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PHYSICS OF THE FUTURE

HOW SCIENCE WILL SHAPE HUMAN DESTINY AND OUR DAILY LIVES BY THE YEAR 2100

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To my loving wife, Shizue,
and my daughters, Michelle and Alyson

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PHYSICS OF THE FUTURE

Empires of the future will be empires of the mind.

—WINSTON CHURCHILL

INTRODUCTION *Predicting the Next 100 Years*

When I was a child, two experiences helped to shape the person I am today and spawned two passions that have helped to define my entire life.

First, when I was eight years old, I remember all the teachers buzzing with the latest news that a great scientist had just died. That night, the newspapers printed a picture of his office, with an unfinished manuscript on his desk. The caption read that the greatest scientist of our era could not finish his greatest masterpiece. What, I asked myself, could be so difficult that such a great scientist could not finish it? What could possibly be that complicated and that important? To me, eventually this became more fascinating than any murder mystery, more intriguing than any adventure story. I had to know what was in that unfinished manuscript.

Later, I found out that the name of this scientist was Albert Einstein and the unfinished manuscript was to be his crowning achievement, his attempt to create a "theory of everything," an equation, perhaps no more than one inch wide, that would unlock the secrets of the universe and perhaps allow him to "read the mind of God."

But the other pivotal experience from my childhood was when I watched the Saturday morning TV shows, especially the *Flash Gordon* series with Buster Crabbe. Every week, my nose was glued to the TV screen. I was magically transported to a mysterious world of space aliens, starships, ray gun battles, underwater cities, and monsters. I was hooked. This was my first exposure to the world of the future. Ever since, I've felt a childlike wonder when pondering the future.

But after watching every episode of the series, I began to realize that although Flash got all the accolades, it was the scientist Dr. Zarkov who actually made the series work. He invented the rocket ship, the invisibility shield, the power source for the city in the sky, *etc*. Without the scientist, there is no future. The handsome and the beautiful may earn the admiration of society, but all the wondrous inventions of the future are a by-product of the unsung, anonymous scientists.

Later, when I was in high school, I decided to follow in the footsteps of these great scientists and put some of my learning to the test. I wanted to be part of this great revolution that I knew would change the world. I decided to build an atom smasher. I asked my mother for permission to build a 2.3-million electron volt particle accelerator in the garage. She was a bit startled but gave me the okay. Then, I went to Westinghouse and Varian Associates, got 400 pounds of transformer steel, 22 miles of copper wire, and assembled a betatron accelerator in my mom's garage.

Previously, I had built a cloud chamber with a powerful magnetic field and photographed tracks of antimatter. But photographing antimatter was not enough. My goal now was to produce a beam of antimatter. The atom smasher's magnetic coils successfully produced a huge 10,000 gauss magnetic field (about 20,000 times the earth's magnetic field, which would in principle be enough to rip a hammer right out of your hand). The machine soaked up 6 kilowatts of power, draining all the electricity my house could provide. When I turned on the machine, I frequently blew out all the fuses in the house. (My poor mother must have wondered why she could not have a son who played football instead.)

So two passions have intrigued me my entire life: the desire to understand all the physical laws of the universe in a single coherent theory and the desire to see the future. Eventually, I realized that these two passions were actually complementary. The key to understanding the future is to grasp the fundamental laws of nature and then apply them to the inventions, machines, and therapies that will redefine our civilization far into the future.

There have been, I found out, numerous attempts to predict the future, many useful and insightful. However, they were mainly written by historians, sociologists, science fiction writers, and "futurists," that is, outsiders who are predicting the world of science without a firsthand knowledge of the science itself. The scientists, the insiders who are actually creating the future in their laboratories, are too busy making breakthroughs to have time to write books about the future for the public.

That is why this book is different. I hope this book will give an insider's perspective on what miraculous discoveries await us and provide the most authentic, authoritative look into the world of 2100.

Of course, it is impossible to predict the future with complete accuracy. The best one can do, I feel, is to tap into the minds of the scientists at the cutting edge of research, who are doing the yeoman's work of inventing the future. They are the ones who are creating the devices, inventions, and therapies that will revolutionize civilization. And this book is their story. I have had the opportunity to sit in the front-row seat of this great revolution, having interviewed more than 300 of the world's top scientists, thinkers, and dreamers for national TV and radio. I have also taken TV crews into their laboratories to film the prototypes of the remarkable devices that will change our future. It has been a rare honor to have hosted numerous science specials for BBC-TV, the Discovery Channel, and the Science Channel, profiling the remarkable inventions and discoveries of the visionaries who are daring to create the future. Being free to pursue my work on string theory and to eavesdrop on the cutting-edge research that will revolutionize this century, I feel I have one of the most desirable jobs in science. It is my childhood dream come true.

But this book differs from my previous ones. In books like *Beyond Einstein*, *Hyperspace,* and *Parallel Worlds,* I discussed the fresh, revolutionary winds sweeping through my field, theoretical physics, that are opening up new ways to understand the universe. In *Physics of the Impossible,* I discussed how the latest discoveries in physics may eventually make possible even the most imaginative schemes of science fiction.

This book most closely resembles my book *Visions*, in which I discussed how science will evolve in the coming decades. I am gratified that many of the predictions made in that book are being realized today on schedule. The accuracy of my book, to a large degree, has depended on the wisdom and foresight of the many scientists I interviewed for it.

But this book takes a much more expansive view of the future, discussing the technologies that may mature in 100 years, that will ultimately determine the fate of humanity. How we negotiate the challenges and opportunities of the next 100 years will determine the ultimate trajectory of the human race.

PREDICTING THE NEXT CENTURY

Predicting the next few years, let alone a century into the future, is a daunting task. Yet it is one that challenges us to dream about technologies we believe will one day alter the fate of humanity.

In 1863, the great novelist Jules Verne undertook perhaps his most ambitious project. He wrote a prophetic novel, called *Paris in the Twentieth Century,* in which he applied the full power of his enormous talents to forecast the coming century. Unfortunately, the manuscript was lost in the mist of time, until his great-grandson accidentally stumbled upon it lying in a safe where it had been carefully locked away for almost 130 years. Realizing what a treasure he had found, he arranged to have it published in 1994, and it became a best seller.

Back in 1863, kings and emperors still ruled ancient empires, with impoverished peasants performing backbreaking work toiling in the fields. The United States was consumed by a ruinous civil war that would almost tear the country apart, and steam power was just beginning to revolutionize the world. But Verne predicted that Paris in 1960 would have glass skyscrapers, air conditioning, TV, elevators, high-speed trains, gasoline-powered automobiles, fax machines, and even something resembling the Internet. With uncanny accuracy, Verne depicted life in modern Paris.

