not patentable, since patent law covers "inventions" and prohibits patenting the "products of nature."[54] But by the mid-1980s, the U.S. Patent and Trademark Office was granting an increasing number of patents for human genes, allowing the researcher who identified a gene to earn royalties on any test or therapy created with that gene.[55] A second radical change in the 1980s was a series of federal laws allowing university and government researchers to reap the profits from their taxpayer-supported research.[56] This encouraged collaborations between researchers and biotechnology companies—and a growing interest in the economic value of genetic technologies.[57]

These legislative changes have had deleterious effects on both the development of technologies and on the quality of information that the public and policymakers receive about the technologies. Researchers may delay publishing their findings about a gene until they attempt to secure patent rights.[58] For example, the scientific report of the discovery of the hemachromatosis gene was submitted for publication more than a year after the patent on the gene was filed.[59] Various studies underscore how commercial incentives to academic genetic scientists can delay the dissemination of scientific information by those scientists. Academic researchers with funds from companies are four times as likely as those without such funds to report that trade secrets resulted from their research.[60] Rates of publication decline as the proportion of research funded by industry increases. The most productive and entrepreneurial faculty are most likely to withhold data.

One of every five medical scientists in one survey had delayed publication of research results for at least half a year in order to protect financial interests.[61] Scientists directly engaged in the commercialization of their research were three times as likely to delay publication and twice as likely to refuse to share information as those doing basic research.[62]

Among the life scientists, geneticists were the most likely to withhold data.[63] A 2002 study found that 47 percent of geneticists surveyed had denied requests from other faculty members for information, data, or materials regarding published research.[64] When geneticists were asked why they intentionally withheld data, more than 20 percent listed the need to protect the commercial value of their results.[65] Even more troubling is the finding that 28 percent of geneticists surveyed reported that they were unable to duplicate published research because another academic scientist refused to share information, data, or materials.[66] This goes entirely against the traditional scientific method of hypothesis-testing and replication.

According to a study by Tufts University professor Sheldon Krimsky, in 34 percent of 789 biomedical papers published by university scientists in a year in Massachusetts, at least one of the authors stood to make money from the results they were reporting.[67] This was because they either held a patent or were an officer or advisor of a biotech firm exploiting the research. In *none* of the articles was this financial interest disclosed, despite the fact that it could have biased the research.

The Application of Market Principles

The corporatization of reprogenetics, the application of a business model to living entities, poses risks ranging from potential physical harms to more subtle, but equally troublesome, shifts in cultural values. The difficulties with the market model are already playing out in the realm of reproductive technologies and somatic-cell genetic experimentation.

Under a market model, short-term gains are emphasized and long-term risks are ignored. There are no systems in place to assess the long-term impacts of reprogenetic technologies. For example, in 1993 doctors began offering intra-cytoplasmic sperm injection (ICSI) to couples in which the man had a low sperm count. Where previously a man was considered infertile unless he produced millions of sperm per ejaculate, now a man could be fertile with a single sperm. Within four years, more than one-third of all IVF procedures involved ICSI.[68]

In Australia and Belgium—unlike the United States—the government keeps track of how many children conceived through reproductive techniques have genetic abnormalities. In 1997, these governments noticed that the children created by ICSI were twice as likely to have major chromosomal abnormalities as were children conceived naturally.[69] A *Lancet* editorial criticized the use of ICSI on people before it had been adequately researched in animals.[70]

The use of genetic technologies poses similar problems. University of Pennsylvania genetic researcher James Wilson founded a gene therapy company and stood to profit handsomely if he could show the therapy worked.[71] In fact, university rules had to be bent to allow Wilson to have such a large investment in the company. The rules allowed for a 5 percent investment; he held 30 percent.[72]

After an eighteen-year-old research subject, Jesse Gelsinger, died while participating in a study conducted by Wilson,[73] a widespread federal investigation found that the potential risks of gene therapy had been covered up at universities and companies alike.[74] At Penn, the informed consent form that Gelsinger signed did not disclose the fact that two monkeys had died after receiving the gene-therapy vector that he, too, was given. And researchers had accepted Gelsinger as a subject despite the fact that, according to the government investigation, his liver function was not good enough to meet the study's criteria.

Perhaps the lure of lucre also influenced other researchers. Despite federal rules that require prompt reporting of research risks, researchers reported promptly to the NIH only 39 of the 691 deaths and illnesses suffered by gene-therapy research participants who had received the same vector as Gelsinger.[75] And when some companies reported risks to the FDA, they were allowed to label them "proprietary" to keep them from being further disclosed. Due to the lack of oversight and the characterization of risks as proprietary information, people who agree to participate in reproductive and genetic technologies—as well as policymakers and members of the public who want to assess the technologies—do not get adequate information.

If human germline genetic intervention is undertaken, major risks can be anticipated—cancer, sterility, or other problems in the next generation.[76] Proponents of genetic engineering of animals and humans suggest that the practice is no different than selective breeding. But geneticist Jon Gordon points out there are enormous differences when only a single gene is being introduced in a complex organism. Gordon notes that unlike selective breeding, where favorable alleles at *all* loci can be selected at one time, gene transfer selects only *one* locus and tries to improve the trait in isolation.[77] Gordon notes that this single-gene approach has, "despite more than 10 years of effort, failed to yield even one unequivocal success."[78] Instead it has produced disastrous results. When a gene shown to induce muscle hypertrophy in mice was inserted into a calf, the animal did exhibit the desired trait initially, but later exhibited muscle deterioration.[79] The animal had to be shot.

In a separate experiment, researchers genetically enhanced the wings of flies to be 300 percent stronger than average. But far from being superflies, these insects couldn't even get off the ground because they were no longer able to move their wings fast enough.

In another study, researchers injected mouse embryos with an extra NR2B gene, linked to long-term memory and increased cognitive and mental abilities. The resulting animals (called "Doogie Howser" mice) seemed to move more quickly through mazes than the mice that had not been altered.[80] Immediately, a question arose about whether such interventions should be undertaken on humans. Yet subsequent research, by other scientists, revealed that the genetic intervention had a downside: the Doogie Howser mice were more susceptible to long-term pain.[81]

The Market Model Encourages Hype

In order to ensure the flow of venture capital, companies and universities send out press releases about their genetic research couched in language that makes it sound as if their findings will be immediately applicable to humans. In doing so, they sometimes make assertions that go beyond the existing data. A university press release about the "obesity gene," for instance, emphasized the human applications even though the research was done on rats, and gave the impression that interventions that worked to slim rats would help humans lose weight.[82] Subsequent research in humans found that this was not the case.[83] A federal committee investigating gene therapy cautioned, "Overselling of the results of laboratory and clinical studies by investigators and their sponsors—be they academic, federal, or industrial—has led to the mistaken and widespread perception that gene therapy is further developed and more successful than it actually is."[84] In fact, the one study that seemed to indicate a clear benefit of somatic cell gene therapy (in treating children with severe combined immune deficiency)[85] was halted recently when some of the children being treated developed a rare leukemia.[86] In response, W. French Anderson, the most prominent gene therapy researcher in the United States (who, in fact, has been awarded a broad patent on the process of gene therapy[87]), said, "We knew it would happen sooner or later."[88] He had not disclosed that earlier, however.

The deterministic approach to genetics set forth in press releases makes people think such technologies are ready for use. Given people's general desire to enhance their health and abilities (and those of their offspring), demand is being created for the use of genetic enhancements. For example, researchers have injected mice with a synthetic gene, IGF-1 (insulin-like growth factor-1), to not only repair damaged muscles but to boost growth.[89] Not surprisingly, athletes want in. Former Norwegian Olympic gold medal speed skater and physician Johann Olav Koss has been approached by athletes who want to be first in line to try IGF-1. And when he told them he didn't have any safety data for its use in humans, they didn't care—their main concern was how they could get it. "Safety data didn't mean anything to them. They basically said they were willing to do it right now," says Koss.[90] Some athletes are already using genetically engineered erythropoietin, a natural hormone that stimulates production of red blood cells and is used in treating kidney disease.[91] As *Sports Illustrated* aptly put it, "They're 21st-century Fausts, willing to bargain future health for present glory."[92] The International Olympic Committee is sufficiently concerned about "genetic doping" that its World Anti-Doping Agency convened a meeting to assess how new genetic technologies might be used by athletes, whether to heal or to enhance their bodies.[93]

In the United States, there is a particular emphasis on immortality. When I spoke on genetic policy issues at a meeting of Fortune 500 chief executives, a number of them pulled me aside individually to ask about the work on telomerase. Would it let them live forever? When James Thomson's embryo stem-cell research was announced, a repairman blocked my car in the driveway so he could talk to me. He'd heard that I worked in this field and wouldn't let me leave the grounds until I told him whether the technologies would be available soon enough to extend his life.

The downsides of hype may be relatively small when it encourages you to buy overpriced designer sneakers or a car that can get up to speeds you'll never use, but hype may be seriously inappropriate when what's at stake is creating food or pets or children. The aggressive marketing of genetic tests, for instance, pressures physicians—and parents—to request an increasing number of such tests for fetuses and children.[94]

The marketing choices may reflect certain fads and trends. Think about what would have happened if cavemen had been given the power to genetically enhance humans. They would almost certainly have chosen as their model Arnold Schwarzenegger rather than Albert Einstein. Even a generation ago, we might have chosen to genetically enhance people who were better linotype operators or typewriter repairmen. In the 1960s, before the space shuttle, scientists proposed cloning legless men to serve as astronauts to fit in the small spaces of a rocket.[95]

Consider what traits our society has valued. There was a run on a sperm bank thought to have Mick Jagger's sperm. Clinics stopped listing the height of sperm donors because no one would choose the short donors. The Repository for Germinal Choice, which initially offered only sperm from Nobel laureates, added a line of athletes' sperm.

These may seem like narcissistic trifles. Why should I care any more about a couple's decision to pay for a genetic enhancement for intelligence than I would if they spent their money on an expensive car or private tutors for their children?

The difference centers around the nonconsensual, undemocratic impacts of these technologies. Harm could be caused to the scores of children subjected to these interventions. Moreover, these are not just "individual" choices in isolation. If wealthy individuals genetically enhance their children to be smarter or taller, others of us may feel pressured to do the same, just to enable our kids to keep up. "Normality" today may be "disability" tomorrow.

"Some will hate it, some will love it, but biotechnology is inevitably leading to a world in which plants, animals and human beings are going to be partly man-made," says Lester Thurow. "Suppose parents could add 30 points to their children's IQ. Wouldn't you want to do it? And if you don't, your child will be the stupidest child in the neighborhood."[96]

Selecting traits also creates a notion, as with previously rejected caste systems or guilds, that people can be born into a particular job or purpose. What if the legless individual did not wish to be an astronaut? What if a clone of Michael Jordan breaks his kneecap at age ten and can't play basketball? Will his parents consider him worthless? Will he consider himself a failure? And if the original Michael Jordan died young of an inheritable cardiac disorder, his clones might find themselves uninsurable or unemployable due to genetic discrimination.

Applying the corporate model to the creation of humans may cause certain types of people to disappear. I was once at a meeting where a geneticist suggested, "Let's use genetics to cure racism. Let's make everyone the same race." When he said that, I looked around the room at the scientists and high-level government officials present—which included one person of color—and I knew what race he would choose.

People May Be Treated as Products

In the future, human embryos might be genetically manipulated and then patented. Already, there has been a patent application in England for a process to genetically engineer mammals to produce pharmaceutical products in their milk. The application asks for the rights to patent genetically engineered *human women* as well. Brian Lucas, the British patent attorney for Baylor University, said that although the focus of the current technology was cows, the desire to cover women was put in because "someone, somewhere may decide that humans are patentable" and Baylor wanted to protect its intellectual property if that happened.[97]

The market is good for some things, but should it govern the type of people we try to create? Lee Silver predicts that genetic enhancements by the wealthy might ultimately cause us to diverge into two species—the Genrich and the Naturals, who will not be able to procreate together.[98]

Genetic enhancement technology may someday allow parents to make consumer choices about which features and extras to request for their babies. Yet children don't come with the same guarantees as do cars or toasters. The child of an attractive model could be downright homely. And Nobel Prizes tend to be awarded to people in the same laboratories rather than in the same families. William Shockley, a Nobel laureate sperm donor, once said that his own children were a "regrettable regression to the mean."

How will parents feel if they pay for "smart" sperm, but $E=mc^2$ isn't the first thing out of their child's mouth? Already, one couple has sued a sperm bank after their babies weren't as handsome as they had expected.[99]

Disability rights activist Marsha Saxton has pointed out a strange contradiction: at the political moment when laws such as the Americans with Disabilities Act have been enacted to protect people with disabilities, genetic technologies are aimed at preventing their birth. "It is ironic," she says, "that just when disabled citizens have achieved so much, the new reproductive and genetic technologies are promising to eliminate their kind—people with Down syndrome, spina bifida, muscular dystrophy, sickle cell anemia, and hundreds of other conditions.[100]

"Women are increasingly pressured to use prenatal testing by claims that undergoing these tests is the 'responsible thing to do,'" says Saxton. "Strangers in the supermarket, even characters in TV sitcoms, readily ask a woman with a pregnant belly, 'Did you get your amnio?'"[101] The Office of Technology Assessment of the U.S. Congress exemplified this approach in a report on new genetic tests, which stated that "individuals have a paramount right to be born with a normal, adequate hereditary endowment."[102] Similarly, the report of an NIH task force on prenatal diagnosis states, "There is something profoundly troubling about allowing the birth of an infant who is known in advance to suffer from some serious disease or defect."[103]

Creating Modes of Governance for Reprogenetics

Numerous judges have expressed dismay that legislators have not acted yet to deal with reproductive and genetic technologies. "It is much like trying to fit a square peg in a round hole," said a Kentucky judge during a case assessing whether surrogate mother arrangements should be governed by existing adoption laws. In January 2002, the Massachusetts Supreme Court faced a similar problem in dealing with posthumous reproductive technologies under existing probate laws. "The questions present in this case cry out for lengthy, careful examination outside the adversary process, which can only address the specific circumstances of each controversy that presents itself. They demand a comprehensive response reflecting the considered will of the people," wrote the court.[104]

The United States notably lacks an adequate structural mechanism for assessing genetic and reproductive technologies. In other countries, however, regulatory mechanisms already exist. In Great Britain, the Royal College of Obstetricians and Gynecologists organized the Interim Licensing Authority to scrutinize research and clinical services involving IVF (such as genetic testing on embryos) and to determine whether such interventions should be offered at all—and, if so, whether particular doctors and clinics should be allowed to offer them.[105] In 1991, the Human Fertilisation and Embryology Authority, a government agency, took over supervision and licensing of research involving human embryos.[106]

In Canada, a Royal Commission was chartered to recommend policies governing genetic and reproductive technologies as a whole. The commission used a variety of innovative methods to address these issues. They instituted a toll-free phone number so that citizens could detail their own experiences with these technologies and express general opinions.[107] In order to assess the values that defined Canadian life, they sought research and analysis from representatives of seventy disciplines on such topics as the psychological and social impacts of infertility, assisted reproduction, human zygote research, genetic testing, and the use of fetal tissue.[108] The commission determined that Canadian social values stressed noncommodification and nonobjectification, as well as protection of the vulnerable.[109] This led the commission to recommend bans on cloning, paid surrogate motherhood, genetic enhancement, and sex selection for nonmedical purposes.[110]

In the United States, however, the most visible social value can be described as "show me the money," as a range of reproductive technologies, some of dubious value, are offered in a variety of settings. The free market's impact on our political system may make it difficult for other social values to be expressed.[111]

Yet letting the market decide may not be the best way to elucidate our social values, harness technologies to benefit humankind, and move toward a society we can respect and admire. The market emphasizes short-term gains, hypes inappropriate technologies, fosters premature adoption of technologies, and creates barriers to access for the underprivileged.

Creating sensible policies will not be easy. Many people think there should be no limits on science or technology. U.S. Senator Tom Harkin defended human reproductive cloning research by explicitly stating that scientists have the right to research, and that there are not "any appropriate limits to human knowledge. None, whatsoever. . . . To my friends Senator Bond and President Clinton who are saying, 'Stop, we can't play God,' I say, 'Fine. Take your ranks alongside Pope Paul V who in 1616 tried to stop Galileo.'"[112] Senator Harkin argues that any governmental ban or limitation on human cloning research is essentially an "attempt to limit human knowledge [which is] demeaning to human nature."[113]

But as the National Bioethics Advisory Commission, created by President Bill Clinton, pointed out, "Because science is both a public and social enterprise and its application can have a profound impact, society recognizes that the freedom of scientific inquiry is not an absolute right and scientists are expected to conduct their research according to widely held ethical principles. There are times when limits on scientific freedom must be imposed, even if such limits are perceived as an impediment by an individual scientist."[114]

When we adopt reprogenetic technologies, we venture toward changing the nature of the human race, altering the species itself. Elsewhere, George Annas, Rosario Isasi, and I have written about how no single company, individual, or country has the moral warrant to do that.[115]

How shall we begin to govern this field? We need to think into the future. We need to trace the history of failure. We tend to let a single potential beneficial use of reprogenetics blind us to all other risks. When President Clinton banned the use of federal funds for human reproductive cloning, a cancer patient went on television and said that the president was interfering with his one chance to cure his cancer. When President George W. Bush indicated he would not implement the Clinton administration's proposal to fund embryo stem-cell research, Christopher Reeve sued the federal Department of Health and Human Services to compel funding of the research. He claimed that stem cells are "a primary source for a cure" for paralysis.[116]

Although medical progress is important, wishful thinking about potential cures should not be the basis for a policy that eliminates all oversight or regulation. After all, most promised cures have not materialized. Researchers promised to cure cancer by 1979[117] and swore in 1984 that gene therapy would eradicate disease within three years.

We need to see through the hype, avoid the sway of individual, highly specific claims, and take a step back to think about our values. What do we want out of our lives and our relationships? How do we want to live? And how can our technologies serve us rather than the other way around?

We need to move forward in two ways. The first is through the more robust use of existing regulatory approaches. The second—and more important—is to foster a civil society in which a values framework—such as that of Canada—can be elucidated.

The government needs to do a better job of monitoring reproductive and genetic technologies and making available information about the risks involved. Serious side effects uncovered in studies paid for by industry are sometimes labeled proprietary information and—though they are reported to the FDA—are not disclosed to the public. Such censorship should not be allowed.

The Department of Health and Human Services has not provided sufficient personnel or resources—in their Office of Biotechnology Activities, for example—to complete important public databases about the risks of experimental technologies. Such data are crucial both to people's decisions about whether to use these technologies, and to determinations about when technologies are too dangerous to continue.

More generally, Congress needs to take action in two areas. The government should extend the federal protections for human research subjects so that they apply not just to federally funded research, but to privately funded research as well. In that way, biotech companies and infertility clinics will be required to tell individuals who use emerging reproductive and genetic technologies what the risks are. Harsh penalties should be employed when that duty of disclosure is breached.

In addition, Congress should reconsider the laws governing technology transfer. By trying to ensure that products are brought to market quickly, lawmakers have so commercialized academe that there are now few neutral scientists who can provide credible assessments of the risks and benefits of new medical developments. Regulation with more teeth is necessary to achieve public trust. A recent study in Europe, for example, showed a lack of faith in government. Fifty percent of the British people surveyed trusted Greenpeace more than members of Parliament when it came to genetic research or cloning (only 19 percent trusted Parliament more).[118]

We also need to develop means for members of the public and other groups to come together to discuss what we want out of our reprogenetic technologies and how the use of such technologies challenges social values. Some promoters of technologies assume that the more people know about science and technology, the more enamored they will be with a particular technology. More scientifically educated individuals, however, are actually more skeptical of technology. Moreover, people are concerned not just about the physical risks of technologies, but about the social values at stake as well. Studies have found that "risk is less significant than moral acceptability in shaping public perceptions of biotechnology."[119]

It may seem that, in a society as fragmented as ours, coming to consensus on a vision for our future might be impossible. But I am optimistic that there is an alternative to the market model. The two opposing ideologies that helped to plunge us into the regulatory void—the pro-life and pro-choice advocates—are coming together as a political force.[120] At a recent behind-closed-doors meeting, leaders of both sides took the abortion issue off the table and instituted a dialogue about other reprogenetics technologies. It was astonishing how much concordance there was about the need for governance in a way that promoted human values and human dignity. It is now time to enlarge that discussion to determine how we can control reprogenetics, rather than allow the technologies to control who—or what—we will become.

7

TECHNOLOGY AND DEATH

Richard Rhodes

Our societies are dedicated to the preservation and care of life. Official concern ceases at death; the rest is private. Public death was first recognized as a matter of civilized concern in the nineteenth century, when some public health workers decided that untimely death was a question between men and society, not between men and God. Infant mortality and endemic disease became matters of social responsibility. Since then, and for that reason, millions of lives have been saved. They are not saved by accident or goodwill. Human life is daily deliberately protected from nature by accepted practices of hygiene and medical care, by the control of living conditions and the guidance of human relationships. Mortality statistics are constantly examined to see if the causes of death reveal any areas needing special attention. Because of the success of these practices, the area of public death has, in advanced societies, been taken over by man-made death—once an insignificant or "merged" part of the spectrum, now almost the whole.

—GIL ELLIOT, *Twentieth Century Book of the Dead*[1]

If the success of a technology is measured by its beneficial effect on human life, then the most successful of all modern technologies is public health. The human population of the earth has increased about sixfold since 1850—from about 1 billion to about 6 billion. Improvements in mortality made this increase possible: bettering nutrition, managing sewage and cleaning up drinking water, developing vaccines, preventing and containing epidemics and, especially, increasing the survival rate of infants and children through such straight-forward measures as pasteurizing milk. In the United States alone, two demographers recently estimated, half of all Americans living today—about 137 million people—owe their lives to improvements in mortality. Without such improvements, more than 68 million Americans would have died prematurely of preventable disease, and because of those premature deaths, another 68 million would never have been born.[2] In the rest of the developed world, comparable percentages probably obtain. Even in the developing world, mortality has declined dramatically since 1850 and life expectancy has significantly improved.

Among the unforeseen consequences of public health technologies has been a remarkable demographic transition. Beginning in the nineteenth century and continuing into the twentieth, lower rates of mortality in the developed countries led to reductions in birth rates. When more children survive to adulthood, parents choose to conceive and bear fewer children. Reflecting more recent improvements in mortality (including a reduction in deaths from war) demographic transition is now occurring in the developing countries as well. Per-capita GDP has risen across the world as larger portions of populations reach working age; this increasing prosperity correlates positively with increasing life expectancy.

The public health enterprise has also had a second, largely foreseen, but nonetheless underappreciated effect, an epidemiologic transition. In the developed countries in the twentieth century, improvements in mortality significantly changed the composition of the disease burden. The World Health Organization, in collaboration with the World Bank and the Harvard School of Public Health, published a 1996 report, the Global Burden of Disease (GBD) study, which estimated the total burden of disease globally in 1990 and projected disease trends to 2020.[3] The study, which examined both premature death and disability, defined three broad categories of health disorders:

Group 1: communicable, maternal, perinatal, and nutritional conditions (such as infectious diseases and malnutrition)
Group 2: noncommunicable diseases (such as heart disease, stroke, lung disease, cancer, and major depression)
Group 3: injuries (both accidental and deliberate)

Epidemiologic transition occurs in the course of decreasing total mortality when predominant causes of death and disability shift from Group 1 to Group 2 disorders. For the developed countries, that shift occurred early in the twentieth century. It was not thought to have yet occurred in the developing countries, but the GBD study, to the public health community's great surprise, revealed that the developing countries are in fact already passing through epidemiologic transition. As the study editors explain:

> In the developing regions where four-fifths of the planet's peoples live, noncommunicable diseases such as depression and heart disease are fast replacing the traditional enemies, such as infectious disease and malnutrition, as the leading causes of disability and premature death. By the year 2020, noncommunicable diseases are expected to account for seven out of every ten deaths in the developing regions, compared with less than half today. Injuries, both unintentional and intentional, are also growing in importance, and by 2020 could rival infectious diseases worldwide as a source of ill health.[4]

The study found, for example, that "adults under the age of 70 in Sub-Saharan Africa today face a higher probability of death from a noncommunicable disease than adults of the same age in the Established Market Economies."[5] For several major developing regions, "more people already die of Group 2 causes than Group 1 causes. In Latin America and the Caribbean, there are almost twice as many deaths from noncommunicable diseases as from Group 1 causes. In China, there are four-and-a-half times as many deaths from noncommunicable diseases as from Group 1 causes."[6] By 2020, the GBD study projects the fifteen leading causes of death or disability worldwide to be, in rank order:

ischemic heart disease (heart disease due to narrowing of the arteries)
unipolar major depression

road traffic accidents
cerebrovascular disease (stroke)
chronic obstructive pulmonary disease
lower respiratory infections (pneumonia)
tuberculosis
war
diarrheal diseases
HIV
conditions arising during the perinatal period (during the weeks immediately before and after birth)
violence
birth defects
self-inflicted injuries
trachea, bronchus, and lung cancers[7]

The increasing burden of Group 2 and Group 3 health disorders in the twenty-first century is a consequence of the changing demographics of the world population (and an unintended consequence of improving public health): as more children survive into adulthood and birth rates decline, the adult portion of the population increases, whereupon health disorders characteristic of adulthood begin to predominate. The study editors note significantly that these results "dispel any remaining notions that noncommunicable diseases are related to affluence."[8] In fact, "the results show that premature mortality rates from noncommunicable diseases are higher in populations with high mortality and low income than in the industrialized countries."[9] The findings of the GBD study thus repudiate a pervasive pseudoscientific mythology of corrupt, decadent prosperity in developed societies and innocent, vulnerable poverty in developing societies.

The Nuclear Transition

The unrecognized factor in this ranking of threats to human life is also technological, though it is one never associated with public health: the capacity to wage nuclear war. Man-made death (primarily death from war and war's attendant privation) emerged from the shortening shadow of biologic death at the beginning of the twentieth century. During the first half of the century it also increased exponentially. The twentieth century was the most violent in human history: man-made death prematurely ended about 130 million human lives.[10] Such deaths had been trending upward since the eighteenth century as nation-states applied technology to make war more lethal and widened the permissible range of victims. Man-made deaths surged to peaks of about 3 million in 1915, about 6 million in 1917 during the period of the Russian Revolution, and about 4 million during Soviet collectivization in the early 1930s, and soared to a historic maximum of about 15 million midway through World War II.[11]

In 1945, something changed. Exponential increase ceased and the trend collapsed. Man-made deaths dropped abruptly postwar to an average, through the rest of the century, of about 1 million per year—an unacceptable but relatively low level—where they have remained.[12] Given the timing, the most probable reason for this midcentury transition was the discovery of how to release nuclear energy and its application to the development of nuclear weapons. The end of World War II marked a turning point in human history, the point of entry into a new era when humankind for the first time acquired the means of its own destruction. The unintended consequences of this diffusion of knowledge (unintended at least by political and military leaders, though predicted by scientists) has been a radical limitation on man-made death.

Physically and materially, war derives from the assumption that there is a limited amount of energy available in the world to concentrate into explosives and that it is possible to accumulate more of such energy than one's enemies and thereby to prevail militarily. The discoveries in nuclear physics removed that limitation by demonstrating that matter, properly arranged, is all energy. So cheap, so portable, so holocaustal did nuclear weapons eventually become that even nation-states as belligerent as the Soviet Union and the United States preferred to sacrifice a portion of their national sovereignty—preferred to forgo the power to make total war—rather than be destroyed in their fury. Lesser wars continued, and will continue until the world community is sufficiently impressed with their destructive futility to forge new instruments of protection and new forms of citizenship. But world war at least has been revealed by science to be historical, not universal, a manifestation of destructive technologies of limited scale. In the long history of human slaughter, that is no small achievement.[13] It deserves a name. By analogy with the terms "demographic transition" and "epidemiologic transition," I propose calling it the nuclear transition.[14]

Violence: The Final Public Health Problem

While the nuclear age has pushed organized violence by nations into the statistical margins, still unresolved as a public health problem is an entirely different and generally unrecognized role for violence. Ischemic heart disease, depression, stroke, emphysema, and lung cancer from smoking, associated prior to the GBD study with high-income societies, are usually attributed to unhealthy "lifestyle choices," implying that high-risk behaviors such as overeating and obesity, alcohol consumption, and the use of illicit drugs and tobacco are indulgences more or less freely chosen. To the contrary, there is compelling new evidence that many chronic noncommunicable disorders are consequences of adverse childhood experiences.

In the 1980s Vincent J. Felitti, a physician in San Diego, California, noticed that the obesity patients who dropped out of treatment in the clinic he directed were often those who were succeeding at losing weight. He interviewed several hundred of these patients, looking for an explanation for their paradoxical and self-defeating behavior, and noticed a high frequency of reports of adverse childhood experiences (ACEs), particularly sexual abuse.

Following this clue, and noticing a similar population among smokers of people who ultimately failed at quitting after weeks or months of success, Felitti organized an investigation with Robert Anda, a public health physician at the U.S. Centers for Disease Control. The two physicians developed a simple questionnaire that asked patients about seven categories of ACEs that had been frequently mentioned by subjects in the obesity clinic interviews. "Three categories were of personal abuse," Felitti summarizes: "recurrent physical abuse, recurrent emotional abuse, and sexual abuse. Four were categories of household dysfunction: growing up in a household with an alcoholic or a drug user; where someone was in prison; where someone was chronically depressed, mentally ill, or suicidal; and where the mother was treated violently."[15] They mailed the questionnaire to 13,494 adults who had completed an annual physical at a large HMO; 70 percent (about 9,000 subjects) responded.

More than half of this group of 9,000 middle-class HMO members, of diverse ethnicity, age, and gender, reported at least one adverse childhood experience. A quarter reported two or more ACEs out of a possible seven. Felitti and Anda compared these findings to the subjects' medical records. The more ACEs, they discovered, the greater the likelihood that the patients took risks with their health—and the greater the likelihood that they suffered from one or more chronic, noncommunicable diseases:

> Persons who had experienced four or more categories of childhood exposure, compared to those who had experienced none, had 4- to 12-fold increased health risks for alcoholism, drug abuse, depression and suicide attempt; a 2- to 4-fold increase in smoking, poor self-rated health, ≥50 sexual intercourse partners and sexually transmitted disease; and a 1.4- to 1.6-fold increase in physical inactivity and severe obesity. The number of categories of adverse childhood exposures showed a graded relationship to the presence of adult diseases including ischemic heart disease, cancer, chronic lung disease, skeletal fractures and liver disease.[16]

"Adverse childhood experiences are vastly more common than recognized or acknowledged," Felitti comments. "Of equal importance was our observation that they had a powerful correlation to adult health a half-century later."[17]

What links ACEs with adult chronic noncommunicable disease? Felitti and Anda hypothesize that adults traumatized by ACEs use food, alcohol, tobacco, sex, and licit and illicit drugs to medicate themselves. Violence, recklessness, and suicide might be added to this list of strategies for self-treatment. The hypothesis is strongly supported by the graded dose-response effect for *all* the associations the ACE study found.

Thus, chronic obstructive pulmonary disease (COPD) is strongly related to ACE score. A person with a midrange ACE score of 4 is 390 percent more likely to have COPD than a person with an ACE score of 0. He is 460 percent more likely to be suffering from depression. "Should one doubt the reliability of [these associations]," Felitti writes, "we found that there was a 1,220% increase in the history of attempted suicide between these two groups."

The ACE study also found strong, graded relationships between childhood adversity and many other personal and Group 2 health disorders, including hepatitis, heart disease, fractures, diabetes, obesity, alcoholism and poor occupational health.[18] This link implies that such adverse experiences are common in the lives of children throughout the world, whether those children are born into affluent or impoverished communities. The GBD study prediction that health disorders in Group 2 and Group 3 (intentional and unintentional injuries) will dominate global ill health by 2020 thus identifies human violence (in the form of adverse childhood experiences) as the fundamental public health challenge of the twenty-first century.

Man-made death and disability, unlike biologic death and disability, have not been (in Gil Elliot's phrase) "tackled and secured by the forces of reason." Much as disease used to be, human violence is widely dismissed as an intractable consequence of the human condition or a manifestation of "something sinful in the nature of man himself" (Elliot again). To the contrary, there is good evidence that serious violent behavior is learned and chosen as another strategy for coping with adverse childhood experiences. This essay is not the place to review that evidence, but it is scientifically sound and persuasive: every individual who uses serious violence voluntarily has experienced brutalization (defined as being violently dominated physically or with credible threats, witnessing intimates being violently dominated, and being coached on the efficacy of using violence), usually but not exclusively in childhood and usually but not exclusively within the family.[19] Victorious violent encounters, and the feedback of social trepidation and violent notoriety that they elicit, are also necessary to the creation of a dangerously violent person, but brutalization is fundamental.

Since violent adults use violence to control their children (the ACE study reflects varying degrees of this phenomenon), the process is cyclical. That fact may seem to deny the possibility of change. But just as epidemic disease is controlled by timely intervention and prevented by changing social arrangements, so also has personal violence been reduced progressively in the West across the past six hundred years by changes in childrearing practices and innovations in social control.

The homicide rate in the United States in 1990 was 9.4 per 100,000 population. In the same year the rate was only 1.5 per 100,000 in Britain, 0.9 in the Netherlands, 1.5 in Sweden, 1.1 in France, and 1.0 in Germany. In contrast, the homicide rate in thirteenth-century England, historians estimate, was about 18 to 23 per 100,000. In fifteenth-century Sweden it ranged from 10 to 45. In London in the fourteenth century the homicide rate was 36 to 52 per 100,000; in fifteenth-century Amsterdam it was 47 or more; in fifteenth-century Stockholm it was 42.5. These high annual rates declined gradually until the eighteenth century, when they dropped rapidly to modern historic lows of about 1 per 100,000 in western Europe and in the United States.[20] The social changes that contributed to declining personal violence included increasing government authority and centralization with monopolization of violence; increasing access to courts of law as an alternative means of settling disputes; progressive reform of childrearing practices (away from brutalization) originating in the upper and middle classes; and, late in the process, the introduction of urban police forces.

The evidence that violence is learned through social experience and that violence has come under increasing social control in the West confirms that violence, like disease, is vulnerable to rational investigation, prevention, and intervention. The powerful methodologies of modern science have hardly begun to be applied to this universal human scourge. Paradoxically, one reason for this neglect may be the success of violence control in the West, which has removed most potential investigators from personal experience with violence. An obvious model for a technology for understanding and controlling human violence at every scale, from intimate violence within families to the violence of war, is the public health system.

Science, going about its profoundly humane project of discovering how the world really works (rather than how we would like it to work), has already limited human violence at the largest scale—world-scale war—by delivering technologies that make such war futilely self-destructive. Violence at every lesser scale continues to blight childhood and to disturb, disorder, and destroy hundreds of millions of human lives every year. Limiting that violence is science's most important emerging challenge.

8

CONFINED TO YOUR LEGS

Gregor Wolbring

The View of the Nonafflicted

Are you normal? If so, I'm sure you will agree that the prospect of science and technology putting an end to human disability is a wonderful step on the path of social progress. All the same, bear with me for a few pages while I explore this question a bit more deeply. Perhaps the issue is not as simple as it seems.

Let me begin with the Nobel laureate James D. Watson, who unraveled the structure of DNA and, more recently, had this to say about disability:

> The truly relevant question for most families is whether an obvious good to them will come from having a child with a major handicap. Is it more likely for such children to fall behind in society or will they through such afflictions develop the strengths of character and fortitude that lead . . . to the head of their packs? Here I'm afraid that the word handicap cannot escape its true definition—being placed at a disadvantage. From this perspective seeing the bright side of being handicapped is like praising the virtues of extreme poverty. To be sure, there are many individuals who rise out of its inherently degrading states. But we perhaps most realistically should see it as the major origin of asocial behavior.[1]

Fortunately, from Dr. Watson's perspective, technology ends such degradation. Existing technology such as ultrasound and amniocentesis, along with emerging prenatal and preimplantation tests, offer abortion and embryo selection as the definitive preemptive solution to disability. In the same essay, Dr. Watson, for example, seems to offer up abortion as a solution to everything from cystic fibrosis to dyslexia. If that makes you squeamish, you can turn for relief to the coming hybridization of biotechnology, genetic technology, and nanotechnology, which promises, someday, to fix disabilities, impairments, diseases, and defects, and so free us from both the confinement of our genes and the confinement of our biological bodies. The future will bring us nonbiological "assistive solutions, from prosthetic limbs that adjust to the changes in the body, to more biocompatible implants, to artificial retinas or ears. Other opportunities lie in the area of neural prosthesis and the 'spinal patch,' a device envisioned to repair damage from spinal injuries."[2] Taken to the extreme, nanotechnology even offers the distant possibility of uploading: "the (so far hypothetical) process of transferring the mental structure and consciousness of a person to an external carrier, like a computer. This would make it possible to completely avoid biological deterioration (aging, damage), allow the creation of backup copies of the mind, very profound modifications and post biological existence."[3] Sound like science fiction? So did cloning humans, twenty years ago.

Dr. Watson's authoritative concerns about the degradations of disability notwithstanding, these promises raise questions. Whose values are embedded in the definitions of disability, and whose perceptions are reflected in descriptions of the resultant "suffering"? Whose values and perceptions should determine the choice of "solutions" for the "problem" of disability?

The nonafflicted majority tends to view disability as a barrier to a meaningful existence. This view may be expressed with various degress of subtlety and compassion but here, courtesy of a Nike advertisement, is the standard perspective unladen by niceties:

> Fortunately the Air Dri-Goat features a patented goat-like outer sole for increased traction so you can taunt mortal injury without actually experiencing it. Right about now you're probably asking yourself "How can a trail running shoe with an outer sole designed like a goat's hoof help me

> avoid compressing my spinal cord into a Slinky on the side of some unsuspecting conifer, thereby rendering me a drooling, misshapen non-extreme-trail-running husk of my former self, forced to roam the earth in a motorized wheelchair with my name embossed on one of those cute little license plates you get at carnivals or state fairs, fastened to the back? . . ."[4]

The unafflicted also understand that disability burdens not just disabled people themselves, but families and friends. Stephens and Brynner explain, in *The History of Thalidomide:*

> How did parents endure the shock [of the birth of a thalidomide baby]? The few who made it through without enormous collateral damage to their lives had to summon up the same enormous reserves of courage and devotion that are necessary to all parents of children with special needs and disabilities; then, perhaps, they needed still more courage, because of the special, peculiar horror that the sight of their children produced in even the most compassionate. Society does not reward such courage . . . because those parents' experience represents our own worst nightmare, ever since we first imagined becoming parents ourselves. The impact upon the brothers and sisters of the newborn was no less horrific. This was the defining ordeal of their family life—leaving aside for now the crushing burden on their financial resources from now on.[5]

Such perspectives share the understanding that disabilities define a "subnormal" state of existence. "Disability" refers to an intrinsic defect, an impairment, disease, or chronic illness leading to subnormal functioning and expectation. The result is suffering, an inevitable, unavoidable consequence of inhabiting an undesirable (subnormal) state of existence.

Defects have scientific and technological solutions. We read that the field of gene therapy holds the "promise of influencing the outcome of a vast array of diseases, ranging from birth defects to neurological disorders,"[6] and that stem cell research "could lead to new ways to prevent and treat birth defects and cancer."[7] This 1972 vision of the future has particular resonance now that the capacity to clone a human is at hand:

> Applied to pathology, the engineering know-how necessary to clone a man could wipe out more than fifty sex-linked hereditary diseases. Mongolism, schizophrenia, diabetes, dwarfism, muscular dystrophy and perhaps even cancer could become things of the past. Genetic engineering will soon make such conveniences as sex selection in offspring a trivial matter. More complex refinements in physiognomy and physiology via hybrid breeding are sure to follow. An Eugenic Age is just around the corner.[8]

What I've just presented is the *medical model* of disability, which views disability as a defect, a problem inherent in the person (or person to be), directly caused by disease, trauma, or other health condition, resulting in a deviation from certain societal norms and a putative low quality of life for the person and his or her relatives. The path to a solution lies with medical care, high technology, rehabilitation, prosthesis, and termination. The path is paved by funding, both public and private, to improve medical technologies that can prevent or cure the disabilities. The solution itself is described by words like "prevention," "adaptation," or "cure." The medical model arises from an emotional response of pity and rejection, and it is precisely this response that conditions scientific and technological choices and the definition of what counts as a solution. As Dr. Watson said, "[S]eeing the bright side of being handicapped is like praising the virtues of extreme poverty."

