Featured Futurist

Merging with the Machines:

Information Technology, Artificial Intelligence, and the Law of Exponential Growth

An interview with Ray Kurzweil

This is Part I of a two-part interview with author and inventor Ray Kurzweil. His many books include *The Age of Spiritual Machines: When Computers Exceed Human Intelligence* (Viking, 1999), *The Singularity Is Near* (Viking, 2005), and his most recent, co-authored with Terry Grossman, *Transcend: Nine Steps to Living Well Forever* (Rodale, 2009). He is the co-founder (along with X Prize Foundation chairman and CEO Peter Diamandis) of Singularity University.

A documentary film about Kurzweil, *Transcendent Man,* had its premiere in 2009, and Kurzweil's own movie version of *The Singularity Is Near,* featuring commentary from Marvin Minsky, Alvin Toffler, and others, is set to appear at film festivals in 2010. He is to be a keynote speaker at WorldFuture 2010.

World Future Review: There are tens of billions of devoutly religious people around the globe. How do you sell the idea of super-intelligence, technological human enhancement, and virtual immortality to a global populace who would have to give up their core religious beliefs to embrace such a future? And would traditional religious beliefs be compatible with a world governed by technology?

Ray Kurzweil: First, I think we should recognize that the major religions emerged in pre-scientific times and we need to update our philosophies based on what we've learned in the thousand years or so that we've had science. However, such ideas are not necessarily inconsistent with religious beliefs. In fact, the major religions have embraced technology and technological progress and the idea of human beings applying tools to overcome human suffering and extend life here on earth. The major religions tend to be very pro-life and clearly support medical and scientific progress to expand human longevity. While they may not necessarily talk about radical life extension, [such concepts] are just natural extensions of the idea of human progress which the major religions do endorse. Even the pope has endorsed the idea of using science to overcome disease.

WFR: However, there is still plenty of controversy surrounding issues like stem cell research.

Kurzweil: There are particular techniques that run afoul of certain ideas, but those are actually pretty narrow. The opposition to embryonic stem cell research centers on one very specific technique, a very small part of biotechnology.

And, in fact, embryonic stem cells are not ideal for other reasons. If I want to grow a new liver or pancreas, I'd like to use my own DNA. Just in the last year or so, techniques to modify my own cells, to take my skin cells and add proteins to them that return them to a pluripotent state, so they are the equivalent of embryonic stem cells, but without the ethical issues attendant to embryos and with my own DNA, have become a reality.

In terms of your question of selling the idea, I spend about half my time communicating my ideas. I see that as a form of invention because I can now invent with the technologies of 2020 and 2030. I can't build those devices yet, but I can write about them—that's the source of material for my books. I got into technology forecasting because of my interest in being an inventor and because I realized that timing was critical to success.

Larry Page and Sergey Brin had a brilliant idea about reverse-engineering the links on the Net to provide a better search engine, and they launched it at exactly the right time. Recognizing this around 30 years ago, I began to be an ardent student of technology trends. I gathered a lot of data to see if there are aspects of the future that we can make educated guesses about. And I made a startling discovery, which is: If you measure the underlying fundamental properties of information technology—things like the number of MIPS [Million Instructions Per Second] per dollar, or bits of memory per dollar, or bits per dollar that you can send out on the Internet … or the cost of sequencing a base pair of DNA, or the number of base pairs being sequenced in a year, or 50 other things, these measures form remarkably predictable trajectories. And what's predictable is that they grow in an exponential manner. And that belies our intuition, which is linear, not exponential. The common wisdom is you can't predict the future, and people are quick to criticize my ideas, saying that you really can't be sure of what's going to happen but it is amazing just how predictable these trajectories are.

I have a theoretical explanation for that which has to do with our always using the latest technology to create the next and how that feedback cycle, if you do the math on it, produces these double exponentials. But the theoretical case would not be interesting if the empirical evidence weren't so strong. The most important classical example is MIPS per dollar, and that's been on an incredibly smooth doubly-exponential rise since the 1890 American census. Nothing, in terms of human history, has had any impact on it. World War I, World War II, the Cold War, the Great Depression ... nothing has had any impact on this very smooth rise.