This was not a fluke, because just a few years later he made another spectacular prediction. In 1865, he wrote *From the Earth to the Moon*, in which he predicted the details of the mission that sent our astronauts to the moon more than 100 years later in 1969. He accurately predicted the size of the space capsule to within a few percent, the location of the launch site in Florida not far from Cape Canaveral, the number of astronauts on the mission, the length of time the voyage would last, the weightlessness that the astronauts would experience, and the final splashdown in the ocean. (The only major mistake was that he used gunpowder, rather than rocket fuel, to take his astronauts to the moon. But liquid-fueled rockets wouldn't be invented for another seventy years.)

How was Jules Verne able to predict 100 years into the future with such breathtaking accuracy? His biographers have noted that, although Verne was not a scientist himself, he constantly sought out scientists, peppering them with questions about their visions of the future. He amassed a vast archive summarizing the great scientific discoveries of his time. Verne, more than others, realized that science was the engine shaking the foundations of civilization, propelling it into a new century with unexpected marvels and miracles. The key to Verne's vision and profound insights was his grasp of the power of science to revolutionize society.

Another great prophet of technology was Leonardo da Vinci, painter, thinker, and visionary. In the late 1400s, he drew beautiful, accurate diagrams of machines that would one day fill the skies: sketches of parachutes, helicopters, hang gliders, and even airplanes. Remarkably, many of his inventions would have flown. (His flying machines, however, needed one more ingredient: at least a 1-horsepower motor, something that would not be available for another 400 years.)

What is equally astonishing is that Leonardo sketched the blueprint for a mechanical adding machine, which was perhaps 150 years ahead of its time. In 1967, a misplaced manuscript was reanalyzed, revealing his idea for an adding machine with thirteen digital wheels. If one turned a crank, the gears inside turned in sequence performing the arithmetic calculations. (The machine was built in 1968 and it worked.)

In addition, in the 1950s another manuscript was uncovered which contained a sketch for a warrior automaton, wearing German-Italian armor, that could sit up and move its arms, neck, and jaw. It, too, was subsequently built and found to work.

Like Jules Verne, Leonardo was able to get profound insights into the future by consulting a handful of forward-thinking individuals of his time. He was part of a small circle of people who were at the forefront of innovation. In addition, Leonardo was always experimenting, building, and sketching models, a key attribute of anyone who wants to translate thinking into reality.

Given the enormous, prophetic insights of Verne and Leonardo da Vinci, we ask the question: Is it possible to predict the world of 2100? In the tradition of Verne and Leonardo, this book will closely examine the work of the leading scientists who are building prototypes of the technologies that will change our future. This book is not a work of fiction, a by-product of the overheated imagination of a Hollywood scriptwriter, but rather is based on the solid science being conducted in major laboratories around the world today.

The prototypes of all these technologies already exist. As William Gibson, the author of *Neuromancer* who coined the word *cyberspace,* once said, “The future is already here. It’s just unevenly distributed.”

Predicting the world of 2100 is a daunting task, since we are in an era of profound scientific upheaval, in which the pace of discovery is always accelerating. More scientific knowledge has been accumulated just in the last few decades than in all human history. And by 2100, this scientific knowledge will again have doubled many times over.

But perhaps the best way to grasp the enormity of predicting 100 years into the future is to recall the world of 1900 and remember the lives our grandparents lived.

Journalist Mark Sullivan asks us to imagine someone reading a newspaper in the year 1900:

> In his newspapers of January 1, 1900, the American found no such word as radio, for that was yet twenty years in from coming; nor “movie,” for that too was still mainly of the future; nor chauffeur, for the automobile was only just emerging and had been called “horseless carriage ….” There was no such word as aviator …. Farmers had not heard of tractors, nor bankers of the Federal Reserve System. Merchants had not heard of chain-stores nor “self-service”; nor seamen of oil-burning engines …. Ox-teams could still be seen on country roads …. Horses or mules for trucks were practically universal …. The blacksmith beneath the spreading chestnut-tree was a reality.

To understand the difficulty of predicting the next 100 years, we have to appreciate the difficulty that the people of 1900 had in predicting the world of 2000. In 1893, as part of the World’s Columbian Exposition in Chicago, seventy-four well-known individuals were asked to predict what life would be like in the next 100 years. The one problem was that they consistently underestimated the rate of progress of science. For example, many correctly predicted that we would one day have commercial transatlantic airships, but they thought that they would be balloons. Senator John J. Ingalls said, “It will be as common for the citizen to call for his dirigible balloon as it now is for his buggy or his boots.” They also consistently missed the coming of the automobile. Postmaster General John Wanamaker stated that the U.S. mail would be delivered by stagecoach and horseback, even 100 years into the future.

This underestimation of science and innovation even extended to the patent office. In 1899, Charles H. Duell, commissioner of the U.S. Office of Patents, said, “Everything that can be invented has been invented.”

Sometimes experts in their own field underestimated what was happening right beneath their noses. In 1927, Harry M. Warner, one of the founders of Warner Brothers, remarked during the era of silent movies, “Who the hell wants to hear actors talk?”

And Thomas Watson, chairman of IBM, said in 1943, “I think there is a world market for maybe five computers.”

This underestimation of the power of scientific discovery even extended to the venerable *New York Times.* (In 1903, the *Times* declared that flying machines were a waste of time, just a week before the Wright brothers successfully flew their airplane at Kitty Hawk, North Carolina. In 1920, the *Times* criticized rocket scientist Robert Goddard, declaring his work nonsense because rockets cannot move in a vacuum. Forty-nine years later, when *Apollo 11* astronauts landed on the moon, the *Times,* to its credit, ran the retraction: “It is now definitely established that a rocket can function in a vacuum. The *Times* regrets the error.”)

The lesson here is that it is very dangerous to bet against the future.

Predictions for the future, with a few exceptions, have always underestimated the pace of technological progress. History, we are told over and over again, is written by the optimists, not the pessimists. As President Dwight Eisenhower once said, “Pessimism never won a war.”

We can even see how science fiction writers underestimated the pace of scientific discovery. When watching reruns of the old 1960s TV series *Star Trek,* you notice that much of this “twenty-third-century technology” is already here. Back then, TV audiences were startled to see mobile phones, portable computers, machines that could talk, and typewriters that could take dictation. Yet all these technologies exist today. Soon, we will also have versions of the universal translator, which can rapidly translate between languages as you speak, and also “tricorders,” which can diagnose disease from a distance. (Excepting warp drive engines and transporters, much of this twenty-third-century science is already here.)