The View of the Afflicted

Most disabled people, whether they have spina bifida, achondroplasia, Down syndrome, or other mobility and sensory impairments, perceive themselves as healthy, not sick. They describe their conditions as givens of their lives, the equipment with which they meet the world. They do not perceive themselves as "subnormal." The same is true for people with chronic conditions such as cystic fibrosis, diabetes, hemophilia, and muscular dystrophy. These conditions entail intermittent flareups requiring medical care and adjustments in daily living, but they do not render a person as unhealthy as most of the public and members of the health profession imagine.[9]

In other words, "the afflicted" view their own conditions and lives very differently than the nonafflicted. Repeated studies by social scientists confirm this conclusion. For example, one study, performed in 1994 at the Craig Hospital in Englewood, Colorado, compared the attitudes toward disability of hospitalized people with spinal cord injuries with the attitudes of nondisabled people working in the hospital's intensive care unit (see table 8.1). Researchers asked both disabled and nondisabled subjects about their feelings of self-worth, and they also asked nondisabled subjects to imagine how they would feel about themselves if they had a spinal cord injury. The study showed that the disabled and nondisabled had similar views about their own value as humans, but when nondisabled people imagined themselves disabled, many of them also imagined that they would be robbed of this

Table 8.1

	Non-disabled Providers	Non-disabled Providers	SCI survivors
	SELF-RATING (N=233)	IMAGINING SELF WITH SCI	COMPARISON GROUP (N=168)
	% Agreeing with the statement		
I feel that I am a person of worth	98	55	95
I feel that I have a number of good qualities	98	81	98
I take a positive attitude	96	57	91
I am satisfied with myself on the whole	95	39	72
I am inclined to feel that I am a failure	5	27	9
I feel that I do not have much to be proud of	6	33	12
I feel useless at times	50	91	73
At times I feel I am no good at all	26	83	39

sense of value.[10] The degradation of disability, in other words, existed primarily in the minds of the nondisabled.

Study after study has revealed that disabled and nondisabled people are essentially alike in terms of either self-described life satisfaction or more formal psychosocial measures. Nor does severity of disability correlate with life satisfaction.[11, 12, 13] One study even found that 60 percent of people with paraplegia from spinal cord injury felt more positive about themselves since becoming disabled.[14] Not even the new miracle antidepressants can deliver this level of performance.

And that's not all. The notion that disabled people destroy families, while continually invoked as a "humanitarian" argument for medical and technological intervention, has also been repudiated by social science research. As in the case of disabled people's self-perceptions, families that include disabled people seem remarkably normal, showing comparable levels of stress, family functioning, and marital satisfaction.[15, 16]

In other words, what the nondisabled think about the disabled is not what the disabled, and their families, think about themselves. Yet when research agendas and public policies about disability and emerging technologies are on the table, the real experts—disabled people and their families—are rarely given a voice, and are often blatantly ignored.[17, 18, 19, 20, 21, 22, 23] Discussions about the application of new biotechnology, genetic technology, and nanotechnology to disability are at about the place where discussions of women's health were at the beginning of the twentieth century. Then, mostly men talked about women's health. Today, mostly the nondisabled talk about disability. Thus, for example, the Canadian Biotechnology Advisory Committee, a committee directly responsible to six cabinet ministers, has no disabled member at all. In general, disabled people are absent from government committees and policy-making bodies (both international and national) that influence the development of science and technology—yet, as we have seen, science and technology are the leading edge of modern society's efforts to confront disability. But this is okay, because "scientists engaged in this research are dedicated to helping patients with debilitating and deadly diseases."[24]

Nor have the disabled gained access to academia in sufficient numbers to have an influence on the intellectual approach to disability issues. It is difficult to convince universities that disability is not simply a medical problem. The field of disability studies (exploring the social dimension of disability) is only slowly emerging. Perhaps even more striking is the field of bioethics, which is supposed to look at the societal implications of biological and medical sciences. Nearly every issue encompassed by the field of bioethics affects disabled people in a very special way. End-of-life decision-making, the allocation of health care resources, the use of genetic technology (gene therapy, genetic testing), research on noncompetent people, questions of futile care, selective nontreatment of newborns, and debates about personhood, mercy killing, and disability-adjusted life-years, to name a few, are all issues of crucial import for disabled people. But disability-oriented approaches to bioethics are more or less nonexistent, as are disabled academic bioethicists. Many conferences where these issues are debated fail to have disabled people present.

Even civil-society organizations tend to exclude disabled people. Later in this essay I'll describe how debates over human rights actually undermine the status of the disabled. For now let me just observe that most organizations devoted to enhancing social well-being have internalized the views of the nonafflicted because they serve the interests of the nonafflicted.

Of course there is a good reason for this disenfranchisement. While disabled people and nondisabled people may have similar views of themselves, society of course does not treat them equally. The living conditions, low income, low levels of education and employment, and inaccessible environment experienced by most disabled people ensure that the majority of them are essentially invisible in public debate and the policy-making process. So disabled people are denied their chance to give their account of disability. The *a priori* assumption of the nonafflicted is that life with a disability is not worth living, and so the role of science and technology is to eliminate disability, either by preventing it in the first place or by "overcoming" it so that the disabled are indistinguishable from everyone else.

Now, the perspective of Dr. Watson and other scientific visionaries would suggest that the disenfranchisement of the disabled is an inevitable and direct consequence of their "inherently degrading" disability. There is another possibility, of course. The fact that disabled people view their own lives so differently from the way they are viewed by the nondisabled shows that disability cannot simply be written off as an inherent attribute of an individual. Rather, it is a reflection of the interaction between the physical and mental attributes of an individual, and the environment in which that individual acts. My wheelchair allows me access to all the same places that the nonafflicted can go—as long as there are ramps. Disability, in other words, is contextual. From this perspective emerges a *social model* of disability, which sees disability as a socially defined problem that can be addressed in ways that allow full integration of individuals into society. The management of the problem requires social action (which, to be sure, can be enhanced by appropriate science and technology), and it is the collective responsibility of society at large to make the environmental modifications necessary for the full participation of people with disabilities in all areas of social life—just as a male-dominated society increasingly makes way for women, and a Caucasian-dominated society increasingly makes way for other ethnicities. The solution to disability cannot be only science and technology, unless one is interested in a final solution. And thus, as I will show, science and technology are part of the problem.

Solutions Follow Perceptions

In any subject area, the way we define a problem affects the solutions that we seek. For example, being gay has been portrayed as a disease or defect (the medical model) and as a variation of human diversity (the social model); these portrayals permit us to envision radically different scenarios for intervention, from "cure" on the one hand to acceptance and equal rights on the other. In the same vein, we might consider that all women suffer from a genetic defect, the double X syndrome, and we could visualize an array of technological interventions—for example, testosterone injections, pills to moderate hormonal cycles, or simply abortion of double X fetuses. Outrageous? In

China and India, where sons are culturally valued above daughters, ultrasound technology plus abortion allows prenatal sex selection, which is widely used.[25]

Any biological reality can be seen as a defect—as a medical condition—or as an issue of human rights. It is rare nowadays, in Western culture at least, to view the biological reality of being female as a medical problem. But at the end of the nineteenth century, a medical model—and the societal norms attached to it—was prevalent in industrialized countries such as England. Women were viewed as biologically fragile and emotional, and thus incapable of bearing the responsibility of voting, owning property, and retaining custody of their own children.[26] As the social model gradually replaced the medical model of gender, equal rights and respect became the cure for societally imposed disparities between women and men. Blacks in the United States have gone through a similar struggle. Today, many gay people oppose the search for a "gay gene" because they fear that it will be seen not as a variation but as a defect.

And what about so-called disabled people? Do people with Down syndrome define themselves as a medical problem, and do they demand a medical solution? Do they demand the development of predictive tests that can be used to prevent the birth of more of their kind? They do not. Instead, they demand the societal cure of access to and acceptance by society.

The apparent logic of the medical model of disability is so obvious to the nonafflicted who drive the scientific and technological agenda that any alternative may seem counterintuitive, nonsensical, and perverse. For example, when Inclusion International, the international organization of people with Down syndrome and their families and supporters, was asked to testify at a recent consultation on biotechnology and genetic technology organized by the International Bioethics Committee of UNESCO, they were invited as a "patient group," reflecting the organizers' expectation that those with disabilities feel unhealthy and want to be fixed. It did not occur to the organizers that Down syndrome people do not perceive themselves this way. The Bioethics Committee was taken by surprise when the representative of Inclusion International denounced the "patient" label. The Canadian Down Syndrome Society writes that "the primary goal of any genetic research should not be to reduce the number of Down syndrome births, but rather to provide improved health care and assistance to persons with Down syndrome so that they may lead full and productive lives. . . . [P]ersons with Down syndrome enrich our communities and they have much to teach us about understanding, acceptance and appreciation for all life has to offer."[27]

So the "cure" for Down syndrome is either technological intervention (prenatal diagnosis and abortion, for the most part) or societal acceptance. People with Down syndrome not surprisingly prefer the latter, but their voice, as I have said, is not central to the process of choosing solutions. I will argue later that preventing or technologically "curing" disability comes with a considerable cost to society; here I simply want to make the point that what counts as a solution depends on who's being counted.

It is worth trying to understand the assumptions embedded in the view of the nonafflicted. In the previous quotation from Stephens and Brynner, they assume or expect the following:

- Normality and beauty requires two legs and two arms.
- Everyone must be able to perform certain functions (e.g., move from one place to another or eat).
- Everyone has to perform these functions in the same way (e.g., walk upright on their own legs or eat with their hands).
- Any variation in form, function, or method will result in severe emotional distress for those involved in any way.

Ich bin ein Thalidomider. When I was a child, my parents and I were presented by our doctors with only one option: to outfit me with artificial limbs. This solution was imposed on almost all thalidomiders, despite the fact that the artificial limbs were rather crude, not very functional, and mostly cosmetic at the time they were being prescribed in great numbers. These limbs had, I suppose, the virtue of satisfying the notions that our doctors and society had of how we ought to function and look. But this single-minded approach excluded nearly all alternatives, such as crawling in the absence of legs—which, by the way, I do quite comfortably—or eating with one's feet in the absence of arms, which many thalidomiders do with great facility.

Most thalidomiders threw away their artificial legs and arms as soon as they were old enough to assert themselves against their parents and their doctors. Once I was old enough to say no, I myself used my legs only when the system forced me to—for example, when my wheelchair was prohibited in the university laboratories where I performed parts of my graduate research in biochemistry. Like most thalidomiders, I did not view my body as deficient and did not see artificial legs as a sensible solution to my primary problem: dealing with a world that saw me first and foremost in terms of my defects, and accorded me so little respect or human dignity that I was not even allowed to choose how I wanted to move around.

Who Chooses? Who Loses?

So, are artificial limbs an optional tool to permit types of function and movement otherwise unavailable, thereby increasing choice, or do they impose a societal norm that in fact dictates a particular type of function and movement, discourages alternatives, and thereby restricts choice? If I choose not to use artificial legs (as I have done), will I be even more stigmatized for refusing to adopt a technology that would permit me to more closely approach the societal norm? And if so, is the apparent option of artificial limbs in fact a form of coercion that impinges upon, rather than enhances, my freedom?

As I have said, immense pressure was applied to coerce parents of thalidomiders, including my parents, into equipping their children with artificial limbs. This pressure emerges from a social hierarchy of modes of mobility, with crawling at the bottom, followed by the wheelchair, which is in turn seen as inferior to artificial legs, particularly legs that appear "natural." This hierarchy is not based on functionality—I can crawl to most places that people can walk (and some that they can't)—but rather on a norm that is not arbitrary (after all, I recognize that most people do have functional legs they can call their own) but aesthetic.

The functionality of technologies like the wheelchair is frequently demeaned in expressions like "confined to a wheelchair." Artificial legs are not subject to such perceptions, even though a wheelchair often leads to safer, easier, and more efficient mobility than artificial legs. No one would use the phrase "confined to natural legs," though in reality people with legs are confined to them, while I can leave my wheelchair when I choose to do so. Nor is the act of driving a car portrayed as "confinement"—instead it is a cultural symbol of empowerment, urban gridlock and stultifying commutes notwithstanding. So the problem is not that technological dependence violates societal norms—modernity is built upon this dependence. The problem is the norms themselves. No one argues about the need for curb cuts for automobiles; but it took years of political activism in the United States to achieve the legislative mandate necessary to require curb cuts for wheelchairs.

The general challenge, then, is to understand the ways in which emerging technologies are likely to affect freedom of choice. The technologies cannot be separated from the normative context in which they are introduced. Cochlear implants provide another example. Do we allow parents to refuse them if they feel there is nothing wrong with their child using sign language, lip reading, or other modes of communication? Might the refusal by such parents be viewed as child abuse?[28] Might my parents have been viewed as child abusers if they had refused to outfit me with artificial limbs? Could a mother be considered to commit child abuse if she refuses to terminate her pregnancy after ultrasound showed phocomelia—hands and feet attached close to the body without arms or legs—in the fetus?

The medical model of disability creates the illusion of choice because it internalizes the belief that disabled people are subnormal, and offers science and technology as the solution to subnormality. But if disabled people are people indeed—if they can experience life as fully as the nonafflicted, and if the main obstacles to this richness can be overcome by social action—then what appears to be choice is unmasked as coercion, as a constriction of choice. And science and technology, mediated through the medical model of disability, become the levers of the coercion.

Robert Edwards, the creator of the first test tube baby, has predicted that the increasing availability of prenatal screening for genetic diseases will give parents a moral responsibility not to give birth to disabled children. "Soon it will be a sin of parents to have a child that carries the heavy burden of genetic disease. We are entering a world where we have to consider the quality of our children."[29] Edwards's statement points to further extensions of the argument: if parents are obliged to consider the quality of their children, are they also obliged to enhance their children's abilities through genetic and other means? If it is child abuse not to "fix" deafness with a cochlear implant, isn't it also child abuse not to give a child hearing abilities that exceed the norm, if means are available? Indeed, as the bioethicist and transhumanist James Hughes says, "If we respect people's right to bodily autonomy we need to permit people to choose germline and enhancement genetic therapies. What better guarantee and reflection of liberty than a society embracing a growing diversity of healthy abled bodies? In the future we will agonize about parents who deny their children routine safe and effective genetic enhancement of health intelligence and ability."[30]

Such views are being gradually codified. The U.S. Supreme Court recently ruled that the Americans with Disabilities Act does not cover persons with correctable impairments.[31, 32] In other words, once medical "cures" are available, civil rights are forfeit. The problem, once again, is that such "cures" may be desirable to the nonafflicted, but not to the afflicted. Choice, again, is restricted, and the medical and technological definition of disability is further embedded in society.

In this way, as technology reduces freedom of choice for disabled people, it gradually disenfranchises them from the human rights movement.[33, 34, 35, 36] I realize that this observation is counterintuitive to the nonafflicted reader, but it is logically unavoidable. First, consider the legal concepts of wrongful life (where the child sues for being wrongfully born) and wrongful birth (where the mother sues for having to give birth to a child).

Wrongful life lawsuits apply only to disability, not to other characteristics such as being born out of wedlock or with the "wrong" skin color. Wrongful birth suits allow a mother to claim damages for having a disabled child if the disability could have been detected and the mother could have terminated the pregnancy. But if a child is unwanted for other reasons, most jurisdictions confer no right of compensation. The prospect of disability, that is, gets singled out for special treatment under the law. A South African judge said:

> Thus the legislature has recognized, as do most reasonable people, that cases exist where it is in the interest of the parents, family and possibly society that it is better not to allow a fetus to develop into a seriously defective person causing serious financial and emotional problems to those who are responsible for such person's maintenance and well-being.[37]

There are, of course, many conditions of birth that can contribute to hardship for parents and relatives, yet that would never be subjected to what amounts to a legal obligation to terminate. What is so special about disability that the right to terminate a disabled fetus should receive particular legal protection? Turn back the clock a hundred years and replace "seriously defective person" in the above quote with "person with black skin" or "person with no known father." What's special is that disability is still viewed as a deviation from the desired norm whose cure lies in science and technology, not in the enforcement of principles of human rights.

Second, consider that laws protecting against genetic discrimination cover characteristics that might in the future lead to disabilities (as medically defined) but are asymptomatic at the time of the test. Yet such laws do not protect those who are actually disabled. In other words, symptomatic disabled people are excluded from the very protections that anti–genetic discrimination laws try to address. Amazingly, lack of disability becomes the criterion that civil libertarians use to justify legal protection:

> The ACLU believes that Congress should take immediate steps to protect genetic privacy for three reasons. First, it is inherently unfair to discriminate against someone based on

> immutable characteristics that do not limit their abilities. . . .
>
> In sum, the ACLU believes that Americans should be judged on their actual abilities, not their potential disabilities. No American should lose a job or an insurance policy based on his or her genetic predisposition.[38]

Apparently jobs and insurance policies are only forfeit when the predisposition becomes a disposition.

Finally, think about where society draws the line between medically defined conditions that should be prevented or cured by science and technology, and those that should be accepted as part of the diversity of the human species. In China, double X syndrome remains a condition that is subject to eugenic termination. But in the West there would be little tolerance for a claim that gender was a sufficient reason to abort a fetus. Should a true gay gene be discovered, the possibility of prenatal tests for a proclivity to gayness would emerge. Would our society really tolerate abortions to prevent the birth of a child who had a high likelihood of being gay? It may seem unlikely, but in the case of disability, we not only tolerate such eugenic practices but are moving toward making them culturally obligatory.

A multitude of options are now or will soon be available for selecting the genotype and phenotype of one's offspring—and, increasingly, for preventing the propagation of specific genotypes and phenotypes: mate selection, adoption, infanticide, abortion, prefertilization diagnostics, preimplantation diagnostics, prenatal testing, postnatal testing, in vitro fertilization, sperm banking, egg banking, cloning, fertilization, and gene therapy. Some of these have been around for millennia; others are products of the new genetic technologies. What these new technologies do in particular is allow us to identify and eliminate an ever-expanding menu of unwanted characteristics from our midst. How, then, shall we make distinctions between characteristics with such names as Tay-Sachs, beta-thalassemia, sickle-cell anemia, thalidomide, Alzheimer's, PKU, female, male, gay, lesbian, bisexual, bipolar condition, cystic fibrosis, cerebral palsy, spina bifida, achondroplasia (dwarfism), hemophilia, Down syndrome, coronary heart disease, osteoporosis, obesity, dyslexia . . . ?

"[M]ost people in my experience have fairly clear views on what level of disability appears to them to be consistent with a worthwhile outcome to themselves," says Robert Williamson, director of the Murdoch Institute for Research into Birth Defects and professor of medical genetics at Melbourne University. "I am actually irritated if people say, 'Everyone thinks that condition X is so bad that we should have prenatal diagnosis and termination of pregnancy, but condition Y (e.g., cleft palate) isn't bad enough.' The truth is, you can't say that in terms of a condition, you can only say it in terms of a woman, of her family, her perceptions, her social context, her economic context and everything else. . . . We must avoid categorizing diseases as severe or not severe. This can only be seen in the context of the overall holistic situation of a family and individuals."[39]

If social action can make it possible for disabled people to engage fully in life's richness and opportunity, then why is abortion of a defective fetus any less repugnant than selection of a child's sex, or deselection of a child's potential sexual preference? Sex selection is widely criticized in our culture because it "lowers the status of women in general and perpetuates the situation that gave rise to it."[40, 41] The prospect of gay deselection is repellent because it would "contribute to discrimination and prejudice against lesbians, gay men and bisexuals."[42] Why on earth don't these arguments apply to disabled people?

Why indeed. The philosopher and bioethicist Ed Stein says there is no comparison between sexual-orientation deselection procedures and "using genetic technology to prevent the birth of babies with serious disorders. Such disorders may dramatically decrease life expectancy, cause great suffering and intrinsically undermine a person's quality of life. . . . Homosexuality and bisexuality are not like this."[43]

Tell that to the writers Oscar Wilde or Reinaldo Arenas, both imprisoned for homosexuality, or for that matter Randy Shilts or the thousands of other gays whose lives were cut short by AIDS. By using human disability as a rhetorical device to argue for protecting gays against eugenic practices, Stein and others have resorted to exactly the same repugnant logic that was used to discriminate against gays in the past.

So where is the line between disability and nondisability? The fact is, this line is defined by social norms. As norms evolve, the line moves. One measure of the advance of social justice and human rights might be the expanding diversity of human attributes and abilities that resides on the "normal" or "acceptable" side of the line. But the medical view of disability still ensures that disabled people reside on the other side. Meanwhile, the rise of the new genetics and other areas of advanced medical technology provides an increasing array of tools for enforcing the arbitrary distinction between what counts, today, as normal, and what does not.

From my point of view, the case is quite simple. New technologies promise the future elimination of a culturally determined category of human beings—the disabled—whose members feel that their lives are intrinsically worthwhile and no less valuable than the lives of those deemed normal. If I had been conceived today, my mother would receive enormous pressure to terminate me. So I see these new technologies as instruments of individual eugenics. They force women to be the social control gates of the gene pool, the unwitting perpetrators of a well-intentioned genocide. Lacking the social will to ensure disabled people a decent quality of life, we unleash our technological cleverness and prevent those lives from the outset.

The point is not so parochial as it might seem to my nonafflicted reader. Any affront to justice and tolerance is an affront to all. The philosopher Philip Kitcher captures the general problem: "[T]raditional views about the differential worth of various kinds of people, coupled with the competitive environment of free-market capitalism, make it hard to sustain any broad and tolerant perspective on the ways in which human lives can flourish—indeed contemporary affluent societies are marked by conditions that are likely to channel prenatal genetic testing towards a very narrow ideal of ourselves."[44]

A Final Word on Arms and Legs

Let's return to the case of artificial limbs. Perhaps prosthetic limbs seem to afford disabled people the option to achieve a wider range of functionality—to enhance choice about how to look and to operate. But as I've said, artificial limbs turn out, in most cases, to be not particularly useful, and they afford little if any advantage over less "lifelike" technologies such as wheelchairs, or over strategies that require no technological fix, like crawling or eating with your feet. Offered as a well-meaning solution to a problem as imagined by the nonafflicted, artificial limbs arise out of the stigmatization of people without limbs, and are in fact a tool for coercing conformity of appearance and function. People like me, who lack limbs, are expected to use them, and this expectation constrains our choices about how to operate in the world.

All that may soon change in an interesting way. Imagine how artificial limb technologies might develop in the future, when hybrid nano-biotechnologies are applied to the problem. Perhaps artificial limbs will be invented with a higher degree of functioning than "normal" limbs? If artificial limbs were intended only to bring deficient people up to the norm, would these "superlimbs" be accepted? Would it be acceptable for disabled people to equip themselves with new "superlegs" that would allow them to run faster or farther than "normal" people? Would it be acceptable for "normal" people to replace their "normal" legs with new "superlegs" so they could keep up? Could these "better than normal" limbs eventually become the norm, thus rendering the "normal" people of today, like you, subnormal, disabled, or deficient, like me?

9

PROGRESS AND VIOLENCE

Shiv Visvanathan[1]

Jacques Derrida, in one of his more "constructive" moments, suggested that the Truth and Reconciliation Commission in South Africa had raised some of the most profound philosophical questions of our time. As a ritual drama, the commission retrieved a host of issues about the nature of violence and evil, the relation between torturer and victim, the politics of memory, the question of forgiveness, and the reconstruction of justice. Of course, critics complained that the politics of pragmatism and immediacy banalized the commission, turning a morality play into a soap opera and rendering cosmetic deeply troubling questions. However, writers such as Michael Ignatieff have claimed that the methodology of the Truth Commission provided a dialogic technique for functioning in a public, open-ended manner that salvaged some truth and some justice.[2]

The Truth Commission can be treated as unique to the specific histories of injustice in South Africa or Argentina, or it can be seen as an experiment that can be repeated and modified. In recent times such a commission has been used more to bring tyrants and torturers to justice, and in most countries it has failed miserably. But if the Truth Commission is reconstructed playfully, it can be a wonderful technique for the new movements in civic internationalism. The challenge before us is to turn it into a fruitful forum for learning—a heuristic for broader forms of inquiry. Can we use a truth commission to consider the implications for democracy and human rights of two centuries of scientific and technological change? The dialogue must include the voices of a variety of stakeholders, including marginal communities that may be disappearing, as well as the arguments of experts. Regional- or continental-scale inquiries can be more open-ended, while others can be structured to capture the complexity of a particular problem.

Changes in science and technology inspire ambivalence—both hope and an anxiety that we need to face through what the philosopher Hans Jonas has called "a heuristics of fear."[3] Why is the idea of a truth commission relevant for a political and moral discussion of the role of science and technology? Apart from the headlines advantage such an approach provides, there are specific reasons why a truth commission on scientific and technological change might be a welcome strategy for the democratic imagination. Science policy today operates in specialized vocabularies of policy narratives and technical audits. It tends to emphasize the logic of numeracy over the language of literacy. One wishes there were more powerful novels on science, genres with the power and intensity of a Tolstoy or a Proust or a Flaubert, something less Manichean than the standard texts of science fiction. A truth commission can combine the methodological rigor of cost-benefit analysis with oral narratives containing a different vocabulary of the good life. Such a combination of genres might help us build a more comprehensive understanding of suffering.

Visualize such an exercise for the debates around the Narmada dam in India, which will provide water and electricity while displacing millions. The debates so far have been truncated: one hears either the tribal view or the official government view. One appears like a scream of pain, the other like a bureaucratic file. But imagine if one were to tease out the economic assumptions of the cost-benefit of dams, the competing definitions of what land means to different groups, the impact on livelihoods, the variety of ideas hidden under an abstract concept such as sustainability, or even the varieties of time and memory underlying the narratives. Such a gambit is urgently needed today, mainly because scientific and technological change has become both text and context for the great dramas of our time. A truth commission might provide a forum for such a dialogue on change.

Then there is the question of evidence and its relation to the observer. The scientific observer is eulogized for his objectivity, for her impersonality. Yet the split between observer and observed so crucial to the axioms of science creates, as it were, its own paradigm of change and how to perceive it. The observer is always disembodied and methodologically distant. The scientific gaze depersonalizes change at the very moment of creation. Suffering even becomes a spectacle for idle curiosity, as in the case of the Nazi doctors and the Tuskegee experiments. The observer, especially the scientifically objective observer exalted by science, is usually seen as a privileged person. Observation is predicated on the idea of value neutrality, of a split between the observer and the observed. It is based on a model of interpreting change, of the self divorced from the body.[4] But such a privileging needs to be questioned, or at least pluralized. The experiences of the political movements around ecology and the bomb show the biases implicit in this myth of objectivity. The privileging of the expert observer also marginalizes the experiences of the periphery and the victims.

The twentieth century provided the grammar for another kind of observer—the witness as spectator, as observer, even as victim of the event. The question of witness has been central to the writings on the Holocaust. It can apply equally, however, to the archives of apartheid, the genocide of Pol Pot's Cambodia, or even the violence of the development paradigm. The witness is not only one who sees but also one who is acted upon. He is both observer and site for many experiments. Crucial to the notion of witness is not only the reconciliation of truth and justice but also the trusteeship of memory in an age subject to change and erasure.

The witness ties the grammar of scientific change critically to the poetics of memory, combining ordinary and scientific languages. Such a combination is ethically and cognitively crucial. The paradigms of science, as Thomas Kuhn observed, have no place for defeated knowledges and, one might add, defeated peoples.[5] Often science has museumized both defeated knowledges and peoples. The poetics and politics of memory, as embodied in the witness, thus become crucial to the methodology of a truth commission. One is not only emphasizing the usual debates on the veracity of memory but the idea that memory operates in multiple times, often adding complexities and fuzziness to the linear histories of scientific and technological innovation. In an inverse sense, one must also explore how speed or the accelerations in time induced by technology affect the commons of memory.

Finally, a truth commission is a model of dialogue. It is an invitation not only to the observer but also to the listener to smell, remember, and touch. A model of dialogue is not only one of reconciliation but one of pluralism, a recognition of the different ways in which change can be perceived and lived out. One often tends to linearize scientific change into the language of progress, but progress often tends to celebrate change through acts of unification and reductionism. It narrows the domain of change by refusing to recognize it as a multiple reality with its own ironies. For example, DDT, which was perhaps progressive for one era, appears differently in a universe viewed for its interconnectedness.

How does a truth commission reconstruct scientific and technological change? Present in the narratives of science are two assumptions that add to its mythic, Promethean power. The first is the myth of the immaculate conception of science, which holds that science is good, or at worst neutral, and if well applied can solve the basic problems of poverty, disease, violence, overpopulation, and malnutrition. The myth of the Fall holds that the primary reason for the ambivalence around science and technology is not any intrinsic flaw but rather the manner in which they have been applied. This myth carries with it the original version of the good Cain/evil Abel dichotomy by claiming that while science is good, technology is flawed. The second variant of the myth holds that while science and technology are sound, it is science policy or the politicians who have ruined science. Nowhere does such a discourse allow for the possibility that violence might be intrinsic to modern science and technology.

To science itself as an ideological barrier to understanding change, we can add the idea of progress.[6] The doctrine of progress cannot be dismissed as merely a nineteenth-century cuticle of twenty-first-century science. It is true that social Darwinism in its overt form is now muted and that despite sociobiology, we talk less confidently of "the survival of the fittest." But science is still read, in a protestant sense, as an outward sign of inward grace: The scientific and technologically advanced somehow feel morally superior. One is reminded of the polymath theologian Raimundo Panikkar's story of a Texan who tried to convince a tribal American that the former had progressed beyond the latter; the Indian replied that he was happy, as both were where they wanted to be.[7]

But such a choice no longer seems available or possible. The ideology of progress is embodied in the idea of the museum and the theories of development, and in models of technology transfer. To understand the violence of the word "progress," you must understand its mirror opposite—museumization. The Indian national movement provided a hard-hitting critique of the concept of the museum. The geologist and art critic Ananda Coomaraswamy asked, "If God were to return today and ask 'civilized' 'western' 'man' what happened to the Incas, or the Australian aborigines, would he take him to the museum?"[8] Coomaraswamy noted, "Our way of life preserves the folksong while simultaneously destroying the folksinger."[9] The idea of the museum embodies the concept of progress. A juxtaposition of objects is all too often read as a time series, with a primitive canoe inevitably evolving into a medieval ship and then into a nuclear submarine. The idea of progress is woven deep into the genetic core of the idea of "development."

Imagine that we are the modern West. Within the developmental framework, today's primitive tribal is the past we have lived out. In turn, we believe that we are the future she has to live out. It is the grammar of progress that allows us to intrude, intervene, and drag her into modernity. Science, as a sign of grace, allows one to inflict "progress" as violence on a reluctant world. One remembers a story told by the human rights lawyer and scholar Leo Kuper of human rights activists who had complained about the death of tribals during major projects in Brazil and Paraguay. When confronted, the Brazilian ambassador to the United Nations admitted the deaths but claimed that they were an inevitable consequence of the logic of development. The lived time of science has to include peasant time, tribal time, the time of the patient, woman time, ritual time, cyclical time, the time of traditions. This is not to emphasize the standard opposition between clock time and lived time, but to show that each notion of time carries with it a package of value and behavior. For example, societies that believe in apocalyptic time have a different sense of ending than societies that have a cyclical notion of time. But more pragmatically, talk of the variety of times helps combat the idea that progress is a cumulative process. It also helps to pluralize the linear time of progress, an idea that is the real favorite not only of scientists, development experts, and dictators committed to dragging their citizens into modernity but of millions of citizens in the mainstream of Western market democracies.

The truth commission needs witnesses from multiple times, people who look at progress and change from a variety of ecologies and not only within the restricted grammar of technology transfer. Language and the inventiveness of language is critical here; one needs a glossary of change-sensitive terms to compete with "progress." The Mexican writer Octavio Paz coined the word "syllogism dagger" to refer to concepts such as "revolution," "development," and "economic growth," which are applied by abstract intellectuals and suffered by ordinary peasants, tribals, and slum dwellers.[10] These concepts build what might be called "the new pyramids of sacrifice." Today, one has to learn how to estimate the genocidal quotient of a large dam, a technology transfer project, and a reproductive health technique. Capturing it requires a forum equally at ease with folklore and science policy, formal languages and ordinary languages.

But fundamentally, one must ask why the language of human rights and the discourse of progress and development follow two separate systems of accounting and representation. The discourse on human rights is activated as soon as a single individual is tortured or incarcerated unjustly. The fact that the individual victim might be from a minority group is not relevant. The question one must ask is why progress always speaks in a majoritarian language? The minorities on the receiving end of progress do not receive the same audience as those relatively small numbers who disappeared in Argentina or were tortured in Chile. One must ask whether the language of Amnesty International applies to the victims of change, or does change necessarily have to speak in a majoritarian language?

What, then, have been the major changes in science and technology over the last two centuries, and how do we perceive them? The emphasis of this chapter is not on inventions as things. One could present glorious exercises on the integrated chip, the hybrid seed, the pill, the synthetic fertilizer, the computer, and the internal combustion engine, but those have already been written. If one sees science and technology as a system of relations rather than an *oratorio* of things, however, a different set of patterns and problems emerges. The changes mapped are not individual indicators but framed as sets of relationships.

The old mechanical models of causation or behaviorism are inadequate as narrative. We are not emphasizing, even with nostalgia, what the American sociologist William Ogburn immortalized as cultural lag theory, which banally claims that societal and cultural change always lag behind technical change.[11] The term "lag" also implies secondarily the process of catching up. What we require instead is a new mythology of causes, connections, levels, and systems.

The clearest sociological fact about science and technology today is its systematicity, what Alfred North Whitehead christened the "invention of invention," the organized integration of science and technology to sustain innovation.[12] This systematicity transforms science and technology from a charismatically perceived activity of individual inventors into a bureaucratically organized activity with an emphasis on defense-sponsored research. Accompanying the institutionalized integration of science and technology is the overall process of scienticization, wherein science becomes an organizer of other mentalities. The scienticization of society has affected the domains of work, education, sex, and even memory.

There are more scientists living than ever before, and more and more people are getting a scientific education. To this banal fact, we add what Daniel Bell has called the importance of scientific knowledge as the axial principle of advanced industrial society.[13] An internalization of these observations also helps explain the confidence, the celebration, around scientific and technological innovation. In the early 1900s, Indian scientists such as P. C. Ray echoed their European colleagues by claiming that the index of a civilization was linked to the amount of sulphuric acid it produced. In the 1920s, Lenin's technocratic visions claimed with all the cold certainty of an equation that Soviets + electricity = Communism. In the early years of Indian independence, the Fabian socialist zeal of India's first prime minister, Jawaharlal Nehru, made him proclaim that the future belonged to science and to insist that dams and laboratories were the temples of modern India. For many Third World nation-states, a science policy document is as significant as the flag. It signals a commitment to modernity and an understanding that change can be planned. It testifies to the urgency of closing the lag between the developed and the developing countries.

It is the systematicity of science and technology that leads to our first major proposition about the advent of a reflexive science. We recognize today the prospect of a socially sensitive, open-ended science and technology, and this is a crucial transition. A generation of scientists has shown that science can no longer be based on a reductionist mechanical model. Philosophers of science have added that science today softens its former claims to omniscience with concepts like uncertainty, risk, chaos, and complexity. Thirdly, social movements such as the peace and antinuclear movements in the West and the Indian grassroots movements against technological projects have demanded new forms of accountability and responsibility from science.

Today there is a political openness even among individuals who feel that scientific innovation is an autonomous process. Science as the impersonal observer seems to have acquired a hearing aid. It might be switched off occasionally, but the prospects for listening are there. The use of peasant juries in the Indian state of Andhra Pradesh to debate the pros and cons of introducing Bt cotton is one recent example from India. One is caught in the appalling divide between a conceptually open science, with its remarkable array of dissenting imaginations, and the inadequacy of its ethical categories. Can words such as "obsolescence," "triage," and "progress" confront the violence of the development process? Do concepts like uncertainty and risk have the moral sweep to encompass the fate of technologies and people? Is the economist's framework of cost-benefit analysis sufficient to address the demands for justice in the recent climate-change controversies, when "costs" in rich countries may refer to new energy technology and in poor countries to drowned cities?

The moral infantilism of modern science raises a crisis revealed in three dimensions. The first, as already stated, is the gap between scientific openness and the moral inadequacy of its categories. The second is a political crisis of science versus democracy. One is not referring only to controversies between expert and layperson or demands for greater participation. There is also the issue of articulating the voice and worldviews of marginals, which often get drowned in a stakeholder model of change. In fact, today even the articulation of these voices is not an adequate guarantee of fundamental rights, for it is often treated as just an emotional protest.

Grassroots movements in India have suggested the ideas of "cognitive justice" and "cognitive representation." Cognitive justice visualizes a polity in which there is a relation between science and the life chances of a people. It holds that knowledge, especially people's knowledge or traditional knowledge, is a repertoire of skills and a cosmology that must be treated fairly in the new projects of technological development. Cognitive justice posits the idea of a plurality, of fairness and dialogue among different knowledge systems to prevent the marginalization or museumization of any of them. Cognitive representation, which is a corollary, presupposes that in the act of science policy-making, the practitioners from various systems would be present to articulate their concepts, theories, and worldviews. Both concepts seek to preempt the liquidation of certain forms of local or marginal knowledge.

To the above two perspectives, we can add a third dimension, the internal crisis of science, which constitutes one of its most fascinating features today. It was the reluctant genius Thomas Kuhn who suggested that the textbook in science ignores defeated hypotheses. The textbook emphasizes a victorious cognitive regime, erasing doubts, alternatives, and multiplicities and thus allowing for a form of rigid governance. Science feels that an agreed-upon, standardized consensus that clearly defines problems, methods, and acceptable solutions is a far superior form of civics than the anarchism of the social sciences, with their endless controversies. Yet science is today full of dissenting imaginations, if not dissenting academies. It is full of doubts, inventions, battles between reductionism and emergence, of physics and ecology still contending with the implications of thermodynamics and indeterminancy. We face a science operating not only with multicausal models but with a variety of times beyond linearity and mechanical time, a science that has to go beyond reductionism to contend with levels of analysis, with complexity, contingency, and chaos.

Today science realizes that it cannot operate on a reductionist plane. Ecological problems have reemphasized the anthropology of *levels* in science. For example, pesticides may no longer be the best solution to the problem of crop pests; science instead must visualize a portfolio of integrated crop management practices. Reductionist approaches to productivity in agriculture may reduce the level of crop diversity. Pragmatically, science might require a pluralist model to handle issues such as chemical disasters, genetically modified foods, and issues in soil chemistry or waste disposal.

One can examine this idea in the context of the Green Revolution in India, a multidisciplinary project to improve the productivity of wheat and rice. As a theory of productivity that increased consumption of synthetic fertilizer and pesticides, the Green Revolution "worked"—but it failed to consider the destruction of soils. Secondly, Green Revolution agriculture was one-dimensional, since it considered only the productivity of grain without paying attention to the fact that crops are also sources of fodder and waste for reuse.

Or consider a present-day forest. Is it a resource for paper, a source of minor forest produce, or a sacred site? Each paradigm would define forest use in a different way, leading to different connections between science and justice and livelihood.

The organization of science as a set of professions and specializations does not permit such a diversity of thought and method. The sanctity of peer review ensures homogeneity, even in the definition of what constitutes a scientific problem. Yet whistle-blowing and dissent have provided crucial breakthroughs in science. During the struggle of social movements against the establishment in India, for example, dissenting scientific views created a possibility for pluralism. Yet the monoparadigmatic nature of official science and its bureaucratization tends to suppress this quarrelsome science; as a result, society has not been able to realize its full benefits. The geography of what Kuhn calls "normal science" often eliminates the pluralism of dissenting views.

Moreover, an internally quarrelsome science still remains handicapped by the moral infantilism of the scientific framework. There seem to be no moral filters in science that prevent every "can" from becoming an "ought." We have to face the awesome observation that many of the great forms of violence were the creations of scientists pursuing everyday questions in the laboratory. When the atom bomb was first exploded at Los Alamos, project director J. Robert Oppenheimer claimed that the physicists had known sin, but during a later congressional hearing he dismissed the atom bomb as a technical answer to a technical question.[14] Such infantilism is made more poignant by the fact that science has raised the prospect of radical evil in our societies. While the concept of radical evil goes back to Kant, this commentary locates itself in the controversy around Hannah Arendt's work on the Eichmann trials.[15]

Arendt, like many other observers, was puzzled by the sheer ordinariness of Eichmann as a man. Eichmann appeared utterly normal—more normal than many psychologists felt after they interviewed him. How was one to understand the discordance between the averageness of the man and the enormity of his crimes? One would like to suggest that the root of his evil might lie in the structure of the bureaucratic and scientific discourse. Arendt, following Karl Jaspers, called it the banality of evil, an evil that was neither perverse nor sadistic. She observed that Eichmann, in his conversation, perpetually spoke in the language of cliches. He saw himself as a bureaucrat responsible for a large-scale technical project, merely following orders. He echoed the social science discourse of being a cog in the machine. Arendt added that Eichmann could not articulate the point of view of the other or even recognize the personhood of the other. Yet while he was committed to the extermination of millions, he was concerned with the minimization of unnecessary suffering. Arendt's discussion operates around two idioms—the language of the bureaucracy, which follows the law of the land, and the language of a technological project, committed to extermination. Eichmann seemed to be part bureaucrat, part scientist.

