Futuristic Forecast of Tools and Technologies

How many of the common high-tech products we use today were once nothing more than products from the fertile minds of science fiction writers many decades earlier? Indeed, technological progress has been turning fiction into fact from the earliest days of computing. In this section, the featured essayists ponder future generations of tools and technologies, and as fictional as they may sound today, there is a basis of fact in their forecasts. Imagine a time when the network is the world and the world is the network. A time when networked devices and mechanisms are so deeply embedded into daily lives that the only time they may ever be noticed, says Jim Waldo, is when they are not working. "Imagine smelling pictures and tasting video," asks Ramesh Jain. Yes, just imagine. . .

Digital Immortality

GORDON BELL AND JIM GRAY

DIGITAL immortality, like ordinary immortality, is a continuum from enduring fame at one end to endless experience and learning at the other, stopping just short of endless life. Preserving and transmitting your ideas is one-way immortality—allowing communication with the future. Endless experience and learning is two-way immortality—allowing you, or at least part of you, to communicate with the future in the sense that the artifact continues to learn and evolve. Current technology can extend corporal life for a few decades. Both one-way and two-way immortality require part of a person to be converted to information (cyberized) and stored in a more durable media. We believe that two-way immortality, where one's experiences are digitally preserved and which then take on a life of their own, will be possible within this century. We are exploring points along the one-way, two-way spectrum in our CyberAll project (Research. Microsoft.com/~gbell).

Hamarabi, Aristotle, Shakespeare, Mozart, Rembrandt, and Euler are immortal—or at least their ideas are. They recorded their ideas in an enduring form that could be passed on to the future. These great ideas, images, music, writing, architecture, and even algorithms will survive as long as people do. Of course, these people are dead, but their ideas are effectively immortal.

Paper and then the printing press made it easier and less expensive to record, preserve, and disseminate ideas. Voice recorders, cameras, and camcorders now make it easy to record events, and, sometimes, even experiences. Moore's Law is bringing recording

JEAN-FRANÇOIS PODEVIN

In the year 3001, 19 new elements will have been added to the periodic table; materials that are 50-times lighter and 50-times stronger have allowed us to build colossal structures with modest resources. The harnessing of gravity has made it possible for contained or gossamer shapes weighing under 10 grams to be virtually gravity-free. —Jean-François Podevin, illustrator

costs down to the point where you can record everything you see and hear.

DIGITAL technologies offer new kinds of information we can convey to the future. They allow almost anyone to create his or her own immortality for any size community—either a family's future generations or an intellectual community. Web sites (www.123456789.net, www.legacy.com, www.forevernetwork.com, and www.memorymountain.com) offer (for a fee) to store letters, essays, photos, videos, and stories "forever" in order to pass them on to future generations. These are the digital equivalents of tombs, crypts, and libraries.

Future technologies will surely enhance our ability to convey ideas and experiences, creating a one-way relationship with future generations (should they care to listen or look.) Even today it is becoming reasonable to record everything we read and hear. For example, retaining every conversation a person has ever heard requires less than a terabyte (for adequate quality).

CAREN ROSENBLATT

CyberAll is being built along the lines envisioned by Vannevar Bush and Bill Gates as a memory aid and research tool. CyberAll is a store for documents, photos, music, audio, and video recordings, and is currently about 12 gigabytes, including the store for four books, 20 encoded video lectures, 150 music CDs, several thousand documents, and an archive of email messages. It has an accumulation rate of two gigabytes per year. This rate will increase as speech and video become part of CyberAll's media capture, but it is still a fairly modest expense. Indeed, the real cost of CyberAll is in the data capture, data organization, and data presentation. This is where our research efforts are directed.

Within 5–10 years, personal stores of a terabyte will cost a few hundred dollars, allowing persons to be immortal in terms of the media they've encountered. For "famous" people, one will be able to access his or her entire life.

There are many unresolved technical and social issues associated with CyberAll. How should the information be preserved, given changes in media, platforms, and programs (www.acm.org/ubiquity/views/g_bell_1. html)? How should it be organized and presented? (Will it take a lifetime to see another's lifetime)? Who should be able to see what, and when? What are the legal and ethical rights and responsibilities concerning information that involves other people? Again, we are exploring some of these issues, but mostly we are focusing on the basic tasks of acquisition, preservation, and recall.

Beyond this one-way immortality, we see hints that at least some aspects of a person could be expressed as a program that interacts with future generations. It is interesting that, given an archive of a person's spoken output, it is possible to make a compelling avatar of that person. This avatar can "live forever" in a virtual world and respond to queries about that person's past life. For example, like many great people, Albert Einstein has several posthumous Web sites. In addition, computer science researchers at CMU (cs.cmu.edu/afs/cs.cmu.edu/project/oz/web/papers/biblography.html) authored an avatar of Einstein that responds to questions from viewers. In fact, the avatar is an actor hired to read quotes from Einstein's writings. Many who have seen this demonstration understand that in the future it will be easier and easier to author such avatars. The real question is whether such a program could ever "learn" enough to stay current. Having an immortal, interactive program begins to look a bit like two-way immortal-

ity—being able to "live and communicate" forever.