Given the glaring mistakes people have made in underestimating the future, how can we begin to provide a firmer scientific basis to our predictions?

UNDERSTANDING THE LAWS OF NATURE

Today, we are no longer living in the dark ages of science, when lightning bolts and plagues were thought to be the work of the gods. We have a great advantage that Verne and Leonardo da Vinci did not have: a solid understanding of the laws of nature.

Predictions will always be flawed, but one way to make them as authoritative as possible is to grasp the four fundamental forces in nature that drive the entire universe. Each time one of them was understood and described, it changed human history.

The first force to be explained was the force of gravity. Isaac Newton gave us a mechanics that could explain that objects moved via forces, rather than mystical spirits and metaphysics. This helped to pave the way for the Industrial Revolution and the introduction of steam power, especially the locomotive.

The second force to be understood was the electromagnetic force, which lights up our cities and powers our appliances. When Thomas Edison, Michael Faraday, James Clerk Maxwell, and others helped to explain electricity and magnetism, this unleashed the electronic revolution that has created a bounty of scientific wonders. We see this every time there is a power blackout, when society is suddenly wrenched back 100 years into the past.

The third and fourth forces to be understood were the two nuclear forces: the weak and strong forces. When Einstein wrote down $E = mc^2$ and when the atom was split in the 1930s, scientists for the first time began to understand the forces that light up the heavens. This revealed the secret behind the stars. Not only did this unleash the awesome power of atomic weapons, it also held out the promise that one day we would be able to harness this power on the earth.

Today, we have a fairly good grasp of these four forces. The first force, gravity, is now described through Einstein’s theory of general relativity. And the other three forces are described through the quantum theory, which allows us to decode the secrets of the subatomic world.

The quantum theory, in turn, has given us the transistor, the laser, and the digital revolution that is the driving force behind modern society. Similarly, scientists were able to use the quantum theory to unlock the secret of the DNA molecule. The blinding speed of the biotechnological revolution is a direct result of computer technology, since DNA sequencing is all done by machines, robots, and computers.

As a consequence, we are better able to see the direction that science and technology will take in the coming century. There will always be totally unexpected, novel surprises that leave us speechless, but the foundation of modern physics, chemistry, and biology has largely been laid, and we do not expect any major revision of this basic knowledge, at least in the foreseeable future. As a result, the predictions we make in this book are the product not of wild speculation but are reasoned estimates of when the prototype technologies of today will finally reach maturity.

In conclusion, there are several reasons to believe that we can view the outlines of the world of 2100:

1. This book is based on interviews with more than 300 top scientists, those in the forefront of discovery.

2. Every scientific development mentioned in this book is consistent with the known laws of physics.

3. The four forces and the fundamental laws of nature are largely known; we do not expect any major new changes in these laws.

4. Prototypes of all technologies mentioned in this book already exist.

5. This book is written by an “insider” who has a firsthand look at the technologies that are on the cutting edge of research.

For countless eons we were passive observers of the dance of nature. We only gazed in wonder and fear at comets, lightning bolts, volcanic eruptions, and plagues, assuming that they were beyond our comprehension. To the ancients, the forces of nature were an eternal mystery to be feared and worshipped, so they created the gods of mythology to make sense of the world around them. The ancients hoped that by praying to these gods they would show mercy and grant them their dearest wishes.

Today, we have become choreographers of the dance of nature, able to tweak the laws of nature here and there. But by 2100, we will make the transition to being masters of nature.

2100: BECOMING THE GODS OF MYTHOLOGY

Today, if we could somehow visit our ancient ancestors and show them the bounty of modern science and technology, we would be viewed as magicians. With the wizardry of science, we could show them jet planes that can soar in the clouds, rockets that can explore the moon and planets, MRI scanners that can peer inside the living body, and cell phones that can put us in touch with anyone on the planet. If we showed them laptop computers that can send moving images and messages instantly across the continents, they would view this as sorcery.

But this is just the beginning. Science is not static. Science is exploding exponentially all around us. If you count the number of scientific articles being published, you will find that the sheer volume of science doubles every decade or so. Innovation and discovery are changing the entire economic, political, and social landscape, overturning all the old cherished beliefs and prejudices.

Now dare to imagine the world in the year 2100.

By 2100, our destiny is to become like the gods we once worshipped and feared. But our tools will not be magic wands and potions but the science of computers, nanotechnology, artificial intelligence, biotechnology, and most of all, the quantum theory, which is the foundation of the previous technologies.

By 2100, like the gods of mythology, we will be able to manipulate objects with the power of our minds. Computers, silently reading our thoughts, will be able to carry out our wishes. We will be able to move objects by thought alone, a telekinetic power usually reserved only for the gods. With the power of biotechnology, we will create perfect bodies and extend our life spans. We will also be able to create life-forms that have never walked the surface of the earth. With the power of nanotechnology, we will be able to take an object and turn it into something else, to create something seemingly almost out of nothing. We will ride not in fiery chariots but in sleek vehicles that will soar by themselves with almost no fuel, floating effortlessly in the air. With our engines, we will be able to harness the limitless energy of the stars. We will also be on the threshold of sending star ships to explore those nearby.

Although this godlike power seems unimaginably advanced, the seeds of all these technologies are being planted even as we speak. It is modern science, not chanting and incantations, that will give us this power.

I am a quantum physicist. Every day, I grapple with the equations that govern the subatomic particles out of which the universe is created. The world I live in is the universe of eleven-dimensional hyperspace, black holes, and gateways to the multiverse. But the equations of the quantum theory, used to describe exploding stars and the big bang, can also be used to decipher the outlines of our future.

But where is all this technological change leading? Where is the final destination in this long voyage into science and technology?

The culmination of all these upheavals is the formation of a planetary civilization, what physicists call a Type I civilization. This transition is perhaps the greatest transition in history, marking a sharp departure from all civilizations of the past. Every headline that dominates the news reflects, in some way, the birth pangs of this planetary civilization. Commerce, trade, culture, language, entertainment, leisure activities, and even war are all being revolutionized by the emergence of this planetary civilization. Calculating the energy output of the planet, we can estimate that we will attain Type I status within 100 years. Unless we succumb to the forces of chaos and folly, the transition to a planetary civilization is inevitable, the end product of the enormous, inexorable forces of history and technology beyond anyone’s control.

WHY PREDICTIONS SOMETIMES DON’T COME TRUE

But several predictions made about the information age were spectacularly untrue. For example, many futurists predicted the “paperless office,” that is, that the computer would make paper obsolete. Actually, the opposite has occurred. A glance at any office shows you that the amount of paper is actually greater than ever.