The question we must ask is whether the renouncing of personal judgment that Eichmann hinted at is of a bureaucratic or a scientific quality. Is the concentration camp as panopticon a scientific project? Bruno Bettelheim observed that Eichmann thought of himself as a scientist. Does the objectivity of science, the split between observers and observed, the anatomization of the body as cadaver add to the banality of evil in Eichmann? Does science contribute to radical evil? Does the notion of a scientific gaze and the impersonality of method allow for an Eichmann in the scientist in all of us?

One would like to suggest that this is a question that a truth commission can no longer ignore. In a fundamental sense, it has to face not only the idea of responsibility but also the roots of evil within a knowledge system. The question is more profound than the idea of Frankenstein, the dualism of Jekyll and Hyde, or the occult notion of the genie in the bottle, all of which simply locate accountability in an aberrant individual. Here the notion is systemic. It encompasses the idea that science and technology house the capacity for this evil and shield it from prosecution through the impunity of scientific objectivity.

The above dimensions in science become amplified by what many Third World human rights researchers see as the emerging battle between science and democracy. This conflict raises the whole question not of mobs versus science, as in the Cultural Revolution, or of science versus power, à la Bruno and Galileo, but of how a consensual expert science combined with majoritarianism can threaten marginals and minority groups.

Science, in its paradigmatic normalcy, operates very much like a democratic regime, emphasizing transparency, majoritarianism, and consensus. But such a majoritarian consensus operates on selective axes in both discourses. Within the democratic project, the notion of human rights protects individuals against torture and other forms of violence, but never against the violence that a scientific project may inflict on them. Similarly, scientific projects focus on majoritarian change but fail to look at their impact on marginal communities. This selectiveness becomes poignant in India, for example, where the middle class is demographically the size of Europe, while the marginals are only a few million strong. The language of protecting minorities and others from being victimized by technological projects does not formally exist in science or human rights. Both remain progress-oriented discourses.

Today, in our celebration of liberal democracy, we are ignoring fundamental issues raised by debates in the politics of knowledge. The basic civics of science and technology today are embodied in the idea of technology transfer—of the innovation chain, with its elements of invention, innovation, and diffusion. Yet the notion of technology transfer, as practiced for much of the past half-century, threatens the idea of plural knowledge systems. It destroys or "de-skills" the gene pool of knowledges on which subsistence communities have thrived for decades. For example, Green Revolution technology transfers may create monocultures, thereby destroying not only crop diversity but also the diversity of knowledges that sustained it.

Technology transfer also raises the question of whether science is going to museumize or assimilate subsistence communities. Third World activists have raised the whole question of the right of different epistemologies of knowledge in agriculture, medicine, and other areas to exist and to be constitutionally represented in the processes of decision-making.

Thus, in a democratic society we face not merely a struggle between expert and citizen over nuclear, medical, agricultural, and ecological issues but also a struggle between scientific and other knowledges. This is a struggle between alternative cosmologies and epistemologies that cannot be trivialized as "local knowledge" in World Bank reports or reduced to battles between science and superstition, a vintage obsession of many in the positivist left.

Science and technology have sustained various forms of systemic violence. An ethnography of each is desperately needed and would utilize witnesses such as Robert J. Lifton, Elie Wiesel, and a generation of feminist writers on science and technology. The twentieth century has provided numerous examples:

1. Planned *obsolescence,* with its de-skilling of communities, a phenomenon often ignored by technology transfer projects.
2. Social *triage,* a rational framework for treating vulnerable communities as dispensable. Originally a system for sorting coffee, triage moved through medicine to social policy, where it is now used to sort out those not amenable to the processes of development. Such a system allows for the abdication of responsibility and even the abandonment of a vulnerable people classified as incompetent. Triage has been advocated in the writings of foreign policy experts and in the works of sociobiologists such as Garrett Hardin.[16]
3. *Extinction,* which is a natural process in an evolutionary sense but today is an accelerated and almost systematic elimination of species, communities, and even ways of life.
4. *Museumization* of tribals and other defeated and marginal groups who are unable to cope with modernity and development. They are reduced to barely surviving, retaining only vestiges of their culture because they have little chance

to practice it, and simultaneously becoming objects of the scientific gaze. Coomaraswamy has complained that museums smell of death and formaldehyde and in fact has suggested that traditional societies should wage a guerrilla war against them.

5. The violence of *development,* including internal *displacement*. The record in a demographic sense is held by India, which according to the *India Disasters Report* has more than 60 million refugees from development projects such as dams. A technological project like a large dam has to go beyond engineering to count how many lives and livelihoods it displaces.
6. The violence of the *genocidal mentality,* including state-sponsored genocide and ecocide. The twentieth century has eliminated about 60 million people through such activities. The violence of Auschwitz and other camps is but one such example.
7. *Nuclearism,* an organized, rational form of violence that accepts the elimination of huge sectors of a population and that became a behavioral obsession with scientists during the Cold War.
8. *Monoculture,* which, on the grounds of the market's efficiency or even an ethnocentric botany, justifies the reductionist use of a crop or organism that does violence to the culture of diversity in which it was earlier embedded.
9. *Exclusion* or *enclosure,* which one discerns not only in the marginalization of certain communities and their forms of life. One sees it as central to the globalization process, in which societies that cannot pursue the Western paradigm of innovation are dropped from the map.
10. *Iatrogeny,* which originally referred to illness or suffering inadvertently induced by a doctor. Here it refers to projects in which the experts' solution increases the endemic violence or suffering of a community.
11. To the list of ten above, we can add the violence of *pseudo-science,* or antitechnological movements which mimic or magnify the violence that supporters of these movements

might have undergone earlier. One thinks of Pol Pot's Cambodia, Mao's Cultural Revolution, or the Lysenkoism of the Stalinist period.

The tragedy is that science and technology, with their euphoric myths of progress, innovation, and obsolescence, have no format for understanding defeated and marginalized communities. Their census of genocide, their demographies of death, have no rituals of grief or mourning. A methodological alienation is also built into scientific expertise. Robert J. Lifton, in *The Nazi Doctors*, explored the link between Nazi ideology and medical ideas and how the two converged in the idea of "biological truth."[17] Lifton is too attuned to subtleties to see Nazism as purely an exercise in "applied biology" centering around the practice of eugenics. In fact, many Nazi doctors saw in National Socialism the promise of a collective revitalization of their professions. The first genocides were more in the nature of social work and community psychiatry programs designed to eliminate useless people, and were adapted later for use in the concentration camps for Jews and gypsies. Lifton's work raises the question of the genocidal impetus of professional expertise. Is transfer of technology a continuation of violence by other means? Does the so-called objectivity of science blind one to issues of marginalization, obsolescence, and triage because science as an activity claims to operate on rational lines?

The question before a truth commission would be this: How can societies thoughtfully reflect on change and learn from their errors, rather than chalking it all up to progress and moving on? What we seek are not societies pursuing some implausible golden age of scientific governance, but an escape from the dualism of Luddism versus progress. Two fascinating archives of debate from India have much to contribute to this discussion: the debates on science and technology between 1904 and 1947, and the debates on science and democracy in the 1980s and 1990s, after the Emergency period of dictatorship imposed by Indira Gandhi between 1975 and 1977.

The partition of Bengal in 1904 triggered not only a political debate but also an efflorescence of innovations in culture, education, and science. Most were attempts to reform the moribund universities at Bombay, Calcutta, and Madras and create indigenously controlled institutions. They also included a spate of entrepreneurial efforts in ceramics, leather, glass, and chemicals. In a technological sense most were disasters, leading neither to employment nor to wealth creation. But what followed was one of history's richest debates on science and technology.

The national movement for Indian independence was not an inward-looking exercise. It saw the British as not only oppressors but also victims, and was determined to rescue them from the consequences of modernity. The debate was seen as not only an experiment for a future India but an exploration of ideas that England and the West had suppressed. It was eccentric and complex, and what follows is only a small sampling.[18]

One of the most fascinating figures in the debate was Ananda Coomaraswamy. His short note on aniline dyes was an immediate response to P. C. Ray's hymn to the economic importance to India of synthetic chemistry. Ray argued that the success of India's synthetic-chemistry industry was the result of the dedication of generations of chemists, of labors that "revolutionized and completely destroyed a staple trade of France, Holland, Italy, and Turkey." Coomaraswamy was provoked by the fact that Ray had failed to question the desirability or consequences of such a distinctly scientific process, which had ruined India's indigo dye trade. Coomaraswamy argued that such a failure was endemic to the structure of science, which justified itself as knowledge pursued for its own sake, and thereby exempted itself from consideration of the social disruption that cleaves unacknowledged to the notion of progress.[19]

Coomaraswamy argued that science lacked the principles for differentiating between progress and obsolescence. He felt that only tradition and the cosmologies of a traditional society could provide the system of controls—the cosmological, religious, and ecological embeddedness—required for directing a technological process. The traditional orders refused to differentiate between a functional tool as an instrumental act and the cosmology it embodied. Coomaraswamy was basically referring to the way crafts employed each other's services. Many villagers, for example, would not take clay except from a certain area. Fishermen in Kerala would not go to sea at spawning time, even if they had to starve. Tribals would not till the soil when they thought it was menstruating. Such a cosmology and ritualized reciprocity gets erased in a secular world, where cosmology and ritual lose to the idea of the contract.

Coomaraswamy argued that the craft idiocy of modern science was reflected in the use of synthetic dyes, an act that forced a whole way of life "to die or sink into oblivion, without an attempt to study it and learn from it." The introduction of synthetic dyes destroyed the craft traditions and the art of dyeing: rather than being a celebration of variegated techniques differing from family to family and district to district, dyeing became a standardized set of scientifically ordained procedures to be applied mechanically from packets distributed by visiting German salesmen. Science became the basis for a proletarianized world in which the craftsman was no longer a master scientist embedded in a culture.

Coomaraswamy saw science as accelerating the process toward the vulgar, anesthetic man, whereas the craft traditions embodied notions of ritualized reciprocity between craft and nature, which eluded the secular structure of technological innovation. In his essay on the gramophone, he sought to articulate some of these normative principles. The gramophone in a mechanical world was no longer an innocent form of entertainment. In fact, Coomaraswamy said, "[E]very time you accept a gramophone in the place of a man, you degrade the musician, take from him his living and injure the group soul of your people."[20] Within the craft tradition each instrument had its own singularity; each moment of song was a communion with a particular audience. But the mechanical production of the gramophone, in which each part was made by a different man and fitted together by another man, wrecked that dynamic. The industrialization of music, Coomaraswamy argues, destroyed it as both a folk and an esoteric art and rendered it vulgar and populist.

Coomaraswamy, unlike modern individualists, believed that property should belong to the commons. The commons, in the original sense, was a piece of land or water to which peasants or tribals had access. It provided them with food, fodder, and building materials and also sustained their technical skills. But the metaphor is a wider one: the heritage of a people is also a commons, one of memory, skills, and cosmologies. Intellectual property was part of a people's common heritage and, like natural resources, should be part of the commons. Any innovation that sought to destroy the continuity of such a heritage should be renounced. Thus, what was rendered obsolescent by the gramophone was not just an artifact but also a community of singers. Coomaraswamy was not against science per se; in fact, he believed that the only appropriate use for the gramophone was for scientific research. He felt, however, that science as a mode of perceiving had to be localized and encompassed within a wider metaphysics of the good, the true, and the beautiful.

Similar arguments came from the "technological gradualists." One of these was Frederick Nicholson, a colonial officer with eccentric views on India, and a great authority on waste. Nicholson faulted both colonialism and swadeshism (a movement for the production and consumption of indigenous goods) for ignoring everyday technologies. He articulated his vision of "intermediate technology" in a remarkable passage on fishing, in which he attempted to classify various forms of technology into niches: "There is a vague popular idea that development means 'steam trawlers'; that there is an illimitable sea harvest outside needing only to be gathered in by a modern plant and by starting steam trawlers. My own idea of Madras' needs and methods is, on the contrary, that we do not need or want steam, save for particular cases; that to jump from the catamaran to the steamer is impossible and unwise if possible, and that our true method is to proceed by the ordinary and historical process of slow development; revolutionary methods, here as elsewhere, are a mistake. We want to develop, *gradatim et pari passu,* the fisherfolk, the fishing industry and the fishing trade by methods which will not necessarily reduce fishing folk to hired labor under capitalists, European or otherwise."[21]

Within such a graduated notion of technology, science could become a tool to prevent the proletarianization of labor. Nicholson claimed that it was the sailboat and the curing yard, rather than the steam trawler and the refrigerator car, which should be the focus of attention. He realized, however, that the days of steam trawling would come, but felt that the old and the new must be ecologically niched and that the superior and more powerful boats should supplement and not oust the catamaran and the canoe. The role of the state lay in being a humane referee between these differing styles of technology.

One must emphasize that what one is discussing here is not merely a safety net for defeated technologies in a welfare state sense, but also a pluralistic order of technologies in which different technologies each have their niche, like different energy levels in a trophic cycle—a model in which "creative destruction" and "inclusive evolution" are both possible. Such an ecological niching of technologies would allow for a wide variety of experiments and styles as well as a sort of affirmative action for certain technologies. Included in this social policy would be individual acts of fasting and renunciation, which would help control the social use of some technologies. For example, a society might decide not to use Bt cotton products because it affects the food chain and contaminates a future gene pool. The notion of taboo can be put to creative and playful use here and is not a repressive but a community-affirming strategy.

The poet Rabindranath Tagore, who also participated in India's debates about science, believed that the modern university, as a collective representation of knowledge, embodied the essential worldview of Western civilization. Thus a student from another land had no difficulty in obtaining a grasp of the Western mind because it was captured synoptically in the modern university. Tagore felt that the East had no equivalent institution, and sought to build one at Santiniketan. He was not content with a swadeshism that settled for a voyeuristic view of the Western university, but argued that before the dialogue between East and West could begin, there had to be an intellectual center that embodied the spirit of knowledge in the East, reflecting each of its great civilizations. Only with the existence of such an institution could the interaction of

East and West be one of equality, of dialogic reciprocity, of exploring differences.

Tagore argued that each university was an embodiment of an archetypal set. The Western university, as the microcosm of the society, reflected the mind of the city. In India, however, civilization was associated with the forest, "taking on its distinctive character from its origin and environment." The forest's intellect sought spiritual harmony with nature, while the mind of the city sought its subjugation, extending its boundary walls around its acquisitions. The sage in the forest hermitage was not interested in acquiring and dominating, but in realizing and enlarging his consciousness by growing with and into his surroundings. Even when the primeval forest gave way to the farm and the city, "the heart of India looked back with adoration upon the great ideal of strenuous self realization and the simple dignity of the forest hermitage."[22]

The West, on the contrary, took pride in subduing nature. As a result, the American wilderness, unlike the Indian forest, lacked an animistic power. For the West, nature belonged to the category of the inanimate. Western thought posited a disjunction between nature and human nature, but the Indian mind freely acknowledged its kinship with nature, positing an unbroken relationship with all. Thus, while a city science sought to subdue nature, in India "a whole people who were once meat eaters gave up taking animal food to cultivate the sentiment of universal sympathy for life, an event unique in history."[23] Tagore predicted that the dialogue between the two universities would be between a city science and a forest science, between a mode of being that sought harmony with nature and a way of doing that sought possession of it.

The nationalist debates were varied and manifold, and most eventually went underground to become a part of the nationalist unconscious. But they did take issues of innovation seriously, emphasizing that governance is possible only when a civilization provides a wider aesthetic, ethical, and cognitive framework for evaluating science and technology.

The technocratic and progress-oriented Nehruvian vision dominated independent India during its first two decades. The great celebrations of science were followed by a period of doubt in the years following the Emergency, in the 1980s and 1990s, when the philosophy of science in India was reinvented by grassroots movements. Their overall critique can be mapped across the civics of technology transfer.

The Marxist-inspired Kerala Sahitya Shastra Parishad, a leftist science movement in Kerala, sought to take the scientific imagination and method to the villages through mass quizzes and plays. It probably enacted more versions of Brecht's *The Life of Galileo* in Kerala than have been performed anywhere else in the world. Intermediate technologists such as Amulya Reddy at Bangalore's Indian Institute of Science worked on the recovery of local knowledges and materials. Experiments centered around the rights of biomass societies and included experiments on biogas and cooking stoves. The Narmada struggle against large dams can also be located in this domain.

A smaller set of groups centering around the Murugappa Chettiar Research Institute argued for opening up the black box called invention, contending that science could not be democratized through public participation and knowledge diffusion; a review of its epistemologies was needed. They felt that agriculture itself was an epistemology of soils, water, and seed, not just productivity, and they challenged the monoculture of the dominant scientific model. As someone said, "A society with 40,000 varieties of rice has 40,000 dreams of cooking and dreaming."

What the new grassroots groups in India did was to argue for these principles:

1. The citizen is a scientist and an inventor and is a trustee of technology.
2. As a citizen, the Indian is responsible for the country's 10,000 varieties of mango, because citizenship is trusteeship.
3. The democratic imagination needs to be reinvented, and the notion of rights is sadly inadequate when confronting diversity or obsolescence either as civilizational questions or as problems of governance. Prevailing notions of rights cannot prevent assaults on diversity or disruptions of obsolescence;

in fact, these notions cannot even provide a language for discussing such conflicts, let alone principles for governing them. The notion of governance needs new life-affirming concepts to understand disasters, vulnerability, disappearance, and the new forms of enclosure created by globalization.

4. Liberal democracy is an impoverished model for confronting science and technology. The groups did borrow from it the idea of choice, however. For instance, the Indian debates on biotechnology are less hysterical than those in the West and more confident about confronting biotechnology.[24] But they take the issue of choice from the individual consumer's level into the collective arena. Choice and diversity become creatively and critically related, bringing to mind a recent debate on the use of genetically modified seeds between Vandana Shiva and leftist activist Gail Omvedt, who argued that farmers should be allowed the right to choose any technology they thought fit. Shiva replied that choice is not only an individual act; collective choices determine the availability of diversity and thus create the availability of greater variety and choice. Succumbing to multinational agribusiness only creates monocultures, which eliminate choice.

The recent impacts of globalization have caught these movements a bit flatfooted, but the debates in India continue—a fascinating attempt by a society to seriously confront the governance of its own scientific and technological transformation.

The views of India's grassroots groups were echoed in the West by agricultural scientist Wes Jackson, who criticized sociologist Manuel Castells for his glorification of the information society. According to Jackson, high-information societies feel they no longer have to remember; the twentieth century tried desperately to devalue the power of the witness. Memory has to be embodied, he argued: computer chips only store information, but witnesses remember. A truth commission would offer not just information but witnesses acting out the lived recollection of other republics of technology with their textures of memory, myth, and tacit knowledges.

One must confront the strange hubris of the high-information society. America claims to be one, yet its very creation myth is an act of genocide; its elimination of the indigenous continuity, a program for museumizing or assimilating the other; and its official future, one grand project of homogenization called globalism. Wes Jackson put it succinctly when he observed that "America lost more information by depopulating its countryside than it gained by all the science and technology in the same period."[25] A country that reduces 160 varieties of apple to 5 is a low-information society. A global-industrial process that is erasing one species an hour is a low-information process.

One should stop here, but first, a story:

The sociologist Edward Shils once told his colleague Andre Beteille a story about the Indian author Nirad C. Chaudhuri. Chaudhuri was an irascible, incorrigible individual who loved everything English. In fact, he thought the British empire was the best thing that had ever happened to India. He loved London but never visited it till he was in his late fifties. He had studied it, though—every road and street—from maps he had diligently obtained.

Finally, the great day came when he went to London. He hailed a cab to see the sights. The cabbie began driving sedately, but Niradbabu kept questioning him, criticizing his knowledge of London. Eventually, in desperation, the cabbie exclaimed, "The roads you talk about were bombed during World War II. Many don't exist anymore. Britain has grown since!"[26]

One hopes this essay is not as irrelevant as Chaudhuri's maps, although one sometimes feels that science, like London, may have changed far beyond one's descriptions.

10

SCIENCE AND HAPPINESS

Daniel Sarewitz

Early on the morning of April 14, 1988, the research vessel R/V *Moana Wave* was cruising the interior seas of the Philippine archipelago. The waters were calm; several members of the scientific party were logging in data and plotting the next day's track lines, but the others were sleeping in their cabins. We were probing the complexities of tectonic collision processes, using an array of marine geophysics technologies that would allow us to assemble an amazingly comprehensive suite of three-dimensional data about the ocean crust that lay beneath us. In particular, we wanted to understand how and why small ocean basins were forming in a region where tectonic plates were colliding.

The cruise had been plagued by technical difficulties. Our bottom-imaging sonar device had been on the fritz almost from the first day out from port, severely curtailing both the quantity and quality of the data we were collecting. After many days of maddening delays and unsatisfactory results, all systems finally seemed to be operating well. We were now exploring some particularly narrow arms of the eastern Sibuyan Sea; the steep mountainous shore loomed only a few hundred meters away. I was now able to relax a bit, and I stood on the foredeck, enjoying the night and the spectacular equatorial stars, Polaris and the Southern Cross both visible in the sky.

Dozens of tiny fishing boats were scattered over the water, and fishermen waved to me and perhaps wondered what our ship was doing in their remote waters. But as we approached yet another cluster of fishermen, the waving turned from friendly to frantic as men in two small outriggers, one to our port, the other to starboard, motioned wildly in an effort to attract our attention. At first I thought they were worried about getting swamped by our wake and wanted us to slow down, but before I could even think about climbing up to the bridge to alert the crew, we passed the fishermen by, and I watched as their hysterical arm-flapping turned to fist-pumping rage. Only then did I realize that the two boats were on the opposite ends of a long net that our ship had snagged and likely severed.

The second mate was at the helm, and I rushed to tell him what I had seen. It happens, he told me; there was nothing we could do. They saw us coming long before we could see them; they didn't have running lights; if they didn't get out of the way, it was their fault.

No doubt. But these fishermen, working out of the tiny villages that dotted the coast, were impoverished, and perhaps even fishing for their own food. What consequences would flow from the destruction of a net, a tool that was central to daily subsistence, and whose replacement might cost a man nearly his entire annual salary?

It is all too rare that scientists can observe the direct effects of their own work on the world around them. The opposite is mostly true, that scientists, in pursuit of a fact, an insight, a more elegant representation of some shard of nature, are not privy to the unfolding implications of what they are doing. They are like soldiers who, perhaps aware of the larger goals of the war, are nevertheless unable to observe its general progress—they must focus on the ground around them, on taking the next hill.

This intimacy of scientific endeavor seems to render obscure, even irrelevant, grand questions about how science contributes to the quality of people's lives. As chief scientist on the *Moana Wave,* my responsibility was certainly not to worry about the larger purpose and ultimate consequences of my research. I was simply a small part of a complex enterprise seeking to bring the workings of our planet into sharper focus.

Research ships like the *Moana Wave* carried the tools that mapped the shape of the seafloor in detail, discovered patterns of magnetization in oceanic rocks, imaged the structure of rocks beneath the seafloor, and drilled deep into the ocean crust. From such observations, earth scientists in the 1960s were able to recognize that the ocean crust was mobile, young (by geologic standards), and part of an ongoing process of simultaneous seafloor creation (along midocean volcanic ridges) and destruction (at deep-sea trenches). These insights in turn made sense of several centuries of scientific observations on subjects ranging from the distribution of fossils and the origins and ages of different types of rocks, to the locations of mountain ranges, oceans, earthquakes, ore bodies, and oil. The result was a revolution in understanding the history of the earth: the new global tectonics.

But this story of scientific advance can be told in the opposite direction. The principal tools of marine geophysics can be traced back to military applications, such as the tracking of enemy submarines, the development of increasingly precise navigational and bottom-imaging devices necessary for modern seagoing warfare, and the need for accurate seismic monitoring of nuclear tests during the Cold War. The synergy between military application and pure research is wonderfully illustrated by the story of Harry Hess, a Princeton geologist who commanded a U.S. transport ship during World War II. Hess kept his ship's echo-sounding device running full time as he traversed the waters of the western Pacific. He then used the data he had gathered to construct detailed surveys of ocean floor topography from which, in a marvelous leap of scientific intuition, he was able to infer the fundamental elements of ocean plate tectonics. His hypotheses were quickly confirmed by the discovery of magnetic stripes on the deep ocean floor—a discovery made possible again by wartime technology, in this case the magnetometers that searched the Atlantic Ocean for German submarines.

Of course Hess's story is emblematic of the more general course of science in the years following World War II. The war had stimulated an unprecedented government investment in scientific research, and this investment had paid off hugely, not just in the development of the atomic bombs that ended the conflict, but in hundreds of other smaller innovations, and, of no less importance, in the expansion of a system of government-funded laboratories and scientists who defined the frontiers of knowledge as the hot war ended and the cold one began. Indeed, the end of World War II marked the beginning of a remarkably broad social consensus in the United States, which held that the material well-being of society depended on the continual advance of science and technology, and that this advance in turn depended on government funding for research.

The result is no less profound for being familiar. Theoretical revolutions not just in earth sciences but in molecular biology, cosmology, environmental science; practical revolutions in electronics, info tech and communications, advanced materials and avionics, now biotech, soon nanotech and robotics; and a resulting era of economic growth and technological advance probably unique in all history.

The foundations of this success were said to lie in the essence of democratic society itself. The sociologist Bernard Barber noted in 1952 that the suite of "deeply rooted moral preferences" that characterized modern democratic society were precisely those that allowed science to thrive: rationality, utilitarianism (by which he meant a focus on our directly experienced world, rather than a spiritual one), universalism, individualism, and, crucially, "meliorism," or progress.[1] In sharing the values of a free society, science in turn supported freedom: "[I]t is consistent with the scientific outlook that [the scientist] should oppose all tyrannical monarchies, such as that of the Czars, and all totalitarian regimes, whether national socialist, fascist, or communist."[2] Freedom of inquiry was not simply a democratic value, it was a buttress to democracy itself. Science and democracy advanced hand in hand.

Thus did science become a central player in the ideological competition between the United States and the Soviet Union. We needed to be first in science not just because of the high-tech arms race, but because free science would deliver to our free society, via the free marketplace, the continuous improvements in quality of life that would prove us superior to our communist foes. Leadership in all fields of inquiry and innovation was a political imperative during the Cold War, and when such leadership seemed in doubt—as when the Soviets beat the United States into orbit with the launching of *Sputnik* in 1957—the nation, suffering deep pangs of insecurity, redoubled its commitment to public support of science and science education.

Not just science, but our kind of science: free, open, unfettered, the antithesis of what took place in the Soviet Union and Nazi Germany, where the crushing of political freedom led to an inexorable subjugation of science to ideology, and where "the borrowed authority of science" in turn lent credence to claims that communism and National Socialism were scientific forms of governance, the one founded on scientific approaches to history and human behavior, the other on Darwinian genetics.[3] Our kind of science advanced knowledge and democracy. Their kind of science worked both to corrode science itself and to strengthen totalitarianism.

Stories of how the Nazis and the Soviets shackled science to ideology in pursuit of practical gains are both chilling and cautionary. Both Hitler's Germany and the Soviet Union under Stalin exiled, purged, and otherwise persecuted thousands of scientists—often their best scientists—in binges of paranoid self-destructiveness. Hitler's notions of an Aryan science led to a rejection of theoretical physics as being "Jewish," and in part account for his unwillingness to commit significant resources to the development of an atomic bomb. The Soviet Union, of course, boasted Trofim Lysenko, a peasant farmer, charlatan, and "unprincipled careerist" who came to dominate Soviet agricultural science for a generation by advancing his eccentric views about crop genetics on the back of Marxist philosophy.[4] Lysenko claimed that desirable, heritable crop traits could be introduced into plant varieties by exposing seeds and young plants to environmental stresses. He promised to gratify Stalin's demand for rapid advances in crop productivity, and did so with a new "proletarian science" that found in the natural world processes of transformation akin to communist political transformation. Lysenko's influence was such that many of his scientific critics—their bourgeois tendencies exposed—were imprisoned and died, the world-class Soviet capability in genetics was destroyed, and the progress of Soviet agriculture came to an end.

Such are the iconic tales that bolster our faith in the inherent virtue of science freely pursued. But they fail to get at what is most important. Yes, science subservient to ideology is repugnant. But it is also futile.

The true danger lies in the opposite condition: when noxious regimes give scientists necessary rein to develop knowledge that can then be used to further malignant ambitions. This was the real problem of science in Nazi Germany and, even more so, in the Soviet Union: these regimes were, in many cases, all too capable of conducting "good" science by the standards of science itself. The Germans were, of course, great weapons designers and rocketeers; they were world-class plant breeders and, in their obsession with health and purity, were the first to document convincingly the connection between smoking and cancer. The Soviet Union excelled in many areas of science, especially in the physical sciences, earth sciences, and mathematics. Good science was crucial to the ambitions and many of the successes of these nations. Today, the authoritarian regime in China is similarly committed to using a highly sophisticated scientific workforce as a key to its economic development.

Science can operate productively in free societies or repressive ones. One of the amazing attributes of science is its resilience even under conditions of extreme repression. We think of Galileo as the archetypal example of science suppressed, but Galileo, Copernicus, Kepler, and others who advanced new notions of cosmology all did so in the face of rigid Church dogma. In the end, their ideas flourished because they were right, while false biblical cosmologies withered away.

Science can even distract from repression. The historian Loren Graham observed that "talented Soviet researchers sought to escape the politically threatening and morally corrupt atmosphere around them by submerging themselves in their work. Even if arrested, they sometimes continued their efforts in prison camps."[5] Later, after the breakup of the Soviet Union, many Russian scientists discovered, as Graham ruefully notes, that they were better able to pursue their research under a repressive Soviet regime that lavished resources upon them, than under an arguably democratic Russian state that has little money to spare for science.

Science does not need a free society in which to operate productively, and science does not operate freely in society. Of course an individual scientist may pursue some line of research out of no motive other than curiosity and love of inquiry. My work on the *Moana Wave* was motivated by my personal fascination with the evolution of tectonic plate boundaries. But the very idea of tectonic plate boundaries—not to mention the high-tech tools used to explore them—could arise only because of military technologies developed not to explore the earth but to fight World War II and the Cold War. As the history of marine geophysics illustrates, modern science is not about individuals like me, it is about institutions like universities or corporations or government laboratories, organized to contribute to specific goals (like beating the Germans or the Soviet Union). These institutions are political, cultural, and historical creations that bound the actions of the scientists who work within them. From this perspective we can even recognize a gentle version of Lysenkoism at play in democracies. Politics has established such impossible scientific objectives as a comprehensive space-based missile defense system, and hundred-year predictive climate models. Much world-class research has been done by scientists happily staking a claim to the billions spent in pursuit of these chimeras. There is no natural relationship between science and democracy.

One of the joys of being a geologist is fieldwork, and one of the joys of fieldwork is that it takes you to places even the most adventurous recreational traveler would never go, precisely because you need to cover the turf, to walk up every streambed, every ridge line, no matter how unremarkable it may seem on a map. So you meet people you would otherwise never encounter. In 1983 I was mapping the mountainous interior of the island of Mindoro in the Philippines, and for two solid days a small family of indigenous Mangyans followed my field party at a distance of perhaps a hundred feet, as we covered ten or fifteen miles of a traverse up a river valley. At the end of the second day they allowed me to approach. Of course, we had no way to speak to each other (Mangyans have so many dialects that those from one river valley may not be able to speak to those from the next), but in the end I managed to figure out that they were not following us out of curiosity, nor were they monitoring our moves to make sure that we did not encroach on their turf or violate their women. They were hungry and wanted food. We gave them everything we could spare; in return, they let me take some family portraits.

The transaction was not without complexity. The father of this family indicated his desire for food by pointing to a member of my field party who was eating a handful of Skyflakes, the ubiquitous Philippine saltine knockoff. So I handed him one of the cellophane-wrapped packages that I was carrying in my field vest. He studied it with great intensity for a few minutes, turning it over and holding it up to the light, first close to his face, then at arm's length. It occurred to me that perhaps he was flummoxed by the wrapper itself, so I showed him the approved opening method: hold the edge of the package between thumb and forefinger of both hands, then tear open with front teeth. With this mystery solved, the family enjoyed what I presume was its first Skyflake experience.

The Mangyans were at the bottom of the technological heap. For the past fifty years or so, Filipino settlers from other islands had been clearing Mindoro's forests for wood and agriculture, gradually pushing the Mangyans deeper into the interior. Whereas the Mangyans generally kept their distance and sometimes even ran away when they saw our field party coming, the Filipino farmers were outgoing and hospitable, always insisting that we share a meal or spend the night or at least take the time for a cup of horrid, Sterno-heated Nescafé. The farmers were poor but, unlike the Mangyans, they weren't hungry. They spoke English, and some of the older ones had served in the U.S. Army during or shortly after World War II, so they didn't hate us—they were, on the contrary, extraordinarily kind.

I carried more on my back than they owned in the world, but they seemed much more content with their lives than I was, more generous and open than would be permissible or wise at home. My point isn't to romanticize. I'm sure they would have traded places with me in a trice. They had malaria, scabies, bad teeth, and hard lives. With a few exceptions (Green Revolution rice varieties, a transistor radio, cellophane-wrapped Skyflakes), they had little access to the fruits of modern science and technology. Water buffaloes provided the power for plowing the paddies. The farmers were human, and no doubt they figured that if they had some more money and stuff their lives would be that much better. But they were, quite simply, happy. So here is the question I want to think about: can the difference between their lives and mine be characterized in terms of some notion of human—as opposed to material or technological—progress?

Only a fool would reject the enormous benefits that science and technology have delivered to modern society. But it also seems impossibly myopic to talk about such benefits with reference only to arbitrary levels of technological achievement. Somewhere in the discussion needs to be an awareness of how science and technology—and the continual remaking of the world that they provoke—interact with and influence the sources of value in people's lives. My friend the subsistence farmer cannot just step from his shoes into mine while retaining all the attributes of his former existence. In promoting material progress, we must somehow believe that the societal transformation that the farmer has to experience, in giving up not just his poverty but his farm, his social networks, his craft skills, and his relation with the land and with nature, would itself be a source of human betterment.

One might ask: What does progress feel like? How do people experience the continual effusion of new knowledge and innovation that adds convenience and novelty to lives on an almost daily basis and makes possible the rising standards of living that characterize life in the industrialized world?

Japan was reduced to nationwide poverty by World War II. In the succeeding several decades it rebuilt its economy, its industrial base, and its scientific and technological capacity to become the second most powerful economy in the world, with, among other things, the healthiest population in the world—a population notably ardent in its consumption of the latest technologies, whether for boosting manufacturing productivity, enhancing the fidelity of recorded music and pictures, or improving the comfort, efficiency, and reliability of automobiles.

Throughout this entire transition period, from dire poverty to preeminent affluence, measures of subjective well-being among Japanese people did not change. The people did not get happier. This phenomenon is not uniquely Japanese—but it may be fundamentally human. Research on subjective well-being in countries throughout the industrialized world gives rise to the amazingly robust conclusion that over the past several decades of historically unprecedented scientific, technological, and economic advance, people's happiness and satisfaction with their own lives have not increased.[6] (Some researchers on the subject even believe they see evidence of a decline in happiness.) The idea that material progress, if it is to have some meaning, must somehow manifest in our own sense of well-being, feels sensible, but appears to be wrong. People get richer, and they own more and more stuff that takes advantage of the most recent advances in research and innovation. They live longer, healthier lives. All this and more is undeniably true. But people do not, on the whole, feel better about their lives, their prospects, or their relationships with others and with the world around them.[7]

How can this be? Researchers have offered several plausible hypotheses that cannot easily be untangled: First, perhaps material desires are not slaked by their satisfaction, at least not for long; getting what we want may simply cause us to aspire for something more or something else. Second, perhaps our absolute level of material welfare counts less toward our life satisfaction than our sense of how we are doing relative to those around us. A third, related possibility is that more material welfare in a society simply exacerbates competition for relatively scarce social resources (think, for example, about yuppies feverishly competing to put their kids in the best kindergartens). Fourth, perhaps the satisfaction of material needs simply does not account for much of what matters in life. Fifth, perhaps the process of pursuing higher incomes detracts from other important sources of life satisfaction, such as the time or ability to pursue meaningful social relations. Finally, perhaps the scientific and technological transformations that accompany increasing material welfare undermine social relations or other important elements of our lives.

If one or more of these hypotheses seem stunningly obvious, we may not unreasonably wonder why we structure our society in a way that encourages the pursuit of material welfare above all other activities, and why, in doing so, we eagerly, even aggressively, sacrifice the integrity of our social institutions and the possibility of achieving any sense of place in the world to the mindless procession of successive transformational technological regimes. We may, that is, wonder at our easy acceptance of the equivalence between material gain and human progress, an acceptance that blinds us to what is actually happening.

The town of Garm, in the central Asian country of Tajikistan, lies in the valley of the Surkhob River, flanked by the peaks of the Peter the First Range and the Tien Shan. Huge uplifted terraces of river gravel adorn the margins of the valley and attest that this incredibly rugged territory is still feeling the effects of the tectonic collision between India and Eurasia that began 45 million years ago and has created the Himalayan range. When Tajikistan was part of the Soviet Union, the government ran a seismological research station just outside of Garm to monitor and study the thousands of earthquakes that occur in the region.

By Soviet standards, the Garm facility was a special place, where scientists could live with their families and work in a relaxed and relatively comfortable and open atmosphere. There was even a swimming pool and a tennis court, although when I came to Garm in the summer of 1989, the pool was empty and the court was badly cracked, the net torn and sagging in the middle. On the other hand, by all reports there was no longer a KGB stooge there to monitor subversive behavior. This was the time of glasnost; the Berlin Wall would come down in another few months, and everyone in the facility was riveted by the live radio coverage of a meeting of the Congress of People's Deputies back in Moscow, where, for the first time, delegates felt free to speak openly and critically about the regime.

I was in Garm to do some reconnaissance mapping as part of a project to understand how the geometries of the local rocks related to the spatial distribution of earthquakes. As a visiting foreign scientist, I stayed with an American colleague in a special apartment that included hot water and private bathrooms—necessities for any visitor from the United States or Europe, but luxuries to all but the most privileged Soviets. Every afternoon, when we returned from our day in the field, the two beautiful young daughters of a Russian seismologist would bring us bowls of fresh cherries picked from a nearby orchard. At night, of course, we drank vodka and sang songs.

The Islamic region of central Asia now known as Tajikistan was brought under Soviet control during the 1920s. Soviet governance subjugated the formal authority of Islam and replaced it with the secular trappings and material benefits of a technocratic state. While Tajikistan was the poorest of the Soviet autonomous republics, every village had electricity, schools, basic medical care, and decent housing. It was hard not to feel that the Tajiks—especially the women and girls—were doing pretty well compared to their neighbors in Afghanistan. Russians and Tajiks mixed freely and apparently comfortably. The scientists who lived at the seismology compound were almost exclusively Russian, but Tajiks from local villages provided the necessary support as drivers, guides, technicians, and translators. A Russian scientist told me that this integration was skin deep. "If they could, they would come down from their villages at night and slit all our throats—except Khalturin's."

Khalturin seemed huge, of bearlike proportions. He had an aura of myth about him. If I recall correctly, he was the first seismologist to come to Garm, in the 1950s, long before our luxurious facilities had been constructed. He learned to speak Tajik and stayed year-round, through the rugged winters, setting up seismometers to monitor local earthquake activity. One particularly harsh winter, when snow blocked the roads and food was scarce in the valley, he survived by eating rats caught by villagers. In return for sustenance, he brought in medical supplies, including vaccinations for children.

On returning from fieldwork one afternoon, we found Khalturin waiting for us. He asked us to put on our nicest clothing and join him on a walk. We accompanied him for an hour or more, wending our way up a mountain road to a small Tajik village. As he walked through the village, people flocked around him, kissed him, touched him, laughed with him. He stopped to see a local cleric, and the two of them engaged in a vociferous and entirely lighthearted debate about some incredibly arcane detail of the Koran. As it grew dark, we moved to the teahouse and sat, along with perhaps a hundred other men from the village, first talking, then drinking tea, then sharing dinner, their nightly ritual. Women were not permitted to take part; they remained home with the children. Several years earlier, when Khalturin did bring a female American seismologist to the village, she was allowed inside the teahouse. This, as Khalturin explained, was no exception: all foreigners were simply that—foreigners, recipients, on the one hand, of traditional Tajik hospitality, but isolated by a uniform otherness that made no distinctions about gender.