We believe along with Ray Kurzweil, Hans Morovec, and others, that it is likely there will be more and more faithful avatars over the next century. By 2040, Morovec predicts robots will be as smart as humans. Successive generations of question-answering avatars will gradually become indistinguishable from the actual persons we know and love in 2001, enabling that person to appear to "live forever." C

Gordon Bell (gbell@Microsoft.com) is a senior researcher at Microsoft, Redmond, WA. He is also a member of *Communications'* Advisory Board.
Jim Gray (Gray@Microsoft.com) is a specialist in database and transaction processing computer systems at Microsoft, Redmond, WA.

We believe that two-way immortality, where one's experiences are digitally preserved and which then take on a life of their own, will be possible within this century.

Closing the Circle of Information Technology

RITA R. COLWELL

Information technology has already penetrated and transformed research in science and technology so fundamentally that younger generations will not know what it was like before the computing revolution. My own career as a microbiologist exploring the linkages between environment and health has paralleled this transformation. My own research experience has given me a deep respect for the power of computing to propel us on to new discoveries in all research disciplines. As this revolution continues, I have very high hopes for the potential of information technology.

As the wellspring of basic research in physics, chemistry, and mathematics nourishes progress in medicine and health, we can hardly imagine what shape the advances will take. But we can be sure that, coupled with the power of information technology, they will dwarf those of the 20th century, or even those through all of human history. We already have experimental nanochips that simulate the electrical activity of a normal nerve synapse by letting nerve axons regrow through the chip. We imagine implanting a chip in the brain, directly in those areas where intention resides. Thus, we would be able to bypass the areas of muscular control. Such a confluence of microelectronics and neural research holds great promise for improving the operation of artificial limbs, or even for bypassing spinal-cord injuries, creating hope that a paraplegic may walk again. Even for some types of mental illness, we can imagine a computer implant that might provide the missing neurological circuitry necessary for normal brain functioning.

In my research in the field of environment and health, computing has already brought us to the threshold of being able to predict epidemics of cholera and other diseases. We are beginning to have at our fingertips information about emerging diseases as they are identified. We can now track the progress of these diseases from

To unravel the complexity of living systems—the web of life and its surrounding environment—will require tools advanced far beyond those we now possess.

anywhere in the world and in a number of languages.

STILL, to unravel the complexity of living systems—the web of life and its surrounding environment—will require tools advanced far beyond those we now possess. We know that ecosystems do not respond linearly to environmental change, and that tracing that complexity is crucial to the future of life on our planet. Yet, we are watching the simultaneous flowering of nano-, bio-, and information technology, each accelerating the other's progress, bringing us to the brink of being able to observe complexity at multiple scales across the hierarchic levels of life. Envision being able to wave a tool packed with sensors—not a Geiger counter, but an "eco-counter," if you will—that would inventory the health of an entire ecosystem. From the Lilliputian level of observing individual atoms and molecules with nanotechnology, to our global ecological observatories in every ecosystem, we are setting up vantage points for viewing at every scale.

As we imagine the new frontiers we can explore by harnessing the power of information technology in medicine, health, and the environment, we confront yet another challenge: How to engage all of our society to realize this dream? This challenge looms particularly large. The top five fastest-growing occupations in the U.S. economy are in the field of computing, but much of our workforce is not poised to take advantage of these opportunities. Women, minorities, and the disabled constitute more than two-thirds of our country's workers, yet these groups are excluded, to a large extent, from the burgeoning science and technology professions. The digital divide cuts both ways—our economy suffers as well as those members of society left behind. If these groups joined the U.S. science and technology workforce in proportion to their numbers, we would no longer have a significant shortage of skilled workers.

A diverse workforce has been called our country's competitive edge in science and technology, and it is as much a part of my hopes for our future in information technology as any technological wonder. I suspect, however, that our technological capabilities will be very integral to fulfilling our hopes to involve everyone in the information revolution. For the first time we are on the threshold of being able to provide anyone—not just the middle-class student in the university, but also the Native American child on a reservation, or a senior citizen in a retirement home—with the ability to learn any subject at any time.

Immersed in a virtual environment, anyone will be able to learn—not from books and tapes, but through a life-like interactive experience. With an unlimited corps of personal online tutors, we will be able to tailor teaching methods to each individual's needs, level of education, and cognitive abilities. At last we will have the technology to enable us to achieve true literacy in science and technology across society, not just for the privileged. This will also mean the world of science and engineering research will be richer for the prospect of fuller participation. When future generations look back at this juncture in time, I hope they will be able to judge us as having exercised the foresight and wisdom to employ information technology not just to speed up the pace of discovery, but to have truly improved and sustained our world. C

RITA R. COLWELL (rcolwell@nsf.gov) is the director of the National Science Foundation, Arlington, VA.