Some also envisioned the “peopleless city.” Futurists predicted that teleconferencing via the Internet would make face-to-face business meetings unnecessary, so there would be no need to commute. In fact, the cities themselves would largely empty out, becoming ghost towns, as people worked in their homes rather than their offices.

Likewise, we would see the rise of “cybertourists,” couch potatoes who would spend the entire day lounging on their sofas, roaming the world and watching the sights via the Internet on their computers. We would also see “cybershoppers,” who would let their computer mice do the walking. Shopping malls would go bankrupt. And “cyberstudents” would take all their classes online while secretly playing video games and drinking beer. Universities would close for lack of interest.

Or consider the fate of the “picture phone.” During the 1964 World’s Fair, AT&T spent about $100 million perfecting a TV screen that would connect to the telephone system, so that you could see the person whom you were talking to, and vice versa. The idea never took off; AT&T sold only about 100 of them, making each unit cost about $1 million each. This was a very expensive fiasco.

And finally, it was thought that the demise of traditional media and entertainment was imminent. Some futurists claimed that the Internet was the juggernaut that would swallow live theater, the movies, radio, and TV, all of which would soon be seen only in museums.

Actually, the reverse has happened. Traffic jams are worse than ever—a permanent feature of urban life. People flock to foreign sites in record numbers, making tourism one of the fastest-growing industries on the planet. Shoppers flood the stores, in spite of economic hard times. Instead of proliferating cyberclassrooms, universities are still registering record numbers of students. To be sure, there are more people deciding to work from their homes or teleconference with their coworkers, but cities have not emptied at all. Instead, they have morphed into sprawling megacities. Today, it is easy to carry on video conversations on the Internet, but most people tend to be reluctant to be filmed, preferring face-to-face meetings. And of course, the Internet has changed the entire media landscape, as media giants puzzle over how to earn revenue on the Internet. But it is not even close to wiping out TV, radio, and live theater. The lights of Broadway still glow as brightly as before.

CAVE MAN PRINCIPLE

Why did these predictions fail to materialize? I conjecture that people largely rejected these advances because of what I call the Cave Man (or Cave Woman) Principle. Genetic and fossil evidence indicates that modern humans, who looked just like us, emerged from Africa more than 100,000 years ago, but we see no evidence that our brains and personalities have changed much since then. If you took someone from that period, he would be anatomically identical to us: if you gave him a bath and a shave, put him in a three-piece suit, and then placed him on Wall Street, he would be physically indistinguishable from everyone else. So our wants, dreams, personalities, and desires have probably not changed much in 100,000 years. We probably still think like our caveman ancestors.

The point is: whenever there is a conflict between modern technology and the desires of our primitive ancestors, these primitive desires win each time. That's the Cave Man Principle. For example, the caveman always demanded "proof of the kill." It was never enough to boast about the big one that got away. Having the fresh animal in our hands was always preferable to tales of the one that got away. Similarly, we want hard copy whenever we deal with files. We instinctively don't trust the electrons floating in our computer screen, so we print our e-mails and reports, even when it's not necessary. That's why the paperless office never came to be.

Likewise, our ancestors always liked face-to-face encounters. This helped us to bond with others and to read their hidden emotions. This is why the peopleless city never came to pass. For example, a boss might want to carefully size up his employees. It's difficult to do this online, but face-to-face a boss can read body language to gain valuable unconscious information. By watching people up close, we feel a common bond and can also read their subtle body language to find out what thoughts are racing through their heads. This is because our apelike ancestors, many thousands of years before they developed speech, used body language almost exclusively to convey their thoughts and emotions.

This is the reason cybertourism never got off the ground. It's one thing to see a picture of the Taj Mahal, but it's another thing to have the bragging rights of actually seeing it in person. Similarly, listening to a CD of your favorite musician is not the same as feeling the sudden rush when actually seeing this musician in a live concert, surrounded by all the fanfare, hoopla, and noise. This means that even though we will be able to download realistic images of our favorite drama or celebrity, there is nothing like actually seeing the drama on stage or seeing the actor perform in person. Fans go to great lengths to get autographed pictures and concert tickets of their favorite celebrity, although they can download a picture from the Internet for free.

This explains why the prediction that the Internet would wipe out TV and radio never came to pass. When the movies and radio first came in, people bewailed the death of live theater. When TV came in, people predicted the demise of the movies and radio. We are living now with a mix of all these media. The lesson is that one medium never annihilates a previous one but coexists with it. It is the mix and relationship among these media that constantly change. Anyone who can accurately predict the mix of these media in the future could become very wealthy.

The reason for this is that our ancient ancestors always wanted to see something for themselves and not rely on hearsay. It was crucial for our survival in the forest to rely on actual physical evidence rather than rumors. Even a century from now, we will still have live theater and still chase celebrities, an ancient heritage of our distant past.

In addition, we are descended from predators who hunted. Hence, we love to watch others and even sit for hours in front of a TV, endlessly watching the antics of our fellow humans, but we instantly get nervous when we feel others watching us. In fact, scientists have calculated that we get nervous if we are stared at by a stranger for about four seconds. After about ten seconds, we even get irate and hostile at being stared at. This is the reason why the original picture phone was such a flop. Also, who wants to have to comb one's hair before going online? (Today, after decades of slow, painful improvement, video conferencing is finally catching on.)

And today, it is possible to take courses online. But universities are bulging with students. The one-to-one encounter with professors, who can give individual attention and answer personal questions, is still preferable to online courses. And a university degree still carries more weight than an online diploma when applying for a job.

So there is a continual competition between High Tech and High Touch, that is, sitting in a chair watching TV versus reaching out and touching things around us. In this competition, we will want both. That is why we still have live theater, rock concerts, paper, and tourism in the age of cyberspace and virtual reality. But if we are offered a free picture of our favorite celebrity musician or actual tickets to his concert, we will take the tickets, hands down.

So that is the Cave Man Principle: we prefer to have both, but if given a choice we will chose High Touch, like our cavemen ancestors.

But there is also a corollary to this principle. When scientists first created the Internet back in the 1960s, it was widely believed that it would evolve into a forum for education, science, and progress. Instead, many were horrified that it soon degenerated into the no-holds-barred Wild West that it is today. Actually, this is to be expected. The corollary to the Cave Man Principle is that if you want to predict the social interactions of humans in the future, simply imagine our social interactions 100,000 years ago and multiply by a billion. This means that there will be a premium placed on gossip, social networking, and entertainment. Rumors were essential in a tribe to rapidly communicate information, especially about the leaders and role models. Those who were out of the loop often did not survive to pass on their genes. Today, we can see this played out in grocery checkout stands, which have wall-to-wall celebrity gossip magazines, and in the rise of a celebrity-driven culture. The only difference today is that the magnitude of this tribal gossip has been multiplied enormously by mass media and can now circle the earth many times over within a fraction of a second.