Shortly after the Soviet Union broke up, civil strife broke out in Tajikistan, mostly pitting secular Russians who controlled the government against a coalition of opposition groups dominated by Islamic conservatives. Khalturin's extraordinary humanity was nothing in the face of such embedded sources of alienation and aversion. People who had worked together amicably were now enemies. The seismological station was abandoned. Garm's strategic location at a narrow point of a major river valley turned it into a war zone where many were killed. Khalturin moved to the United States.

The Soviet Union brought to Tajikistan many of the technological advances that made the twentieth century a more comfortable time for more people than ever before in history. It also tried to dissolve the cultural foundations of Tajik society and replace them with the omniscient authority of the modern secular state. The post-Soviet history of Tajikistan was a bloody reminder of the futility of that project. Certain aspects of the human condition are simply not curable. These have nothing to do with material well-being; rather, they have to do with the diversity of ways that people look at the world, and the profound obstacles to achieving reconciliation. Once the steel fist of Soviet authority was removed, the conflict between Tajik values and Russian values came into the open, and the process of technological transformation itself was revealed as essentially coercive.

Indeed, from the introduction of the iron stirrup, to the longbow at Agincourt, to Hiroshima and the Cold War, the compulsory nature of technological assimilation has been a central cause of social change. Kurosawa's film *Yojimbo* includes a scene in which the villain brings to town a new and overwhelming weapon to use against his samurai foes: a pistol. Although the villain is slain by the sword-wielding samurai hero, we now know that all samurai, and their code of living, are doomed. This doom can arrive in two forms: either through a refusal to adopt the new technology, which brings literal death, or through its acceptance, which brings the death of a way of being.

In modern market democracies, things are different. We have integrated the process of technological transformation into the very essence of our existence. A social system built on the value of consumption transmutes the human competitive spirit into an insatiable desire for more stuff. The effects of capitalist consumption on culture turn out to be even more transforming than the imposition of a technocultural regime by a totalitarian state, because capitalism is so much better at fostering innovation than are systems of central planning, and markets are so much better at moving innovation into society than are planned economies. The difference is supposed to be that in capitalist democracies, the transformation is consensual.

This is an illusion. Since the Industrial Revolution, efficiency improvements in manufacturing (freely adopted by factory owners trying to reduce costs or labor problems) have left tens of millions out of work and led to broad social upheaval. At the level of the consumer, apparently free decisions made by individuals—say, to buy a car—cumulate to transforming outcomes that no one anticipated or intended—say, the disappearance of cohesive neighborhoods; the separation of living place from workplace; the physical mobility of a complex society; the translation of mobility into sprawl and traffic. People move far from their place of upbringing; parents grow old away from children; more old people live alone. . . .

Science and technology have continually destabilized social and institutional relations as well as cultural norms. (Science, too—not just technology. Think of what Copernican astronomy, or Darwinian evolution, meant for a Judeo-Christian worldview that put the earth and its human inhabitants at the center of a meaningful universe. The truth sets some people free, while others it destroys.) Science and technology undermine, in other words, the careful relations among competing values that operate in any society, and that allow members of a society to have some sense of grounding and meaning. So it is not surprising that a subtext to the history of technical progress, from the printing press and telescope to weaving machines and nuclear reactors, is a tale of resistance.[8] Protests met the first English stagecoaches in the mid-seventeenth century because they signaled "the end of the noble art of horsemanship," not to mention the destruction of the saddlemaking trade.[9] At the dawn of the twentieth century, Edith Wharton, of all people, pronounced the icebox a "deplorable" innovation because of its contributions to "the extinction of the household arts."[10] A generation later, psychologist Floyd Allport, writing in *Harper's,* noted that "in our drive toward technological leisure we have now become too busy to keep up [our] old contacts. On the highway we used to meet men and women. Whether on foot, on horseback, in buggies, or even on bicycles, it was always persons whom we encountered. Now we do not meet individuals, but automobiles (and tomorrow, airplanes)—grim, impersonal machines which we try to crowd past, unmindful of our fellow-being concealed behind the glass and metal."[11]

This centuries-old tradition of opposition and dismay in the face of transforming technologies may begin to look comical in its consistency and futility. Despite all the displacement and dislocation—the uncontrollable amplification of change and mortal power too often wielded for purposes of greed or destruction, here we are now in our current comfortable situation. Can we feel anything other than grateful that the technology won out?

Two writers expatiate on science and technology. One sees a golden staircase, the other a hamster wheel:

> Could any man fail to reflect that our scientific civilization is the first one in history which has not been built on . . . human slavery, the first which offers the hope, at least, and a hope already partly realized, of relieving mankind forever from the worst of the physical bondage with which all civilizations have heretofore enchained him. . . . Within the past half century, as a direct result of the findings of modern science, there has developed an evolutionary philosophy—an evolutionary religion, too, if you will—which has given a new emotional basis to life, the most inspiring and the most forward-looking that the world has thus far seen. . . . [W]ar is no longer, in general, the best way to enable the fittest to survive. The Great War profited no one. It injured all the main participants. Modern science has created a new world in which the old rules no longer work.[12]

And this:

> A wider and wider experience with inventions has . . . convinced the more thoughtful that a man is not, as once was said, twice as happy when moving at the rate of fifty miles an hour as he would be if he were proceeding at only half that speed. . . . Science, though it fulfills the details of its promises, does not in any ultimate sense solve our problems. . . . We are disillusioned with the laboratory, not because we have lost faith in the truth of its findings, but because we

> have lost faith in the power of those findings to help us as generally as we had once hoped they might help. . . . And if we were compelled to sum up our criticism of modern science in a single phrase we could hardly find one better than this—that it does not seem so surely as once it did, to be helping us very rapidly along the road we wish to travel.[13]

It was the spring of 1928. The first writer was Robert A. Millikan, the Nobel Prize–winning physicist; the second was the humanist Joseph Wood Krutch, whose essays on nature foreshadowed the environmental movement by decades. Black Friday was eighteen months away; the vortex of the Great Depression would then circle for ten years before sucking much of the world into an apocalyptic conflict whose unprecedented scale of devastation was made possible by new technologies ranging from the high-altitude bomber to the gas chamber, and which was brought to a practical and symbolic end by, of all things, the most devastating technology of them all, the unleashed power of the atom. The succeeding forty-five years of Cold War were driven by humanity's efforts to figure out what to do about the ridiculously powerful weaponry it had gifted to itself. In the process, modern industrial economies unleashed wave after wave of transforming technologies, in transport, communication, manufacturing, information management, aeronautics, health care, and entertainment.

So much change, yet with a little tweaking of gender and syntactic conventions one could situate the sentiments of Millikan and Krutch in our own times. Here is the naturalist E. O. Wilson, who lapses into biblical cadences while finding in science an unavoidable optimism:

> Once we get over the shock of discovering that the universe was not made with us in mind, all the meaning the brain can master, and all the emotions it can bear . . . can be found by deciphering the hereditary orderliness that has borne our species through geologic time and stamped it with the residues of deep history. Reason will be advanced to new

> levels, and emotions played in potentially infinite patterns. The true will be sorted from the false, and we will understand one another very well, the more quickly because we are all of the same species and possess biologically similar brains.[14]

And Václav Havel:

> We have to abandon the arrogant conviction that the world is merely a puzzle to be solved, a machine with instructions for use waiting to be discovered, a body of information to be fed into a computer in the hope that sooner or later it will spit out a universal solution. . . . The way forward is not in the mere construction of universal systemic solutions, to be applied to reality from the outside; it is also in seeking to get to the heart of reality through personal experience. . . . In short, human uniqueness, human action, and the human spirit must be rehabilitated.[15]

Despite the incredible scientific and technological advance, the proliferation of concepts and machines, the global networks of information and communication exceeding any reasonable imaginings of the 1920s—despite all this, the tension remains unresolved.

And from one perspective this is fortunate. We must have some ideal of progress so that we don't give up on building the technological house of cards that we will need if we are to continue to evade the Malthusian trap. But the idea that continued scientific and technological advance moves us automatically and inexorably toward some better sort of society has to be abandoned because it presumes that the essential challenges of the human condition can be solved by changes in our material state. For this presumption to be true, science and technology would first have to replace the subjective, individual human sensibility with something homogeneous, predictable, and therefore nonhuman. Until that happens, we will continue to find personal meaning from our private lives, our culture, our work; from that particular slice of complex reality that we choose to try to understand; from our approach to that which remains beyond understanding. Science and technology are provoking radical changes in the balance and makeup of these and other sources of meaning, but science and technology will not resolve competing views of how to act or of what matters. Between what we know and what we are lies an ever-widening gulf.

Thus does the giddy 1990s vision of a globalized society of happy consumers fail not just for want of the right economic policies or political institutions, but from an irresolvable internal contradiction: the process of creating a world of happy consumers is also a process of wrenching social transformation guided by no shared vision of what we should be transforming into. The idea that we can innovate our way out of this contradiction is every bit as nonsensical as the idea that technocratic Leninism would secularize the Tajik tradition. Yet we continue to focus with laserlike intensity on increasing the rate of change by linking an ever more powerful science and technology capacity to the driverless chariot of consumerism and the worship of infinite growth.

The explosion of opposition to a variety of types of science and technology in recent years, from nukes to evolutionary biology to Bt corn to embryonic stem cell research—an opposition that is not captured by any conventional ideology—is a completely unsurprising response to this state of affairs. Material conditions change for what we like to believe are the better, but the process of change builds a growing disquiet. As we pass from the industrial revolution to the information revolution to the genetic revolution to whatever is bearing down on us now, "the modern mood is one of revolt, born of the growing impatience with limits that stubbornly persist in spite of all the celebrated advances in science, technology, and organized benevolence."[16]

Too much has been promised. The claims made on behalf of science and technology to a society already drowning in the fruits of its affluence begin to seem utterly beside the point. Rather than embrace a constant flailing toward the next level of cleverness, we could instead choose to ratchet down the pace of transformation, even just a little, to create some space for reflection, readjustment, and catching-of-breath, to consider what is worth preserving and where we want to go: to make the course corrections that could prevent the destruction of fishing nets. To do so would not mean we were Lysenkoists, Luddites, or Inquisitors from the Dark Ages. It would mean that we had finally become wise enough to accept responsibility for the consequences of our own ingenuity.

11

WHAT KINDS OF SCIENCE SHOULD BE DONE?

Philip Kitcher

Around the affluent world, many people devote their attention to issues of science and technology policy. They decide to invest available funds in encouraging research on global warming, or on AIDS, or on genomic sequencing, or on particle physics. Typically, their decisions are made against the background of institutional guidelines; occasionally, they will step back and wonder if the guidelines themselves need revision. Looming behind their inquiries, however, although rarely posed explicitly, is the fundamental question of my title: What kinds of science should be done?

To that question there are short and relatively uncontroversial answers. Scientific research should promote human understanding of the world; it should help us to alleviate human suffering and increase the quality of our lives; it should yield truth.

Despite the fact that these slogans are intoned at moments when piety seems appropriate, they are not much help. Such bland invocations provide little guidance when we come to hard questions about particular proposals for inquiry. Even before we confront specific issues, however, there are already tensions. How is understanding to be balanced against the possibilities of intervention and control? Can we claim to arrive at truths about nature, and do we need to do so to achieve our ends? And, perhaps most importantly, who are the people who hide behind the convenient first-person plural—the "we" whose lives are to be enhanced by the sciences?

Perhaps it was futile to start at such a high level of generality. A different way of approaching our question would be to list specific directions in which scientific research should now go: we ought to invest in programs that capitalize on recent achievements in sequencing technology (in developmental biology and in molecular genetics, for example), in efforts to extend the possibilities of quantum computing, in . . . [there follows a more or less lengthy list]. Prominent scientists in different fields will surely offer alternative lists, and from a synoptic perspective, each list may resemble Saul Steinberg's famous cartoon of the New Yorker's view of the United States. None of the list makers can reasonably be crowned as an authoritative figure. Nor will it do to let the conflict be resolved in simple head-counting, for we have no reason to expect that projects appearing on many lists are more worthwhile than those whose merits are appreciated only by an informed few. Further, there ought to be a serious question about whether a collection of scientists, even one that represents the current scientific community (however we define that), is authoritative with respect to the direction of research.

To obtain a serious answer to our question we need defensible principles, claims about the purposes of scientific inquiry, that can be applied to the current array of research possibilities to justify a ranking. My initial response was misguided not because it was overly general, but because it contained difficult concepts, left vague and undefined, so that it couldn't be articulated to bear on the specific decisions that confront both communities of inquirers and the societies in which they are embedded.

The failing just indicated is constitutive of the history of science policy. I'll point to just two prominent exhibits, both of them serious and important efforts to wrestle with issues about what kinds of science should be done. In the twentieth century's most influential science policy document, Vannevar Bush campaigned for public investment in scientific research on the grounds that "[s]cientific progress is one essential key to our security as a nation, to our better health, to more jobs, to a higher standard of living, and to our cultural progress."[1] In effect, Bush set the ultimate standards for funding scientific research in terms of what he took to be major components of human well-being—practical factors like security and health, as well as a much murkier ideal of "cultural progress"—without explaining them or considering how they were to be balanced against one another. The lack of articulation of those standards was crucial to his successful (but deeply problematic) defense of the need for "basic research," and for his masterly appropriation of a space within which leaders of the scientific community could obtain support for the types of inquiry that they took to be most interesting and important.

In similar fashion four decades later, an Institute of Medicine committee chaired by Leon Rosenberg, a group of acute, well-informed, and well-intentioned scholars, addressed the issue of whether there should be greater public input into biomedical research by listing general desiderata and suggesting that the criteria receive "balanced employment."[2] Lacking any articulation of their ultimate standards, the committee was able to offer only the most banal proposals for reform, urging, for example, that a small number of outsiders might be permitted to attend some discussions.[3]

The situation is dismal because analysts have failed to take up the most fundamental normative question about science: What is the institution of the sciences good for? In general, if our social institutions are to function well, it'll be because there's some understanding of what they aim to accomplish, and because that understanding informs the adaptation of means. Scientific research should be no exception.

Before grappling with the fundamental question, it'll be worth approaching our topic from another angle, one that'll expose some considerations we'll need later. Instead of asking what kinds of science should be done, we could have inquired after the projects that should *not* be pursued. Here we'd have gained a more immediate partial success.

Some lines of research are off limits because they require procedures that contravene the rights of human beings. Today nobody supposes that scientists should recapitulate the

Tuskegee experiment (in which black men suffering from syphilis were allowed to go untreated) or emulate the Nazi doctors in coercing subjects into damaging experiments—even though there might be important facts about the world that could be discovered only by procedures like these. Medical researchers may sometimes chafe at the decisions of Institutional Review Boards, which by law assess the ethics of all government-funded research involving human subjects, but their reactions reflect differences about the limits, not the existence, of the protections. There are, of course, more systematic disagreements. Some members of affluent societies protest research that involves subjecting nonhuman animals to pain; others believe that clusters of human cells must not be created for purposes of experimentation. There's general agreement that scientific research can't override the basic rights of individuals, and agreement about paradigmatic instances (as with Tuskegee and the Nazi interventions); but that leaves scope for dissension about which rights are basic and which individuals have them.

We might summarize these points by saying that there are moral constraints on the *means* that scientific inquiries should employ, and that some of these constraints are generally acknowledged while others are matters of dispute. Let's suppose (highly idealistically!) that we could clear up the residual disputes. Would that automatically yield an answer to the question with which we began? That is, is any project that survives the moral scrutiny of means an appropriate—or least a permissible—project for researchers to undertake? I claim that this isn't sufficient. Some types of inquiry are dubious not because of the *means* they employ but because of the *ends* at which they aim.

There are two types of cases. First are examples of scientific research that would deliver results likely to intensify human suffering without any compensating gain.* A longtime philosophical example, perhaps more forceful since September 11, imagines a line of inquiry that discloses how to create vast

*Here I adopt a hedged formulation because of the complex issue of whether coming to know uncomfortable truths is ever worthwhile. For discussion of this issue, see Kitcher, *Science, Truth, and Democracy,* chapters 12–13.

explosions from combinations of readily available ingredients. The second group consists of "sins of omission." In a world of finite resources, an individual society, or the entire species, can't afford to lavish time and energy on trivial projects when urgent needs are going unmet. Thus, even when a proposal for inquiry passes the test of meeting the moral constraints on means, it may still be judged inappropriate and impermissible on the grounds that the ends at which it aims are either bad (dangerous, destructive, and so forth) or else less good than those we might expect to achieve from an alternative use of the resources required for the inquiry.

The investigation of moral constraints on means is an important part of our task but can't be the whole.

What, then, are the benefits we expect—and receive—from the sciences? They divide into two main types, the *epistemic* and the *practical*. Vannevar Bush's list offered familiar subdivisions of the latter category, viewing practical benefits in terms of health, security, higher standard of living, and so forth, and alluding vaguely to the epistemic benefits under the label of "cultural progress." Many scientists, including probably Bush himself, would regret the rhetorical necessity of adding what's truly important to them—the epistemic benefit—as an afterthought to the practical. Indeed, Bush's most sustained argument for "basic research" delicately avoided developing the idea of "cultural progress," emphasizing instead the "seed corn" argument, in which pure scientific knowledge was touted as opening the way to future practical achievements.[4] We can't rest content with such evasion (effective though it was in founding the National Science Foundation). We need to understand clearly the nature of epistemic benefits, and to consider how such benefits might be balanced against our practical concerns.

Science is said to bring us an epistemic gain in that we are better off simply by knowing about nature, even before (or independently of) our use of scientific information to predict future events or to intervene in the natural world. The Newtonian explanation of the motions of the planets improved the human condition well in advance of any technological method of exploiting it. Perhaps the point can be recognized most clearly in those areas of knowledge that are (or, at least, currently seem) detached from practical intervention. When paleontologists reconstruct the evolutionary relationships among hominids, they teach us things that don't yield practical applications, and yet we take learning those things to be a gain. What exactly does this gain consist of?

One answer is that people benefit simply from acquiring a true belief about nature or, at any rate, a well-grounded true belief. Passing from a state in which one believed something false to believing the truth is a genuine advance—as is replacing the absence of opinion with true belief. Attractive as this proposal may be (and it surely underlies much of the rhetoric about the importance of "scientific truth"), it can't withstand serious scrutiny. That isn't because the notion of truth is incoherent or because the sciences can't aspire to attain the truth.[5] On the contrary, the truths about nature are too many, too various, and, for the most part, too insignificant. Take any modest region of space-time (the room in which you are currently sitting, during a period of an hour, will do). There are infinitely many languages that could be used to enunciate infinitely many truths about that region; virtually none would be worth knowing. With respect to any of that huge collection of truths, agnosticism is as good as correct opinion—maybe even better if it's a bad thing to clutter one's mind with trivia.

Sometimes it's said that the aim of the sciences is to provide us with a complete true story of our world. That can't be right. Some parts of the universe are completely inaccessible to us; regions outside our light cone are a prime example. Even with respect to the bits we can explore, the *whole truth* lies far beyond our cognitive capacity.* But this is no serious loss, for virtually all of the "whole truth" has no significance for us whatsoever. We can cheerfully accept ignorance of it. The view that science aims at the complete true story of the world is as misguided as the suggestion that geography seeks to provide a universal map, one that will reveal every feature of the globe. As that astute

*Assuming, that is, that the notion of the "whole truth" is even coherent.

logician Charles Dodgson (Lewis Carroll) saw, the only complete map would be the terrain itself.[6]

There's a distinction, then, between the truths it's worth knowing and those it isn't. Call the first sort the "epistemically significant" ones. The right way to formulate the position we've been considering is to say that scientific inquiry aims at generating epistemically significant truth and that replacing false opinion or no opinion with correct belief, within the sphere of the epistemically significant, is a genuine gain. So far, I think this position is a step in the right direction, but it's useless unless we can say more about the notion (effectively introduced as a label) of epistemic significance.

Many philosophers and reflective scientists have, tacitly or explicitly, assumed that there's a notion of epistemic significance that's quite independent of human beings and their evanescent interests. They've been beguiled by the idea that nature "sets an agenda for science," that there are specially revealing ways of dividing up the world and privileged statements that count as the "laws" of nature. The scientific enterprise aims to formulate the categories that "carve nature at the joints" and to enunciate the "laws." But all this is metaphor. Upon a sober appraisal, the idea of an objective "agenda for science" evaporates, and we're left with the conclusion that what counts as epistemically significant depends on us, on human cognitive capacities, and on the interests we happen to have.

I'll only sketch the argument here.[7] Early defenses of natural philosophy—and it's important to remember that the inquiries that came to be known as "the sciences" needed defense in the sixteenth and seventeenth centuries—introduced the idea of fathoming the laws of nature in an explicitly theological context. Copernicus, Kepler, Descartes, Boyle, and Newton all imagined that their research would reconstruct part of the divine rulebook used by the Creator in setting up the show, and that they would enable human beings "to think God's thoughts after him."[8] They provided an objective (human-independent) notion of epistemic significance, but hardly one that a contemporary secular vision is likely to endorse.

When the theology drops away, we're left with the idea that our universe operates *as if* it had certain fundamental rules, and these rules are the paradigms of the epistemically significant; the Schrödinger equation, a fundamental general principle of quantum physics, furnishes a plausible candidate. Now, it's plainly true that some parts of the sciences achieve greater generality than others, and that generality is valuable when we can get it. (After all, knowing general truths about nature often enables us to answer lots of questions in parallel fashion and to intervene in a systematic way.) But the popular image of a hierarchy of sciences arrayed as a colossal pyramid, with microphysics at the apex, is a serious oversimplification. Different sciences employ categories that can't be smoothly integrated with one another, and it's evident that biology, psychology, and the social sciences can't be derived as complex consequences of allegedly fundamental physical laws.* The multiplicity of the sciences reflects the fact that we've developed lines of inquiry about phenomena that are salient for animals like us, research projects that answer to our interests. Instead of thinking of science (in the singular) as concerned with nature as a whole, we're forced to conceive of the sciences (plural) as focused on bits and pieces of nature; and these bits and pieces are not, in any sense, all the bits and pieces there are, but the bits and pieces that matter to us.

A prominent symbol of the myth I'm trying to debunk is the notion of a "theory of everything." In a certain sense, there's absolutely nothing wrong with the aspiration. A deeper account of the properties of matter would be enormously valuable, partly because it would be epistemically significant (it would answer questions that now seem extremely difficult and perplexing) and partly because the history of science suggests that probing the microstructure of physical things yields dividends for further research (some of it practical). What's troubling is the name. The theory envisaged wouldn't answer *all* the questions that concern us; it would shed little (if any) further light on genetics or economics, paleontology or neuroscience,

*Indeed, some philosophers hold that chemistry and large parts of physics resist reduction to the allegedly fundamental laws.

and would probably leave many puzzles in physics and chemistry unresolved.

Let me suggest a different way of thinking about the sciences. Over the millennia, and especially since the seventeenth century, brilliant and dedicated people have developed bodies of knowledge that answer questions about which human beings are curious. The epistemic significance of the knowledge they've produced resides precisely in the fact that it resolves actual human curiosity. Because of our cognitive capacities as animals, certain features of the universe are salient for us, and particular questions arise; further, as we attempt to answer those questions, other issues evolve—the agenda of the sciences changes with our scientific discoveries and with the ways in which we apply knowledge to modify our environments. *The agenda is set by us.* The notion of epistemic significance depends on the ways our curiosity is aroused, which is in part a matter of the kinds of animals we are and in part a matter of our history and culture.

At this point, the notion of epistemic significance may appear to have lost its dignity, and, in consequence, those of a pragmatic turn may begin to wonder why we should bother with it at all. Wouldn't it be enough to specify the aims of the sciences in terms of the practical goals they enable us to realize, forgetting this ethereal stuff about pure knowledge? I answer that that is to adopt a one-sided vision of the sciences. We can no more ignore the fact that some great scientific achievements answer human curiosity than we can slight the impact that scientific knowledge has on human lives. There are three simple, but misguided, suggestions about the aims (and therefore about the proper pursuit) of scientific research.

A. The aim of inquiry is to discover epistemically significant truth.
B. The aim of inquiry is to discover practically significant truth.
C. The aim of inquiry is to discover practically significant truth, but, since history shows that epistemically significant

truths are a good means to that end (they "renew the seed corn"), seeking epistemically significant truths is an appropriate derivative goal.

If we could understand the notion of epistemic significance in terms of our higher (theological) duty, as Copernicus, Kepler, and Newton all did, then there might be some plausibility to A. But even if epistemic significance is understood as human-independent (in terms of the dubious idea of "nature's agenda"), it's clear that it can't have absolute priority over mundane needs that might be extremely urgent; under some circumstances, scientific issues that bear on the well-being of people whose lives are wretched can't responsibly be ranked behind the esoteric concerns of theorists. By suggesting that epistemic significance is a matter of human curiosity, and that our interests can evolve over time, I haven't thrown pure theory into the balance with applied sciences; it was already there. I've only removed some of the packaging that has enabled people to pretend that it wasn't.

Moreover, I don't repudiate A in favor of B or C. All three positions should be rejected. Focusing just on the practical (as B recommends) would probably be misguided and inefficient (as proponents of C will point out): often the best route to large practical gains down the road is to investigate quite recondite questions (think of Thomas Hunt Morgan's brilliant decision to postpone consideration of human medical genetics and concentrate on fruit flies). But C inherits a major error from B, for both proposals don't understand that satisfying human curiosity, answering the large questions that concern us, is an intrinsic good, not a mere means to filling our bellies or staving off disease.

I said earlier that the fundamental question was to decide what the sciences are good for. We can now begin to see why that question is so difficult. Even before we arrive at the topic of how to rank practical goods (the sorts of things that figure on Vannevar Bush's list before he gestures at "cultural progress"), any serious answer must weigh two types of goods that are very hard to reduce to a common measure: the value that accrues from finding a true answer to a large question that arouses our curiosity and the value that derives from improvements in human welfare. *We are in the balancing business, and it's not easy* *to see how to do—or even begin—the balancing.* (Nor is the problem of balancing solved—or even seriously addressed—by what is sometimes taken to be its solution, the division of labor between government and the private sector, with the former concentrating on epistemically significant research and the latter on practically significant questions.)

In fact, once we recognize the form of the problem and the sources of its difficulty, we ought to appreciate the many ways in which balancing is required. Provided we take seriously the idea that the sciences are for *human* good (not American good, not the good of intellectuals, not the good of affluent well-educated people), we see that it's going to be necessary to balance the interests of different groups. Further, there'll be questions about the schedule on which goods are provided: whether we should pursue strategies that are likely to be successful in the long term or whether some problems are too urgent to be postponed. An adequate answer to the title question must thus begin from a multidimensional balancing act.

So how do we do it?

You might think that at this point, after so much philosophical (in the pejorative sense?) maneuvering, I'd finally provide the answer. But I can't do that. Nor do I believe that any other people—even though they speak with the tongues of men and of angels—would be better qualified. For any single individual, however wise, it would be the height of arrogance to suppose that he/she could offer the objective ranking of multiple ends that would combine with an accurate picture of current research possibilities to yield a specification of the kinds of sciences we should do.

The aims of science, I've suggested, arise from human interests—from the needs, wants, and curiosities of social animals who find themselves in a particular physical and social environment at a particular stage in the development of inquiry. Properly conducted science would address these *collective* interests, and each of us has only a partial perspective. The problem is to find a way to reconcile and integrate these partial perspectives.

We know something about related problems, for they arise as the problems of democracy. Perhaps, then, instead of giving a direct answer to the question, it's possible to specify a procedure for answering the question.* But the most obvious procedure should provoke serious worries. Let's say that the standard set by *vulgar democracy* is to demand that the scientific projects pursued accord with the ordering of potential projects that would result from a vote among members of the population.† It's natural to fear that this standard will favor short-term practical inquiries over research of long-term theoretical significance, that the proposed agenda will be myopic and likely unfruitful. From the first discussions of the public role and public funding of research, scientists have shuddered at the thought of democratic control. Vannevar Bush's masterstroke was to argue for a framework of decision-making which ensured that the reins could never be pulled tight, that scientists would always have ways of pursuing the research projects that interested them.

The problem, however, lies not with the democracy but with the vulgarity. In balancing different—and seemingly incommensurable—concerns, most people know how to figure out a good way of proceeding. Most of us recognize that alternative ways of spending our time would yield quite different benefits, and we try to balance our activities so as to achieve a plurality of ends. Similarly, in joint projects with those close to us, we don't simply vote according to our initial preferences. We're eager to understand the full range of options, to come to appreciate how others see them and why they're inclined to rank them as they do. We use deliberation as a basis for eventual consensus, or if not consensus, for a decision with which each of the participants can live. These successes can inspire an attempt to delineate a democratic standard for scientific inquiry that will avoid the pitfalls of vulgar democracy.

*Here there's an obvious analogy with some predicaments in mathematics (and in the mathematical sciences) in which one doesn't know how to answer a question but can specify a way of finding an answer.

†I deliberately speak vaguely of a "population" here without considering how it is to be bounded. This issue will arise for us acutely later on.

Let me summarize, and present the form of my way of addressing the title question. While I don't think that the question can responsibly be answered directly, I do think it's possible to offer a procedure for answering it. The abstract structure of that procedure is as follows. First, we specify a way of setting a standard for proper inquiry. That standard must articulate the collective good to be achieved by well-conducted science, and it sees that collective good as the ordering of priorities and projects that would be generated from a particular type of democratic discussion. Second (and this lies beyond the scope of this essay and beyond my expertise), we try to identify social structures and institutions that will operate in a manageable fashion to produce, as reliably as possible, a ranking that would accord with that envisaged in the ideal discussion. If such structures and institutions are in place, we can then be confident that the kinds of science that are done will be those that should be done.

In the remainder of this essay, my principal concern will be in understanding the appropriate standard for proper inquiry, giving substance to the idea of a particular style of democratic discussion. But it's important, at this stage, to separate the standard we hope to meet from the social methods we employ in our attempt to do so. In presenting an *ideal,* a form of discussion whose results would specify the proper agenda for the sciences, I don't suppose that we should institute that type of discussion as a *method* for resolving policy issues. To conflate the two would be to confuse ends and means. The challenge for the philosopher is to provide an account of the end to be attained, since this is a necessary but not sufficient condition of improving our ability to achieve it. I undertake that challenge by specifying the end as the outcome of a particular type of discussion; once that challenge has been met, those with knowledge of relevant parts of social science can try to find ways of proceeding that would be likely to yield the specified end—and it's quite clear from the start that actually instituting an ongoing actualization of the ideal discussion would be far too cumbersome to serve! To return to a point made in the first section, the failures of many attempts to answer our title question can be traced to the idea that one can do the social-scientific part without a prior philosophical foundation. It would be a complementary error to assume that the philosophical work, the specification of the ideal, is all we need.

I'm going to sketch a notion of *well-ordered science.*[9] Well-ordered science undertakes an array of research projects, pursues them by particular methods, and applies the results to intervene in the world. The array of projects and the interventions conform to the list of priorities that would be specified in an ideal discussion; the methods satisfy the constraints that would be recognized in an ideal discussion, and are efficient at promoting the priorities. What needs to be explained is the character of the ideal discussion.

I start from the idea of a population of human beings with differences in initial ("raw") preferences, interests, needs, and situations. I'll consider two ways of delineating the population. In the *conservative conception,* the population consists just of the people in the society where the research agenda will be carried out. We might think of this population as a political unit—paradigmatically, one of the affluent democracies. In the *radical conception,* the population consists of the entire current human population. The reasons for entertaining two rival conceptions will become clear shortly.

In the ideal discussion, representatives of each of the perspectives are found in the population. At the first stage of the discussion, the representatives learn about the contemporary state of the sciences, about what significant findings have so far been achieved, about the sources of significance, and about the possible developments from the current position. As they receive this information, they modify their raw preferences, acquiring *tutored* preferences instead. (Intuitively, they come to appreciate possibilities of which they had hitherto been ignorant.) At the second stage, they come to learn about the tutored preferences of all the others, and they understand why the others hold the tutored preferences that they do. Because of their commitment to honoring the interests of others and to participating within a collective enterprise, they now arrive at *other-oriented tutored preferences.* At the third stage, they offer and discuss their conceptions of the individual rights that undergird the moral constraints to be placed on potential inquiries. Throughout the discussion, these proposed constraints are confronted with the existing scientific knowledge about the properties of potential bearers of rights (poor people in distant lands, future generations, postpartum human beings, fetuses, clusters of cells, animals, and so forth), and the representatives exchange reasons for adopting particular requirements. The third stage closes with an articulated set of moral constraints, either one that expresses a consensus view or one that emerges from a vote among fully informed rational agents committed to recognition of one another's points of view.

Our agents now determine what projects are to be pursued and what applications carried out by considering, for various feasible levels of resources, the bundles of projects and applications that could efficiently be pursued subject to the moral constraints, and how these potential bundles relate to the distribution of other-oriented tutored preferences. In the ideal situation, the commitment to cooperative action will be sufficient to reach a consensus position, in which a level of resources is assigned and a single bundle chosen. Failing that, the discussion may identify a collection of bundles, each of which is viewed as acceptable by all the participants, from which one option is chosen by majority vote. The worst outcome would be a determination by majority vote in a situation in which no bundle counts as acceptable for everyone.

This is a bare sketch of an ideal discussion, one that sees that discussion as definitive of the collective good to be achieved by the sciences. I've ignored all sorts of important questions about how potential projects are recognized, how their significance is explained, how disagreements on factual matters are to be handled, and how one judges efficiency.[10] Yet even without the details, I hope it's clear how my ideal offers an account of a collective good, seeing the judgments of fully informed, mutually committed rational agents as constitutive of that good.

It's important, however, to take up the issue I noted earlier. Should our population conform to a political unit (the conservative option), or should it be species-wide (the radical choice)? The difficulty is to satisfy simultaneously two plausible principles, one that recognizes the impact on the welfare of all human beings of the scientific research that is undertaken, and another that emphasizes the importance of commitment to collective action. (The radical option gives priority to the former, the conservative choice to the latter.) My attempt at compromise would modify the conservative option by supposing that, at the second stage, the representatives become aware of the raw needs and preferences of those who lie outside the population and that they are moved by a concern to take these needs and preferences seriously. The ideal discussion would thus take into account perspectives that are not fully represented in it, treating those outside the political community in the same way that it accommodates members of future generations. I am not sure that this compromise is adequate, and this is an important philosophical issue that deserves to be explored.

At this point, it should be clear why I claimed earlier that nobody is in a position to provide a direct answer to our title question, for no single individual has a clear vision of the full range of scientific accomplishments and their significance, of the prospects for further inquiry, of the grounds of differences about moral constraints, of the variety of raw needs and preferences, and of how the raw needs and preferences would be transformed in the kind of ideal discussion envisaged. Substantive answers to the question can only be guesses—partial, provincial, and ignorant guesses to boot.

Indeed, I think we can go further. Although we don't know what the outcome of the ideal discussion would be, I think we can be fairly sure that our existing ways of setting scientific priorities don't accord with it. I'll close with some brief, provocative hypotheses.

1. *Decisions among scientists aren't likely to produce well-ordered science.* If one had to pick one single group to decide on what kinds of science should be done, scientists might well do better than nonscientists. But we should expect individual scientific visions to be parochial. If those perspectives come into free and open competition with one another, the result would almost surely fall short of well-ordered science, for it would neglect many of the interests of outsiders,

and there's no reason to think that the pressures of competition would replicate the ways in which those interests would be developed in light of tutoring and other-orientation. In fact, of course, the competition among areas of science (and among subareas within sciences) is far from free and open. In the affluent democracies, it operates within a framework that bears traces of all kinds of historical accidents (think of the organization of the National Institutes of Health!). Further, as I'll emphasize shortly, the interests of remote people are almost completely ignored.

2. *The flaws of vulgar democracy are inherited by existing systems of public input.* The most obvious problem with vulgar democracy is that it votes on the basis of raw preferences. Contemporary public procedures for shaping the research agenda proceed from two sources: either government (typically responses to large perceived problems, sometimes slanted toward the constituencies important to the politicians involved) or special groups of concerned citizens, sometimes well informed about the particular issue they raise but quite ignorant about the entire range of scientific possibilities and about the diverse needs of their fellow citizens (let alone outsiders). There's a haphazard shouting of more or less powerful voices, each expressing, at best, some partial truth. Whether this process improves the results that would be achieved by leaving the scientific community to its own devices is an empirical issue that ought to be explored. (The exploration can be undertaken only in light of a standard, such as the one I've tried to provide in the last section.)
3. *The privatization of scientific research will probably make matters worse.* Government pressures and the clamor of interest groups sometimes, perhaps usually, have the advantage of representing those with urgent needs. Private investment in scientific research, ever more apparent in the biomedical sphere, is—in the long run and very probably in the short as well—tied to considerations of financial profit. The net result is likely to be a slighting of epistemic interests (and this is already a concern of many biological researchers) and

the orientation of inquiry to areas in which profits can be expected. In hypotheses 1 and 2, I've suggested that the decisions issuing from two large groups—the scientific community and the general public—are likely to be unsatisfactory on account of their parochiality. But it should be recognized that each of these groups has some connection with the ideal agents who work out well-ordered science; the scientists appreciate the significance of achievements at least within their own specialist areas, while members of the public recognize their own urgent needs. Entrepreneurs are at a further remove. Moreover, to the extent that the decisions respond to genuine needs, those needs will be raw (not tutored or other-oriented) and they'll be the needs of those who pay. Markets may sometimes work wonders, but there are systematic reasons for believing that, in the area of scientific research, the market will produce a travesty of well-ordered science.

In light of my first three claims, the fourth is hardly surprising.

4. *The current neglect of the interests of a vast number of people represents a severe departure from well-ordered science.* A well-known statistic holds that the diseases and disabilities that afflict more than 90 percent of the human population receive less than 10 percent of biomedical investment. I suspect that a similar pattern holds for science more broadly (although this deserves serious investigation). Whether we develop the ideal of well-ordered science according to the radical conception or according to my proposed compromise, it's plain that such a lopsided distribution ill-accords with the standard I've sketched.

   Contemporary genetic research furnishes an obvious example. With the ability to sequence whole genomes, strategies are readily available for developing vaccines against a large number of infectious diseases: very crudely, one can use the sequence information about a pathogen to identify particular forms of coat proteins and experiment with cocktails of immune stimulants injected into appropriate animal models.*

*Plainly there is no guarantee of success, but there is a significant likelihood that some major diseases may be treated in this way.

In the current research agenda, these strategies are grossly underfunded in comparison with the resources lavished on inquiries that have far less chance of success but that are directed toward maladies that affect a relatively small number of people in the affluent world. This is *not* to suggest that investment in research on diabetes, cardiovascular disease, and cancer isn't worthwhile, but simply to note an imbalance between that investment and the attention given to major infectious diseases.

5. *Our existing discussions of moral constraints are ill-informed and fruitless.* It's a common complaint among researchers that discussions about the ethical limits on their work are frustratingly fuzzy and inconclusive. Yet institutions for attempting to identify appropriate constraints, at least in the United States, are painstakingly open to rival points of view: debates about stem-cell research and cloning involve representatives of major religions as well as people who hope to achieve substantial medical benefits. What goes wrong in this case is not the failure to form an adequate pool of discussants but a pronounced inability to insist on tutoring. So long as parties to the conversation are allowed to assert their tendentious interpretations of texts whose authority is never challenged, and to avoid explaining how their claims are to be reconciled with established scientific facts, there can be no meeting of minds, and the well-being of uncontroversial rights-bearers (people with neurodegenerative diseases) will be slighted. An ideal discussion cannot, for example, rest content with the idea that a blastocyst—effectively a bundle of cells at a stage well prior to that at which the *pattern* for the central nervous system is laid down—deserves a protection that prevents scientists from striving to ameliorate the condition of people with, say, Parkinson's disease. Religious claims to the effect that protection is in order need to be subjected first to serious discussion of the basis for interpreting ancient texts as pronouncing on the issues, second to a demand for the explanation of why the texts should be taken as authoritative on

such matters, and third to a confrontation with the known mechanisms of fertilization and early embryogenesis. The aim of such interchanges, indeed the aim of the ideal discussion, is not to critique individual beliefs insofar as they affect only the life of the person who holds them but to achieve the accuracy and clarity of thought that ought to attend our efforts to promote and support the well-being of all. An ideal discussion cannot allow raw prejudices to block the claims of others to relief from their suffering.

This does not mean that religious perspectives and values can't inform ideal discussions. The point is that they can't assume veto power. Unless the moral authority of a text can be defended in open discussion, that text can't serve as the bedrock on which barriers to the well-being of people are erected.