This is also true of many other phenomena. If we look at the number of bits that we can move around through wireless communication, going back a century to Morse code transmissions up through today's G4 networks, again, we can track a very smooth exponential increase. The amount of genetic data sequenced, or the cost of sequencing a base pair of DNA, has doubled in terms of total data and come down by half each year in terms of cost, in a very smooth and predictable pattern. And it's not something I noticed last week. … I've been making accurate, forward-looking predictions based on this for 30 years. All of the graphs in my book *The Singularity Is Near* that go through 2002 have just been updated through 2008, and indeed, they continue to track right on course. This is predicting what appears to be completely unpredictable, which is human creativity and innovation and competition.

I can point out another phenomenon where you get predictable results out of individual events, each of which is unpredictable—namely, thermodynamics. Thermodynamics actually models each particle in a gas as following a random path so I cannot tell where this particle will be 10 seconds from now. But I can predict very accurately to a high level of precision the overall properties of the gas, which are made up of a very large number of particles, each following a chaotic path. The same thing with technology, particularly when you can measure the information properties of it. Each project and each company's technical standards are unpredictable but the overall result follows these very predictable trajectories.

So that's a very important point: (a) it's predictable, and (b) it's exponential. And exponential trajectories are not intuitive because our intuition about the future is linear and that's actually hard-wired in our brains. When we saw an animal coming at us thousands of years ago, we made a linear prediction where that animal would be in 10 seconds and what to do about it and that worked very well.

I had a debate a while back with a neuroscientist who had modeled 1% of an ion channel in one particular dendrite over the last year and concluded that it would take a century [to complete the project], as if nothing were going to happen to accelerate that work despite the fact that supercomputers that simulate these processes are doubling in power every year, that the spatial resolution of non-invasive brain scanning is doubling every year, that the amount of data we're gathering about the brain is doubling every year, that the scale and precision of the simulations we have of brain regions is doubling every year. As he sees it none of that is going to have an impact on his work. The genome project itself was dismissed halfway through by mainstream scientists who said, "I told you this wasn't going to work. Here you are halfway through the project and you've only finished 1% of the project." But that's actually right on schedule for an exponential progression because you start out doubling little numbers—it looks like nothing is happening—by the time you get to 1%, you're only seven doublings away from 100%. Indeed, the project continued to double very precisely every year and was finished seven years later, a year ahead of schedule. We see many examples of this exponential rise. So it's a profoundly important observation.

People are walking around with linear assumptions about the future, and if you make a linear assumption, you would think that none of these new emerging technologies will amount to much because linear growth is very slow. I would agree with such pessimistic perspectives if information technology really did progress linearly, but it doesn't. And if you look at exponential growth, you conclude that these exponentially-growing information technologies do have the scale to address the major challenges of humanity—in fact, they're the only thing that does!

The province and coverage of information technology is expanding. Fields such as health and medicine are now becoming information technologies and therefore are subject to exponential growth, not linear growth. We have the genome, which is the software of life. We have the means of changing genes—not just in a newborn but in a mature individual. RNA interference can turn genes off, new forms of gene therapy can add new genes, we can design these interventions on computers, we can test them out on increasingly sophisticated biological simulators, and as a result, health and medicine—at least the development of new methods—new drugs, for example—has become an information technology. Therefore, these techniques will be a thousand times more powerful in 10 years, a million times more powerful in 20 years.

There are two reasons why people need to understand this: First, to recognize where the solutions to problems lie, and second, to also recognize that it will bring new dangers and be aware thatwe should focus on those as well.

Some observers, like Bill McKibben, actually agree with me on these progressions but focus only on the dangers and come to the conclusion that, because of the dangers, we should relinquish these technologies, not pursue them. Bill McKibben's book *Enough* (2004) basically says, enough already of advanced technology, and he cites the dangers and the downsides I've discussed in my own books.