The sudden proliferation of social networking Web sites, which turned young, baby-faced entrepreneurs into billionaires almost overnight, caught many analysts off guard, but it is also an example of this principle. In our evolutionary history, those who maintained large social networks could rely on them for resources, advice, and help that were vital for survival.

And last, entertainment will continue to grow explosively. We sometimes don't like to admit it, but a dominant part of our culture is based on entertainment. After the hunt, our ancestors relaxed and entertained themselves. This was important not only for bonding but also for establishing one's position within the tribe. It is no accident that dancing and singing, which are essential parts of entertainment, are also vital in the animal kingdom to demonstrate fitness to the opposite sex. When male birds sing beautiful, complex melodies or engage in bizarre mating rituals, it is mainly to show the opposite sex that they are healthy, physically fit, free of parasites, and have genes worthy enough to be passed down.

And the creation of art was not only for enjoyment but also played an important part in the evolution of our brain, which handles most information symbolically.

So unless we genetically change our basic personality, we can expect that the power of entertainment, tabloid gossip, and social networking will increase, not decrease, in the future.

SCIENCE AS A SWORD

I once saw a movie that forever changed my attitude toward the future. It was called *Forbidden Planet*, based on Shakespeare's *The Tempest*. In the movie astronauts encounter an ancient civilization that, in its glory, was millions of years ahead of us. They had attained the ultimate goal of their technology: infinite power without instrumentality, that is, the power to do almost anything via their minds. Their thoughts tapped into colossal thermonuclear power plants, buried deep inside their planet, that converted their every desire into reality. In other words, they had the power of the gods.

We will have a similar power, but we will not have to wait millions of years. We will have to wait only a century, and we can see the seeds of this future even in today's technology. But the movie was also a morality tale, since this divine power eventually overwhelmed this civilization.

Of course, science is a double-edged sword; it creates as many problems as it solves, but always on a higher level. There are two competing trends in the world today: one is to create a planetary civilization that is tolerant, scientific, and prosperous, but the other glorifies anarchy and ignorance that could rip the fabric of our society. We still have the same sectarian, fundamentalist, irrational passions of our ancestors, but the difference is that now we have nuclear, chemical, and biological weapons.

In the future, we will make the transition from being passive observers of the dance of nature, to being the choreographers of nature, to being masters of nature, and finally to being conservators of nature. So let us hope that we can wield the sword of science with wisdom and equanimity, taming the barbarism of our ancient past.

Let us now embark upon a hypothetical journey through the next 100 years of scientific innovation and discovery, as told to me by the scientists who are making it happen. It will be a wild ride through the rapid advances in computers, telecommunications, biotechnology, artificial intelligence, and nanotechnology. It will undoubtedly change nothing less than the future of civilization.

Everyone takes the limits of his own vision for the limits of the world.

—ARTHUR SCHOPENHAUER

No pessimist ever discovered the secrets of the stars or sailed to an uncharted land or opened a new heaven to the human spirit.

—HELEN KELLER

1 FUTURE OF THE COMPUTER *Mind over Matter*

I remember vividly sitting in Mark Weiser's office in Silicon Valley almost twenty years ago as he explained to me his vision of the future. Gesturing with his hands, he excitedly told me a new revolution was about to happen that would change the world. Weiser was part of the computer elite, working at Xerox PARC (Palo Alto Research Center, which was the first to pioneer the personal computer, the laser printer, and Windows-type architecture with graphical user interface), but he was a maverick, an iconoclast who was shattering conventional wisdom, and also a member of a wild rock band.

Back then (it seems like a lifetime ago), personal computers were new, just beginning to penetrate people's lives, as they slowly warmed up to the idea of buying large, bulky desktop computers in order to do spreadsheet analysis and a little bit of word processing. The Internet was still largely the isolated province of scientists like me, cranking out equations to fellow scientists in an arcane language. There were raging debates about whether this box sitting on your desk would dehumanize civilization with its cold, unforgiving stare. Even political analyst William F. Buckley had to defend the word processor against intellectuals who railed against it and refused to ever touch a computer, calling it an instrument of the philistines.

It was in this era of controversy that Weiser coined the expression "ubiquitous computing." Seeing far past the personal computer, he predicted that the chips would one day become so cheap and plentiful that they would be scattered throughout the environment—in our clothing, our furniture, the walls, even our bodies. And they would all be connected to the Internet, sharing data, making our lives more pleasant, monitoring all our wishes. Everywhere we moved, chips would be there to silently carry out our desires. The environment would be alive.

For its time, Weiser's dream was outlandish, even preposterous. Most personal computers were still expensive and not even connected to the Internet. The idea that billions of tiny chips would one day be as cheap as running water was considered lunacy.

And then I asked him why he felt so sure about this revolution. He calmly replied that computer power was growing exponentially, with no end in sight. Do the math, he implied. It was only a matter of time. (Sadly, Weiser did not live long enough to see his revolution come true, dying of cancer in 1999.)

The driving source behind Weiser's prophetic dreams is something called Moore's law, a rule of thumb that has driven the computer industry for fifty or more years, setting the pace for modern civilization like clockwork. Moore's law simply says that computer power doubles about every eighteen months. First stated in 1965 by Gordon Moore, one of the founders of the Intel Corporation, this simple law has helped to revolutionize the world economy, generated fabulous new wealth, and irreversibly altered our way of life. When you plot the plunging price of computer chips and their rapid advancements in speed, processing power, and memory, you find a remarkably straight line going back fifty years. (This is plotted on a logarithmic curve. In fact, if you extend the graph, so that it includes vacuum tube technology and even mechanical hand-crank adding machines, the line can be extended more than 100 years into the past.)

Exponential growth is often hard to grasp, since our minds think linearly. It is so gradual that you sometimes cannot experience the change at all. But over decades, it can completely alter everything around us.

According to Moore's law, every Christmas your new computer games are almost twice as powerful (in terms of the number of transistors) as those from the previous year. Furthermore, as the years pass, this incremental gain becomes monumental. For example, when you receive a birthday card in the mail, it often has a chip that sings "Happy Birthday" to you. Remarkably, that chip has more computer power than all the Allied forces of 1945. Hitler, Churchill, or Roosevelt might have killed to get that chip. But what do we do with it? After the birthday, we throw the card and chip away. Today, your cell phone has more computer power than all of NASA back in 1969, when it placed two astronauts on the moon. Video games, which consume enormous amounts of computer power to simulate 3-D situations, use more computer power than mainframe computers of the previous decade. The Sony PlayStation of today, which costs $300, has the power of a military supercomputer of 1997, which cost millions of dollars.

