Viewpoint

Reflections on Critical Technologies

Arno Penzias

Before I address individual technologies, let me set the stage by reviewing four technology-related concerns that are uppermost in the minds of demanding technology users: productivity, ease of use, location-independence, and trustability.

Productivity. Over the past ten years, I have been embarrassed by the fact that the productivity of workers in U.S. factories – people who make brooms, bulldozers, and bassinets – has been increasing by something like 4 percent a year, while information workers have seen essentially no increase in their productivity. Since there are four times as many information workers as factory workers, the productivity of the U.S. economy as a whole is creeping upward at about 1 percent a year. In short, the so-called Rust Belt has been supporting the rest of us.

Fortunately, this situation is about to change. Technology has caught up, and so has our ability to adapt to it. As we have flattened our organizations and redeployed our work forces, productivity has increased – albeit at the cost of significant human dislocation. As a result, we are seeing at least the beginnings of the benefits that were promised us in the 1960s and ‘70s. (By the way, *The Arthur D. Little Forecast on Information Technology Productivity,* by Norman Weizer et al., offers some fine material on how to make such integrated enterprises work.)

Ease of Use. I’ve just returned from visiting my grandchildren, whose parents have between them two electrical engineering degrees, an advanced degree in computer science, and an MBA. Nonetheless – and despite the fact that they’ve had their VCR for five years – the number *12:00* is still blinking at them, because they haven’t taken the trouble to figure out how to set the clock. Personally, I was pleased to see that blinking *12:00,* because a similar model in my own home still blinks *12:00*. On the other hand, a VCR I bought last year virtually set itself. Ease of use has become the hallmark of truly high technology. Our customers don’t want to spend so much time learning to use „labor-saving“ systems.

Location-Independence. Remaining in one place in order to receive calls and access information simply doesn’t work anymore. We can’t spend our lives playing telephone tag – any more than we can afford to leave our computing environment behind every time we stray from our desks.

Trustability. Computers and information technology are part of everything we do. When they go down, costs can be horrendous. In this decade, for example, I expect paper to be integrated with electronic technology. But if your „papers“ are finally stored inside a computer, what will you do if that computer goes down? What back-up will you have? Vendors must offer trustable answers to such concerns.

These four considerations – productivity, ease of use, location-independence, and trustability – will play a major role in shaping the technologies of the next several years. In my view, the critical technologies – those that will differentiate businesses – are:

• Biology

• Multimedia networking

• Manufacturing

• Systems integration

• Information capture, processing, and presentation

• Software

• Technology management

Biology

I don’t know enough about biology to say much more than that I see it as extraordinarily important in the longer term. I think biology may well offer some of the 21st century’s most exciting scientific opportunities. In fact, at Bell Labs we are building the best neurobiology capability we can, as fast as we can, because we think information companies will need that kind of capability in the future.

Multimedia Networking

The acronym WYSIWYG, „What You See Is What You Get,“ is commonly used in desktop publishing. As we look out at the next decade, I expect to see a similar term in telecommunications: WISIWYS, „What I See Is What You See.“ WISIWYS represents the visual sharing of information so critical to meaningful interaction. In the future, instead of constantly traveling in order to sit across some table, conferees will be able to stay in their respective offices and use technology not only to look at one another but also to display information, point to its features, and modify it interactively.

In other words, we will be able to bring our software into our conversations. By now, everyone has seen at least one brochure showing a computer screen with video windows on it, an approach that allows documents and software to play together. The focus is on shared visual space.

In multimedia networking, wireless interfaces deserve special mention. I see wirelessness as tomorrow's automatic transmission. I am old enough to remember when manual transmission was called „standard." Recently there was a bank robbery in New York City in which a bunch of people dressed in police uniforms tried to steal an armored car. They had almost pulled it off when they discovered that the armored car had a stick shift. Having gone through life without learning about clutches, the thieves couldn't drive the car. They were obliged to flee empty-handed. In my view, wired connections to personal interfaces are destined to become as outmoded as „standard" transmissions.

In the meantime, I tend to apply very low-tech solutions to my own portability problems. In my weekend house at the seashore, for example, I have a lovely new study, but I really like working at the kitchen table. There's a nicer view, and it's nearer to where things are going on. So I have hooked together two 25-foot modular phone cords and plugged them into my PC, so that I can cart it from one end of the house to the other and do my E-mail in the middle of my family. The next one I get is certainly going to have a wireless modem.