Most of what I've offered in this essay is philosophy (and, I confess, it's philosophy that aims to be accessible at the cost, sometimes, of completeness and of exactness). Philosophy is often dismissed as irrelevant, a luxury for dilettantes. But the philosophical question I've tried to answer—What is the standard for deciding what kind of science should be done?—is absolutely crucial. Without an answer, we can make science policy only while blindfolded. And as my five hypotheses are meant to bring home, the results of doing so are not good. Doing better will require more than philosophy, for the standard must be supplemented with empirically grounded proposals about how to satisfy it. Perhaps, then, a philosopher should stop right here?

When I wrote my initial draft of this essay, I believed that was so. Subsequent discussions of its themes and proposals have convinced me otherwise. During those discussions, with intelligent and thoughtful people who wanted to understand how scientific research can promote the human good, I have often been impressed by what was not said. Like Sherlock Holmes, I was struck by the curious behavior of the dog in the night.* So I

*See "Silver Blaze" in Arthur Conan Doyle, *The Memoirs of Sherlock Holmes.* Holmes is able to disentangle the mystery of the disappearance of a racehorse by using the information that a dog in the vicinity did not bark.

want to extend my philosophical mandate by framing some questions that deserve empirical exploration.

Even when informed scientists and policymakers try to think broadly about research options and how they might promote the collective good (conceived after the fashion of well-ordered science, as described above), the visions are still partial and limited. As one advocate succeeds another, the focal challenge or opportunity swerves—from global warming to genetic privacy, nanotechnology to conservation biology, and so forth. There's no denying the importance of each of the topics, but there's little prospect of any ranking of *relative* significance. How can we do better?

I suggest that we need a place for a more synthetic view of the possible developments of our current sciences. Instead of jumping from one partial perspective to the next, we should create a space in which the entire range of our inquiries can be soberly appraised. I propose an institution for the construction and constant revision of an *atlas of scientific significance.* That atlas would contain systematic pictures of the ways in which significance accrues to projects in all areas of scientific research; its individual parts would trace the lines connecting the technical questions, to which scientists dedicate much of their lives, with the broad issues about which human beings are curious and with practical consequences for human lives. Those pictures—*significance graphs,* as I've elsewhere called them—would enable people interested in setting policy priorities to appreciate the full range of opportunities, to understand all the ways in which some inquiries might, given our present understandings, be expected to bear fruit.[11] The atlas would allow a more reflective view to replace the successive tugs from individual research areas.

By itself, however, the atlas isn't enough. It should be coordinated with serious efforts to learn how people, especially those whose voices are not currently heard, identify their needs. To the extent possible, that identification should itself be informed by presentation of the available research opportunities. Instead of guessing that a particular group—whether in a depressed urban area or in an impoverished society—sets its priorities in a particular way, it's worth investing in a serious effort to find out. In discussion, Rockefeller Foundation president Gordon Conway remarked that his field workers had been surprised to learn that African pastoralists had been less interested in vaccines for their children than in vaccines for their livestock—although once it was explained that if the goats died the people would all starve, the response made excellent sense. So I propose that the institution compiling the atlas of scientific significance work in tandem with an institution constructing a picture of human needs.

The partnership I've envisaged still leaves us short of well-ordered science, since there are reasonable doubts about the extent to which we can arrive at fully tutored preferences and, even more importantly, since the task of balancing various needs against one another hasn't yet been broached. But creating these more synthetic perspectives on possibilities and preferences is, I suggest, a necessary intermediate step, after which we can consider ways of mimicking the process of ideal deliberation. Imagine that social-scientific research can offer us an answer to the question "How can we design a feasible surrogate for the ideal deliberation over scientific opportunities in the context of a distribution of participant needs?," an answer that can be applied to any set of opportunities and any distribution of needs. Then that surrogate could be applied to the actual opportunities (disclosed in the atlas) and to the actual needs (disclosed in the index) to generate a simulacrum of well-ordered science. Even if the social-scientific question as I've framed it is too hard, we might still hope to answer a less ambitious question: What ways of balancing opportunities and needs would enable us to do better than we currently manage (perhaps by avoiding some of the problems I've raised already)? One obvious thought is that we could do significantly better than we now manage by making more salient the plight of people whose needs are currently ignored by scientific research, and by displaying some of the promising ways of directing research toward those needs. But my main concern here is to suggest how the atlas and the index might set the stage for inquiries into how to improve our decision-making.

I'll close by taking up an obvious challenge. Critics routinely object to proposals like mine on the grounds that scientific research is "unpredictable," that scientists do best when they follow their "hunches" (or, at least, the truly gifted do best when they can do that), that "directed" research doesn't produce the benefits at which it aims. In my experience, many scientists are confident that these claims are true. While they may well be correct, I find an interesting irony in the confidence, for the evidence is all anecdotal—it falls far short of the standards that the same scientists would demand of a piece of research in their own fields. In some instances, people have traced the ways in which an extremely beneficial consequence flowed from research that seemed to hold no such promise (often research that was exceptionally "pure"). But when we are reflecting on the opportunities for promoting the collective good, it's irrelevant that *sometimes* we can retrospectively discover these connections. What we need to know is the frequency with which large payoffs are quite unanticipated: How often does "serendipity" produce wonderful things? How frequently does "directed research" fail? These are open empirical questions. With the answers to these questions in hand, it would be possible to make an informed choice, to say (perhaps) that the verdict of well-ordered science would be to set aside a certain proportion of resources to enable those identified as "brilliant" (I'll waive the question of who does the identifying) to follow their hunches. The important point, however, is that we can't *assume* a priori that this is the best way to organize research for the collective good. If research does end up being organized in this way, it should be as the result of an enlightened democratic decision. In fact, what scholars of science and technology have already discovered suggests that the picture is far more complicated than the enthusiasts for "free creativity" and "scientific serendipity" assume, that epistemically significant questions (new forms of "basic research") sometimes emerge from planned attacks on social needs. So the challenge I've anticipated is not only a piece of armchair speculation, but probably wrong to boot.

A medical analogy may help to underscore the point. Sometimes, when someone is sick, there's conflicting advice. Various treatments are recommended, but nobody is quite sure what will work best. Yet we're typically not much moved by someone who tells a few tales about spontaneous recovery and suggests that, in general, we do best to let nature take its course. We can appreciate that this will be right in some cases, but we want to know just when to intervene and when to leave things alone. So, too, I suggest with scientific inquiry. Careful investigations in social science might enable us to see how to approximate the state of well-ordered science more closely, and they shouldn't be dismissed with the blithe assurance that we already live in the best of all possible worlds—especially when the global health gap between rich and poor makes it excruciatingly clear that we don't.

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THE HUMPTY DUMPTY PROBLEM

Mitchell Kapor

When I was the chief executive of Lotus Development Corporation in the 1980s, we faced a serious business dilemma about our flagship product, the Lotus 1-2-3 electronic spreadsheet. Its popularity at the time was so great that unauthorized duplication of the floppy disks on which the product shipped was becoming a serious problem. People were simply stealing our product rather than paying for it. My initial instinct was to employ technical measures to prevent, or at least make very difficult, copying the program from the diskette once it had been installed on a computer's hard drive. Given the state of the technology, however, we were unable to do so without also substantially impinging on legitimate uses, such as making a backup copy. User resentment was growing intense, especially among important corporate customers. We soon realized we were better off dropping technical copy protection measures entirely and relying principally on licensing and self-policing by corporations to protect our sales. This is what we did, and it became the norm for a very healthy personal computer software industry for almost a generation.

You will forgive me, I hope, if I regard the current controversies over music downloading as "déjà vu all over again." Yet the recording industry doesn't seem to get it. In the first decisive battle of the intellectual property (IP) wars, the Recording Industry Association of America prevailed in a lawsuit to shut down the fantastically popular Napster music-downloading service. RIAA's public rhetoric asserted that Napster users were stealing musical recordings belonging to the RIAA's member companies. Downloading is theft and is therefore legally and morally indefensible, the argument goes.

The RIAA won that battle. Napster's owners were forced to shut it down, but the larger war rages on. Napster's fancifully named successors KaZaA, Morpheus, and Blubster are more popular than Napster at its peak. The rapid growth of high-speed broadband connections now makes it feasible for those with the urge to download first-run movies as well as hot music. Users are beginning to do so at the rate of half a million per day. Movie studios have counterattacked, persuading allies in Congress to introduce a bill giving them the vigilante right to barricade users from the Internet and disrupt service if their property is being stolen.

Unquestionably, the widespread use of the Internet to download media content is disrupting business in the entertainment industry. It threatens not only profits but entire business models. That aside, disruptive technology threatening the economics of incumbents is nothing new. It was only 1976 when Universal Studios brought a suit to ban home taping of movies. Universal feared that movie-theater attendance would drop if the public were permitted to tape films for home viewing. The studio argued that since they owned the movies, they had a right to control their uses. They lost the case. But in an ironic and possibly precedent-setting development, far from putting the movie industry out of business, the VCR in fact spurred an enormous expansion of the market for movies through sale and rental of films on videocassette.

I am not arguing that movie and music downloading is an actual boon to the entertainment industry. I cannot forecast the impact of the Internet on the business of entertainment, and I do not believe anyone can. What lies on the far side of the technology chasm is fundamentally unpredictable. We do not know which companies may prosper and which may fail. Nor do we know which art forms may gain or lose an economic base of support. Prior to the invention of the phonograph, no popular music artist made a living from music. That is, there was no such thing as a professional nonclassical musician. Live performance alone was insufficient to guarantee a livelihood. When the phonograph made it possible to sell large numbers of a recording, however, a significant number of musicians could for the first time devote themselves to music.

What I do believe is that technology will continue to evolve at an accelerating pace. Users on the leading edge of technology can continue to be counted on to invent and find new ways of using digital media to satisfy their needs and interests. In the face of this, existing industries will seek to prevent encroachment, i.e., they will fight to preserve the status quo before embracing new technology. From this, new conflicts will be born, and new battles will be fought in the home, the marketplace, the courtroom, and ultimately the Congress.

The public has a major stake in the outcome of these battles. Most of us are neither members of the technocultural vanguard nor minions of Global 2000 businesses at war with each other. Neither group represents the public's interest. Public opinion polls showed that at the time free and arguably illegal downloading of music was skyrocketing, most people would have preferred to pay for a legal downloading service if it had been offered.

The practice of capitalism in this society dictates that business is going to act out of self-interest, first and foremost; and business's self-interest typically, regrettably, does not leave much room for the public interest. Both the defenders of the entertainment-industry status quo and the self-styled information anarchists are prone to extremes of rhetoric. This is too bad, for what is at stake is nothing less than the future of information and the public's rights to create, use, enjoy, and share it as it sees fit, without undue constraint or coercion. The outcomes will affect all of us. New laws will lay the foundation for an IP regime we will all have to live with. Clear thinking requires transcending partisan rhetoric.

To simply equate downloading songs and movies with theft, as media companies do, brings to bear all of our social conditioning about the sanctity of private property (which, at the extreme, is virtually a fetish in the United States) and the criminal nature of property transgression. It predisposes legislators to create harsh and punitive treatment for "intellectual property criminals." The Digital Millennium Copyright Act (DMCA) of 1998 for the first time made it a criminal act to publish information that might be used in a future act of copyright infringement. It is one thing to punish the transgressor for an act already committed; it is entirely another, which borders on Orwellian thought-crime, to criminalize the dissemination of information in the anticipation of its possible, not actual, use.

Dmitry Sklyarov, a Russian programmer, was arrested and carted off to jail when he came to the United States to speak about a program of his that restored disabled functionality in Adobe's eBook software. One could equally well say that the law has been hijacked by powerful media interests for their own benefit, as a species of domestic crony capitalism. In short, framing the problem as halting the theft of property and criminalizing user behavior is a self-serving distortion. Unchecked, it leads to bad law and the public's loss of rights to use media it has purchased—for instance, to lend it, to give it away, to copy it to another medium for personal use, and to understand how it works.

The development and adoption of new technologies changes the ground rules for the control/freedom of knowledge. With the spread of the Internet and the increasing pervasiveness of digital media, the changes in the ways in which knowledge and information are produced, distributed, and consumed has in turn upset the balance between freedom and control that characterized the prior era. A system in rough equilibrium has been destabilized, perhaps permanently. We may or may not be able to put Humpty Dumpty back together again, but we can see the cause of his fall.

What does it mean, after all, to "own knowledge"? Our society's notions of ownership derive from and are thus tied to tangible property (things one can actually touch), but knowledge is intangible. On the face of it, the very idea of intellectual property is a bit of an oxymoron.

What happens when society frames laws in a way that transfers and reapplies the concept of ownership from its original domain of the physical to the domain of the intangible? Consider the principal attributes of tangible property as they relate to ownership.

- Use of an item of property is exclusive. If I have possession of something and use it, your simultaneous usage is prohibited. If I have a lawn mower and am using it, you can't borrow it to mow your lawn.
- The value of an item is diminished by use. Employing material objects tends to use them up. If you borrow my lawn mower, you contribute to its wear and tear and use up gasoline.
- Exclusivity and diminishment of use are dynamics that create scarcity of resources. Protecting scarce resources by awarding exclusive rights of ownership obeys a certain cultural logic when it comes to tangible property: you may not steal what I have, nor even use it without my permission. The logic does not translate to the realm of the intangible, however, because information and physical objects are fundamentally different.
- My use of information in no way impedes your use of the same information. If I use a recipe to cook a meal, you can do the same. Recipes are not like lawn mowers.
- My use of information does not in any way reduce its value. If I cook a meal from a recipe, the recipe is just as valuable to you for cooking the same meal. In fact, under the concept of "network effects," certain kinds of information—for instance, the communications protocols used in the World Wide Web—gather value with more use.

Despite any rhetoric to the contrary, the justification for IP rights must therefore be based on something other than direct translation of the norms for ownership of physical property.

In the United States, IP protection is discussed in the Constitution (Article I, Section VIII), where Congress is given power to "promote the Progress of Science and useful Arts, by securing for limited Times to Authors and Inventors the exclusive Right to their respective Writings and Discoveries." It's a kind of social bargain. Creators of IP can be protected against certain uses by others in order to ensure that they do not lose economic incentive to create their works. Society as a whole is intended to be the ultimate beneficiary. This is the ultimate point of IP law.

Why do creators of IP need legal protection? Simply put, suppose an author labors extensively to create a work and have it published. The author depends on income from sale of the book for her livelihood. Now suppose there were no legal barrier to another publisher's coming along, making copies of the author's book, and selling it for less than the author's publisher is selling it for. Because the second publisher doesn't have to bear the cost of development of the work, but only its printing and distribution, it will be able to underprice the work and still make a profit. Obviously, if this situation existed, people would buy the less expensive version, it being equal in other regards, and the original author would be deprived of sales, royalties, and the ability to earn a livelihood through writing. If this were the case, society would be the loser, because books would not be written and ideas not developed that could benefit all of us.

Note that the granting of rights is not unconditional but instrumental—that is, as a means, not as an end in itself. IP rights should be enough to avoid creating a disincentive for the creation of knowledge works and, when necessary, to create sufficient incentive to stimulate the creation of new knowledge and information. The scope of IP protection has expanded steadily since the U.S. Constitution was written, as new technologies have produced new media such as sound recordings and movies, which have been afforded copyright protection. By the constitutional standard, writers and inventors get protection in order to serve a social purpose: the creation and dissemination of knowledge that serves the public's interests.

Too much protection is as bad as too little protection, a situation that is often overlooked in today's debates. Invention and creation do not occur ex nihilo, despite popular images such as a light bulb going on over a cartoon character's head. They require not only "first movers" but also "fair followers" who build upon and improve the ideas of others. The first electronic spreadsheet, VisiCalc, was a true creative breakthrough, but its successor, Lotus 1-2-3 (of which I was the original designer), which legally borrowed and improved on many of the ideas in VisiCalc (as well as adding its own), was a fair follower. If IP rights holders enjoy too much protection, innovation is crippled as it becomes impossible to build legally upon the work of others.

Note also that certain uses of IP by the public, such as fair use, have long been protected. The doctrine of fair use basically exempts certain user-directed activities from constituting copyright infringement, e.g., making a Xerox copy of a magazine article for personal use.

Overprotection is pernicious in that it can inhibit both the production and the consumption of knowledge. All this is something that we have lost sight of today. Businesses (particularly in the entertainment and media industries) usually assume that the purpose of IP rights is to protect their interests. This is just not so, despite widespread protest. Courts, too, have been swayed in this direction, however, both by the well-funded advocacy efforts of business and by the recent cultural tendency to assume that what business wants is what it should get.

But IP systems are not held in place simply because of legal strictures. The integrity of the system depends on a combination of conditions that support each other: the law itself, the technologies for the production and distribution of knowledge and information, and the cultural practices and norms of a particular time and place.

Copyright has roughly stayed in balance during the print era, from Gutenberg until the dawn of the computer age. With advent of intensive "digitalization," this traditional balance has been upset, threatening the system with failure. There are many modes of failure: economic threats to rights holders, decline in production of new knowledge, and even threats to research and academic freedom.

There is never 100 percent compliance with any legal regime. With respect to retail shopping, for instance, management tolerates "inventory shrinkage"—but only to a point. Technical protection measures such as inventory control tags are used as a means of enforcement. Widespread knowledge of these measures creates disincentives to steal.

Marginal infringements of copyright that are not economically significant have been long tolerated. The casual copying of books and magazines for college courses, for instance, was a long-standing practice. When such practices became institutionalized through the production of large numbers of standardized reading packets, the negative economic impact on publishers grew to the point where they could no longer tolerate it. Litigation was undertaken against the Kinko's chain, the result of which was an end to the practice of copy shops engaging in large-scale copyright infringement and its replacement by a system of obtaining copyright clearances that resulted in the restoration of royalties to authors and publishers.

In the digital era, practical barriers to copying have fallen as technology has enabled the marginal costs of reproduction and distribution over the Internet to drop to zero. Copying of cassette tapes was time-consuming and required materials such as blank tapes, which are not free, but trading MP3s over the Internet is instantaneous and costless. There's more copyright infringement because the opportunity (and desire to obtain the fruits of such activities) is now so much greater and there have not yet been countervailing laws, technologies, or shifts in norms sufficient to bring the system into equilibrium again.

IP rights holders have come forth with predictably heavy-handed responses: threatening to litigate, actually litigating, seeking passage of new legislation, and sometimes getting it. To date, this has been the basic strategy of the entertainment industry. Most recently, U.S. Representative Howard Berman has introduced legislation that would grant copyright holders near-immunity from the law while barring Internet access to citizens suspected of possessing illegally obtained content.

When a new technology service that has immense appeal (such as Napster) emerges, and no comparable service is offered on a commercial basis, it is not surprising that it is widely adopted. Napster's appeal lies in its ability to immediately obtain almost any recorded music. The lawsuits that shut down Napster have not been successful in preventing the ever more widespread adoption of similar services such as Morpheus and KaZaA, nor are they likely to be. The commercial music-downloading services just launched have not as yet offered a service comparable to what people can now do for free. Until recording companies can match Napster's breadth of selection and ease of use, one can expect poor adoption and continued reliance on alternatives. As I have said, consumer surveys show it is not a matter of money.

In fact, the first generation of downloading services backed by recording companies, such as MusicNet and Pressplay, offer less utility to consumers than they enjoyed in the predigital world. A record, cassette, or CD, once purchased, was permanently available for usage, while downloaded digital songs are typically not sold but rented. Failure to pay the monthly subscription fee causes the recording to disappear. Previously, personal copying of music legally obtained (e.g., from an LP record to a cassette tape to play in the car) was clearly permitted under fair use doctrines, but it is impossible to copy a downloaded song to another device. In the face of the failure of such first-generation services, the reintroductions of these and of new services brought to market in 2002 are more liberal in what they permit consumers to do, such as allowing copying to portable MP3 players, though still more restrictive than consumers are used to. This trend is a hopeful sign that recording companies are beginning to understand it is worth offering a product consumers actually want.

As of this writing, however, no one has offered a commercial service with the combination of broad selection and freedom of use that could enable it to be the basis of a successful music-downloading service. If that does happen, it may bring a truce to this era of mutual escalation. If not, the results are wholly unpredictable. In one extreme scenario, record companies themselves become irrelevant as artists and their audience interact directly. Such a seemingly remote scenario becomes more likely in the absence of a modus vivendi between consumers and media companies.

Instead of genuine innovation through new services and business models, the entertainment industries have tried to protect status quo business models through the passage of legislation such as the Digital Millennium Copyright Act, but in so doing have upset the traditional balance between the rights of

IP creators and the public's right to determine their own uses of those works.

One of the purposes of the DMCA was to provide legal ammunition against commercial piracy of entertainment products such as DVDs and audio CDs. It does so through the inclusion of an anti-circumvention clause, which prohibits the use of technical and other means for purposes of avoiding copy protection measures used to inhibit unauthorized duplication. Producers of digital media such as DVDs use specialized encryption techniques to inhibit the unauthorized making of copies (e.g., of new movies). The scope of such piracy, especially outside the United States, is very large.

In general, there has been a trend toward globalization of IP protection through the adoption of treaties via the World Intellectual Property Organization (WIPO). These efforts are driven largely by the economic interests of large multinational corporations, especially in the fields of media and entertainment. Members of the World Trade Organization are now obligated to adopt IP regimes consistent with WIPO. In effect, nations that wish to be players on the world economic scene must bring their IP laws into line with the most restrictive policies in the WIPO framework.

In 1999 a Scandinavian high school student helped to develop a program called DeCSS, which provided owners of Linux-based personal computers with a way to play DVDs on their own computers. A commercial DVD player contains a special chip used to decrypt the content of the DVD. A computer with a licensed DVD player has the same program in software. A Linux computer, not having a chip and not eligible to license the software (the license requires that the source code remain secret), cannot normally play a DVD. To solve this problem, the student figured out the encryption system used on commercial DVDs and found a way around it. Then he posted the program on the Internet for others to use.

The DVD industry sued one of the subsequent publishers of the program under the DMCA and won. A U.S. Appeals Court has prohibited the distribution of the software.

Should the producer of the DVD have this degree of control over how its products are used, or does the legitimate purchaser of a DVD have the right to enjoy the product she has bought in a way of her own choosing—for instance, by playing it on a Linux-based computer?

Since the DeCSS software itself consists of an algorithm (a written series of steps that perform certain actions), the question comes down to whether the algorithm should be banned. The courts have emphatically said that this kind of writing is not legal, an opinion that is of great concern to civil libertarians because distributing the algorithm amounts merely to publication, which is a matter of free speech—a fundamental civil liberty. Contrast this with the fact that while making bombs is illegal, publishing or distributing a book on how to make bombs is not. The DMCA crosses a fundamental line and sets a dangerous precedent.

A further and more troubling example in this direction has to do with the security system proposed to protect recorded music. The Secure Music Digital Initiative (SDMI) was an effort, since abandoned, by the music industry to develop technical standards to encode digitally recorded music such that the industry could entirely control the circumstances under which the music could be played and enjoyed.

As part of its development of the SDMI, the RIAA issued a challenge to the computer security community to attempt to break the security scheme. They announced a contest in which participants had to agree to submit their work to the contest sponsors. Professor Edward Felten of Princeton University and students of his found weaknesses in the scheme, but Felten chose not to submit his work; instead, he sought to present his scholarly, technical findings in public. The RIAA responded with a letter threatening to prosecute Felten under the DMCA. Although the RIAA later claimed they had not meant to make such a threat, the damage had been done and the real issue was exposed: researchers now face the possibility that publication of their work may be suppressed by commercial interests concerned that such work is inimical to their self-defined economic interests. The academic community is alarmed by this prospect, which, given the initial failure to gain injunctive relief against future maneuvers of this type, remains of grave concern.

Finally, in this arena, there is legislation pending in Congress—the Consumer Broadband and Digital Television Promotion Act (CBDTPA)—that would require computer and electronics manufacturers to include digital watermark technology or other copyright-protection technologies in the production of computers as well as a myriad of other types of devices, including electronic cameras, wristwatches, electric pianos, televisions, ATM machines, cell phones, home security systems, and medical equipment.

Many legitimate uses of technology would be prohibited or impaired by such requirements, including research in computer science and computer security and the basic teaching of computer science and programming in high schools, colleges, and universities.

The process by which new IP legislation is developed in the United States is one dominated by extremely well-funded lobbyists representing the economic interests of affected industries. Opposing forces, represented by academic, library, and civil liberties communities, are vastly outnumbered and outspent. Is this kind of contest and this array of forces the way a society ought to be developing new policy?

Can Humpty Dumpty be put back together again? In one of the most accessible analyses of the issues to date, legal scholar Lawrence Lessig argues in his book *The Future of Ideas* that the Internet has now produced a counterrevolution in which the Net's original virtue, as a commons in which ideas and information can be fruitfully developed and distributed by anyone to anyone, has been challenged by commercial interests using both technology and law to restrict uses of the Net to those compatible with their current business models.

How will this sort out?

In one scenario, the breach between the entertainment industries and consumers will be healed when, for instance, the recording industry offers music-downloading services that meet with great consumer acceptance and that are profitable for their providers. Legislative attacks on the free exchange of information will cease as the business interests of the recording industry are once again met.

Another view is that an irreversible shift has occurred, rendering the scenario above impossible, in which case it is unclear who will ultimately benefit and who will lose. If music is much more freely available, it might actually expand the market for commercial sales rather than contract it, by virtue of stimulating overall demand. This is not as farfetched as it might seem. For years the Grateful Dead, Phish, and other successful musicians and bands have encouraged their audiences to tape live performances and freely share those tapes. Meanwhile, sales of the ever-growing catalog of commercially released live recordings of the Grateful Dead have steadily increased, not decreased, making them one of the most financially successful bands in history.

Changes have been suggested that could mitigate the conflict between the consumer's desire for access to music and the recording industry's business interests. In *The Future of Ideas,* Lessig suggests that there could be other means besides copyright for music recordings, e.g., compulsory licensing, which would provide compensation for rights holders yet allow works to be freely distributed.

Further, Lessig makes the case that content rights represent but one dimension of a larger struggle over freedom versus control in the Internet era. The underlying infrastructure that enables the production and distribution of information in digital form, including the fiber-optic networks of the Internet, the wireless spectrum, and computer and network operating systems, should all be considered in a policy framework that ensures everyone has equal access to that infrastructure.

The struggles over the commercial future of recorded music are just one initial skirmish in a multifront engagement, and this skirmish is far from over. Continued exponential increases in technical capability (in storage capacity, most notably) are going to up the stakes. Today's hand-held Apple iPod can store 1,000 songs. In seven years, it will be possible to hold perhaps 100,000 songs, or roughly the entire corpus of commercially significant music of the past decades. By the time the generation of teenagers raised on Napster are running the entertainment industry, all of Hollywood's historical output, from the silent era to the present, will be squeezed onto a single disc.

In the predigital era, naturally occurring limits on time, money, and labor constrained the duplication of created works. In the era of ubiquitous networks, the natural constraints largely disappear. Importantly, in this sphere as with traffic and taxes, the self-control and self-restraint exercised by people themselves in the absence of surefire enforcement will come to matter more and more. Norms about what is proper and what is not have clearly begun to shift as we move from an era of information scarcity and expense to an era of the plentiful and the cheap.

My hunch is that consumers will believe in and insist on significant freedom to use media as they see fit, and law and practice will have to respect this. People are going to download music, no matter what. Unpopular laws that attempt to limit usage by directly constraining technology and its uses, and that are not supported as behavioral norms, just will not work. The legal component of any workable solution must have the moral support of the majority or we will have Prohibition of the digital era. The wise long-term course for business will be to take advantage of changing norms and practices, not resist them. To put it bluntly, the only hope for the entertainment industry lies in showing flexibility and seeing whether new sources of revenue, such as commercial downloading services, will replace losses in current sources, e.g., from the diminishing sales of recorded CDs.

The chief practical barrier to serious consideration of confronting the unfolding implications of IP and technological change is the political dominance of a narrow business ethic of short-term self-interest and the consequences that flow from it. As a successful businessperson, I believe that corporations ought to focus more on their long-term self-interest (which is often the opposite of the short-term), even if it means defying conventional norms and expectations.

Faced with the irresistible combination of radical changes in both technology and consumer preferences, businesses have a do-or-die choice: stick to the old business model on the belief it will survive and thrive, or abandon it and strike out in new directions. The sheet music business, which dominated the entertainment media in its day, never recovered from the introduction of the piano roll. Minicomputer companies such as Digital Equipment Corporation, Wang, and Data General did not survive the transition to the personal computer in the 1980s and 1990s.

It is tempting for management to hang on to the old model and try to forestall change, much as record companies and movie studios are inclined to do. But to do so is to yield the initiative to other, less risk-averse, more nimble businesses that have learned to embrace change, not prevent it. Whether the record companies and movie studios gain or lose in the years to come, whether they live or die, is much more under their control than might be imagined. Change is hard. Successful businesses resist change, but the most successful of all, such as Microsoft, recognize the inevitability of disruptive change and strive to be its beneficiary, not its victim, as did Gates and company in making the transition from the world of individual personal computers to the connected world of the Internet.

The entertainment industry should recognize that its real self-interest is in embracing change. It should remember, as well, to do so without alienating the customers it ultimately depends upon or trampling on the basic norms of the society that allows it to flourish in the first place. In this regard, a commitment to operating within a framework respecting the principle of user rights would be a good place to start.

13

WHO OWNS YOUR DINNER?

Carl-Gustaf Thornström

In the early 1990s, I started a small computer firm that produced visual scenery software for PC-based flight simulations. My firm released its first commercial software version in 1992 after roughly 3,000 hours of unpaid design work. Five years later, having released four updated versions, I had to cease operations because I was unable to protect my copyright and the prospects of reclaiming some financial benefit for my work investment. We had sold around 560 legal copies of the software program, but for every legal copy sold, up to thirty pirate copies had been made, according to retail trade shop estimates. The market was flooded, and the result was significant financial loss for my firm. Even more damaging to our prospects, we were unable to attract the investment capital that we needed to adapt the program to the Windows environment—the logical next step in expanding our market. So intellectual property rights became something very real for me.

Of course, the issue of knowledge ownership goes far beyond this simple story. Rising living standards in society are always related to the socialization and broad use of technical innovation, whether in mechanical inventions (such as the water wheel or steam engine) or in the application of new concepts and discoveries about nature (such as Newtonian physics or the laws of thermodynamics). To encourage useful innovation, and thus to catalyze rising standards of living, society has found different ways to compensate innovators—whether individuals or institutions—for their efforts. Normally this takes place through the granting of some kind of time-limited exclusivity over the innovation. In today's world we use intellectual property rights (IPRs) in such forms as patents, copyrights, trademarks, and plant variety protection as an incentive for innovating.

But there is another side to the intellectual property (IP) story. Who determines what should be protected and what should be left in the public domain? The boundary between what is public and what is private is not found in nature; it is determined by people. As science, technology, and innovation have moved deeper into the realm of genetics, this question of ownership becomes extraordinarily complex and raises deep issues of political, economic, and moral import.

In 1976, John Moore, a Seattle engineer, was diagnosed with a rare and deadly cancer called hairy-cell leukemia. In an apparently successful effort to reverse the disease, doctors at UCLA Medical Center removed Moore's spleen. They also, unbeknownst to Moore, extracted and cultured cells from his spleen and eventually applied for a patent for the resulting cell line, based on its special ability to produce certain types of white blood cells. The patent was granted in 1984 and assigned in part to the pharmaceutical giant Sandoz. Its commercial potential was estimated in billions of dollars. Moore sued, claiming, in essence, that a part of his body had been stolen. The case eventually went to the California Supreme Court, which ruled against Moore: he did not have legal ownership of the genetic products of his own body.

Such questions of genetic ownership are becoming increasingly significant. In 1998, Iceland signed a contract with La Roche and deCODE Genetics to commercialize the genetic information of all Icelandic citizens, with the ultimate goal of developing new pharmaceuticals for treating, for example, heritable diseases. In 2001 Myriad Genetics claimed a proprietary monopoly over the marker genes that indicate a higher risk of female breast cancer. Biobanks contain samples of human genetic material (contained in blood, tissue, sperm, embryos, and the like) that are used by scientists in private- and public-sector research. Among other applications, the samples can be used to identify proteins that code for promotion of and resistance to human disease pathogens. Information contained in biobank samples can also be used to determine a particular individual's predisposition to a variety of heritable diseases.

The integration of countless new developments in human biotechnology with IP regimes and market economics suggests a range of plausible scenarios on the near-term horizon. One of these—already realized on a limited scale—is private biobanks for trade-secret research in pharmaceuticals. The banks do not require prior informed consent from the people who have donated the blood and tissue. Genetic material and genomic information from human beings thus become commodities.

Commercialization of genetic information has implications for fundamental social and ethical issues, ranging from protection of human dignity to the right to privacy, that are only now beginning to unfold. Stem cell research and the trade in human embryos have already announced themselves as extremely challenging and provocative issues.[1] The way we draw the line between what is private—what can be owned as private intellectual property—and what is public will influence social welfare, human rights, and democracy. The issue, in the end, is control of knowledge: who has it, how much they have, and how broadly they can exercise it.

The growth of information technology and biotechnology in the 1980s and 1990s offered the world new and powerful tools to communicate and exchange information and begin to control life itself. In the late 1990s nanotechnology promised yet another innovation revolution that could transform life and society. Among many other ethical, political, and economic considerations, the continued acceleration of technological innovation is changing the power relations among multinational corporations, sovereign states, the private sector, the public sector, and the individual and society. We have no idea where these changes are leading.

The new technologies of the past few decades are characterized by, among other things, their knowledge intensity and high development costs. Billions if not trillions of dollars are needed to energize and deploy the research and development (R&D) infrastructure that can create and tap these new opportunities. Grand capital, mostly available in stock markets and the private sector, must be mobilized. To access these large amounts, investors must be guaranteed a likelihood of reasonable economic returns. The current notions of IPRs—the way we define and enforce them now—gives an innovator a time-limited monopoly on the technical application of an idea. Without that protection, as illustrated by my own doleful tale of business failure, innovation can be stifled.

Modern IP regimes emerged in the late nineteenth century to protect industrial innovations such as the radio, telegraph, gramophone, and light bulb. During the last few decades, IPRs have been applied to biotechnology, especially via breakthroughs in genomics research, and thus have expanded into life itself. Conservative estimates suggest that between 2002 and 2010 the global market for pharmaceuticals, seed, and human tissue will increase fourfold, fivefold, and twentyfold respectively. This means at least a $2 *trillion* market in 2010. The true figures might turn out to be much lower or higher, but the point is indisputable: there is big money in high biotech. The private sector must of course be able to reclaim its investment in research and development. The rules of the game, however, are extraordinarily complex, and require close and further scrutiny. For biological material alone, there are now in place half a dozen different IP regimes that affect use in the public domain.[2]

The expansion of IPRs into the depths of biology during the last two decades has created new legal boundaries that determine access to, and exchange and use of, genetic resources and the results and products of genetic research. In the life sciences we are now talking about enclosing the genetic commons—attaching IPRs to genetic material that was formerly a public good, that is, free for the taking or at least not owned by anyone.[3] We even have a new concept to characterize this emerging sociopolitical reality—proprietary science—in which access to and exchange of scientific results are subject to control under IP regimes.[4] In the wake of such changes, concepts such as public goods and public domain may have to be redefined.

As we assign rights over biological information to private corporations, we are taking goods out of the public domain and placing them in private hands. This in turn shifts the balance of power over the use of genetic information from sovereign states to multinational corporations and from the public to the private sector. Indeed, of the hundred most important actors in the global economy, about half are multinational corporations.[5] By 2010, genetic resources could be involved in as much as 40 percent of global trade.[6]

At the same time that I was trying my hand in the software business, I was also in charge of the unit for research funding in rural development and the environment at the Swedish Agency for Research Cooperation with Developing Countries (SAREC). During this period, IPR issues were attracting increasing controversy and political attention in international fora such as the Food and Agriculture Organization of the United Nations (FAO), the Consultative Group on International Agricultural Research (CGIAR), and the multilateral negotiations leading up to the Convention on Biodiversity (CBD), adopted in 1992 at the Earth Summit in Rio de Janeiro. We in SAREC worked to raise awareness about the emerging problems surrounding ownership of genetic resources, including challenges to the production and use of international public goods, and threats to farmers' rights to knowledge and practices acquired and developed through their own informal selection and breeding for food and agriculture.

In early 2001 these issues seemed, momentarily, to culminate when the international media reported a scientific breakthrough to fight hunger and poverty. The golden bullet was GoldenRice, a transgenic (GMO), pro–vitamin A rice that would help hundreds of millions of poor people in the tropical South overcome vitamin A deficiency. Publicity surrounding GoldenRice claimed this breakthrough as proof that advanced biotechnology could benefit poor farmers and consumers. In fact, previous advances in agricultural biotechnology, such as "terminator technology," designed to prevent nonhybrid crops from producing usable seeds, had provoked heated public debate and international controversy over the environmental, socioeconomic, and health implications of GMO technologies. But GoldenRice, whose development had been funded by the public and nonprofit sectors (mainly the Rockefeller Foundation) with some additional private sector contributions, seemed to deliver a knockout punch to the critics of ag-biotech. How could we in the North deny poor people in the South access to GMO seeds that would improve their lives?

The question, however, is not simply about a genetically engineered plant. There are as many as seventy different intellectual properties in each grain of GoldenRice, and they are owned by some forty different companies and public institutions.[7] Until the international agreement on Trade Related Intellectual Property Rights (TRIPS) is fully implemented on a global scale, each of these IPRs remains territorial, that is, valid in some countries but not in others. The very interesting analysis of GoldenRice by Kryder and colleagues points unavoidably to the practical conclusion (not given in the study, of course) that the gene constructs for vitamin A access in rice could appear in plants in the fields of poor farmers only if the forty owners of the IP gave up most of their proprietary claims.[8] Indeed, in the shadow of the controversy over developing-country access to HIV/AIDS drugs, most IP-owning companies did bow to political pressure in 2001 and agreed to offer free licensing of their claims in the three GoldenRice gene constructs. But this happy scenario will not be easy to replicate.

How will the traditional practices of breeders and farmers be affected by the expansion of IPRs into the plant genetic commons? Over millennia, farmers have saved seed to select, experiment with, and propagate for the next farming season. This tradition is acknowledged by FAO treaty as “farmers’ rights.” With proprietary seed—that is, seed protected by patent or other IPRs—farmers won’t be able to experiment on their own. Selecting seed for the next planting may be controlled and even prohibited.[9] To avoid IPR infringement, the breeder and the farmer must obtain approval from the owner of the protected seed.

For patented seed, farmers normally need to sign a contract specifying the seed amount and the land area to be planted. The saving of seed for the next season is typically subject to a royalty payment. If the patented seed contains several patent claims (as GoldenRice does), the seed merchant may enter into agreements with patent holders to apportion the royalty incomes. For example, in the European Union, farms annually producing less than ninety tons of cereals equivalent (approximately thirty to thirty-five hectares of cultivated land) may save seed for the next planting. Overall, proprietary seed (especially patented seed) puts the farmer in a position of dependence on seed merchants. In agriculture in the South today, only about 15 percent of the annual seed used is commercial, and thus certified property. As this proportion increases, national food sovereignty in poor countries may be threatened.

Even in the mid-1970s most genetic resources were free international public goods—no one owned them, mainly because there was no way of preventing others from using them too.[10] But that all began to change in 1980, when the U.S. Supreme Court ruled that General Electric microbiologist Ananda Chakrabarty could receive a patent for his creation of an oil-eating bacteria made through cell fusion. IPRs thus began to expand into the depths of biology, starting with engineered life forms such as Chakrabarty's bacteria, but quickly moving to encompass natural biological materials, such as John Moore's cancerous cell line. At the same time, and in response to this expansion of the realm of IP, communities in the South were arguing for legal protection of traditional knowledge for the use of genetic resources such as medicinal plants, fearing that their natural heritage could become subject to privatization and corporate ownership. The result of these competing interests has been an increasingly complicated genetic policy landscape, where laws, regulations, and treaties conflict with one another and winners and losers are still being sorted out.

Consider the 1992 Convention on Biodiversity, which gave nations sovereign rights over their genetic resources. Under this treaty, when a multinational corporation wants to use a unique genetic resource in a product, it may have to obtain prior informed consent (PIC) from the nation of origin. And if that corporation wants to establish IPRs over genetic material, it will, in some cases, have to supply a certificate of origin (CO) to prove that the material is legitimately subject to protection. Biopiracy is the term assigned to violation of these requirements, and indeed developing nations such as India, Bolivia, and Peru have made accusations of biopiracy against U.S. corporations (including RiceTec and Monsanto) that have sought IPRs over genetic material or products derived from turmeric, quinoa, basmati rice, and the neem tree, among other plants. These cases may appear simple: corporations are seeking to control the use of plant varieties and cultivars that have been known, used, and consumed for centuries by people in the South. But the issue becomes more complex when plant breeding and conflicting cultural expectations become involved.