We can see the difference between linear and exponential growth of computer power when we analyze how people viewed the future of the computer back in 1949, when *Popular Mechanics* predicted that computers would grow linearly into the future, perhaps only doubling or tripling with time. It wrote: "Where a calculator like the ENIAC today is equipped with 18,000 vacuum tubes and weighs 30 tons, computers in the future may have only 1,000 vacuum tubes and weigh only 1½ tons."

(Mother Nature appreciates the power of the exponential. A single virus can hijack a human cell and force it to create several hundred copies of itself. Growing by a factor of 100 in each generation, one virus can generate 10 billion viruses in just five generations. No wonder a single virus can infect the human body, with trillions of healthy cells, and give you a cold in just a week or so.)

Not only has the amount of computer power increased, but the way that this power is delivered has also radically changed, with enormous implications for the economy. We can see this progression, decade by decade:

- **1950s.** Vacuum tube computers were gigantic contraptions filling entire rooms with jungles of wires, coils, and steel. Only the military was rich enough to fund these monstrosities.

- **1960s.** Transistors replaced vacuum tube computers, and mainframe computers gradually entered the commercial marketplace.

- **1970s.** Integrated circuit boards, containing hundreds of transistors, created the minicomputer, which was the size of a large desk.

- **1980s.** Chips, containing tens of millions of transistors, made possible personal computers that can fit inside a briefcase.

- **1990s.** The Internet connected hundreds of millions of computers into a single, global computer network.

- **2000s.** Ubiquitous computing freed the chip from the computer, so chips were dispersed into the environment.

So the old paradigm (a single chip inside a desktop computer or laptop connected to a computer) is being replaced by a new paradigm (thousands of chips scattered inside every artifact, such as furniture, appliances, pictures, walls, cars, and clothes, all talking to one another and connected to the Internet).

When these chips are inserted into an appliance, it is miraculously transformed. When chips were inserted into typewriters, they became word processors. When inserted into telephones, they became cell phones. When inserted into cameras, they became digital cameras. Pinball machines became video games. Phonographs became iPods. Airplanes became deadly Predator drones. Each time, an industry was revolutionized and was reborn. Eventually, almost everything around us will become intelligent. Chips will be so cheap they will even cost less than the plastic wrapper and will replace the bar code. Companies that do not make their products intelligent may find themselves driven out of business by their competitors that do.

Of course, we will still be surrounded by computer monitors, but they will resemble wallpaper, picture frames, or family photographs, rather than computers. Imagine all the pictures and photographs that decorate our homes today; now imagine each one being animated, moving, and connected to the Internet. When we walk outside, we will see pictures move, since moving pictures will cost as little as static ones.

The destiny of computers—like other mass technologies like electricity, paper, and running water—is to become invisible, that is, to disappear into the fabric of our lives, to be everywhere and nowhere, silently and seamlessly carrying out our wishes.

Today, when we enter a room, we automatically look for the light switch, since we assume that the walls are electrified. In the future, the first thing we will do on entering a room is to look for the Internet portal, because we will assume the room is intelligent. As novelist Max Frisch once said, “Technology [is] the knack of so arranging the world that we don’t have to experience it.”

Moore’s law also allows us to predict the evolution of the computer into the near future. In the coming decade, chips will be combined with supersensitive sensors, so that they can detect diseases, accidents, and emergencies and alert us before they get out of control. They will, to a degree, recognize the human voice and face and converse in a formal language. They will be able to create entire virtual worlds that we can only dream of today. Around 2020, the price of a chip may also drop to about a penny, which is the cost of scrap paper. Then we will have millions of chips distributed everywhere in our environment, silently carrying out our orders.

Ultimately, the word *computer* itself will disappear from the English language.

In order to discuss the future progress of science and technology, I have divided each chapter into three periods: the near future (today to 2030), the midcentury (from 2030 to 2070), and finally the far future, from 2070 to 2100. These time periods are only rough approximations, but they show the time frame for the various trends profiled in this book.

The rapid rise of computer power by the year 2100 will give us power like that of the gods of mythology we once worshipped, enabling us to control the world around us by sheer thought. Like the gods of mythology, who could move objects and reshape life with a simple wave of the hand or nod of the head, we too will be able to control the world around us with the power of our minds. We will be in constant mental contact with chips scattered in our environment that will then silently carry out our commands.

I remember once watching an episode from *Star Trek* in which the crew of the starship *Enterprise* came across a planet inhabited by the Greek gods. Standing in front of them was the towering god Apollo, a giant figure who could dazzle and overwhelm the crew with godlike feats. Twenty-third-century science was powerless to spar with a god who ruled the heavens thousands of years ago in ancient Greece. But once the crew recovered from the shock of encountering the Greek gods, they soon realized that there must be a source of this power, that Apollo must simply be in mental contact with a central computer and power plant, which then executed his wishes. Once the crew located and destroyed the power supply, Apollo was reduced to an ordinary mortal.

This was just a Hollywood tale. However, by extending the radical discoveries now being made in the laboratory, scientists can envision the day when we, too, may use telepathic control over computers to give us the power of this Apollo.

NEAR FUTURE (PRESENT TO 2030)

INTERNET GLASSES AND CONTACT LENSES

Today, we can communicate with the Internet via our computers and cell phones. But in the future, the Internet will be everywhere—in wall screens, furniture, on billboards, and even in our glasses and contact lenses. When we blink, we will go online.

There are several ways we can put the Internet on a lens. The image can be flashed from our glasses directly through the lens of our eyes and onto our retinas. The image could also be projected onto the lens, which would act as a screen. Or it might be attached to the frame of the glasses, like a small jeweler's lens. As we peer into the glasses, we see the Internet, as if looking at a movie screen. We can then manipulate it with a handheld device that controls the computer via a wireless connection. We could also simply move our fingers in the air to control the image, since the computer recognizes the position of our fingers as we wave them.

For example, since 1991, scientists at the University of Washington have worked to perfect the virtual retinal display (VRD) in which red, green, and blue laser light are shone directly onto the retina. With a 120-degree field of view and a resolution of 1600 × 1,200 pixels, the VRD display can produce a brilliant, lifelike image that is comparable to that seen in a motion picture theater. The image can be generated using a helmet, goggles, or glasses.