When AT&T was broken up, most analysts predicted the merger of computers and telecommunications. But that merger has yet to happen, in part because the two groups go to different standards bodies and deal with different kinds of messaging. The „bursty" nature of data communications – as opposed to the call-based, person-to-person, continuous nature of voice conversations – splits the computer and telecommunications views of networking into two camps. Everybody talks about broadband data networking as a necessary part of multimedia networking, but the two groups of potential services providers have been talking past one another.

In the future, however, users will insist on multimedia networking – no matter who provides the services. Users won't want to talk unless they can also send data. And video is clearly important for both. Fortunately, we now see a consensus building around the asynchronous transfer mode, or ATM, a transmission standard based on fixed-length packets. ATM sits between telephony's time-division multiplex and computer datagrams. Instead of single pulses or variable-length packets, it ships fixed-length groups of pulses (or „cells"), with limited headers.

The potential of this common interface standard has attracted support from companies as varied as Next, Sun Microsystems, the German Bundespost, NTT, and Ameritech. We see the ATM broadband networking standard as important to bringing all this together.

Finally, the interface appliances themselves will become much more than the sums of their parts. Users don't want a whole bunch of bits and pieces that don't work together. They want one screen on which they can see the people they're talking to and which also permits the exchange of documents, the sharing of software, convenient links to databases, and access to so-called virtual meeting rooms that will permit conferees to enter and leave meetings as desired. Overall, this capability should add tremendously to productivity by allowing people to travel to meetings only when they want to.

Manufacturing

The software content of every product and service we sell dominates its functionality to an astonishing degree. Nonetheless, the expression of any service ultimately makes its presence known through some physical object. We build customer relationships through such objects, we provide services through them, and vendors use them to gain advantage over each other.

When AT&T was a voice-networking company, no one called us by that name; we were called „the telephone company" instead. A telephone is an object that sits there. Never mind the transmission equipment, the switches, or the operations support systems – all the networking „stuff" that goes behind the telephone.

As far as the customer was concerned, we were „the telephone company." As long as that Bell System phone sat on a person's desk, that person felt connected to the Bell System.

Such a presence is tremendously important. It provides a tangible connection to the customer. In every field, market share depends increasingly on customer relationships. In telecommunications, those relationships are focused on the entity that sits on the desk – or on the body, because the difference between „the desk" and „the person" is disappearing quite rapidly.

Manufacturing a winning product depends on highly tuned processes. For example, I recently talked with an executive from Seiko about cognitive dissonance as it applies to inexpensive wrist watches. Whenever I see a new technology, I explained, I try to pay attention to it and check out its implications. One technology that I noticed, thought about, and then – because the conclusion seemed so unlikely – forgot about, was those $ 15 watches you can buy out on the street. I thought, How could they possibly work at those prices?

Only later did I come to appreciate the manufacturing miracle associated with that product. When you take out the profit and the cost of the case, the strap, the face, and all the other things that go into each watch, there are only a couple of dollars left – at most – for the drive mechanism. Yet the drive mechanism contains a battery, a calibrated crystal, the hardware to put the thing together, an oscillator circuit, an analog-to-digital converter, a counter, a divider, an amplifier, a stepping motor, and reduction gears – all for less than S2 assembled. And these watches work so well that *they don't have to be tested!*

You might say, „That's a different business. Why should someone working for AT&T care about watches sold by street vendors?" Well, at least one wrist-watch company is now making wrist pagers with leather straps. Since a wrist pager needs an antenna, most use some kind of plastic-encased metal band that fits around the user's wrist. But one manufacturer has managed to build a helical antenna around the clock face inside the case. So they've got a nice funky plastic watch that also happens to be a wrist pager, with a display that can show you the calling number or even a short message.

All of a sudden, a manufacturing process that was developed for inexpensive watches has moved over to support a key telecommunications interface. If the owners of that process now become the vendor of choice, new services will come into being, thanks to their unique manufacturing technology.

The changing value mix rearranges everything. What we think of as electronic components are disappearing rapidly. For example, it used to be that personal computer manufacturers created most of their products' value when they built a box, stuffed circuits onto boards, and put them together. But when we look to the future, the only items worth anything in those PCs will be the keyboard and the display. So manufacturers must ask themselves how they can add value to that display as it takes over the keyboard's role, and when all the chips sit right on that display's back surface. Will display manufacturers just include chips with their product? Will the „computer factory" become just a systems integrator? All the stuff that we used to think of as „the computer" may well disappear onto the back of the display, just as the whole watch drive industry has disappeared into those little $2 gadgets that you can now buy on street corners as easily as in jewelry stores.