WFR: Dangers such as?

Kurzweil: For example, the very same technologies that are going to enable us to reprogram our biology away from cancer and heart disease could also be used by a bioterrorist in a routine college bioengineering lab to reprogram a biological virus to be more deadly, more communicable, and more stealthy, and create a bioweapon. Because of such dangers, some observers like Bill McKibben advocate relinquishment.

That would be a bad idea in my view for three reasons. First, it would deprive us of the profound benefits that we need to overcome suffering. Second, it would require a totalitarian government to enforce a ban on technology development. We're not talking about technology development in only two or three labs that could be easily shut down. This is really the pervasive result of literally hundreds of thousands of projects. And third, it wouldn't work. It would actually just drive technology development underground, where it would be even more dangerous. Responsible scientists would not have easy access to the necessary tools to develop defenses against abuse. If we're ever going to solve, or at least ameliorate the world's existing problems, plus have some hope of avoiding new ones, then it's important for people to have this perspective.

WFR: What does it mean to build "new and improved" human intelligence? And where are we in terms of bringing this to reality?

Kurzweil: There are two components to creating human-level artificial intelligence, but before I come into that, I'll just point out that people are often oblivious to just how pervasive artificial intelligence is already. When people ask me, "Whatever happened to AI?" it's like going into the rainforest and asking, "Where are all the species that I heard were supposed to be here?" There are 25 species of ants within 50 feet of them but they don't see the ants because the ants are hidden in the ecostructure.

AI is all around us. We use it all the time but it's hidden in our modern infrastructure. Every time you send an email or connect a cell phone call, intelligent algorithms route the information. Pick up any electronic product—it was designed in large measure with intelligent computer-assisted design and assembled in robotic factories. Intelligent algorithms fly and land airplanes, guide intelligent weapons systems, automatically diagnose electrocardiograms and blood cell images and I could mention many other applications—and these were research projects just 15 years ago. In fact, our whole modern infrastructure would fall apart without AI. You couldn't get money from your bank, transportation and communication would halt, and that was not the case 15 years ago. But these programs are not yet at human levels. They are at human levels for specific applications. Very often, they're better than humans at specific tasks but they don't have the flexibility and suppleness and subtlety of human intelligence. However, that's going to come from two sources: First, by achieving the hardware capacity of the human brain and second, by emulating the brain's own software techniques.

There are a number of different ways to analyze what the hardware requirements are. If you take the most conservative analysis, which is 1016 calculations per second [10 million billion calculations per second or 10 billion MIPS], we'll actually have that by next year in a supercomputer and we'll have it for about $1000 by 2020. By 2029, that level of computation will be very inexpensive.

The more salient issue is: What about the software? And we've actually done very well without even looking in the human brain, just by using engineering techniques. Just as we created flying machines that were not simulations of birds, we've created intelligent applications, but it will be useful to actually understand how the human brain produces intelligent decision making, and there's a grand project underway, not an organized project, kind of a self-organizing project of 50,000 scientists and engineers studying different aspects of the human brain to reverse-engineer it, which includes all kinds of things—elaborate simulations of single neurons and simulations of whole regions of the brain and many other kinds of analyses. Already, 20 regions of the brain have been modeled, simulated in software, and tested with sophisticated tests. This includes simulations of slices of the cerebral cortex.