Back in the 1990s, I had a chance to try out these Internet glasses. It was an early version created by the scientists at the Media Lab at MIT. It looked like an ordinary pair of glasses, except there was a cylindrical lens about ½ inch long, attached to the right-hand corner of the lens. I could look through the glasses without any problem. But if I tapped the glasses, then the tiny lens dropped in front of my eye. Peering into the lens, I could clearly make out an entire computer screen, seemingly only a bit smaller than a standard PC screen. I was surprised how clear it was, almost as if the screen were staring me in the face. Then I held a device, about the size of a cell phone, with buttons on it. By pressing the buttons, I could control the cursor on the screen and even type instructions.

In 2010, for a Science Channel special I hosted, I journeyed down to Fort Benning, Georgia, to check out the U.S. Army's latest "Internet for the battlefield," called the Land Warrior. I put on a special helmet with a miniature screen attached to its side. When I flipped the screen over my eyes, suddenly I could see a startling image: the entire battlefield with X's marking the location of friendly and enemy troops. Remarkably, the "fog of war" was lifted, with GPS sensors accurately locating the position of all troops, tanks, and buildings. By clicking a button, the image would rapidly change, putting the Internet at my disposal on the battlefield, with information concerning the weather, disposition of friendly and enemy forces, and strategy and tactics.

A much more advanced version would have the Internet flashed directly through our contact lenses by inserting a chip and LCD display into the plastic. Babak A. Parviz and his group at the University of Washington in Seattle are laying the groundwork for the Internet contact lens, designing prototypes that may eventually change the way we access the Internet.

He foresees that one immediate application of this technology might be to help diabetics regulate their glucose levels. The lens will display an immediate readout of the conditions within their body. But this is just the beginning. Eventually, Parviz envisions the day when we will be able to download any movie, song, Web site, or piece of information off the Internet into our contact lens. We will have a complete home entertainment system in our lens as we lie back and enjoy feature-length movies. We can also use it to connect directly to our office computer via our lens, then manipulate the files that flash before us. From the comfort of the beach, we will be able to teleconference to the office by blinking.

By inserting some pattern-recognition software into these Internet glasses, they will also recognize objects and even some people's faces. Already, some software programs can recognize preprogrammed faces with better than 90 percent accuracy. Not just the name, but the biography of the person you are talking to may flash before you as you speak. At a meeting this will end the embarrassment of bumping into someone you know whose name you can't remember. This may also serve an important function at a cocktail party, where there are many strangers, some of whom are very important, but you don't know who they are. In the future, you will be able to identify strangers and know their backgrounds, even as you speak to them. (This is somewhat like the world as seen through robotic eyes in *The Terminator*.)

This may alter the educational system. In the future, students taking a final exam will be able to silently scan the Internet via their contact lens for the answers to the questions, which would pose an obvious problem for teachers who often rely on rote memorization. This means that educators will have to stress thinking and reasoning ability instead.

Your glasses may also have a tiny video camera in the frame, so it can film your surroundings and then broadcast the images directly onto the Internet. People around the world may be able to share in your experiences as they happen. Whatever you are watching, thousands of others will be able to see it as well. Parents will know what their children are doing. Lovers may share experiences when separated. People at concerts will be able to communicate their excitement to fans around the world. Inspectors will visit faraway factories and then beam the live images directly to the contact lens of the boss. (Or one spouse may do the shopping, while the other makes comments about what to buy.)

Already, Parviz has been able to miniaturize a computer chip so that it can be placed inside the polymer film of a contact lens. He has successfully placed an LED (light-emitting diode) into a contact lens, and is now working on one with an 8 × 8 array of LEDs. His contact lens can be controlled by a wireless connection. He claims, "Those components will eventually include hundreds of LEDs, which will form images in front of the eye, such as words, charts, and photographs. Much of the hardware is semitransparent so that wearers can navigate their surroundings without crashing into them or becoming disoriented." His ultimate goal, which is still years away, is to create a contact lens with 3,600 pixels, each one no more than 10 micrometers thick.

One advantage of Internet contact lenses is that they use so little power, only a few millionths of a watt, so they are very efficient in their energy requirements and won't drain the battery. Another advantage is that the eye and optic nerve are, in some sense, a direct extension of the human brain, so we are gaining direct access to the human brain without having to implant electrodes. The eye and the optic nerve transmit information at a rate exceeding a high-speed Internet connection. So an Internet contact lens offers perhaps the most efficient and rapid access to the brain.

Shining an image onto the eye via the contact lens is a bit more complex than for the Internet glasses. An LED can produce a dot, or pixel, of light, but you have to add a microlens so that it focuses directly onto the retina. The final image would appear to float about two feet away from you. A more advanced design that Parviz is considering is to use microlasers to send a supersharp image directly onto the retina. With the same technology used in the chip industry to carve out tiny transistors, one can also etch tiny lasers of the same size, making the smallest lasers in the world. Lasers that are about 100 atoms across are in principle possible using this technology. Like transistors, you could conceivably pack millions of lasers onto a chip the size of your fingernail.

DRIVERLESS CAR

In the near future, you will also be able to safely surf the Web via your contact lens while driving a car. Commuting to work won't be such an agonizing chore because cars will drive themselves. Already, driverless cars, using GPS to locate their position within a few feet, can drive over hundreds of miles. The Pentagon's Defense Advanced Research Projects Agency (DARPA) sponsored a contest, called the DARPA Grand Challenge, in which laboratories were invited to submit driverless cars for a race across the Mojave Desert to claim a $1 million prize. DARPA was continuing its long-standing tradition of financing risky but visionary technologies.

(Some examples of Pentagon projects include the Internet, which was originally designed to connect scientists and officials during and after a nuclear war, and the GPS system, which was originally designed to guide ICBM missiles. But both the Internet and GPS were declassified and given to the public after the end of the Cold War.)

In 2004, the contest had an embarrassing beginning, when not a single driverless car was able to travel the 150 miles of rugged terrain and cross the finish line. The robotic cars either broke down or got lost. But the next year, five cars completed an even more demanding course. They had to drive on roads that included 100 sharp turns, three narrow tunnels, and paths with sheer drop-offs on either side.

Some critics said that robotic cars might be able to travel in the desert but never in midtown traffic. So in 2007, DARPA sponsored an even more ambitious project, the Urban Challenge, in which robotic cars had to complete a grueling 60-mile course through mock-urban territory in less than six hours. The cars had to obey all traffic laws, avoid other robot cars along the course, and negotiate four-way intersections. Six teams successfully completed the Urban Challenge, with the top three claiming the $2 million, $1 million, and $500,000 prizes.

The Pentagon's goal is to make fully one-third of the U.S. ground forces autonomous by 2015. This could prove to be a lifesaving technology, since recently most U.S. casualties have been from roadside bombs. In the future, many U.S. military vehicles will have no drivers at all. But for the consumer, it might mean cars that drive themselves at the touch of a button, allowing the driver to work, relax, admire the scenery, watch a movie, or scan the Internet.