To succeed, modern manufacturing must become truly coherent – all the way from product research through sales and service to recycling. When someone designs a new battery for a portable appliance, for example, the chemical system in that battery will affect its serviceability and, ultimately, its disposal requirements. Manufacturing can't afford the inefficiencies that stem from sequential hand-offs from one function to the next. Today's manufacturers have to follow their products all the way from research to recycling.

Systems Integration

A few years ago, I used to go around touting the economic benefits of electronic document storage. I would point out that a sheet of paper stored in a filing cabinet in New York City would cost its owner about five cents a year in rent. Well, rents have gone down a bit since then, but so has the price of the huge optical juke boxes that can store document images electronically. Nonetheless, few people bought these juke boxes on the basis of relative cost. Sales began to pick up only when the vendors of these systems – and their customers – began to integrate them. The organizations that have integrated electronic document storage with their other systems – such as Los Angeles County – are doing fairly well. Los Angeles County is a big place. I'm told that if it were a country, it would rank among the 50 biggest countries in the world. It encompasses something over two million privately owned parcels of land. Think of the number of people every day who die; get divorced; move; buy, refinance, or sell property; or sue someone. The number of inquiries that come into the county property office every day must be staggering.

Let's say you call up to ask for a copy of your tax records. The person there says, „Fine, I'll arrange to get your record." You call back the next day, but that person isn't at his or her desk. You speak to a supervisor, but the supervisor can't help you either. The record isn't down in the basement. It has been sent over to reprographics to have a copy made, so the supervisor has no way of locating it. We can see how things get lost, how the same transactions are repeated needlessly, and how much inefficiency results.

That doesn't happen in L.A. County any more, because images of millions of such documents are available on-line. When citizens call up now, the clerk handling each transaction has instant access to images of the sheets in question, as well as to tax records and all the other material related to those documents. Note that this access requires connections to ASCII files, a mainframe database, and telecommunications. In other words, the system pays off because integration creates a productivity advantage by bringing all these disparate modalities within easy reach.

Why do I assert that systems integration is finally coming after all these years? After all, we've been using this buzz word for as long as I can remember. Too many systems still can't „talk" to one another. But I believe we can now say that systems integration is truly on the way, because applications such as electronic document management and multimedia conferencing demand it, and because customers will demand it. Vendors will therefore adopt de facto standards in order to provide those services. Although there has been some good work in standards bodies – in areas such as video coding, for example – the main engine for standards may well arise from these applications.

Information Capture/Processing/Presentation

At the recent Olympics in Barcelona, I saw a videotape in which two people were engaged in a conversation about currency transactions via a PC with a special plug-in board attached. The two people were talking at a natural pace, but one was speaking English and the other Spanish. With the PC as an intermediary, the English speaker could say, „I would like to buy some pesetas. What is the rate for U.S. dollars, please?“ The other person heard a Spanish translation and responded in that language. With no more than a two- or three-second delay, the machine converted his answer back into English.

Three years ago, I would have expected this technology to become operational early in the 21st century. Progress in the recognition of fluent speech has been amazingly rapid. Also, designers have taken some shortcuts. This application employs a highly task-specific vocabulary, for example. Because this conversation concerns only money, the machine doesn't have to worry about other meanings for some of the words.

Along with progress in speech, we are seeing a lot of promising work on images, especially in video. We find that there isn't just one type of video, but at least five categories of service – ranging from low-bit-rate conferencing to full-scale HDTV – each requiring its own technology. By tuning the technology, we are making wonderful advances. This year, for instance, my colleagues at AT&T have produced a set of three chips, each the size of my fingernail: a coder, a decoder, and a networking chip. With this chip set installed on the corner of a PC board, users can enjoy videoconferencing capability over digital voice lines. Interestingly, the most powerful of those three chips routinely performs something like eight billion multiply-adds per second. Supercomputer vendors, please take note!

These chips work well because they have been designed specifically for teleconferencing. Another R&D group is making a very different set of chips for HDTV. In videoconferencing, images are likely to stay much the same over time. But in HDTV some viewers will want to see rock videos, which feature rapid scene changes from one body part to another. For this application, you can't expect to use the motion-estimation algorithms that work so effectively in teleconferencing applications.

Portable video cameras will very likely become important information-capture tools, particularly when combined with the context-enhanced recognition of images. Some day, for example, if I want electronic help for my rather poor ability to remember names, faces, or conversations, I might consider installing a couple of iris-sized video cameras on the corners of my glasses – with tiny radio transmitters linked to the cellular phone in my pocket. Probably, I would also be wearing a number of microphones on my jacket. The microphones would self-steer, as an array, toward whatever person appeared to be talking.