In the new world of biotechnology and genetic policy, nothing is quite what it seems. Consider a hypothetical problem in plant and fruit breeding from *Seeding Solutions*:

> *Invention:* A (specified) anti-sense DNA-ripening gene driven by (any suitable) constitutive promoter, used to delay ripening in fruit and vegetables. The specification shows several specific examples, and suggests many alternatives and uses. The ripening gene was originally obtained from a U.K. apple variety, although it is found in one form or another in most fruit species. One of the suitable constitutive promoters (used in several examples) was obtained from cucumber mosaic virus, which is endemic in nearly all countries that grow cucumbers. No one can establish the original source of the particular promoter, which has been circulating widely in academic circles for some years. The specification gives detailed working examples of transformed apples (two varieties, one British and one Mexican), melons (one U.S. and one Spanish variety) and bananas ("bought in a U.K. supermarket"), and proposes and claims (without giving any experimental detail) use of the constructs in peaches, guavas and durian. *Question:* From whom, and for what, should CO and PIC be obtained in this case?[11]

Protection of traditional knowledge is another topic cutting across the genetic policy landscape:

> Designated members of Community A engage in a ritual involving the blessing and application of a mixture of medicinal plants. Researcher X wants to publish a description of that ritual and the medicine. Assume that the ritual and mixture originated in the community, and are embodiments of traditional methods and products. As such, the community would enjoy nonexclusive rights with respect to that knowledge (i.e., the community would have to be recognized as the source of the knowledge and would receive royalties on the sale of the book containing the descriptions). That might be satisfactory. But assume, in addition, that the ritual and medicinal mixture are sacred, and the overriding interest of the community is to prohibit reproduction (i.e., publication) altogether. If the community can establish that the knowledge is novel outside the community, or has been revealed only as a result of a breach of confidence, then the community could be allowed the exclusive right to prohibit Researcher X from publishing (if novelty or confidentiality are part of a graduated scheme of conditions for protection within the law, or part of an entirely separate law). A similar result might be obtained if the law included the possibility of an ad hoc reference to the customary laws of the community in question to establish whether the community law prohibited reproduction of the relevant knowledge.[12]

There are no simple or even correct answers to these types of questions. But when you cross one regulatory regime with another, the offspring may not be viable. And when rich countries and multinational corporations are matched against poor countries, the results are also likely to be inequitable. What rights will be enforced to keep cultural knowledge secret in order to protect customary practices among traditional healers and shamans? The answer to such questions will be determined when the contradictions and conflicts between different agreements on and notions about ownership are resolved.

The economic, cultural, and political stakes are huge. Who shall have authority and exclusive domination over genetic material and related information and innovation? Who, that is, shall control the basic resources of life itself? Ownership of genetic resources confers political power far beyond that of parliaments, and raises issues that are beyond the reach of principles of democracy and human rights. The Nazis perfectly realized the importance of owning genetic resources. Planning by the Wehrmacht, academia, and Heinrich Himmler's Waffen-SS to conquer the Soviet Union (in the *Generalplan Ost*) counted on controlling fossil oil, bread baskets, slave labor, and centers of genetic diversity.[13] In fact, in late 1942, Himmler ordered a comprehensive study of the Caucasus (*Totalerforschung des Kaukasus*) extending over Iran into Afghanistan, India, and China and thus covering five out of the seven then-known centers of food crop diversity.[14] But this is not just a Nazi ambition. For almost a century the United States has understood the strategic importance of food sovereignty—controlling plant genetic resources for food and agriculture. More recently, India and Brazil have come to see this need as well. But strangely enough, given the significance of the matter, most contemporary states have not pursued food sovereignty.

In 1994 the World Trade Organization tried to harmonize the welter of IP regimes through the Trade Related Intellectual Property Rights agreement. TRIPS went into force for industrialized countries in 2000; for the least-developed countries, implementation was extended until 2006, and application to pharmaceutical products was later extended to 2016. But the geopolitical, legal, and moral complexities of the challenge were revealed when South Africa refused to respect U.S. patents on drugs inhibiting HIV/AIDS, and later when the United States and Canada threatened to violate patents on the antibiotic Cipro in the wake of the anthrax attack in the United States.[15] In both cases, compromises were reached that amounted to a temporary relaxation of IPRs to accommodate emergencies—and political pressure. But the larger point is this: for poor nations that cannot afford life-saving drugs, or rich ones that want to expand production of such drugs to meet an emergency, IP regimes have repercussions that go far beyond the simply economic—they can be matters of life and death.

And they can profoundly influence the global distribution of economic winners and losers.

A recent World Bank study estimates that Southern country recognition of IPRs under TRIPS will mean, in the short term, a $20 billion transfer of royalty payments from technology-importing countries (many or even most of which are poor) to the exporting countries such as the United States, France, and Germany.[16] The implementation of TRIPS means that countries like Brazil and India will no longer be able to follow the economic path taken by Japan, Singapore, Taiwan, Hong Kong, South Korea—and even the United States—and "pirate copy" themselves into the developed world. This is a crucial point, and a historical fact: successful economic development has, in almost every case, been facilitated by "borrowing" and learning from the technologies created in other nations. The argument that stronger IP regimes will help poor countries develop is a theoretical one only, based mostly on the idea that well-enforced regimes will attract foreign investment and lead to economic growth.

In reality, the question of whether stronger IP regimes will help or harm poor countries is not well understood. TRIPS affords global protection to innovators, but the conditions of "innovation" have yet to be defined coherently across the many organizations and agreements that govern IP regionally and globally. For example, TRIPS requires signatory parties to recognize patents on microorganisms and microbiological processes (mainly to meet the demands of the private pharmaceutical sector). This requirement is opposed, however, by the Organization of African Unity, which has argued that such life forms may fall under the category of traditional knowledge, and are thus afforded protection by individual nations under the Convention on Biodiversity. To complicate matters even further, TRIPS may allow for the possibility of protecting traditional knowledge and local varieties, or land races.[17]

The point of this sampling of issues is to demonstrate how genetic resources and the genetic commons are increasingly limited and subject to enclosure by proprietary measures whose implications are just beginning to play out. New governance regimes and implementation measures almost all aim at restricting the realm of public goods. IP legislation focuses on exclusion and rivalry, not access. Determination of what is in the public domain reacts to crises and contradictions rather than arising from well-considered principle.[18] The new public domain becomes simply what is left after all the private proprietary claims have been met.

Poor countries are using whatever tools they have to fight back. Biodiversity laws in such nations as India, Costa Rica, and Ecuador seek to prevent biopiracy by impeding the once-free flow of genetic material and related information across national boundaries. As of today some thirty countries, mainly in the South, have introduced so-called access and benefit sharing legislation to help protect their genetic resources. One of the latest examples is the Peruvian Decreto Supremo No. 102-2001-PCM (August 2002), which introduces a very protective regime for access by foreign scientists and collectors to Peru's genetic resources and traditional knowledge. Why? Simply because in the wake of progress in molecular genetics and biotechnology, these Southern countries fear they will be biopirated. This may be their only way to apply pressure for a softening of IP requirements in TRIPS.

Yet such actions may make matters even worse. The IPR wars locate public science—science supported by public funds and aimed at social goals that the private sector neglects—precisely in the crosshairs of these geopolitical confrontations. International scientific cooperation in the entire biological realm—but especially for agricultural research—may be hobbled by increased transaction costs due to prior informed consent requirements and other comprehensive protocols regulating the conditions under which national biological material can be collected and used by foreign partners. The consequences of these new regimes are beginning to emerge as botanical collection and bioprospecting expeditions become subject to regulation by host countries. For example, trips to *in situ* locations to collect domesticated plants and their wild relatives sponsored by the publicly funded Consultative Group on International

Agricultural Research have been reduced by more than 50 percent, as have international food plant variety trials, since the implementation of the prior informed consent rules.

The CGIAR, established in 1971, now comprises sixteen international research centers located mostly in the South. Its annual budget of around $340 million is funded mainly through overseas development assistance (ODA)—foreign aid contributions—from its fifty member countries. The CGIAR focuses its research on germplasm improvement and natural resource management in agriculture, forestry, and fisheries.

From 1965 through 1985, the CGIAR played a significant role in providing improved and high-yielding crop germplasm varieties and management practices in support of the Green Revolution. Developed, as it was, by publicly funded science, this improved germplasm was defined as an international public good with no proprietary claims attached. In preparing to contribute to a more environmentally friendly "Doubly Green Revolution" with higher yields and lower chemical inputs, the CGIAR finds itself in a much more complicated geopolitical context than it was thirty years ago.[19] The emerging dilemma for the CGIAR is largely created by the immense complexities of the IP regime and its encroachment on the plant genetic commons. In short, how can an institution dedicated to generating public knowledge and public goods operate in a world of increasingly privatized knowledge?

There is no easy answer for the CGIAR: 75 percent of cutting-edge agricultural biotechnology occurs in the private sector. The CGIAR needs access to private-sector material and technology to keep pace with progress in proprietary science. Mechanisms to allow access to proprietary material and information on preferential terms are being developed to cope with this new global context. But the CGIAR's role as a "bridge" between the private sector and public goods accommodates two-way traffic: under FAO treaty the CGIAR also provides private-sector access to genetic material and emerging seed markets in the South. Overall, the products of a prospective Doubly Green Revolution will likely be more proprietary than those of the Green Revolution. The CGIAR's survival in this new genetic landscape has required it to develop comprehensive guidelines for handling intellectual property and the transfer of genetic material and related information. Such guidelines are complex and restrictive, and demand collaboration agreements, confidentiality assurances, and a range of restrictions and controls on third-party participation. Given these circumstances, the organization will remain under heavy pressure to maintain its credibility and demonstrate its continued commitment to serving the poor in the South.

In 2002 the International Plant Genetic Resources Institute (a CGIAR center in Italy) launched an initiative to establish a Global Conservation Trust for the CGIAR gene banks to secure their survival in perpetuity. Plans also call for incorporating the famous Vavilov World Collections in St. Petersburg, Russia, which comprise the world's second-largest *ex situ* collection of plant genetic material, and which are of great importance to global food security. As a first step, the initiative seeks to set up a $250 million trust fund to secure the long-term survival of the CGIAR gene banks. This goal is extremely important; in the face of increased privatization of the genetic commons and global loss of biodiversity, the absence of secured "genetic libraries" means that continued plant breeding and global agriculture may be at risk in the long run. But here we run into a familiar problem: the initiative may be delayed because of a lack of clarity about ownership and governance of the Trust. In particular, some countries of the South fear that the Trust may represent a first step toward privatization of the CGIAR gene banks.

The 2001 *Human Development Report* of the United Nations Development Programme (UNDP), subtitled *Making New Technologies Work for Human Development,* provides an interesting and balanced analysis of the potentials and problems presented by new and emerging technologies for development of poor countries.[20] The report highlights the extreme imbalance between the North and South in the use of modern technologies, and in most areas of research and development. But the South holds biodiversity and genetic material that is of great interest to both public science and corporations in the North.

The question is how to translate these resources into economic benefit for poorer countries. The answer, at this point, is supposed to be TRIPS. The participation of developing countries in a harmonized global IP regime is supposed to encourage increased private investment aimed at turning genetic resources into profits for the pharmaceutical, seed, and agrochemical sectors. Of course this will also mean an accelerated privatization of the genetic commons. And, as I've explained, it will mean that poor countries will have to pursue a path to economic growth that is different from that followed by most of the world's affluent countries.

To facilitate the North-South transfer of new technologies in a privatizing world, the UNDP report proposes, among other things, the establishment of a United Nations–administered "global intellectual property clearinghouse" that would assist governments with information and advice in the daily application of current and forthcoming IP regimes. Meanwhile, the Rockefeller Foundation is providing assistance to African states in setting up an African Agricultural Technology Foundation (AATF) to facilitate joint access by African countries to proprietary ag-biotech. The AATF is designed to create a credible, locally owned and operated institution with which the private sector in the North can negotiate the transfer of IP-protected technologies and products. Such products can, in turn, stimulate local technology-based development. While still in its early planning phase, this sort of initiative has the potential to help catalyze an African agenda for proprietary research and development.

To ensure that the South can benefit from increasing privatization of the plant genetic commons, best practices for public-private partnerships for management of proprietary biotechnology must be developed and applied. A recent study commissioned by the United Nations Industrial Development Organization proposes some promising approaches to handling potentially divergent public- and private-sector interests in the use of ag-biotech.[21] In one example, a multinational seed company provides access to proprietary germplasm or technology (such as insect- or disease-resistant seed varieties) for use in cultivation and local plant breeding among poor farmers in a developing country in Africa or Asia. The company's IP is protected through a segmented market agreement: farmers may sell or exchange the resulting crop in local markets, but it may not be exported abroad. The seed company gets early access to a (hopefully) emerging market, as well as positive public relations from working in partnership with poor countries. At least this is the idea.

Do these sorts of constructive initiatives indicate the beginnings of a successful response to the new complexities of the genetic policy landscape? Perhaps, but stakeholders on all sides of the IP spectrum have increasingly come to understand that TRIPS and other IP regimes are not narrowly concerned with trade issues but in reality affect a much larger public agenda with implications for many sectors of civil society, national sovereignty, and the global and national governance of new technologies. From a public-sector and public-interest point of view, we need to ask ourselves if we adequately understand these implications and interactions, or if we need to consider demanding a "time-out" to assess the full picture. But who could grant such a dispensation?

In 2001, the secretary-general of the United Nations, Kofi Annan, initiated a dialogue with corporations to begin bringing private-sector R&D to international and multilateral public efforts in peace and development work. The core goal is to encourage multinational corporations to exercise increased social responsibility toward the South, for example, by not testing products in poor countries as a way of evading safety concerns and regulations in rich countries. Similar initiatives have been launched by the World Bank, and even by major multinational corporations. An international "genomics summit" has also been suggested by the World Bank and several multinational corporations to facilitate discussion and forge a consensus following the implementation of new agreements in trade, agriculture, and biodiversity. There are also calls by international civil society organizations for a special session of the U.N. General Assembly on new genomic technologies and conservation, control, and use of genetic resources.[22]

Perhaps we should focus as well on developing a global social contract between the public and private sectors. The type of global social contract I am envisioning would set out moral foundations, ethical guidelines, and economic and political rules under which existing and new proprietary genetic technologies could be used to promote human and environmental benefits. And at the very base of such a social contract must be the common insight gained by humankind and civilization over millennia that as more people get early access to an innovation, there will be more diversity in possible application and greater potential for further innovation and development. Such a contract would need to be a legally binding international agreement. Sovereign states would of course be the principal signatories, but multinational corporations could also be co-signers. This sort of vehicle would probably need to emerge from the U.N. General Assembly. If such a contract is viewed as analogous to international agreements on human rights such as the Helsinki Accord, it may not be as farfetched as it sounds.

This type of approach might require that the TRIPS hardliners (such as the United States and a few other wealthy countries) take a step back, by accepting a less inclusive structure for patenting biological innovations, perhaps by raising the bar on what constitutes an innovative and thus patentable step for isolating and describing a DNA sequence, microorganism, or microbiological process. Excessively broad patent protection of genetic material, such as the award to a corporation called POD-NERS for the Enola bean (which contained thirteen claims, including a patent on pollen), needs to be limited, to keep certain classes of material in the public domain. Such claims can be interpreted very generously—for example, to cover similar beans with similar genetic makeup. This trend in genetic IP goes far beyond normal seed variety protection.

One very concrete but controversial step could start us moving in the right direction. We are beginning to experience the global consequences of the expansion of IPRs into the depths of biology, and the concomitant transaction costs borne by society at large. To begin to compensate for these costs, the plant genetic commons needs to be protected and expanded. The FAO treaty on Plant Genetic Resources for Food and Agriculture opens the genetic base of thirty-five globally important food crops for multilateral access and benefit sharing. This list needs to be further expanded through continued negotiations. To ensure an open and equitable global exchange of biological material, the TRIPS will need to be modified to include compulsory certificate-of-origin requirements that better protect poor countries from biopiracy. By combining this protection of an expanded commons with the implementation of more rigorous requirements for granting IP protection for biological innovation, the colonization of genetic resources by proprietary science may be slowed. Ultimately such a process could narrow the gap between the haves and the have-nots—at least that would be one way to judge its success.

My unsuccessful foray into software development taught me the importance of IPRs for innovators. If instead of developing computer software, I had put my 3,000 hours into work to isolate and describe the use of a new microorganism in high-temperature industrial processes (collected, perhaps, in geothermal areas on Iceland), I might have come out better in terms of socioeconomic reward. But my work in the plant genetic arena has convinced me that the application of IP to living material raises issues and dilemmas that are conceptually and morally different from those raised by IP for physical matter or processes such as mechanical innovations or computer software. Different because the genetic makeup of plants and animals changes over time, so it is very hard to define precisely what is being protected. Different because genes are building blocks of life, and life is simply not subject to the same governance regimes as inanimate matter. Different because the plant genetic commons—unlike a new light bulb or computer chip—is the *sine qua non* of survival for much of the world's population.

Privatizing the basic properties of life itself is a profound step that grants power to innovators and corporations far beyond what we give to national governments or international governance regimes. The type of new social contract I am proposing here acknowledges that addressing our newfound scientific and technological mastery over the genetic foundations of life will demand painful compromise from all participants in the global economy, including the creation of new institutions and frameworks to govern the conduct and use of science and its technological products. But such compromise will be necessary if we are to ensure that the benefits of our inventiveness do not end up sowing the seeds of further inequality, discord, and injustice.

14

BLOWBACK IN GENETIC ENGINEERING

Mark Schapiro

The word “science” evokes a world of men and women driven by curiosity to explore the cosmos, the magic of chemical interactions, the decoding of the genetic combinations of a cell. Following trails of suspicion and experimentation, scientists have over centuries aimed to unlock the mysteries of life on earth.

But “science,” for the last century, has also evolved into a multibillion-dollar business. Today, pharmaceutical companies, agricultural biotechnology firms, weapons labs, semiconductor producers and countless other research and technology–based businesses are among the key players in a global industry that plays a critical role in spurring scientific inquiry and in fueling American economic growth.

The centrality of science and technology to the U.S. economy was outlined in 1945, when Vannevar Bush, director of the Office of Scientific Research and Development for President Franklin D. Roosevelt, authored a report proposing the establishment of a national science policy to deliver expanded government support for science in the post–World War II era. That report, titled *Science: The Endless Frontier,* set the template for an ever more formalized relationship between publicly supported scientific innovators and the private sector. “New manufacturing industries can be started and many older industries greatly strengthened and expanded if we continue to study nature’s laws and apply new knowledge to practical purposes,” stated the Bush report, which recommended large increases in government support for basic scientific research as a means of fueling innovation in the post-war economy.

But Bush was, unwittingly perhaps, setting into motion a science policy that has repeatedly neglected to address key questions linked to the long-term implications of scientific innovation and to the actual real-time beneficiaries of those innovations. What, for example, was the primary social good to be addressed in fueling scientific innovation? Who were the primary winners? And who or what were the possible losers?

On the one hand, Bush's report made an important contribution to spurring basic research and demonstrating the importance of scientific advance to social and economic life. But half a century later, we are also now living with Bush's legacy in the form of the environmental, ethical, and health-related impacts of what were once considered unequivocally "positive" scientific innovations.

Under the mounting pressure of Bush's unanswered questions, the old Enlightenment ideal of science pursuing knowledge for the large-scale benefits of humanity is starting to crack. While the bounty of scientific innovation has delivered great benefits, we are now living in a time in which the implicit assumption that scientific advances equal advances for the common good is shaken by such new developments as spliced frogs and sheep, genetically engineered (GE) plants designed to produce pesticides, and manufactured synthetics that suggest a sort of time-release chemical warfare against ourselves. Popular unease is coming to a head in an era in which "science," that noun used to describe a multifarious community of inquirers, is coming increasingly to manipulate the firmament of life itself.

The implications of the blurring between the pursuit of knowledge and the pursuit of profit are exemplified in the ongoing controversy over GE food crops. The starting point of that research was a simple and profound curiosity: the desire to identify how genetic codes are translated into actual characteristics in a plant. That was in 1982, when scientists at public institutions and private companies such as Monsanto began their quest to unravel the clues embedded in the double helix. When in 1983 three researchers at Cornell University used a shotgun to blast into an onion a tungsten-coated "bullet" containing new DNA, the curtain was opened onto an entirely new arena for genetic research.

In the 1980s, I spent a good deal of time reporting on the toxic effects of agricultural chemicals (for the book *Circle of Poison,* as well as for numerous articles on the environmental and health impacts of pesticides). At the time, the idea of genetically engineered crops, a gleam in the eye of some avant-garde researchers, was presented by many—including those in the environmental as well as scientific community—as a potentially "green" alternative to chemical-dependent agriculture. The impetus for the research was framed in a public-spirited way: Monsanto itself began promoting its increasingly formidable research and marketing capabilities as a step toward "sustainable" agricultural development strategies in both developed and developing countries, suggesting that GE crops could be the answer to the food productivity problems in Africa and elsewhere.

Two decades later, serious questions about the long-term impacts of ag-biotech have become a source of growing friction between the United States and the rest of the world. U.S. policies encouraging the proliferation of genetically modified organisms (GMOs) in the food supply have given rise to a major trade conflict between the United States and Europe, and created an embarrassing standoff in which U.S. donations of food are actually being refused because of fears of what may or may not be contained in those genetically altered crops. The journey of GE foods—once considered an environmental alternative, now a source of fear—into the heart of the American food system illustrates the importance of the questions that Bush and subsequent generations of scientific policy makers failed to ask.

Today no one uses a shotgun to do the work, but the principle remains the same: customized DNA insertions in order to obtain customized characteristics. First it was onions; then corn, soybeans, canola, wheat, tomatoes, and other food crops began to feature genetically engineered components. Walk through your local supermarket, and you'll find them in breakfast cereals, canned drinks, and processed foods of every sort. One-third of the corn and three-quarters of the soybeans, America's most economically significant food crops, contain genetically engineered components. GE research, begun with grand hopes of saving the world's food supply from demographic, political, and environmental catastrophe, has in fact been oriented not toward the conditions of Africa, Asia, or Latin America, where such problems are acute, but toward the developed nations' industrial-scale agriculture. Three out of every four patents issued over the past ten years for genetically modified crops have been issued to just five multinational companies—Monsanto, Dow, DuPont, Syngenta, and Aventis. And while that research has been speeding into ever-newer varieties, funds for research at public institutions responsible for green revolution initiatives in developing countries, such as the International Maize and Wheat Improvement Center (CIMMYT) in Mexico, are drying up as public and private monies are devoted increasingly to biotech solutions to agricultural problems.[1]

In the summer of 2002, I found myself driving a pickup truck through the fields of Frank McLain, an Iowa corn and soybean farmer. I had met Frank and his father, Fred, in 1982, while reporting a story about the consolidation of the American seed industry. At the time, the number of independent players in the industry was undergoing rapid decline as regionally based seed companies were being bought out by large multinational chemical and pharmaceutical companies, which subsequently emerged as the key drivers behind genetic engineering research.

Now I was paying the McLains a visit once again, this time in the company of a film crew for the PBS newsmagazine program *NOW with Bill Moyers,* for a story on the impact of the genetic revolution on America's farmers.[2] Here in the heart of America's breadbasket is where that revolution is being wrought.

McLain was growing 1,500 acres of corn and soybeans. His "Bt corn" contains an inserted Bt gene that delivers a toxic insecticide that kills a corn pest, the European corn borer; his

Roundup Ready soybeans have been engineered to resist the application of Roundup herbicide, so that the herbicide kills only unwanted weeds and not the soybean plants it is designed to protect. For McLain, the GE crops have delivered some considerable short-term benefits: he applies half the amount of pesticides to his corn as he used to, and with the Roundup Ready soybeans he doesn't have to go into his fields and manually remove the weeds the way he and his father used to, which in turn protects his soil from destructive overtilling.

McLain's experience with genetic engineering illustrates both the allure and the potential dangers of the new technology. One-third of the cornfields in Iowa are planted with Bt corn seeds, and almost all of the soybeans are planted with Roundup Ready seeds. For many American farmers, GE crops offer a level of predictability in a risky business that every season can rise or fall with a few degrees of Fahrenheit.

McLain expressed to me his incomprehension about why these crops, which have aided him in his daily work, have become so controversial. "We're using a technology," he said, "that's been given us to make our life easier and to raise better crops."

A half-hour's drive from McLain's farm, in the university town of Ames, I encountered Fred Kirschenman, director of the Leopold Center.

Sponsored by a state tax on pesticide sales, the center is one of the foremost institutes in the United States for research on sustainable agriculture. Kirschenman acknowledged that there have been short-term benefits from the technology of genetic engineering, but he takes the long-term view, and sees the controversies over GE food technology as arising from the policies prompted by that fateful report produced by Vannevar Bush at the close of World War II.

"In agriculture," Kirschenman commented, "we haven't been asking the right questions at least since 1945. What that policy statement said was that we need to use science to dramatically improve our technological capabilities. We were very successful in using technology to win the war; therefore we ought now to apply that technology to increase our crop production. Since then, we have geared up our whole scientific agenda to solve problems with technological innovation.

"But there's a larger issue here. Over the past fifty years, little attention has been paid to ecological issues, the interactions between plants and organisms. We have been rapidly reengineering organisms without asking what their ecological niche is. Why not ask: How will this change the physiology of the plant? How will it affect the organisms around it? And then there's the question, Can we ever back out of it? These are self-replicating organisms. Once they're in, you can't get them out again. All we ask now is 'Does it work?'"

The answers to Kirschenman's questions are coming in rapidly from research institutions around the world, and are providing a sobering picture of the impact of the technology years after its massive introduction into the food system. Reports from scientists in Switzerland and elsewhere indicate that, in fact, there are profound impacts on the physiology of GE corn, primarily in toughening the lignin, or stems, of the plants. While there is little evidence suggesting acute harm to human health from GE crops, there are indications that GE foods may not contain as much nutrition as traditionally bred crops.

More ominously, toxins now bred into Bt corn to kill off the corn borer are leaving residues in the soil, having toxic effects on beneficial insects and, after runoff into waterways, on marine life. In some parts of the United States, weeds have developed resistance to Roundup herbicide, and the corn borer is showing signs of evolving resistance to the Bt toxin. And the self-replicating lab-produced Bt variety of corn is, indeed, replicating itself—in places where it is not wanted. Organic farmers across the country are being denied organic certification—representing millions of dollars in lost sales—due to the discovery of genetically modified material in their corn, delivered to their organic fields by windblown corn pollen from neighboring farms.

What those emerging problems suggest, and evidence of such problems is mounting from around the world, is the legacy of policies set in motion back in 1945. Pursuing the mysteries of the genetic makeup of the plant cell (foreshadowing by several years the Human Genome Project), the age-old scientific dynamic went to work: curiosity—hypothesis—experimentation. From there evolved a greater understanding of how different genetic elements of the plant genome play a role in expressing certain characteristics. At any stage along this continuum, the government could have intruded into the process by requiring assessments about the long-term environmental safety and health implications of what amounts to a profound shift in the way new plant varieties are created.

That did not happen. Rather, private companies, utilizing much of the basic research conducted in public research facilities, took the lead in developing the technology, with few brakes put on their work. Throughout the 1990s, the U.S. Department of Agriculture (USDA) appropriated just 1 percent of its annual agricultural biotechnology research budget to risk assessments. (In 2002, Ohio congressman Dennis Kucinich succeeded in upping that to 2 percent, a still-minuscule figure that itself was a compromise from the 10 percent originally proposed by Kucinich, and that was approved despite the resistance of lobbyists from the ag-biotech industry). Overseas, the USDA and the U.S. Agency for International Development have become ever more aggressive in promoting the use of ag-biotech to foreign governments.

Beginning with the government's support in the earliest days of ag-biotech research, and on into the present day, the parallel evolution of private industry's and the government's commitment to GE technology was critical to the introduction of GMOs on a mass scale. The government sent its most powerful signal of compliance with the onrushing train of GE research in mid-1992 when the USDA, under heavy industry pressure, made the determination that GE crops were the "substantial equivalent" of traditionally bred crops. This designation—first articulated in a speech on U.S. technology policy by Vice President Dan Quayle—helped ag-biotech producers avoid any significant federal or regulatory oversight over a technology that essentially introduces entirely new living organisms into the ecosystem and the food chain. No single regulatory agency now has the power to monitor on a sustained basis the growing of GE food crops.

At the same time, while some GE initiatives do suggest the technology's potential in aiding the development of agriculture in economically and environmentally stressed regions of the globe, the reality is that most of the new GE varieties are tailored not for people living in harsh tropical or arid environments, or for lands undergoing desertification or other stresses, but for the temperate conditions of the American and other industrial-scale agriculture systems, and for lands that have already reached a point of high efficiency in food production. But it is here where the true profits lie for the companies behind the research. By not asking the right questions—not submitting the new technology to what Kirschenman describes as "ecological screening"—we end up with a technology that is now being tested in a massive real-time experiment on the environment of America's farmlands and on living human subjects: American consumers.

Charles Benbrook, an independent agricultural economist and former director of the National Academy of Sciences Board on Agriculture, has been studying the long-term environmental impacts of genetically engineered food crops. He traces the rapid rollout of genetic technology into the food system to the powerful momentum generated by the alliance between government and industry.

> The reality is, when you have companies and technologies that are so powerful economically, the country can't afford to have them fail. And that's a problem, when it becomes too costly for the government to admit that there might actually be a problem with something. . . . Corn and soybeans are the backbone of the whole U.S. food system. If there were any problem in either of those crops, it's fair to say the government's going to do everything in its power to try to convince people that everything imaginable is being done to address the problem, that it's not a serious threat, and that people should not lose confidence in the safety of the U.S. food supply.

What the U.S. government didn't plan for has come to pass anyway. The questions that Vannevar Bush—and generations of scientific policy makers since—did not address have nevertheless been reverberating through the global channels of agricultural trade. While on the trail of GE corn from Iowa to Mexico, I visited the town of Capulalpan, deep in the Sierra Norte mountains of the Mexican state of Oaxaca. Villagers who had farmed hillside plots for generations discovered that elements of the Bt gene had found their way into their corn, stoking fears in the village and around the world that genetic engineering was out of control.[3]

Since the commercial introduction of GE technology, the piñata of American agriculture has sent transgenic candies from one end of the earth to the other. But the world's food consumers are signaling that they do not want what American farmers are producing:

Mexico, 2001–2002: Fears grow throughout the country after it is discovered that GE corn has mixed with indigenous corn varieties in the state of Oaxaca, despite the fact that Mexico has banned the planting, though not consumption, of GE seeds.

New Zealand, 2002: The incumbent government's position on GMO technology becomes a major issue in that country's national election.

Zambia, 2002: Fearful of contaminating its agriculture with GMOs, the government refuses to accept U.S. offers to donate 20 million tons of corn to help the country deal with a food crisis threatening millions with starvation.

Europe, 2002–2003: The European Union (EU) warns the United States that its refusal to label food exports grown with GE varieties threatens future imports to EU member countries. The United States threatens to bring suit in the World Trade Organization, which could lead to a major trade and political battle over GMO technology between the world's two largest trading partners.

Australia, January 2003: A 48,000-ton shipment of U.S. corn is refused entry at the dock in Brisbane after health department officials determine that the grain must be crushed and steamed to destroy any lingering GE remnants in food pellets intended for chickens.

India, January 2003: The government refuses to permit the importation of American soybeans and corn due to fears that it might contain genetically modified ingredients hazardous to human health.

Japan, 2003: Japanese international merchants begin turning away U.S. corn imports en masse after reports that previous American shipments contained traces of StarLink, a gene-spliced corn that has never been approved for human consumption in the United States or any other country.

At the root of this resistance lie deep-seated fears about the long-term impacts of genetically modified organisms, GMOs, on the environment and on human health; and a wariness over a technology that seems entwined with a corporate-driven agriculture threatening family farmers and treasured biological resources. The resistance also comes at a time when many consumers—in Europe particularly—lack faith in their government's regulatory authority to watch out for the public interest after the debacle of mad-cow disease and other food-related scandals. All of these concerns suggest a dwindling of the public's trust in scientific authority.

Twenty-seven countries, including the fifteen nations of the European Union, have imposed either bans or severe restrictions on the import or growing of genetically modified food. For developing countries, concern is also focused around their future ability to sell agricultural products to the many developed nations—most prominently Europe and Japan—that have instituted strict labeling requirements. Thus, one of the unanticipated consequences of globalization has been illuminated through the ongoing controversy over GMOs: the emergence of new channels of global trade have led to the evolution of new levers of power over the products that are traded. Brazil, Mexico, and other countries, for example, face conflicting pressures in their policy decisions on GMOs: to accede to U.S. demands to accept the new products, or retain their restrictions in order to preserve trading relations with Europe and other trading partners skeptical of GMOs.

The United States now finds itself on both ends of the boomerang, as the repercussions of international resistance to GE technology take a severe toll in the American farm belt. To a great extent, the questions prompted by GMOs that have been left unanswered in this country—or at least within this country's official regulatory structure—are being answered elsewhere. The American Corn Growers Association estimates that U.S. farmers lost nearly a billion dollars' worth of export sales to Europe and Japan between 1997 and 2002 due to restrictions on genetically modified food imports imposed by Europe, Japan, and other world buyers. Those losses have contributed to driving thousands of American farmers out of business. U.S. food exports, once the backbone of the American farm economy, are increasingly seen as tainted goods in international markets.

It is the rest of the world that is now forcing the United States to pay attention to the long-term consequences of genetic engineering—a sharp twist of agricultural blowback, in which policies decided upon early on in the research process are coming back to haunt us.

Michael Crow, former executive vice provost of Columbia University and currently president of Arizona State University, says an unwillingness to ask the right questions has been the central flaw of U.S. science policy ever since the Bush report. We need to analyze scientific advances through a new prism, Crow says: "There is no policy mechanism at this time which engages the question, What is the purpose of this or that inquiry? If you say, for example, that the aim of science is to more equitably distribute a higher quality of life, that in itself would change the nature of science. That would be a new means of measuring success. It would no longer be enough to say that you have helped unravel another aspect of nature and the universe."

Having asked the right questions from the outset might have helped the United States avoid a situation in which its farmers are losing business, its consumers are participating unwittingly in an experiment of unknown consequences, and the government is continuing to promote a technology being actively challenged by governments and individuals around the world.

15

ONLY CONNECT

Christina Desser

A few years ago I visited the Bellagio Hotel and Casino in Las Vegas. Developer and impresario Steve Wynn built it to be the "greatest hotel of all time . . . romantic in a literary sense; a lovely place, perfect, even nicer than the real world."[1] Wynn hired architect Jon Jerde, whom he considers to be "the Bernini of our time," to design the Bellagio, one of the "cathedrals of our time." The hotel-casino joins a panoply of other contemporary consumption-driven temples, including the Mall of America, also designed by Mr. Jerde. The Bellagio opened in 1998 to great media fanfare, including articles in the *New York Times* and *Vanity Fair.*

Built at a cost of $1.6 billion, the Bellagio Hotel and Casino attempts to replicate the Mediterranean style of its namesake and inspiration, Bellagio, Italy, which Wynn regards as "sort of a universal symbol of the good life." The real Bellagio is nestled in the Italian Alps next to the azure waters of Lake Como. The Bellagio Hotel and Casino, located in the Mojave Desert, is nestled next to an eleven-acre human-made lake that exists only due to the possession of rights to hundreds of thousands of acre-feet of water from the Colorado River, many miles away. The power of that same river, harnessed by the engineering marvel of the Hoover Dam and transformed into electricity through an enormous hydroelectric complex, also lights up the Bellagio Hotel and Casino twenty-four hours a day. Through a massive technological infrastructure, the integrated historical beauty of the village of Bellagio is reduced to the Bellagio.

The Bellagio offers an indoor botanical "experience" that replicates the seasons with "four different scenes—summer, fall, winter and spring." "Every 90 days," says Wynn, "we change for the season and then in each of the four seasons the blooms last for 30 days. The hotel's smell and look change every 30 days. . . . We have 111 people in the horticulture department of this hotel. We can make a season change in 18 hours—three nights, six hours a night, on the graveyard shift. In the spring, we've got full-size cherry trees—like in Washington." Wynn's goal in creating the Bellagio: "[t]he way God would do it if he had money."

Wynn's trees and blooms are real, not silken substitutes: the cherry trees of spring will be followed by an explosion of chrysanthemums in the summer. Fall will look like the Halloween New England of Ichabod Crane, and December a winter wonderland. The seasons at the Bellagio Hotel and Casino do not change; they are changed. Unlike the seasons of Bellagio, Italy, which reflect the functioning of an integral ecosystem, the seasons at the Bellagio exist as discrete, unrelated "scenes." They are "just this moment" frozen in time.

I had never been to Las Vegas, but I've always imagined it to be pretty awful. When I read about the Bellagio, however, part of me feared that I might actually enjoy it. I find it hard to resist the comfort of a luxury hotel, I like to gamble, and I enjoy delicious food. The Bellagio Hotel and Casino promised all those things in abundance. I decided to go and see for myself.

As the plane approached McCarran Airport after crossing miles of subtle desert landscape, Las Vegas rose, Oz-like, out of the expanse of the eastern Mojave. I could see the Great Pyramid, the Eiffel Tower, Grand Central Station, the Empire State Building, Coney Island. Every casino had a lake or a moat or a fountain and at least one pool. On leaving the airport, only the heat and aridity reminded me that I was in the desert.

The Bellagio's lobby is a cacophony of jazz, rock and roll, standards, and new age music; it sounds like a dozen radio stations playing simultaneously. Slot machines ring and clang. The elevators play classical music on the way up to the rooms, rock and roll on the way down. This was intended to adjust my mood for the activities of the bedroom or the casino. Although it appeared we were being shepherded with care, no one seemed to know where they were going. In the casino, rather disoriented myself, I overheard a woman behind me say, "I have no sense of which way to go where." Her friend answered flatly, "I think people just give up and stay here."

Despite almost continuous shoulder-to-shoulder proximity, the patrons of the Bellagio seemed oblivious to each other. Doors frequently closed in my face. The dominant human contact came from accidentally bumping into people. Although together, we were in no way connected. After a few hours of wandering around I felt claustrophobic, engulfed. The Bellagio's gimmicks, gardens, and gambling were distracting but lacked any depth or richness that would make them compelling. Everything began to look, feel, and sound the same. Weary and alienated, I retreated to my room.

The view from the twenty-first floor encompassed five swimming pools and a tangled intersection that joined the freeways surrounding the city. Smog obscured the mountains I knew were there. With the curtains drawn, my admittedly comfortable but nevertheless generic hotel room could have been anywhere. Although I was here specifically to experience the Bellagio, I just couldn't face the noisy, crowded maze downstairs. I called room service and ordered dinner.

Having finished my perfectly cooked medium-rare lamb chop and a quite good Caesar salad, I leaned against the abundant down pillows on my bed to savor my glass of wine. For some reason the story "The Nightingale," by Hans Christian Andersen, came to mind. One of my childhood favorites, in the Bellagio Hotel and Casino that night, I began to understand what it was about. Written in the 1840s, the story is a reflection on the seductions of technology and its limitations, especially when it supplants our direct experience of the natural world.

In the Bellagio I felt acutely the contrast between the technologically manipulated and manufactured environment and the natural one. The Bellagio felt uncomfortably isolated from the living world; it offered me nothing of essential value while insulating me from the connection to anything that might. I could not shake a constant feeling of anxiety in this technologically sustained land of the lotus-eaters.

"The Nightingale" is about an emperor of China who lived in a gorgeous palace entirely made of porcelain. The most sophisticated technology of the time had been deployed to create, like the Bellagio, "a lovely place, perfect, even nicer than the real world." Although the gardens stretched as far as the eye could see, they ultimately came to a great forest that sloped down to the sea. In that forest lived a nightingale who sang so beautifully that even the poor fisherman, who had so many other things to do, would stop and listen.

Travelers from all over came to admire the porcelain palace, but when they heard the nightingale in the forest, they all declared her to be the loveliest of all. They wrote books and poetry about her. Through these books the emperor came to know of the nightingale and demanded to hear her sing for him in the palace. When the emissaries of the court finally found her, the nightingale accepted their invitation, even though, she said, her song sounded best in the forest.

Back at the palace great preparations were made. At last the nightingale arrived, and at the emperor's signal she sang. Her song brought tears to his eyes. The nightingale declined the golden collar he offered, saying his tears were reward enough. The emperor kept the nightingale at court in her own gilded cage, allowing her to go out only with twelve servants holding a silken string fastened to her leg.

One day the emperor received a large box containing a jewel-encrusted mechanical nightingale, a gift from the emperor of Japan. Around its neck hung a ribbon on which was inscribed, "The Emperor of Japan's nightingale is poor compared with the Emperor of China's." The bird sang when wound. Everyone in the court was delighted. One day while the windup bird was singing and attention was diverted, the real nightingale escaped into the woods.