I had a chance to drive one of these cars myself for a TV special for the Discovery Channel. It was a sleek sports car, modified by the engineers at North Carolina State University so that it became fully autonomous. Its computers had the power of eight PCs. Entering the car for me was a bit of a problem, since the interior was crammed. Everywhere inside, I could see sophisticated electronic components piled on the seats and dashboard. When I grabbed the steering wheel, I noticed that it had a special rubber cable connected to a small motor. A computer, by controlling the motor, could then turn the steering wheel.

After I turned the key, stepped on the accelerator, and steered the car onto the highway, I flicked a switch that allowed the computer to take control. I took my hands off the wheel, and the car drove itself. I had full confidence in the car, whose computer was constantly making tiny adjustments via the rubber cable on the steering wheel. At first, it was a bit eerie noticing that the steering wheel and accelerator pedal were moving by themselves. It felt like there was an invisible, ghostlike driver who had taken control, but after a while I got used to it. In fact, later it became a joy to be able to relax in a car that drove itself with superhuman accuracy and skill. I could sit back and enjoy the ride.

The heart of the driverless car was the GPS system, which allowed the computer to locate its position to within a few feet. (Sometimes, the engineers told me, the GPS system could determine the car's position to within inches.) The GPS system itself is a marvel of modern technology. Each of the thirty-two GPS satellites orbiting the earth emits a specific radio wave, which is then picked up by the GPS receivers in my car. The signal from each satellite is slightly distorted because they are traveling in slightly different orbits. This distortion is called the Doppler shift. (Radio waves, for example, are compressed if the satellite is moving toward you, and are stretched if it moves away from you.) By analyzing the slight distortion of frequencies from three or four satellites, the car's computer could determine my position accurately.

The car also had radar in its fenders so that it could sense obstacles. This will be crucial in the future, as each car will automatically take emergency measures as soon as it detects an impending accident. Today, almost 40,000 people in the United States die in car accidents every year. In the future, the words *car accident* may gradually disappear from the English language.

Traffic jams may also be a thing of the past. A central computer will be able to track all the motions of every car on the road by communicating with each driverless car. It will then easily spot traffic jams and bottlenecks on the highways. In one experiment, conducted north of San Diego on Interstate 15, chips were placed in the road so that a central computer took control of the cars on the road. In case of a traffic jam, the computer will override the driver and allow traffic to flow freely.

The car of the future will also be able to sense other dangers. Thousands of people have been killed or injured in car accidents when the driver fell asleep, especially at night or on long, monotonous trips. Computers today can focus on your eyes and recognize the telltale signs of your becoming drowsy. The computer is then programmed to make a sound and wake you up. If this fails, the computer will take over the car. Computers can also recognize the presence of excessive amounts of alcohol in the car, which may reduce the thousands of alcohol-related fatalities that happen every year.

The transition to intelligent cars will not happen immediately. First, the military will deploy these vehicles and in the process work out any kinks. Then robotic cars will enter the marketplace, appearing first on long, boring stretches of interstate highways. Next, they will appear in the suburbs and large cities, but the driver will always have the ability to override the computer in case of an emergency. Eventually, we will wonder how we could have lived without them.

FOUR WALL SCREENS

Not only will computers relieve the strain of commuting and reduce car accidents, they will also help to connect us to friends and acquaintances. In the past, some people have complained that the computer revolution has dehumanized and isolated us. Actually, it has allowed us to exponentially expand our circle of friends and acquaintances. When you are lonely or in need of company, you will simply ask your wall screen to set up a bridge game with other lonely individuals anywhere in the world. When you want some assistance planning a vacation, organizing a trip, or finding a date, you will do it via your wall screen.

In the future, a friendly face might first emerge on your wall screen (a face you can change to suit your tastes). You will ask it to plan a vacation for you. It already knows your preferences and will scan the Internet and give you a list of the best possible options at the best prices.

Family gatherings may also take place via the wall screen. All four walls of your living room will have wall screens, so you will be surrounded by images of your relatives from far away. In the future, perhaps a relative may not be able to visit for an important occasion. Instead, the family may gather around the wall screen and celebrate a reunion that is part real and part virtual. Or, via your contact lens, you can see the images of all your loved ones as if they were really there, even though they are thousands of miles away. (Some commentators have remarked that the Internet was originally conceived as a "male" device by the Pentagon, that is, it was concerned with dominating an enemy in wartime. But now the Internet is mainly "female," in that it's about reaching out and touching someone.)

Teleconferencing will be replaced by telepresence—the complete 3-D images and sounds of a person will appear in your glasses or contact lens. At a meeting, for example, everyone will sit around a table, except some of the participants will appear only in your lens. Without your lens, you would see that some of the chairs around the table are empty. With your lens, you will see the image of everyone sitting in their chairs as if they were there. (This means that all participants will be videotaped by a special camera around a similar table and then their images sent over the Internet.)

In the movie *Star Wars*, audiences were amazed to see 3-D images of people appearing in the air. But using computer technology, we will be able to see these 3-D images in our contact lens, glasses, or wall screens in the future.

At first, it might seem strange talking to an empty room. But remember, when the telephone first came out, some criticized it, saying that people would be speaking to disembodied voices. They wailed that it would gradually replace direct person-to-person contact. The critics were right, but today we don't mind speaking to disembodied voices, because it has vastly increased our circle of contacts and enriched our lives.

This may also change your love life. If you are lonely, your wall screen will know your past preferences and the physical and social characteristics you want in a date, and then scan the Internet for a possible match. And since people sometimes lie in their profiles, as a security measure, your screen will automatically scan each person's history to detect falsehoods in their biography.

FLEXIBLE ELECTRONIC PAPER

The price of flat-screen TVs, once more than $10,000, has dropped by a factor of about fifty just within a decade. In the future, flat screens that cover an entire wall will also fall dramatically in price. These wall screens will be flexible and superthin, using OLEDs (organic light-emitting diodes). They are similar to ordinary light-emitting diodes, except they are based on organic compounds that can be arranged in a polymer, making them flexible. Each pixel on the flexible screen is connected to a transistor that controls the color and intensity of the light.

Already, the scientists at Arizona State University's Flexible Display Center are working with Hewlett-Packard and the U.S. Army to perfect this technology. Market forces will then drive down the cost of this technology and bring it to the public. As prices go down, the cost of these wall screens may eventually approach the price of ordinary wallpaper. So in the future, when putting up wallpaper, one might also be putting up wall screens at the same time. When we wish to change the pattern on our wallpaper, we will simply push a button. Redecorating will be so simple.