And the goal is not just to create a simulation. The actual goal is to understand how it works, understand its basic principles. Then we can engineer systems that don't have the restrictions of a human brain, which , for example, has to fit into a less than 1 cubic foot skull that runs on a chemical substrate that sends messages at a few hundred feet per second (which is a million times slower than electronics), that computes at a mere 200 calculations per second, and so on. We won't be limited to a billion pattern recognizers in the cerebral cortex—we could have a trillion. And if we understand the basic principles by which the brain creates intelligent behavior, we can focus and leverage it and create much more powerful systems. And I make that case in *The Singularity Is Near.*

I'm actually writing a new book to amplify that case called *How the Mind Works—and How to Build One* which will talk about the tremendous progress since *The Singularity Is Near* came out in 2004 in this reverse-engineering project. Human level intelligence in machines is not going to displace us, compete with us, it's not an invasion coming from Mars—these are tools we're creating to basically expand ourselves, who we are. And that's what we've done with tools since we've had tools. Ever since we picked up a stick to reach a higher branch, we've used it to extend our reach—the things we couldn't otherwise do. First physically and now mentally.

The device I have on my belt makes me smarter. I can access all of human knowledge with a few keystrokes. Very few people today could do their jobs without mind extenders. They are part of who we are, part of our civilization, and they make us smarter and they enable us to do things we couldn't otherwise do.

The computer is going to make its way into our bodies and brains. Blood cell-sized robots with computers in them will augment our immune systems, destroying diseases at the cellular level, and keep us healthy indefinitely. [There will be] nanobots that go into our brain, interact with our biological neurons, enable us to have brain-to-brain communication, full immersion virtual reality from within the nervous system, and so on.

There are people who have computers in their bodies and brains already. If you're a Parkinson's patient, you can replace the neurons destroyed by that disease—at least for the first 10 years of the disease—with an FDA-approved neural implant that's a computerized device, the latest generation of which actually allows you to download new software to the computer inside your brain from outside your body. There was an article in *The New York Times* a few months ago expressing concern about people hacking into the software that people are downloading into their brains, and it wasn't a tongue-in-cheek article.

It's important to understand that, due to exponential growth, as powerful as computers are today, they will be a billion times more powerful per dollar in 25 years, they will be a hundred thousand times smaller in size (what fits now on my belt will fit in a blood cell in 25 years), and it will be a very different era.

The primary application of my technology forecasting is to time my own projects. I have a team of ten people that gather data in different fields and we use these models in our business and technology plans. Our major project right now is called Blio. It's an e-reader, a joint venture with Baker & Taylor, the world's largest book distributor. It's a free software product with a million free books. We have a business and technology plan and if we describe what will the world look like, in terms of related technologies—portable computers, pocket computers, tablet computers, wireless communications—and we can actually describe in quite some detail what those underlying technologies will be like in 6 months, a year, 18 months, and so on—we can make sure that our plans coincide with that capability. We used to do this every two years. Then every year. Now we do it every 6 months.

People generally look at the world of today and assume that there will be little difference, but look at how much the world has changed in the last three years. Three years ago, most people didn't use social networks, wikis, or blogs. In 2004, Facebook was only a Harvard dorm project. ...

The world has changed enormously in a very short period of time. It's going to change even more quickly as exponential growth accelerates the paradigm shift rate. So it's very important for inventors to time their projects, which is why I started [forecasting]—any project generally has a trajectory over several years and you need to understand where the world is going, but even more importantly, in terms of looking at humanity's major problems, [you need to understand that] only these exponentially growing information technologies have the scale to address the challenges we face.

Solar energy is subject to information technology because we're applying nanotechnology, which is a form of information technology, to reorganize matter and energy at the level of molecules to create new materials and new devices using information controlled processes. As a result, the cost per watt of solar energy is coming down dramatically. ...

You hear all of these Cassandras going around saying, "we're doomed, we're running out of energy, we're running out of water," but actually, we're awash in energy, we have 10,000 times more energy just from the sun than we need, and nano-enginered solar panels will ultimately enable us to generate that energy at very low cost. We only have to capture 1 part in 10,000 of the sunlight that falls on the earth to meet 100% of our energy needs. We're literally awash in water, excuse the pun, but most of it's dirty or full of salt, but there are also new nano-enginenered technologies that can make dirty or salinated water pefectly drinkable, and it's important to look at these particular solutions as well as the new issues that arise from them.

[End of Part I. Part II will be published in the next issue of *World Future Review.*]