Upon noticing her absence, the court decided that it preferred the windup bird anyway. With the real nightingale you could never tell what was going to be sung; with this bird everything was settled. The poor fisherman, however, who heard the windup bird, said, "It sounds prettily enough, and the melodies are all alike; yet there seems something wanting, I cannot exactly tell what."

Sitting in the contrived elegance of my hotel room at the Bellagio that night, I had the same feeling. Although this environment tried to anticipate my every need and respond with comfort and diversion, something was missing. I knew what the nightingale sounded like—her song was the icy, sweet, and delicious taste of the mountain water I drank as a teenager when I went backpacking in the Sierra with my friends. Her song was the sound of crashing waves on the beaches of Mexico where, as a child, I sipped coconut milk while leaning against the palm that had provided it. The nightingale's song was the subtle and varied fragrances of the roses growing in my father's garden.

Yet all too often, like the emperor and his courtiers, I become enamored of the mechanical delights around me, and I do not even notice when the nightingale slips away. In San Francisco, my climate-controlled house reliably keeps me comfortable and protected from the elements. My FasTrak pass allows me to bypass the long lines of bumper-to-bumper congestion as I travel back and forth across the Golden Gate Bridge. My cell phone saves me precious minutes. It enables me, while en route, to warn people that I am early or late for a meeting or lost and need directions. While grocery shopping, I can simultaneously check the wait at my favorite restaurant or order movie tickets. I regard e-mail, voice mail, and the Internet as essential to my life; they allow me to be readily in touch with people and to handle business easily and quickly.

Like the emperor's courtiers, I am glad for technology's predictable song. I depend on it without question. In the back of my mind I sometimes notice something is missing, but usually, with nearly unconscious acquiescence, I succumb to the technologically rich environment that eases and encompasses my daily life. Only when I find myself without these conveniences do I really remember what is missing and how essential it is.

One summer I spent a month at the Blue Mountain Center, in the Adirondack Mountains of upstate New York. Built as one of the "great camps" at the beginning of the twentieth century, it is now a retreat for artists and writers. The Blue Mountain Center is a series of Craftsman-style structures each with a view of Eagle Lake through broad-leafed maple trees. Technology there is minimal. While the erratic electricity was sufficient to power my miraculous office-in-a-box laptop, there was only one pay phone and one fax to be shared among the twenty residents. Cell phones were prohibited. Sending and receiving e-mail, something I normally do several times an hour, required an inconvenient trip to the basement.

At first, being technologically limited felt like a huge inconvenience. Before long, however, as the distractions of these mediating technologies fell away, a more finely tuned awareness of my surroundings began to arise. My trips to the basement dwindled to a few times a week. Uninterrupted by the ringing of my own cell phone and the pseudosymphonic signals of others', spared overhearing the loud and uninteresting phone conversations of strangers, I found myself tuning in to the sounds of the place itself. I realized that when I am on my cell phone, regardless of where I am physically—in my car, walking down the street, in some store—mentally I am in the ether of the conversation. Where I am is nowhere. Without the distraction of phone calls, without the illusion of connection through fax and e-mail, I began to connect to the place where I actually was.

At Blue Mountain I ran every day, about six miles through the forest. The loamy path was soft and springy, so much more forgiving to human knees than the asphalt road I usually pound. At home I cannot conceive of running without my iPod, in part to shut out the noise of the city, in part to distract me from the boring and sometimes painful experience of running itself. But running in the woods at Blue Mountain felt different, and I wanted to be able to fully experience it. I set the iPod aside and ran in silence. The quiet of the forest was palpable against my ears; it was pierced by the trilling of woodcocks and wood thrushes, the wind through the birches, the rustling of surprised creatures as they darted away, unseen, through the leaves. My senses were engaged. I felt sharply aware.

With no city lights or streetlamps, it was very dark at night; the stars were profuse. The Big Dipper was perfectly framed in my bathroom window. My evening reverie was accompanied by the calling of loons, the sound of water lapping. Alert and present as I gazed up at the Milky Way, I felt connected, related, a part of something greater than myself. I felt at home in the universe.

This natural experience was not, of course, without its discomforts. The only "climate control" in my room was a portable fan that simply moved around the unrelenting heat that set in for a few days. My brain slowed, my body felt heavy. Screens on the windows offered the most advanced comfort-providing technology, but even they were insufficient to keep out the no-see-ums. For several nights I was beset by them. I scratched my countless bites to the point of drawing blood. The bedsheets excruciatingly abraded the sores on my legs, but without their cover I was afraid I would get more bites. I could find no distraction—even reading was out of the question since the light I required would be a beacon for the bugs.

In the moments when my world was defined by the discomfort caused by this tiny scourge, I watched my own futile attempts to escape it—to resort to Benedryl or cortisone—anything—for relief. I do not like to suffer, but suffering, an unmediated (and ultimately unavoidable) experience, is quite illuminating. The pain heightened my awareness of my body and the experience of being alive at that moment in that place. I would have preferred Blue Mountain without the no-see-ums and, while I would have taken anything to relieve the discomfort, I would not have altered that world to avoid it. Horrible as the no-see-ums were, they were part of an intricately connected environment. Bug-free Bellagio, comfortable and opulent though it was, felt deadening and insulated; I couldn't wait to get home. When my month at Blue Mountain was over, I did not want to leave nor to return to my technologically mediated life. I had rediscovered what was missing.

In *The Origins of Knowledge and Imagination,* eminent mathematician and biologist Jacob Bronowski wrote, "I believe that the world is totally connected: that is to say, that there are no events anywhere in the universe which are not tied to every other event in the universe."[2] Even if the "event" is the simple experience of a rose or a no-see-um bite, when a Bellagio designer is not calibrating the fragrance level or programming when and how I will have a particular experience, I can know that connection directly.

The experience of such connections, while freely available in the natural world, is not limited to it. Visiting Chartres Cathedral, I experienced this same totality of presence. I felt focused and concentrated, in awe of the boldness of vision and purpose that created such a majestic structure. The jewel colors of the stained-glass windows, with their images of suffering and redemption, penetrated not only the cathedral's soft darkness but also something inside me. I felt the loosening of the boundaries that isolate a self; I felt enveloped in a unifying intimacy with the strangers around me. The specific place and specific moment were fixed in time, yet also transcended time.

Impressive medieval technologies were responsible for raising the edifice that evoked this experience, but the force I felt intimately connected to was something other than the sheer physical or mechanical power to erect a monument, even one so large and magnificent. In the autobiography, *The Education of Henry Adams,* an entire chapter, "The Virgin and the Dynamo," is devoted to the study of how power and force shape people and history.

Although Adams marveled at the new technology of dynamos introduced at the Great Exposition of 1900 in Paris, he knew that there was another "kingdom of force" equally powerful, if not more so. "All the steam in the world could not," said Adams, "like the Virgin, build Chartres." I knew what he meant. At Chartres I could feel the élan vital, the force that created the cathedral, and I was silenced. For some time afterward I did not want to speak or be spoken to. Generating this experience was surely the intent of Chartres's designers and builders. It was the perception of connection—the apprehension of what, according to Adams, medieval science called "immediate modes of the divine substance" and what I, less theologically inclined, call direct experience.

Such unmediated experiences are not limited to the natural world. Painter Barnett Newman tried to evoke this experience of connection in his work. When I stand before Newman's *The Stations of the Cross,* a series of fourteen canvases in black and white, I feel, through their terrible beauty, the suffering that is unavoidable in life. In an article about Newman, art critic Arthur C. Danto wrote, "[A] picture represents something other than itself; a painting presents itself. . . . Painting and viewer coexist in the same reality."[3] As Danto describes it, I "feel myself there, in relationship to the work, like someone standing by a waterfall."[4] For Newman this awareness of place, self, and relationship necessarily encompasses both pain and exaltation; without both, there can be no wholeness.

The actress Fiona Shaw recently afforded me a similar experience of connection in her performance of Euripides' *Medea.* Shaw was not a window into Medea, a picture of Medea—she *was* Medea, the spurned sorceress who exacts revenge on her husband by murdering their children and his betrothed. Shaw portrayed Medea's indecision over whether to murder her children with excruciating agony. "I must do it, I can't do it," she wailed, and although I knew the end of the story, her extremity was so immediate I hoped she might yet change her mind. By the end of the play I understood Medea's choices and the actions that followed; and I experienced the pain of her impossible situation. Science and technology may have advanced dramatically in 2,400 years, but we humans are pretty much the same. None of us can escape the price of the human condition. We recognize each other in the happiness and suffering that connect us.

Like experiences in the natural world, Chartres Cathedral, Newman's paintings, and Shaw's Medea are conduits of connection. As they reveal and illuminate the full spectrum of human experience, we find ourselves enfolded in a universe that encompasses all of our foibles and inspires all of our greatness; in that embrace we are restored, made whole. Experiences in the natural world have the same effect, perhaps even more profoundly. Through them we discover and can feel our relationship to all life and the planet that sustains us. Through that connection, our lives become more meaningful—more purposeful.

In *Howards End* by E. M. Forster, Margaret exhorts her husband to open his heart to such direct experience—in both the natural world and the humanly constructed one—so that he may live a more complete and integrated existence: "Only connect! That was the whole of her sermon. . . . Live in fragments no longer."[5]

Several years after the nightingale fled, the emperor became gravely ill. By this time the windup bird had worn out and was too fragile to sing more than once a year. Because there was no one there to wind it, the bird sat silent on its pillow next to the ailing emperor. Death entered the room and stared at the monarch with his cold, hollow eyes. Terrified, the emperor lay helpless. Suddenly, through the open window came the sound of the most beautiful singing. It was the nightingale. Hearing of the emperor's illness, she had come to sing to him of hope and trust. As she sang, the emperor slowly gained strength.

The grateful emperor wanted to reward the nightingale for banishing death, but she wanted nothing. Her reward, she replied, had been his tears the first time she sang. She stayed with him until the next morning, when he woke, fully recovered. The emperor asked her to live with him at the palace and sing when she pleased; he would destroy the artificial bird. The nightingale told him not to do that, that the bird did well as long as it could. The nightingale refused to live in the palace, but promised to return and sing to the king of "those who are happy, and those who suffer; of the good and the evil hidden around you; of the faraway fishermen and peasants."

The story's finale reveals the essential difference between the force of nature and the limited power of technology. The ability of the nightingale's song to heal rests on the fact that it leaves out nothing. She sings of beauty and happiness, but does not shirk from singing of evil and suffering as well. Offering the emperor no buffer from the totality of his realm, the nightingale connects him to the lives of those in his kingdom who support him with their fish and grain but whom he never sees. Through her song, the emperor expands his awareness beyond his insular porcelain walls and discovers his relationship to a larger world. The nightingale sings the truth of what is, and through her song the emperor is made whole. Even if the emperor had succeeded in making the mechanical bird sing, it would have failed to invigorate him. Its predictable song could not express or evoke the feelings that the all-encompassing song of the living bird could. Inanimate and mechanical, the windup bird could not create for the emperor the essential experience of connection.

Alone, like the emperor, in my hotel room at the Bellagio, I had available to me a wealth of technological distractions and entertainments: first-run movies, DVDs, a CD player and a wide choice of music, a Jacuzzi, a fully loaded minibar. These technologies dazzled with their power to amuse, but they did not inspire. The Bellagio felt like the antithesis of Chartres. The experience of the Bellagio offered me mind-numbing distraction; Chartres afforded me a deeper connection to myself and the world.

With each experience of connection I discover that I must push out the boundaries of the relevant further and further. This ever-widening perspective affects how I relate to other people—those near as well as those on the other side of the world. It affects the way I act upon the natural world, and it affects the choices I make in the humanly constructed environment. As the boundary of what is relevant to me expands, I am increasingly confronted with the question of how my behavior and my choices affect this interconnected whole. Through these experiences of connection and the insights they engender, I have discovered the purpose and passion of my life—doing what I can to ensure that this planet continues to be a place where all people have the opportunity to experience the power of connection that helps them discover their own passion and purpose in life. Inherent in these experiences is the desire to preserve the opportunity for others to know them.

Bronowski describes the process of science—the process by which we gain knowledge—as that of decoding a "completely connected world." This decoding requires dividing that completely connected world into what is relevant and what is not relevant to the matter at hand. But in so doing, Bronowski says, we do violence to the connections in the world. We must always bear in mind that we are "certainly not going to get the world right, because the basic assumption that [we] have made about dividing the world into the relevant and irrelevant is in fact a lie. When we practice science (and this is true of all our experience), we are always decoding a part of nature that is not complete. We simply cannot get out of our own finiteness."[6]

To artists who convey the force of connection through their work, nature is essential to the creative process. For writer and painter John Berger, landscape painting is about experiencing that moment of wholeness—the connection—that arises in direct awareness. For Berger, "the process of painting is the process of trying to re-achieve at a higher level of complexity a previous unity which has been lost."[7] For abstract painter John Wells, direct experience of the natural world is both the object and the source of his creative force. "[A]ll around the morning air and the sea's blue light, with points of diamond and the gorse incandescent beyond the trees; countless rocks ragged or round and of every color; birds resting or flying, and the sense of a multitude of creatures living out their minute lives. . . . All of this is part of one's life and I want desperately to express it; not just what I see, but what I feel about it . . . but how can one paint the warmth of the sun, the sound of the sea, the journey of a beetle across a rock, or thought of one's own whence and wither? That's one argument for abstraction. One absorbs all these feelings and ideas: if one is lucky they undergo an alchemistic transformation into gold and that is creative work."[8]

The creative personality, according to Bronowski—whether an artist or a scientist or an activist—"is always one that looks on the world as fit for change and on himself as an instrument for change."[9] She understands that the world she paints or studies or acts on is but a fragment of a connected whole, and the integrity and truth of her creative act depends upon operating and acting within the truth of that connection. Nobel Prize–winning biologist S. E. Luria distilled Bronowski's message to this: "that the integrity of the doer should be matched by the vision of the thinker; that such vision consists as much of what the viewer projects outward as of what it receives; that passivity before the supposedly inexorable march of events—

whether the Industrial Revolution or the mechanization of society—can only lead to slavery; and that freedom must be created by the interaction between human wisdom and the physical world."[10]

Now, perhaps more than ever, if we are to survive meaningfully on this planet we must interact wisely with the world. The choices we make about science and technology, as individuals and societies, must be regarded as creative, world-altering acts made within the context of the whole. This awareness has rarely guided our actions in the past, but it must guide us now lest our creations continue to systematically annihilate that which matters most: because of the off-road vehicles and tractor-trailers that make cattle grazing possible at 7,000 feet, cattle dung has polluted most Sierra streams with giardia, an intestinal parasite, and I can no longer drink the Sierra stream water I once relished.

There are far fewer palm trees now than when I sat sipping coconut milk on the beach in Mazatlan only decades ago. Their habitat has been destroyed by urban development, their seeds eaten by the foraging pigs and other animals introduced to support expanding urban populations. Today 80 percent of the palms in the world are endangered.[11]

While the roses in my father's garden still bloom, 14 percent of all rose species are endangered. Their habitat has been imperiled by development and the seeds of invasive exotics that hitch a ride on our shoes and clothing as we travel on planes, trains, and automobiles, or find their way into packing crates shipped on freighters or by rail.[12] In fact, one out of every eight plants on the planet is imperiled—nearly 34,000 plant species at last count.[13] With each of these losses, not only is the opportunity to experience them severed, but the whole web of relationship within which the plant exists is affected. As the self-perpetuating fabric of nature disintegrates, our opportunity to experience a connected self in a connected world is diminished.

On my final evening at the Bellagio, I went up to my room to pack. As I watched darkness descend on the desert, the glow of the Strip's bright lights and neon masked the stars. Words from a poem by Richard Shelton came to mind: ". . . oh my desert / yours is the only death I cannot bear."[14] If we capitulate to an ever more mediated and constructed world, then the death of the desert and all that it represents is certain. The nightingale enjoins: only connect. . . .

16

THE WORLD IS TOO MUCH WITH ME

Alan Lightman

Not long ago, I was sitting at my desk at home and suddenly had the horrifying realization that I no longer waste time. It was one of those rare moments when the mind is able to slip out of itself, to gaze down on its convoluted gray mass from above, and to see what it is actually doing. And what I discovered in that flicker of heightened awareness was this: from the instant I open my eyes in the morning until I turn out the lights at night, I am at work on some project. For any available quantity of time during the day, I find a project; indeed, I feel compelled to find a project. If I have hours, I can work at my laptop on an article or book. If I have a few minutes, I can answer a letter. With only seconds, I can check telephone messages. Unconsciously, without thinking about it, I have subdivided my waking day into smaller and smaller units of "efficient" time use, until there is no fat left on the bone, no breathing spaces remaining. I rarely goof off. I rarely follow a path that I think might lead to a dead end. I rarely imagine and dream beyond the four walls of a prescribed project. I hardly ever give my mind permission to take a recess, go outdoors, and play. What have I become? A robot? A cog in a wheel? A unit of efficiency myself?

I can remember a time when I did not live in this way. I can remember those days of my childhood, when I would walk home from school by myself and take long detours through the woods. With the silence broken only by the sound of my own footsteps, I would sit on the banks of Cornfield

Pond and waste hours watching tadpoles in the shallows or the sway of water grasses in the wind. My mind meandered. I thought about what I wanted for dinner that night, whether God was a man or a woman, whether tadpoles knew they were destined to become frogs, what it would feel like to be dead, what I wanted to be when I became a man, the fresh bruise on my knee. When the light began fading, I wandered home.

I ask myself: What happened to those careless, wasteful hours at the pond? Has the world changed, or just me? Of course, part of the answer, perhaps a large part, is simply that I grew up. Besides the unreasonable nostalgia that most of us have for our youth, adulthood undeniably brings responsibilities and career pressures and a certain consciousness of the weight of life. It is extremely difficult to disentangle the interior, personal experience of aging, strapped with these new burdens, from any change in the exterior world. Yet I sense that some enormous transformation has indeed occurred in the world from the 1950s and '60s of my youth to the twenty-first century of today—a transformation so vast that it has altered all that we say and do and think, yet often in ways so subtle and pervasive that we are hardly aware of it. Among other things, the world is faster, less patient, louder, more wired, more public.

Some anecdotal examples: A friend who has been practicing law for thirty years wrote to me that her "mental capacity to receive, synthesize, and appropriately complete a legal document has been outpaced by technology." She says that with the advent of the fax machine and electronic mail, her clients "want immediate turnaround, even on complex matters," and the practice of law has been "forever changed from a reasoning profession to a marathon." Another friend who works at a major software company described to me the job-interview process. An applicant is interviewed independently by several different people on the selection committee. Afterward, there are no face-to-face meetings of the committee to discuss the applicant. Instead, each interviewer, within twenty minutes of completing the interview, must write up his or her impressions and send them by e-mail to the other members of the committee. If the transmission of judgment isn't completed within this time frame, that interviewer is out of the loop. Other business presses on. Or consider time away from the office. A family that vacations in the same area of Maine where I spend the summer arrives at their rented cabin with sunglasses, beach towels, and canoe paddles. My friends also unpack cell phones and laptops and modems, so that they can stay connected to their workplace throughout the holiday.

Although I cannot document any general conclusions, I believe that these anecdotes represent common experiences. Haven't we all seen people talking on cell phones while dining or riding the train, deadlines and lead times grow shorter and shorter, video screens imposed in the most unexpected of places? All around me, everywhere I go, I feel a sense of urgency, a vague fear of not keeping up with the world, a vague fear of not being plugged in. I feel like the character K in Kafka's *The Trial,* who lived in a world of ubiquitous suspicion and powerful but invisible authorities. Yet there is no real authority here, only a pervasive mentality. I struggle to understand what has happened to the world and to me, why it has happened, and what exactly has been lost.

The dramatic development of technology, especially high-speed communication technologies, has certainly played a major role in shaping the world of today, both for good and for ill. Technology, however, is only a tool. Human hands work the tools. Behind the technology, I believe that our entire way of thinking has changed, our way of being in the world, our social and psychological ethos. The various qualities of this new world are far too complex and broad to easily categorize, but I will attempt to gather them under the simplistic heading of the "Wired World." Certainly, few people could deny that the new technologies of the Wired World have improved life in many ways. Some of the less agreeable symptoms and features of the Wired World seem to be:

1. An obsession with speed and an accompanying impatience with all that does not move faster and faster. Among the many examples of our accelerating society in James Gleick's recent book *Faster* is the speed of printers. In my

childhood, there were people known as typists, who measured their speed in words per minute, perhaps 50 words per minute for a good typist. Authors accepted that they would need to wait weeks to have a manuscript typed. In the 1970s, with the advent of computer printers, speed became gauged in characters per second. A daisy wheel could spit out forty to eighty characters per second, or a single-spaced page every minute, and an author could print an entire manuscript in one day. Ten years later, that same author quickly became discontented with a mere page per minute when the new generation of ink jet and laser printers could create five pages per minute. When we become accustomed to speed, it is natural to be impatient with slowness.

2. A sense of overload with information and other stimulation. Our computers not only are faster but store more and more data. The Internet offers an almost infinite amount of information, at easy access. In the face of this avalanche of facts, far more than can be excavated or digested, it becomes easier to confuse information with knowledge. Television screens now are subdivided to show not only the regular program but also, simultaneously, weather information, the latest values of the Dow Jones and Nasdaq indices, and news headlines. Many people have become accustomed to performing several tasks at the same time, such as conducting business on cell phones while driving or walking or eating.
3. A mounting obsession with consumption and material wealth. According to figures from the U.S. Department of Commerce, adjusted for inflation: In 1960, the middle of my childhood, the consumption per person in the United States was $10,700 (in year 2000 dollars). In 2000, it was $24,400, more than double. Researchers have documented that spending and consuming in the United States are higher than anywhere else in the world.
4. Accommodation to the virtual world. The artificial world of the television screen, the computer monitor, and the cell phone has become so familiar that we often substitute it for real experience. Many new technologies encourage us to hold at a distance the world of immediate, face-to-face con-

tact. Electronic mail, although very useful in some respects, is fundamentally impersonal and anonymous. The sociologist Sherry Turkle, in her book *Life on the Screen: Identity in the Age of the Internet,* discusses how people in "multi-user domains" (MUDs) have created entire artificial communities in cyberspace, escaping for hours at a time the small rooms and meager closets, the relationships or loneliness, of their real lives. This increasingly large part of the population refers to real life as "RL," in contrast to "VR," standing for virtual reality.

5. Loss of silence. We have grown accustomed to a constant background of machine noise wherever we are: cars, radios, televisions, fax machines, telephones, and cell phones—buzzes, hums, beeps, clatters, and whines.
6. Loss of privacy. With many of the new communication technologies, we are, in effect, plugged in and connected to the outer world twenty-four hours a day. Individuals are always accessible, always able to access the world around them. Each of us is part of a vast public network of information, exchange, communication, and business. This mentality of public connectedness is invisible but always present, like the air.

Aside from the particular technologies, these fundamental qualities of the Wired World have not appeared suddenly, nor even only during the period since my childhood at Cornfield Pond. They are part of a trend of ever-increasing speed and public access over the last couple of centuries and longer. In recent decades, however, this trend has accelerated to a disturbing degree. If we have indeed lost in some measure the qualities of slowness, have lost a digestible rate of information, immediate experience with the real world, silence, and privacy, what exactly have we lost?

More narrowly, what have I personally lost when I no longer permit myself to "waste" time? When I never let my mind spin freely, without friction from projects or deadlines, when I never let my mind think about what it wants to think about, when I never sever myself from the rush and the heave of the external world—what have I lost?

I believe that I have lost something of my inner self. By inner self, I mean that part of me that imagines, that dreams, that explores, that is constantly questioning who I am and what is important to me. My inner self is my true freedom. My inner self roots me to me, and to the ground beneath me. The sunlight and soil that nourish my inner self are solitude and personal reflection. When I listen to my inner self, I hear the breathing of my spirit. Those breaths are so tiny and delicate, I need stillness to hear them, I need aloneness to hear them. I need vast, silent spaces in my mind. Without the breathing and the voice of my inner self, I am a prisoner of the world around me. Worse than a prisoner, because I do not know what has been taken away from me; I do not know who I am.

The struggle to hear one's inner self in the noise of the Wired World might be thought of in terms of private space versus public space. Public space—the space of people and clocks and commerce and deadlines and cellular phones and e-mail—is occupying more and more of our physical and psychic terrain. But the truly important spaces of one's being cannot be measured in terms of square miles or cubic centimeters. Private space is not a physical space. It is a space of the mind. It is "soul space," to use writer Margaret Wertheim's words. It is the domain of the inner self. When Dante makes his great journey through heaven and hell in *The Divine Comedy,* he moves not only through physical space but also through spiritual space. He visits immaterial realms of good and evil, beauty, truth. No wonder his companion and guide is the poet Virgil: poets are masters of the inner self. In earlier centuries, physical space and soul space were united in a whole way of being in the world, of understanding the world. That dualism and wholeness is what I have lost.

Sometimes I picture America as a person and think that, like a person, our entire nation has an inner self. If so, does our nation recognize that it has an inner self, nourish that inner self, listen to its breathing in order to know who America is and what it believes in and where it is going? If citizens of that nation, like me, have lost something of our inner selves, then what of the nation as a whole? If our nation cannot listen to its inner self, how can it listen to others? If our nation cannot grant itself true inner freedom, then how can it allow freedom for others? How can it bring itself into a respectful understanding and harmonious coexistence with other nations and cultures, so that we might truly contribute to peace in the world?

It is a warm spring day, and I stand in my classroom at the Massachusetts Institute of Technology, one of the world's great temples of technology. A freckle-faced student has just opened the large swinging window to allow some fresh air to waft into the room. I've had a schizophrenic career at MIT, teaching both physics and creative writing. Indeed, that split has followed my life's double passions in the sciences and the arts. Today, as usual, my students wander in late to class, eating bagels and pizza slices (which I permit), wearing cut off jeans and shorts and T-shirts and halter tops, complaining about some difficult problem on their physics or chemical engineering homework. My students are so bright, so quick, so eager to take their training into the world, and every one of them assumes, without question, that faster and more equals better. Hasn't that been the guiding assumption since the Industrial Revolution, that all developments in technology constitute progress? According to this view, if a new optical fiber can quadruple the transmission of data, then we should develop it. If a new plastic has twice the strength-to-weight ratio as the older variety, we should produce it. If a new automobile can accelerate at twice the rate, we should build it. MIT and many other institutions of science and technology do indeed have good departments in the arts and humanities, with the intention of graduating well-rounded human beings, and yet do not challenge the basic supposition: technology equals progress. "Progress" is some kind of ordained imperative of our species, an abstract conception of evolution, an inevitable direction of development like the increase in entropy, the future.

Centuries ago, technology was first and foremost associated with improving the quality of life and the human condition. (I use the word "technology" here retrospectively. In fact, the word did not enter the public vernacular until the founding of the Massachusetts Institute of Technology, in 1861. Early technologists and scientists might have called themselves craftsmen or engineers or natural philosophers.) One of my heroes in the history of science is Francis Bacon, whose *Novum Organum* (1620) proposed that nature could be understood only by careful, firsthand observation, as opposed to the acceptance of knowledge handed down by prior authorities. In his *New Atlantis* (1617), Bacon envisioned a kingdom of science and technology, much of it unheard of at the time, which included living chambers where the air is treated for the preservation of health, the perfection of agriculture, the development of flowers and plants especially for medicinal use, the development of glass lenses for "seeing objects afar off, as in the heavens and remote places," and the study of sound and the creation of devices "which set to the ear do further hearing greatly." In this utopian kingdom, called Solomon's House, three "Benefactors" were charged with sifting through the experiments of all the House scientists "to draw out of them things of use and practice for man's life and knowledge."

Soon after Bacon, the development of technology became part of a major Western intellectual theme called Progress. Progress was centered around the notion that human beings were inevitably advancing to a higher plane—socially, politically, intellectually, scientifically, and morally. In France, the Marquis de Condorcet's *Sketch of the Intellectual Progress of Mankind* (1795) proposed the concept of the "infinite perfectibility" of humankind. In England, the influential sociologist and philosopher Herbert Spencer attempted to synthesize the physical and social sciences and argued that a fundamental law of matter, "the persistence of force," inevitably brought about complexity, evolution, and progress in all things, cosmic and human alike.

In this grand idea of progress, which took on almost mythic proportions in the eighteenth century, intellectual progress was represented most notably by the theoretical discoveries of Isaac Newton and his sweeping laws of motion. The laws of gravity, discovered by the mind of man (Newton), governed everything from the orbit of the moon to the fall of an apple. Material progress was nowhere better symbolized than in James Watt's remarkable steam engine, the centerpiece of the Industrial Revolution. Power looms, for example, enabled textile workers to perform at ten or more times their previous rates and reasonably promised to raise the standard of living and relieve the exploitation of factory workers, as well as increase the wealth of nations. Concern for the human condition was central in these developments: technology in the service of humanity. On this score, I've always been inspired by the attitude of Benjamin Franklin, another of my heroes: inventor and scientist, statesman, philosopher, complete human being. Franklin refused to patent his many inventions for private profit because he felt citizens should serve their society "freely and generously." In his famous *Autobiography* (1790), after giving a tedious account of his new invention for improving street cleaning, Franklin writes, "Human felicity is produced . . . by little advantages that occur every day." For Franklin and many other scientists and technologists of his day, the human being always came first.

Leo Marx, the distinguished historian of American literature and traditions and my colleague at MIT, occasionally joins me for lunch. Leo's landmark book *The Machine in the Garden* (1964) examined the way that the American self-identity, defined since early days by pastoral themes and images, has been confronted with and reshaped by the advent of technology. Leo is now in his early eighties. He still has most of his hair, his striking blue eyes still look back at me with a penetrating clarity, and, as we sit on a bench with our cheese and turkey sandwiches, he gently suggests how I might think about technology and other large forces of the day. In his recent articles, Marx says that sometime in the mid-nineteenth century, the intention and direction of technology changed. Technology went from a means to humanitarian progress to an end in itself. The idea of progress, which had once meant an improvement in the human condition, became equated directly with technology. Progress was technology, technology was progress.

According to Marx and other historians of technology, at least two developments in the mid-nineteenth century helped change the nature and perception of technology. First, some areas of technology began to evolve from the individual-oriented "mechanic arts," such as glass blowing and woodworking, to large, depersonalized systems like the railroad. Secondly, these vast technological systems became hugely more profitable than any previous technology in the history of the world, offering great personal wealth to their creators. Technology became an instrument of the powerful enterprise called capitalism.

The earlier, mechanic arts were characterized by the skill of a small number of individuals and often a direct, personal contact between producer and consumer. By contrast, technological systems were large, amorphous organizations of machinery, people, and bureaucratic structures, with many levels between producer and consumer. Each railroad, the largest new technology of the nineteenth century, required thousands of workers, tracks laid for hundreds or thousands of miles, many stations, layers of bureaucracy and management, huge outlays of capital. No longer was technology a humanistic activity, with its principal purpose to improve the quality of life. This turn of events led Henry David Thoreau to make one of his more famous and witty remarks: "We do not ride on the railroad, it rides upon us."

An example that Marx uses to illustrate his point is a speech given by Daniel Webster, one of the foremost orators of the day, at a dedication of a new railroad in 1847: "It is an extraordinary era in which we live. . . . We have seen the ocean navigated and the solid land traversed by steam power, and intelligence communicated by electricity. Truly this is almost a miraculous era. . . . The progress of the age has almost outstripped human belief; the future is known only to Omniscience." Aside from the reference to Omniscience, the tone does not seem dissimilar to some of the speeches and writings of Bill Gates and Larry Ellison and Gordon Moore. Nowhere in these words is there any reference to the quality of life, or human happiness, or the social betterment of humankind.

I look at my bright young students, so full of life, and wonder whether they can slow down enough to think about the real purposes of their studies, think about what is truly important to them, as individuals and as members of a society.

My investigations turn to capitalism, possibly the most powerful organizing force in the world today, certainly in the United States of America. I am not surprised to learn that capitalism has helped redirect the thrust of invention. And I even wonder: perhaps capitalism has always fueled the fires of technology, even Watt's steam engines and power looms. Capitalism lives on product, and no human creation has yielded product, with such high efficiency, as technology. More precisely, capitalism lives on profit, but the products of recent technologies have often translated into profits. Railroads, airplanes, telephones, automobiles, electric ranges and blenders, vacuum cleaners, dishwashers, microwaves and refrigerators, televisions and radios, Walkmans and CD players and video players, humidifiers, copying machines, fax machines, personal computers—all have been gold mines for capitalism, returning great monetary gain to their inventors, creators, producers, and distributors.

As a consumer, I have benefited, as have most people, from these rapid developments. I purchased one of the first Hewlett-Packard pocket calculators in the early 1970s and have owned a succession of powerful desktop and laptop computers ever since. I am a member of a two-cell-phone family. I have an electric garage door opener. I watch videos at home. I use the Internet to keep up with friends in other countries. I have certainly benefited from the advances in technology. But I have also paid a heavy price. And that price is what I most want to understand. That price, and even my personal benefit, are not of direct concern to capitalism. The first goal of capitalism is not to improve society and its members but to maximize the personal wealth of the capitalist. This goal is both the great strength and the great weakness of capitalism. I take out my copy of Adam Smith's *The Wealth of Nations* (1776), the bible of capitalism, and read: "It is not from the benevolence of the butcher, the brewer, or the baker, that we expect our dinner, but from their regard to their own interest. We address ourselves not to their humanity but to their self-love."

A good illustration of the relentless way in which capitalism and technology operate together is in the production-consumption-work cycle of modern business. In the 1950s, academics forecast that as a result of new technology and increased productivity, by the year 2000 we could have a twenty-hour work week. Such a development would be a beautiful example of technology at the service of the human being. In newly formed institutes of leisure studies and in such books as *Mass Leisure* (1958), experts pondered how Americans would spend their impending leisure time. More family vacations? More time for sports? More movies? More reading, more attendance at musical concerts or stage productions or art galleries?

According to the Bureau of Labor Statistics, the amount of goods and services produced per hour of work in the United States has indeed more than doubled since 1950. Half of the forecast was correct. Instead of reducing the work week, however, the increased efficiencies and productivities have gone into increasing the salaries of workers. Managers, desiring more and more profit, have found it against their interests to shorten the work week or to stitch together part-time positions. Workers, for their part, have generally not lobbied for fewer hours but rather used their increased efficiencies and resulting increased disposable income to purchase more material goods. As mentioned earlier, consumption in the United States per person, in real dollars, has more than doubled since 1950. Indeed, in a cruel irony, the work week in America has actually lengthened. The sociologist Juliet Schor, in her important book *The Overworked American* (1991), found that the average American worked 160 hours longer each year in 1990 than twenty years earlier. And that increase in working time cuts across all income levels. More work is required to pay for more consumption, fueled by more production, in an endless, vicious cycle.

And what is it that we are consuming so voraciously, what impels us to work faster and longer hours, even in the face of higher efficiency? What are these burning material needs, when Americans have become wealthier and wealthier, more than doubling their real income per person in the last fifty years? One of the methods of capitalism is to create demand for its product, even when that demand does not previously exist. I was astonished to read this aim so unabashedly spelled out by Charles Kettering, a major inventor and general of GM Research Labs. In

1929, at the beginnings of the automobile industry in the United States, Mr. Kettering wrote in *Nation's Business* magazine that business must create a "dissatisfied consumer" and "keep the consumer dissatisfied." A more recent example of the same idea was voiced by the economist John Kenneth Galbraith as he surveyed the future of capitalism in an ever-wealthy America. In his book *The Affluent Society* (1984), Galbraith writes that in modern America, production will have to "create the wants it seeks to satisfy." In short, a large part of our consumption is what we are told to consume, told that we need. And the cycle continues.

So it seems that we are running round and round like hamsters on the wheel of capitalism, production, demand, consumption, and work. Instead of slowing down the wheel, increased productivity has only sped it up. Instead of creating breathing spaces in the work week, increased efficiency has caused us to work faster and longer. In this maze of counterintuitive results, it is hard to tell cause from effect, effect from cause. But the larger import seems clear. Ever since the physician George Beard commented in 1881 that "American nervousness" had increased since the invention of the telegraph, the pace of daily life has been set by the speed of communication and business. Everything in our lives has become faster, more hurried, more urgent. I cannot help but recall the first lines of William Wordsworth's 1807 poem, prescient in the way that artists often can divine the future:

> The world is too much with us; late and soon,
> Getting and spending, we lay waste our powers:
> Little we see in Nature that is ours;
> We have given our hearts away, a sordid boon!

Many people in the United States, both in intellectual forums and in daily conversation, have begun to express a fervent desire to slow down their lives, have begun to express a sense of being trapped in a world that they cannot control. The word "helpless" is often repeated. For many of us, the practical difficulties of changing our work conditions and life rhythms are indeed enormous. Living in the Wired World as we do, are we then helpless to create private spaces and silences to contemplate our inner selves? Are we helpless to disconnect from the network?

I do not think so. In an odd way, my growing understanding of the vast forces that shape modern life has only increased my resolve to counter those forces, to build a parallel universe for my inner life and spirit. I am convinced that such an interior world is both possible and necessary. And here I disagree in part with two distinguished technology visionaries, Bill Joy, the American co-founder of Sun Microsystems, and the French philosopher and sociologist Jacques Ellul. Joy, in his provocative essay "Why the Future Doesn't Need Us" in *Wired* magazine, argues that the world is being taken over by machines. Ultimately, Joy says, we humans will be the machines of the machines. Joy's prediction, which has much sympathetic resonance, is just too extreme. Although technology is proceeding at a dizzying pace, I believe that the human mind will always have control of itself. And since the human mind has a degree of infinity and imagination unlikely to be matched by a machine for a very very long time, I don't think that we will become the machines of the machines.

Ellul, in his *Technological Society* (1964), claims that technology and technical thinking have torn apart our world and rebuilt it into a rigid and unthinking society. Technology, according to Ellul, has so transformed our culture that "the human personality has been almost wholly disassociated and dissolved through mechanization." In Ellul's view, the technological mentality, the mentality of efficiency and production, is so pervasive that we have "no intellectual, moral, or spiritual reference point for judging and criticizing technology." I don't agree with Ellul for the simple reason that I did indeed have the moment of awareness that I described at the start of this essay. I did become conscious of the life I was living in the Wired World, I did remember the silences and inner solitude that I experienced as a child, I did remember my places of stillness. I am writing this essay.

A critical element, it seems to me, is awareness—in particular, becoming aware of the choices we have. Some of those choices are visible, some are not. Every day, each of us decides, consciously or unconsciously, what to buy from the marketplace, what machines to have in our offices and homes, how to use those machines, when and how to communicate with the outer world, how to spend our time, what to think about. When do we unplug the telephone? When do we take our cell phones with us and when do we leave them behind? When do we read? When do we buy a new microwave or television or automobile? When do we use the Internet? When do we go out for a quiet walk to think? These decisions may seem petty and trivial. But at stake in these hundreds of daily decisions is the survival of our inner selves. We have choices, but we must become aware of the choices.

Of course, we are not completely free agents in these choices. We are individuals but we are also members of a society, and that society places hard demands on us in our jobs and in our lifestyles. A schoolteacher does not have the same demands as a stockbroker or a construction worker. Thus, for practical reasons, the exercise of our choices is far more difficult for some people than for others. We cannot ignore the practicalities. To varying degrees, the workplace, the society, the nation all entangle us in the Wired World. We are inescapably part of the capitalistic-technological complex.

Still, I do not believe that needed changes can be mandated from the top down. First, the underlying malaise of the Wired World is not primarily economic or legal; rather, it is philosophical, psychological, spiritual. And second, individuals have different priorities, different values. It is the slowness and silence and privacy for reflection on those values that we must regain.

While it would be helpful for governments to enforce new laws—such as that cell phones are forbidden in restaurants or that all businesses must provide six weeks of vacation for their workers (as in some European countries) or that all public and corporate spaces are required to have noise-free zones or that transactions in the stock market must have a twenty-four-hour delay—none of these mandates can by themselves alter attitudes of self. Changes in philosophy of life come about slowly, and at the level of the individual.

A comparison is the institution of slavery. Slavery has existed in all parts of the world since the earliest recorded history. The involuntary servitude of one class of individual to another is sanctioned in Mosaic law and described in the Old and New Testaments. Despite their life of high culture and refinement, the ancient Greeks not only permitted slavery but organized much of their society around it. For millennia, slavery was accepted as part of the natural order of things. Without question, it was believed that some human beings were naturally inferior to others, could rightfully be owned by others. Even many of the founding fathers of America, such as Thomas Jefferson, counted slaves among their possessions. The various antislavery laws in Pennsylvania in the late seventeenth century, in Denmark and France in the late eighteenth century, and in England in the early nineteenth century did not stop slavery. What ended slavery was the gradual recognition by individual members of human society that slavery is dehumanizing, not only to the slaves but also to their masters.

