Technology and Disabilities in the Century Ahead

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INTRODUCTION

I have been involved in inventing since I was five, and I quickly realized that for an invention to succeed, you have to target the world of the future. But what would the future be like?

To find out, I became a student of technology trends and began to develop mathematical models of different technologies: computation, miniaturization, evolution over time. I have been doing that for 25 years, and it has been remarkable to me how powerful and predictive these models are.

Now, before I show you some of these models and then try to build with you some of the scenarios for the future—and, in particular, focus on how these will benefit technology for the disabled—I would like to share one trend that I think is particularly profound and that many people fail to take into consideration. It is this: the rate of progress—what I call the "paradigm-shift rate"—is itself accelerating.

We are doubling this paradigm-shift rate every decade. The whole 20th century was not 100 years of progress as we know it today, because it has taken us a while to speed up to the current level of progress. The 20^{th} century represented about 20 years of progress in terms of today's rate. And at today's rate of change, we will achieve an amount of progress equivalent to that of the whole 20th century in 14 years, then as the acceleration continues, in 7 years. The progress in the 21st century will be about 1,000 times greater than that in the 20th century, which was no slouch in terms of change.

When you say the pace of change is accelerating, most people are quick to agree, as if that is an obvious statement. But when you ask otherwise thoughtful observers—including Nobel Prize winners—what they expect to see 50 years from now, they often vastly understate the progress of technology.

This happened at a conference I spoke at recently. *Time* magazine held a conference on the 50th anniversary of the discovery of DNA. Most speakers looked at the last 50 years and saw how much change there was and used that as a model for the next 50 years. No less a luminary than James Watson, the co-discoverer of DNA, said that in 50 years we will have drugs that will allow us to eat as much as we want and we will not gain weight. I said, 50 years? We have done that in mice already by identifying the fat insulin receptor gene. The drugs are on the drawing board now and will be in FDA tests in several years—and we will have these available in close to five years, not 50.

The first step in technological evolution took a few tens of thousands of years: fire, the wheel, stone tools. And now paradigm shifts take only a few years' time.

The one exponential trend people have heard of is Moore's Law, pertaining to the accelerating rate of computers and electronics. Every two years, we can place twice as many transistors at the same cost on an integrated circuit. They work twice as fast because the electrons have half the distance to travel, so the speed of computing doubles every two years.

Scientists have been debating when that particular paradigm will come to an end. Optimists say 18 years, pessimists say 12—but sometime in the teen years, we will not be able to shrink computing components any more because they will be just a few atoms wide. Will it be the end of Moore's Law? Perhaps—but other paradigms will emerge that hold even greater potential.

3-D MOLECULAR COMPUTING

When the trend for traditional computers runs out of steam—and we can see the end of that road—we will have three-dimensional molecular computing.

I pointed this out in my book *The Age of Spiritual Machines* four years ago, and it was considered a radical notion then—but there has been a sea change in attitude toward that idea. It is now the mainstream view that we will have 3-D molecular computing long before Moore's Law runs out.

There has been enormous progress in four years. In fact, the favorite technology appears to be the one I have felt would win: nanotubes, comprised of carbon atoms, that can be organized in three dimensions and that can compute very efficiently. They are up to100 times as strong as steel, so you can use them to create structural components and little "machines." A one-inch tube of nanotube circuitry would be a million times more powerful than the human brain.

We are miniaturizing all technology. The first reading machine we created in the early 1970s used a large washing-machine-sized computer that was less powerful than the computer in your wristwatch now and cost tens of thousands of dollars. And we are also miniaturizing mechanical systems, which inevitably will lead to nanotechnology by the 2020s.

Nanotechnology was first described by Eric Drexler in a pioneering thesis he did at MIT in the 1980s. Marvin Minsky, who was also my mentor, was the only professor willing to be his thesis advisor because it was such a radical idea. Drexler described machines that could be built atom by atom, and then replicated millions or billions of times. Recently, scientists have used supercomputers to simulate some of his original designs from 1986.

THRESHOLD OF HUMAN INTELLIGENCE

Right now, $1,000 of computing power is between that of the brain of an insect and a mouse, at least in terms of hardware capacity. We will cross the threshold of the hardware capacity of the human brain by 2020, and the computers we use then will be deeply embedded in our environment. Computers per se will disappear; they will be in our bodies, in tables, chairs, and everywhere. But we will routinely have enough power to replicate human intelligence in the 2020s.

Critics say, "Sure, we will have computers that are as powerful as the human brain, but they will just be fast calculators and will not have the other aspects of human intelligence." So, really, the challenge is this: Where will the software—where will the templates of human intelligence—come from?

To achieve this, another grand project is needed, comparable to the human genome project, to really understand the methods used by the human brain. This project is already well underway, in terms of scanning the human brain and developing detailed mathematical models of neurons and brain regions.

Resolution, speed, price, performance, and bandwidth of human brain scanning is growing exponentially. An upcoming technology will be able to see the structures, non-invasively, of clusters of thousands of neurons, giving scientists an ability to see how memories work. At that point, we will begin to understand how the human brain applies different cognitive functions.

One point about the human brain: It is not really one organ.

Asking "How does the brain work?" is a little like asking, "How does the human body work?" You cannot answer that question unless you break it down. Well, the body consists of a lot of different parts, and the lungs work differently from the heart, and the liver has many regions.

It is the same with the brain. The brain is actually several hundred information-processing organs, and they have an intricate architecture. We are beginning to describe in mathematical models how the different modules of the brain work.

REVERSE-ENGINEERING THE BRAIN

In my view, it is a conservative projection to say that within 20 or 25 years we will have reverse-engineered the principles of how the human brain works, and we will be using that knowledge to produce biologically inspired models of computation. We are doing that already. We learned things about how the human auditory system processes sounds. We used that in speech recognition, as I demonstrated, and