In creating the Wired World and the mentality that goes with it, we have unintentionally imprisoned ourselves. That imprisonment has happened slowly and unconsciously. Our manacles are subtle and invisible as air, but they are real. Although the regaining of our freedom and the reclaiming of our inner selves will take time, it is possible.

The Wired World, for good and for ill, is the world that we live in. Capitalism and technology, for good and for ill, are here to stay. But as potent and pervasive as these forces are, I do not think we can blame them for the absence of privacy and silence and inner reflection in our lives. We must blame ourselves. For not letting my mind wander and roam, I must blame myself. For allowing myself to be plugged in to the frenzied world around me twenty-four hours a day, I must blame myself. Only I can determine my personal set of priorities and values, reflect on who I am and where I am going, become aware of those many small decisions I make throughout the day. The responsibility is mine. Understanding that the responsibility is mine is a kind of freedom in itself.

Thoreau framed the problem well a century and a half ago when he said that we must produce better dwellings "without making them more costly; and the cost of a thing is the amount of what I will call life which is required to be exchanged for it, immediately or in the long run." Somehow, each of us must figure out how to measure the "life," our personal life, our inner self, that we exchange for each piece of technology or scheduled project or public connection. This accounting may have to be done item by item, hour by hour, but I believe that it must be done, and it can be done only by the individual. Only individuals can measure their own values and needs, their own spirit, their own quality of life.

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Chapter 2. The Origin of the Genie

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Chapter 3. Promise and Peril

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3. The web contains extensive information, including military manuals, on how to build bombs, weapons, and explosives. Some of this information is erroneous, but accurate information on these topics continues to be accessible despite efforts to remove it. In June 1997 Congress passed an amendment (the Feinstein Amendment, SP 419) to a Defense Department appropriations bill banning the dissemination of instructions on building bombs. See Helmenstine, Anne Marie, "How to Build a Bomb," chemistry.about.com/library/weekly/aa021003a.htm, posted February 10, 2003. Information on toxic industrial chemicals is widely available on the web and in libraries, as is information and tools for cultivating bacteria and viruses. Techniques for creating computer viruses and hacking into computers and networks are also widely available on the Internet. Note that it is my policy not to provide specific examples of such information, since it might be helpful to destructive individuals and groups. I realize that even stating the availability of such information has this potential, but I feel that the benefit of open dialogue about this issue outweighs this concern. Moreover, the widespread availability of this type of information has been widely discussed in the media and other venues.

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11. The Internet, as measured by the number of nodes, was doubling every year during the 1980s, but was only tens of thousands of nodes in 1985. It grew to tens of millions of nodes by 1995.

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13. Electromechanical card-reading equipment was used in the 1890 U.S. census. Alan Turing and his colleagues built the first special-purpose computer out of electromagnetic relays in 1942. Vacuum tubes were used in the 1952 computer that predicted the election of Eisenhower, the first time the networks had used a computer to predict a presidential election. Computers based on discrete transistors were used in the space flights during the 1960s. Integrated circuits began to be used in the late 1960s.

14. Silicon nanowires and carbon nanotubes are now the candidate nanoscale

technologies that could begin to replace standard transistors in the decade after 2010. Because nanotubes are small, a large number can be packed in a given space and will enable very high-density processors and memory-storage devices. IBM (www.ibm.com/news/2001/04/27.phtml) and other institutions are currently researching this technology. For a survey of recent developments in nanotubes and other recent breakthroughs, see "Top KurzweilAI.net News of 2002," www.kurzweilai.net/meme/frame.html?main=/articles/art0550.html, posted February 5, 2003.

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35. Alexander Keyssar, *Out of Work: The First Century of Unemployment in Massachusetts* (Cambridge: Cambridge University Press, 1986).

36. Karl Polanyi, *The Great Transformation: The Political and Economic Origins of Our Time* (1944; reprint, Boston: Beacon Press, 1957), p. 163.

37. Langdon Winner, *The Whale and the Reactor: The Search for Limits in an Age of High Technology* (Chicago: University of Chicago Press, 1986), p. xi.

38. Charles E. Lindblom, *The Intelligence of Democracy* (New York: The Free Press, 1965); Joseph G. Morone and Edward J. Woodhouse, *Averting Catastrophe: Strategies for Regulating Risky Technologies* (Berkeley: University of California Press, 1986); Joseph G. Morone and Edward J. Woodhouse, *The Demise of Nuclear Energy?: Lessons for Democratic Control of Technology* (New Haven: Yale University Press, 1989); Lindblom and Woodhouse, *The Policy-Making Process.*

39. Michael Crichton, "How Nanotechnology Is Changing Our World," *Parade,* November 24, 2002, pp. 6–8.

40. Freeman Dyson, "The Future Needs Us!" *The New York Review of Books,* February 13, pp. 11–13.

41. Other books offering related warnings and analyses include Francis Fukuyama, *Our Posthuman Future* (New York: Farrar, Straus and Giroux, 2002); and Douglas Mulhall, *Our Molecular Future: How Nanotechnology, Robotics, Genetics, and Artificial Intelligence Will Transform Our World* (New York: Prometheus Books, 2002).

42. B. Christie, "Doctors Revise Declaration of Helsinki," *British Medical Journal* 321:913 (October 14, 2000).

Chapter 5. Your Breath Is Your Worst Enemy

1. U.S. Department of Energy, *Department of Energy FY 2000 Congressional Budget Request: Energy Efficiency and Renewable Energy, Energy Conservation, Building Technology, State and Community Sector.* http://www.efo.doe.gov/budget/00budget/ec/building.pdf.

2. U.S. Department of Energy, Office of Building Technology, State and Community Programs, Energy Efficiency and Renewable Energy, *High Performance Commercial Buildings: A Technology Roadmap* (Washington, D.C.: U.S. Department of Energy, 2000), p. 6.

3. The term "HVAC" will be used throughout this essay in its broadest meaning, referring to all mechanical systems that are used to provide temperature or humidity control of building interiors.

4. Lewis Leeds, *Lectures on Ventilation* (New York: John Wiley & Son, 1869).

5. U.S. Congress, House Select Committee on Ventilation, *Report of the Select Committee on Ventilation,* March 3, 1871, 41st Congress, 3rd Session, Report No. 49. The committee had asked several well-known ventilation experts, including Henry Gouge, to submit proposals for improving the ventilation of the Capitol building. Gouge's proposal was singled out by the committee as one of the more promising.

6. See Katherine Ott, *Fevered Lives* (Cambridge: Harvard University Press, 1996), for a discussion of class and sanitarium accessibility.

7. Data from Milbank Memorial Fund, *Report of the New York State Commission on Ventilation* (New York: E. P. Dutton & Company, 1923).

8. Gail Cooper, *Air-Conditioning America* (Baltimore: The Johns Hopkins University Press, 1998), p. 74. Chapter 3, "Defining the Healthy Indoor Environment, 1904–1929," provides an excellent overview of the debates that took place between the open-air enthusiasts and the supporters of mechanical ventilation, primarily engineers.

9. Alfred Crosby, "Influenza: In the Grip of the Grippe," in *Plague, Pox & Pestilence,* ed. Kenneth F. Kiple (New York: Barnes & Noble, 1997), p. 153.

10. Carrier Engineering Corporation, *The Story of Manufactured Weather* (New York: 1919), p. 5.

11. Nancy Tomes, *The Gospel of Germs* (Cambridge: Harvard University Press, 1998), p. 183.

12. Ellsworth Huntington, *The Human Habitat* (New York: D. Van Nostrand Company, 1927), p. 15.

13. Le Corbusier, *Precisions on the Present State of Architecture and City Planning,* trans. Edith Schreiber Aujame (Cambridge: MIT Press, 1991), pp. 64–66. The work was originally published in French in 1930. Le Corbusier was rephrasing the Roman architect Vitruvius's first century B.C. treatise on the rules of architecture. Vitruvius had written that each house, whether in Spain or in Egypt or in Rome, must be different due to the different climates.

14. Cited from a roundtable conversation between architects and engineers in Richard Rush, ed., *The Building Systems Integration Handbook* (New York: John Wiley & Sons, 1986), pp. 34–35.

15. Cited from U.S. Energy Information Administration, *Annual Energy Outlook 2002 with Projections to 2020,* Report # DOE/EIA-0383[2002], December 2001, p. 3.

16. *Ibid.*, p. 2.

17. *National Energy Policy,* Report of the National Energy Policy Development Group (Washington, D.C.: Office of the President of the United States, 2001), p. ix.

18. Pacific Northwest Laboratory, "Heat Pumps of the Future: Smaller than a Dime," press release, September 2, 1994, cited in S. Ashley, "Turbines on a Dime," *Mechanical Engineering* 19(10):82.

19. Pacific Northwest Laboratory, *The Potential for Microtechnology Applications in Energy Systems: Results of an Expert Workshop,* U.S. Department of Energy Publication PNL-10478.

20. Freeman Dyson, *Imagined Worlds* (Cambridge: Harvard University Press, 1997), p. 34. Dyson was referring to the politically accelerated timetables and ideologically constrained developments that resulted in the ultimate failure of several twentieth-century technologies, including the R101 airship, the Comet jetliner, and the nuclear power industry.

Chapter 6. Changing Conceptions

1. Karl Mihail, who with Tran T. Kim-Trang created Gene Genies Worldwide, www.genegenies.com.

2. In 2002, Italian infertility specialist Dr. Severino Antinori told the press that several of his female patients were pregnant with clones. John Crewdson, "Gynecologist Claims Impending Births of 5 Cloned Human Babies," *Chicago Tribune,* June 23, 2002, p. 1.

3. In 2002, a couple screened their embryos prior to implantation in order to choose one that would not have a genetic predisposition to Alzheimer's disease. Yury Verlinsky et al., "Preimplantation Diagnosis for Early-onset Alzheimer Disease Caused by V717L Mutation," *Journal of the American Medical Association* 287:1018–1021 (February 27, 2002).

4. Shannon Brownlee, "Designer Babies," *The Washington Monthly,* March 2002, pp. 25–31, 26.

5. Lee M. Silver, *Remaking Eden: Cloning and Beyond in a Brave New World* (New York: Avon Books, 1997), p. 69.

6. Gregory Stock, director of UCLA's Program on Science, Technology, and Society, has stated, "The computer has become a necessity for modern society, and if a process were developed to triple human intelligence or to enable people to get along with no sleep, these too would soon become 'necessities.' But asking whether such changes are 'wise' or 'desirable' misses the essential point that they are largely not a matter of choice; they are the unavoidable product of the technological advance. . . ." From the symposium "Engineering the Human Germ Line," University of California at Los Angeles, March 1998, www.ess.ucla.edu/huge/report.html. See also www.hgalert.org/topics/ hge/justin.htm; Gregory Stock, *Metaman: The Merging of Humans and Machines into a Global Superorganism* (New York: Simon & Schuster, 1993), pp. 168–99.

7. From the symposium "Engineering the Human Germ Line."

8. Gregory Stock, "The Prospects for Human Germline Engineering," *Telepolis* (Frankfurt, Germany), January 29, 1999.

9. In one such technique, sperm or spermatocyte heads obtained from the male are placed in a detergent or are rapidly frozen and thawed to disrupt the cell membranes (J. Knight, "Saved by Sperm," *New Scientist,* May 22, 1999, www.newscientist.com/hottopics/animalexperiments/animalnews21.jsp). This increases the chance that desired DNA construct would incorporate with the host DNA. The sperm or spermatocyte heads are then incubated in a solution that contains the desired transgene. The treated sperm or spermatocyte heads act as carriers for the desired gene once microinjected into the unfertilized oocytes. One advantage of intracytoplasmic sperm injection is that this method yields more than 80 percent of transgenic offspring (L. Criado et al., "Gene Targeting Facility—Production of Transgenic and Knockout Mice: Current Methods and New Tendencies," available at http://dio.cnb.uam.es/Main/Information/DIOAR2000/AR2000-Gene-3.html).

Another advantage is that although pronuclear microinjection is the most successful method in mice, it is still difficult in non-mouse species (C. S. Shashikant and F. H. Ruddle, "Transgenic Mouse Models," in *Genetic Models in Cardiorespiratory Biology,* ed. Gabriel G. Haddad and Tian Xu [Marcel Dekker, 2001]).

10. Pronuclear microinjection is the most commonly used method for genetic intervention on embryos; it involves the direct microinjection of the chosen DNA construct into the pronucleus of fertilized oocytes (Shashikant and Ruddle, "Transgenic Mouse Models," in Haddad and Xu, citing J. W. Gordon et al., "Genetic Transformation of Mouse Embryos by Microinjection of Purified DNA," *Proceedings of the National Academy of Sciences USA* 77 [1980]). Nucleotides for a particular identified gene are sequenced, usually along with a promoter, to create a DNA construct (transgene plus promoter). The DNA construct is replicated in a plasmid vector, producing multiple exact copies, which can then be microinjected into the pronucleus of an embryo. Freshly fertilized eggs are placed in a sterile dish in a solution of buffer.

The insertion of the DNA in pronuclear microinjection is a random process. The frequency of live-born transgenetic offspring from the injected oocytes is only 30 percent (Jon W. Gordon, "Transgenic Technology and Laboratory Animal Science," *ILAR Journal* 38 [1997]). The disadvantages of pronuclear microinjection are that the rate of integration is low and not always uniform (Susan B. Harper, "How

Transgenics Are Produced," *FDA Veterinarian Newsletter,* July/August 1999). The transgene usually inserts into a single site in the genome either as a single molecule or as head-to-tail concatemers of two or more molecules; more than fifty copies might be inserted at one site, and multiple-site insertions are also possible ("Transgenic Mouse Technology," *University of Illinois at Chicago RRC Reporter* 2 [winter 2001]). Also, it is not possible to specify or target the locus of integration for the transgene in the host DNA (Harper, "How Transgenics Are Produced").

In an alternative approach, undifferentiated embryonic stem (ES) cells are harvested from the inner cell mass of the blastocyst stage of the embryo and are grown in culture in vitro (Shashikant and Ruddle, "Transgenic Mouse Models"). To prevent differentiation and the loss of pluripotency, the ES cells must be maintained under stringent conditions ("Transgenic Mouse Technology," *RRC Reporter*). The desired gene is replicated in a plasmid vector and is developed into a DNA construct that is analogous to a specific segment of the host DNA by adding a selectable marker. The new DNA transgene is introduced into the nuclei of the ES cells by means of a vector or by electroporation (Harper, "How Transgenics Are Produced"), a process that uses strong, brief pulses of electrical current to create pores across the cells' membranes, which produces a transient permeability of the cells' membranes. The pores close after one to thirty minutes without having significant damage to the exposed cells. (Available at www.genetronics.com/tech_98/electroporation.htm. The transgene will incorporate into some of the cells' nuclei, replacing the existing segment of the DNA. The targeted ES cells are microinjected into the blastocyst-stage embryos in a method similar to pronuclear microinjection.

Only about one-third of the implanted embryos will develop into healthy, viable offspring ("Transgenic Animals," available at www.ultranet.com/ `jkimball/BiologyPages/T/TransgenicAnimals.html). The frequency of insertion for the desired gene is no more than 10 to 20 percent ("Transgenic Animals"). The advantages of the ES cells are that only one copy of the transgene is incorporated and that the site of the integration is highly controlled. The disadvantages are that the process is very time consuming and the desired DNA sequence must already be known (Harper, "How Transgenics Are Produced").

11. Pronuclear microinjection of artificial chromosomes has been used to create transgenic mice. Around 50 percent of the mouse embryos survived the microinjection, and 50 percent of the viable SATAC-injected zygotes developed into the blastocyst stage. The SATAC was detected in 44 percent of mouse embryos analyzed, though the embryos did exhibit varying degrees of mosaicism, ranging from 8 to 67 percent of the cells expressing the gene (D. Co et al., "Generation of Transgenic Mice and Germline Transmission of a Mammalian Artificial Chromosome Introduced into Embryos by Pronuclear Microinjection," *Chromosome Research* 8 183–91 [2000]).

The principal advantage of using mammalian artificial chromosomes is that larger pieces of DNA can be inserted into the cell (Nancy J. Nelson, "Faux Chromosomes Hit the Streets, Hold Real Promise for Gene Therapy," *Journal of the National Cancer Institute* 89 [July 2, 1997]). Another advantage is that the mammalian artificial chromosomes are able to replicate in parallel with the host genome but without integration into the host genome (Co et al., "Generation of Transgenic Mice").

Researchers at Case Western Reserve University have been working on developing human artificial chromosomes (HACs), which can potentially be used for gene transfer and as gene therapy vectors. HACs are formed when bacterial cloning vectors that contain alpha-satellite DNA are transfected into cultured human cells (B. R. Grimes, A. A. Rhoades, and H. F. Willard, "Alpha-Satellite DNA and Vector Composition Influence Rates of Human Artificial Chromosome Formation," *Molecular Therapy* 5:798–805 [June 2002] [abstract only]). HACs are nonviral vectors that will not elicit an immune response and have the ability to carry tissue-specific promoters that would allow expression in the correct cells (Nelson, "Faux Chromosomes").

12. Ellen Licking, "Gene Therapy: One Family's Story," *Business Week,* July 12, 1999, p. 94.

13. Todd Ackerman, "The New Millennium: A Brave New World of Designer Babies; Genetic Engineering to Open Pandora's Box of Ethical Questions," *The Houston Chronicle,* June 27, 1999, p. A1.

14. Michael D. Lemonick, "Designer Babies: Parents Can Now Pick a Kid's Sex and Screen for Genetic Illness—Will They Someday Select for Brains and Beauty Too?" *Time,* January 11, 1999, p. 64.

15. Ackerman, "The New Millennium."

16. Barbara Demick, "Some in S. Korea Opt for a Trim When English Trips the Tongue," *Los Angeles Times,* March 31, 2002, p. A3.

17. Richard Hayes, "The Quiet Campaign for Genetically Engineered Humans," *Earth Island Journal,* March 22, 2001, p. 28. See also Silver, *Remaking Eden,* pp. 10–11.

18. John Leo, "A New Medical Skill: Counting," *U.S. News & World Report,* December 8, 1997, p. 20.

19. Dolores Kong, "What Price Pregnancy?" *Boston Globe,* August 4, 1996, p. A35.

20. Lori B. Andrews, *The Clone Age: Adventures in the World of Reproductive Technology* (New York: Henry Holt, 1999).

21. National Council for Adoption, "Hotline Information Packet" (1997), p. 1.

22. "What is it going to take before we get some regulation in this area?" asks renowned bioethicist Arthur Caplan. "We've already had an untold number of women undergoing 'selective reductions,' a 55-year-old woman on welfare who had multiples, and an unmarried man who contracted to have a surrogate bear his child and then killed the baby. If that hasn't prompted regulation, what will?" Statement at "Changing Conceptions: A Symposium on Reproductive Technologies," Chicago-Kent College of Law, December 5, 1997.

23. The enhanced interest in reproductive technologies across all sectors of society is evinced by the massive media coverage given the topic—from *Oprah* to *Nightline,* from the *New York Times* to the *Wall Street Journal,* and by the diversity of individuals, groups, and institutions that testify in Congress on reprogenetics issues and file amicus briefs in cases. For example, among the groups filing amicus briefs in the Baby M surrogacy case were feminists, Catholic bishops, sociologists, and a major labor union.

24. Statement of Robert Edwards, the scientist who facilitated the world's first successful in vitro fertilization, at "Changing Conceptions: A Symposium on Reproductive Technologies."

25. Silver, *Remaking Eden,* p. 69.

26. "Mary and Tracy Hunt Talk About Wanting to Clone Their Deceased Baby," *Good Morning America,* September 7, 2001.

27. See Eduardo Kac's website, ekac.org, for more information about the project.

28. Eduardo Kac, personal communication with author, October 15, 2002. It should be noted that the 1999 preparation of the gene was done in one pass. The 2001 gene was created using a less expensive machine in several parts and assembled by a geneticist who donated his time.

29. His colleague, Peter Gena, another professor at the Art Institute of Chicago and the leading practitioner of DNA-synthesized music, has created a haunting symphony based on the DNA sequence of the Genesis gene. As the genetic makeup of the creature in the disk mutates, so too does the music.

30. Rick Weiss, "Mouse Gene Test Can't Quite Make Louse a Spouse," *Chicago Sun-Times,* August 25, 1999, p. 37S; Larry J. Young et al., "Increased Affiliative Response to Vasopressin in Mice Expressing the V1a Receptor from a Monogamous Vole," *Nature* 400:766–68 (1999).

31. The Human Genome Project (HGP) determined that there were many fewer genes than previously thought (around 30,000 instead of 100,000). Since there are more than 30,000 proteins, the HGP's findings "contradicted the one-to-one correspondence of gene to protein and have broken the DNA gene's exclusive franchise on the molecular explanation of heredity." Other molecular mechanisms have a major role as well. Barry Commoner, "Unraveling the DNA Myth," *Harper's,* February 2002, pp. 39–47.

32. Andrea L. Bonnicksen, *In Vitro Fertilization: Building Policy from Laboratories to Legislatures,* (New York: Columbia University Press, 1989), pp. 76–77.

33. Fla. Stat. Ann. §390.0111(6); La. Rev. Stat. Ann. §9:121 *et. seq.;* Me. Rev. Stat. tit. 22 §1593; Mass. Ann. Laws. ch. 112 §12J; Mich. Comp. Laws. §§333.2685 to 2692; Minn. Stat. Ann. §145.421 (applies only until 265 days after fertilization); N.D. Cent. Code §§14-02.2-01 to -02; 18 Pa. Cons. Stat. Ann. §3216; R.I. Gen. Laws. §11-54-1; S.D. Codified Laws §34-14-16 to 34-14-20.

34. The new policy stated, "No application or proposal involving human *in vitro* fertilization may be funded by the Department or any component thereof until the application or proposal has been reviewed by the Ethical Advisory Board and the Board has rendered advice as to its acceptability from an ethical standpoint." 40 Federal Register 33528 (August 8, 1975). For the federal regulations regarding human research protections for pregnant women, fetuses, and neonates, see 45 C.F.R. §46.204.

35. Soupart's proposal, "Cytogenetics of Human Preimplantation Embryos," did not include any plans to attempt implantation.

36. Bonnicksen, *In Vitro Fertilization,* p. 79.

37. *Ibid.,* citing Ethics Advisory Board (EAB), *Report and Conclusions* in Grobstein, *Chance to Purpose,* p. 201.

38. *Ibid.,* p. 81. Bonnicksen further notes that Califano's departure as secretary of HEW may have been due in part to the EAB report. See p. 163, note 32.

39. Brownlee, "Designer Babies."

40. *Ibid.*

41. *Ibid.*

42. 45 C.F.R. §46.204(d) was nullified by §121(c) of the NIH Revitalization Act of 1993, Pub. L. No. 103-43 (June 10, 1993).

43. See 45 C.F.R. §46.208(a)(2).

44. 45 C.F.R. §46.111(a)(2).

45. Peter J. Paganussi, "Fertility Frontier," *Washington Post,* February 23, 1998, p. A18 (letter).

46. Susan E. Volkert, "Telemedicine Rx for the Future of Health Care," *Michigan Telecommunications and Technology Law Review* 6 (2000), pp. 147, 246, note 73, citing 21 U.S.C. §§301–338.

47. These states are Arkansas, California, Connecticut, Hawaii, Illinois, Maryland, Massachusetts, Montana, New Jersey, New York, Ohio, Rhode Island, Texas, and West Virginia.

48. "The FDA does not regulate the practice of medicine, but it is undisputed that insurers do." William L. Christopher, "Off-Label Drug Prescription: Filling the Regulatory Vacuum," *Food and Drug Law Journal* 48:247, 256 (1993).

49. See, e.g., *Curlender v. Bioscience Laboratories,* Cal. Rptr. 165:477 (Cal. App. Ct. 1980).

50. E. R. te Veld, A. L. van Baar, and R. J. van Kooij, "Concerns about Assisted Reproduction," *Lancet* 351:1524–1525 (1998).

51. Don P. Wolf and Martin M. Quigley, "Historical Background and Essentials for a Program in In Vitro Fertilization and Embryo Transfer," in *Human In Vitro Fertilization and Embryo Transfer,* ed. Don P. Wolf and Martin M. Quigley (New York: Plenum Press, 1984), pp. 1, 3.

52. Commercialization has pushed genetics into new settings. The genetics industry and the funeral industry have teamed up to market a kit that allows funeral directors to take some DNA from the deceased. Gina Kolata, "A Headstone, A Coffin, and Now, the DNA Bank," *New York Times,* December 24, 1996, p. C1. The kit is promoted by the manufacturer, GeneLinks, as a way to obtain genetic information about the deceased for the aid of other relatives, but the need for such an approach is decreasing, as direct gene testing is replacing the need for family linkage studies. Rather, the company is cashing in on the glamour of genetics, creating new psychological needs and then meeting them. Some families say they find it comforting to have a bit of their dead relative around by keeping some of their DNA in storage.

53. *Diamond v. Chakrabarty,* 447 U.S. 303 (1980).

54. *Funk Bros. Seed Co. v. Kalo Inoculant Co.,* 333 U.S. 127 (1948).

55. See, for example, Rebecca S. Eisenberg, "Patenting the Human Genome," *Emory Law Journal* 39:721 (1990).

56. 15 U.S.C.S. §3701 *et seq.;* 35 U.S.C. §200 *et seq.* See also Sheldon Krimsky, *Biotechnics and Society* (New York: Praeger, 1991).

57. In the context of advances in biotechnology, the 1980s legislation led to important changes in the goals and practices of science and medicine. Leon Rosenberg, when he was dean of the Yale University School of Medicine, described the influence of the biotechnology revolution on scientific research: "It has moved us, literally or figuratively, from the classroom to the boardroom and from the *New England Journal* to the *Wall Street Journal.*" Leon Rosenberg, "Using Patient Materials for Production Development: A Dean's Perspective," *Clinical Research* 33:412–54 (October 1985).

58. See generally Jon F. Merz et al., "Diagnostic Testing Fails the Test," *Nature* 415:577–79 (2002). Their survey found that researchers decreased research efforts because of issues pertaining to patents on medical procedures.

59. *Ibid.,* p. 578.

60. David Blumenthal et al., "University-Industry Research Relationships in Biotechnology," *Science* 232:1361, 1362 (1986).

61. David Blumenthal et al., "Withholding Research Results in Academic Life Sciences," *Journal of the American Medical Association* 277:1224 (1997).

62. *Ibid.,* pp. 1226–1227.

63. *Ibid.,* pp. 1227–1228.

64. David Blumenthal et al., "Data Withholding in Academic Genetics," *Journal of the American Medical Association* 473, 477 (2002).

65. *Ibid.,* p. 478.

66. *Ibid.*

67. Vincent Kiernan, "Truth Is No Longer Its Own Reward," *New Scientist,* March 1, 1997, 11.

68. Silver, *Remaking Eden,* p. 72.

69. Jennifer J. Kurinczuk and Carol Browner, "Birth Defects in Infants Conceived by Intracytoplasmic Sperm Injection," *British Medical Journal* 315:1260 (1997).

70. E. R. te Velde, A. L. van Baar, and R. J. van Kooij, "Concerns about Assisted Reproduction," *Lancet* 351:1524–1525 (1998).

71. Michael D. Lemonick and Andrew Goldstein, "At Your Own Risk: Some Patients Join Clinical Trials Out of Desperation, Others to Help Medicine Advance. Who Is to Blame If They Get Sick or Even Die?" *Time,* April 22, 2002, p. 46. James Wilson was the founder of Genovo, a biotechnology company that provided about 20 percent of the research budget to Wilson's lab. Both Wilson and the University of Pennsylvania stood to profit if the research proved successful. Wilson owned 30 percent of Genovo's stock; the University of Pennsylvania owned 3.2 percent.

72. Joseph N. DiStephano, Huntly Collins, and Shankar Vedantam, "Penn Reviewing Institute's Ties to Company," *Philadelphia Inquirer,* February 27, 2000, p. A01.

73. Sheryl Gay Stolberg, "Senators Press for Answers on Gene Trials," *New York Times,* February 3, 2000, p. A25.

74. Tim Friend, "Risky Gene Therapy Gets Personal; Human Trials Could Help Hemophiliacs," *USA Today,* October 8, 2001, p. D1.

75 Rick Weiss and Deborah Nelson, "Victim's Dad Faults Gene Therapy Team," *Washington Post,* February 3, 2000, p. A2.

76. Stuart Newman, "Don't Try to Engineer Human Embryos," *St. Louis Post-Dispatch,* July 25, 2000.

77. Jon. W. Gordon, "Genetic Enhancement in Humans," 283 *Science* 2033–2024 (1994).

78. *Ibid.*

79. R. A. Bowden et al., "Transgenic Cattle Resulting from Biopsied Embryos: Expression of c-ski in a Transgenic Calf," *Biological Reproduction* 50:664–68 (March 1994).

80. Joe Tsien, "Building a Brainier Mouse," *Scientific American,* April 2000; Ya-Ping Tang et al., "Genetic Enhancement of Learning and Memory in Mice," *Nature* 401:63–69 (1999).

81. Feng Wei et al., "Genetic Enhancement of Inflammatory Pain by Forebrain NR2B Overexpression," *Nature Neuroscience* 4(2):164–69 (2001). See also

Deborah L. Stull, "Better Mouse Memory Comes at a Price," *The Scientist* 15(7):21 (April 2, 2001); Rick Weiss, "Study: Rodents' Higher IQ May Come at Painful Price," *Washington Post,* January 29, 2001, p. A2.

82. "News from The Rockefeller University, 'Fat, Body Weight Regulated by Newly Discovered Hormone,'" press release, July 27, 1995.

83. Robert V. Considine et al., "Serum Immunoreactive-Leptin Concentrations in Normal-Weight and Obese Humans," *New England Journal of Medicine* 334:292–95 (1996).

84. Stuart H. Orkin and Arno Motulsky, co-chairs, *Report and Recommendations of the Panel to Assess the NIH Investment in Research on Gene Therapy,* December 7, 1995, pp. 1, 2.

85. Marina Cavazzana-Calvo et al., "Gene Therapy of Human Severe Combined Immunodeficiency (SCID)-XI Disease," *Science* 288:669–72 (April 28, 2000).

86. Rick Weiss, "Gene Therapy Apparently Leads to Illness in Boy," *Washington Post,* October 4, 2002, p. A11.

87. Lori Andrews and Dorothy Nelkin, *Body Bazaar: The Market for Human Tissue in the Biotechnology Age* (New York: Crown, 2001), p. 62; U.S. Patent No. 5,399,346 (issued March 21, 1995) to W. French Anderson, Michael R. Blaese, and Stephen Rosenberg, "Gene Therapy."

88. Sheryl Gay Stolberg, "Trials Are Halted on Gene Therapy," *New York Times,* October 4, 2002, p. 1.

89. E. M. Swift and Don Yeager, "Unnatural Selection," *Sports Illustrated,* May 14, 2001, p. 88.

90. Stolberg, "Senators Press for Answers."

91. Jocelyn Kaiser, "New Biotech Laws Shores Up U.S. Firms," *Science* 270:728 (1995).

92. Swift and Yeager, "Unnatural Selection."

93. *Ibid.*

94. The manufacturer of genetic tests for melanoma predisposition sent letters to dermatologists noting that "early screening with this easy and painless test is particularly useful when testing children." Gina Kolata, "Tests to Assess Risks for Cancer Raising Questions," *New York Times,* March 27, 1995, p. A1.

95. See, for example, J. B. S. Haldane, "Biological Possibilities for the Human Species in the Next Thousand Years," in *Man and His Future,* ed. Gordon Wolstenholme, 1963, pp. 337, 355.

96. Lester Thurow, "Say 'No' to Germline Engineering" (open letter to participants at the Asilomar Symposium on Science, Ethics, and Society), February 16, 2000, www.genetics-and-society.org/resources/cgs/2000_asilomar_letter.html.

97. Steve Connor, "Patent Plan for Breasts Set to Stir Passions," *The Independent (London),* February 19, 1992, 3.

98. Silver, *Remaking Eden.*

99. *Harnicher v. University of Utah Medical Center,* 962 P.2d 67 (Utah 1998).

100. Marsha Saxton, "Disability Rights and Selective Abortion," in *Abortion Wars: A Half Century Struggle, 1950–2000,* ed. Rickie Solinger (Berkeley: University of California Press, 1998).

101. *Ibid.*

102. Office of Technology Assessment, U.S. Congress, *Mapping Our Genes* (Washington, D.C: 1988), p. 84.

103. Eric Juengst, "Prenatal Diagnosis and the Ethics of Uncertainty," in *Health Care Ethics: Cultural Issues for the 21st Century,* ed. J. Monagle and D.

Thomasma (Rockville, Md.: Aspen Publishing, 1997), p. 19, citing National Institute of Child Health and Human Development, *Antenatal Diagnosis: Report of a Consensus Development Conference,* NIH Publication 79-1973 (Bethesda, Md.: National Institutes of Health, 1979), pp. 1–192.

104. *Woodward v. Commissioner of Social Sec.,* 760 N.E.2d 257, 272, 435 Mass. 536, 557 (Mass. 2002).

105. See Derek Morgan and Robert G. Lee, *Blackstone's Guide to the Human Fertilisation and Embryology Act 1990* (London, England: Blackstone Press, 1991), 83–84.

106. *Ibid.,* p. 84.

107. Royal Commission on New Reproductive Technologies, "Royal Commission on New Reproductive Technologies—Update" (December 1993).

108. *Ibid.*

109. *Ibid.*

110. *Ibid.* See also Royal Commission on New Reproductive Technologies, *Proceed with Care,* vols. 1 and 2 (Canada: Minister of Government Services, 1993).

111. Similar concerns about the power of money were the impetus behind campaign finance reform.

112. See Sheryl Stolberg, "Sheep Clone Researcher Calls for Caution Science," *Los Angeles Times,* March 1, 1997, p. A18. Although there is no specifically enumerated right to research in the U.S. Constitution, certain commentators argue that support for such a right could be derived from the First Amendment right to free speech. John Robertson, "The Scientist's Right to Research: A Constitutional Analysis," *Southern California Law Review* 51:1203, 1212 (1977).

113. Sen. Tom Harkin, D-Iowa, "Today Said That He Is Investigating President Clinton's Authority to Ban Federal Spending for Human Cloning Research," *Congress Daily,* March 12, 1997.

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6. *Ibid.,* Summary, p. 15.

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11. Elliot, *Twentieth Century Book of the Dead,* p. 195.

12. An order-of-magnitude estimate based on Sivard, p. 28, adding in victims of famine adjunct to war and to other forms of state-sponsored violence. Sivard, Ruth L. 1987. *World Military and Social Expenditures 1987–88*. New York: World Priorities.

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14. Deterrence does not depend on the presence of actual nuclear weapons in the world as long as the knowledge of how to build them is maintained and extensive and cooperative surveillance continues to forestall the assembly of clandestine arsenals: deterrence post-abolition would simply mean delivery times from factory to target of perhaps three months rather than current delivery times from silo or submarine to target of thirty minutes or less.

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Chapter 9. Progress and Violence

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Chapter 10. Science and Happiness

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Chapter 11. What Kinds of Science Should Be Done?

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4. *Science: The Endless Frontier.*

5. For defenses of the notion of truth and of the power of the sciences to achieve truth, see the early chapters of Kitcher, *Science, Truth, and Democracy,* and also Philip Kitcher, "Real Realism: The Galilean Strategy," *Philosophical Review* 110:151–197, 2001.

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8. E. A. Burtt makes this very clear in his classic monograph *The Metaphysical Foundations of Modern Physical Science.* (London: Routledge and Kegan Paul, 1932).

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Chapter 13. Who Owns Your Dinner?

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2. The World Trade Organization (WTO) governs trademarks, plant variety protection, patents, other *(sui generis)* IP regimes, and geographical indication (protected names such as Cognac or Champagne). The U.N. Food and Agriculture Organization covers the farmer's rights to protection of traditional knowledge, benefit sharing, and seed saving, as well as the protection of agricultural land races. The Convention on Biodiversity (CBD) deals with access to genetic resources, benefit sharing and protection of traditional knowledge. The International Union for the Protection of New Varieties of Plants (UPOV) addresses plant variety protection, breeder's rights, and farmer's privilege to save IP-protected seed.

Today IPRs are mainly territorial, not global. The Trade Related Intellectual Property Rights (TRIPS) annex to the WTO agreement is an attempt to introduce a global minimum standard for IPRs. One of the main goals of TRIPS is to promote global free trade as well as foreign direct investment in, and technology transfer to, developing countries by requiring global recognition of intellectual property rights. Thus a country will no longer be able to "pirate copy" itself into development (as Japan, South Korea, Taiwan, and Singapore did). On the other hand, TRIPS contains provisions that enable the countries of the South, which are weak in research and development, to acquire advanced IP-protected technologies on favorable terms by recognizing IPRs.

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6. Fowler, C. (1994): "Unnatural Selection: Technology, Politics, and Plant Evolution," *International Studies in Global Change* 6:31ff.

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8. *Ibid.*

9. UPOV stipulates that breeders and farmers may use and reproduce seed under certain circumstances, including for further research and breeding ("breeder's exemption") and as seed for the next farming season ("farmer's privilege").

10. See Sagasti, F., and Bezanson, K. (2001): *Financing and Providing Global Public Goods—Expectations and Prospects,* Report prepared for the Ministry of Foreign Affairs, Sweden, Study 2001:2, Stockholm. Goods that are potentially subject to IP protection are typically defined as those that can be used exclusively (i.e., if one person is using them, another cannot) and that are rivalrous (i.e., if one person is using them, it diminishes the value of the item). A light bulb is an example of such a good. A typical example of something that was formerly treated as nonexclusive and nonrivalrous (i.e., not subject to IP) is scientific knowledge.

11. *Crucible II Group (2001): Seeding Solutions,* Volume 2. "Options for National Laws Governing Control over Genetic Resources and Biological Innovations." Rome: International Development Center, International Plant Genetic Resources Institute, and Dag Hammarskjöld Foundation, p. 210.

12. *Ibid.,* pp. 105–6.

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15. Roffe, P. (2000): "The Political Economy of Intellectual Property Rights: An Historical Perspective," in *Law in Its Social Setting: Governance, Development, and Globalization—A Tribute to Lawrence Tshuma,* ed. Julio Faundez et al., Blackstone Press Limited, London, England: Penguin.

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17. For examples, see *Seeding Solutions,* vol. 2.

18. See Bragdon, S., et al. (2001): *Rights and Responsibilities for Genetic Resources: Understanding the Role of the Public Domain and Private Rights in the Production of Public Goods* (draft), International Plant Genetics Resources Institute, Rome.

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22. Mooney, "The ETC Century."

Chapter 14. Blowback in Genetic Engineering

1. J. Knight, "Crop Improvement: A Dying Breed." *Nature* 421 (Feb. 6): 568–570.

2. *NOW with Bill Moyers,* October 4, 2002; see also*The Nation* (special report), October 29, 2002.

3. The appearance of the Bt gene in Oaxacan corn was reported by Dr. Ignacio Chapela and his graduate student David Quist, based at the University of

California at Berkeley. When the findings were published in the journal *Nature* in 2001, they ignited a firestorm of controversy over the scientists' two major assertions: one, that the Bt genes had made their way into Oaxaca's corn; and, two, that those genes were unstable within the genome. The barrage of criticism—from both industry and publicly supported scientists—led *Nature* to issue an editorial comment suggesting that Chapela and Quist's results were not sufficiently supported by the data. Chapela and Quist's first assertion is now unquestioned, however, even by their critics; a follow-up study in August 2002 by the Mexican government confirmed that the Bt genes were indeed in Oaxaca's corn. Questions remain, however, over their second assertion: many scientists continue to claim that their testing methodology was inadequate to discern the potential for subtle changes in the genome.

Chapter 15. Only Connect

1. All quotations in the first three paragraphs are from Colacello, Bob, "Picasso Comes to Vegas," *Vanity Fair,* October 1998, pp. 295–298, 342–344.

2. Jacob Bronowski, *The Origins of Knowledge and Imagination* (New Haven: Yale University Press, 1978).

3. Arthur C. Danto, "Barnett Newman and the Heroic Sublime," *The Nation,* June 17, 2002, p. 26.

4. *Ibid.*

5. E. M. Forster, *Howards End* (New York: Modern Library, 1999), p. 170.

6. Bronowski, *The Origins of Knowledge,* p. 59.

7. John Berger, *Selected Essays* (New York: Vintage Books, 2003), p. 210.

8. Martin Gayford and Karen Wright, *The Grove Book of Art Writing* (New York: Grove Press, 1998), pp. 40–41.

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