Then, I could use a code phrase, such as „It's nice to see you,“ which my system would recognize as a call for help, i.e., „Who is this person?“ Voice and images would be transmitted to a database, which would pick out possible matches and resolve ambiguities by analyzing voices – as well as checking to see who would be most likely to attend the event in question. Once it found the identity of the person I was looking at, the system would relay the name back to a tiny speaker in my ear.

When I asked some colleagues of mine about this idea, they thought we could produce it in five years, simply by defining the context. We wouldn't have to take everybody's face and match it against everyone else's in the world, because the system could deduce the gender and approximate age of the person in question from his or her voice. Knowing the location would also help, because that same recognition system would probably have access to a list of likely attendees. So futuristic systems need to do what human beings always do: use context to focus searches.

By bringing other kinds of information concerning context into the representation, we can frequently solve difficult problems seamlessly. Attacking problems from the ground up without taking any shortcuts seems to be way off-base in the real world. Accordingly, I expect straight theorem-proving approaches to remain very much behind methods that use context-enhanced representation.

Ultimately, all these technologies will require interfaces with people. As far as I'm concerned, the physical prototype of the „computer of the future“ already exists. It's my favorite information interface: a blue-lined yellow pad. I will have to give up the blue lines and the yellow color temporarily when I want a video interface, but I would insist on a voice-operated option that allowed me to change it back to a blue-lined yellow writing surface.

I want the „pad“ to contain my modem and access my files, so I want it able to accept ASCII input, video, and all the modalities. But most of all, I want electronic paper. Ultimately, I am only willing to carry something about as thick as – and probably not a lot heavier than – one of my yellow pads. Since it will be stiffer, I'll add in the weight of one of those binders that we all get in meetings. (Not one of the thick ring binders, but the thinner ones with the name of the conference on them that seem too good to throw away when you get home.) I'd also like a key-word search capability that will hunt through my stored scribbles; that should also be available with tomorrow's interface technology.

Software

When we mention software, most people think about coding. But in the next few years, I see the greatest progress coming in front- and back-end practices, i.e., requirements and testing. Testing seems an archaic feature in modern software methodology. I can't imagine someone at Seiko, for example, building a whole bunch of watches and then having engineers sit down and say, „What could have gone wrong with them? Let's go look and find out.“

A modern hardware factory wouldn't operate that way – no self-respecting hardware manufacturer would dare do that. But that is what we do with software when we test the quality afterwards. To meet tomorrow's software quality standards, we will need to test against requirements automatically. That need will compel us to base testing on requirements that match what the ultimate user expects. People will need to determine in the beginning what they really want the software to do, instead of rushing off to do the coding.

Software methodologies are improving. For example, I was really impressed by a recent software visualization demonstration. Imagine a program 20,000 to 30,000 lines long (the size of a good novel). The chapters of that novel – the files of the program – appear as vertical bars on the screen of a high-resolution monitor. Each bar consists of several hundred thin horizontal lines. While you can't read an individual line when a thousand lines of text are squeezed onto a screen on top of one another, your eyes can resolve color differences between quite thin adjacent lines – thin enough to fit several hundred into a single screen-height stack.

The program in question had a five-year history. In the demonstration, the visualization system assigned a different color to every day of those five years (starting with blue at one end and moving toward red at the other, like a rainbow). And thus, when I looked at this representation of that program, each horizontal line in each vertical bar bore the color corresponding to the date on which it was written. Thus, if a bar has a nice solid color, the viewer recognizes the file as being written all at the same time. But when a bar is cut by horizontal lines of many different colors – like a kid's scribble – multiple modifications become instantly apparent.

This kind of visual representation offers new insights to people who can't necessarily read code. Through its use, they can get some understanding of the history and structure of one of their most important assets. With this tool, programming neophytes can compare one piece of code to another and assess its quality. Financiers acquiring companies whose main assets consist of software will get a better look at what they are buying. And auditors who can't read software may soon be able to visualize that software's history. Visualization is a whole new technology that can bring complex information within the reach of intuitive understanding.

Finally, it will also be important to produce code that is provably correct as each line is written. So far, we can do it only with so-called finite-state-machine systems that apply in special cases, such as the design of communication protocols. Provable correctness is another direction we really have to pursue for total software reliability.

Technology Management

With the future of technology advances so dependent on a long-term commitment to innovation, people frequently ask me, „Is Bell Labs still doing basic research these days, or just applied research?“ To me, that question presupposes that basic and applied research behave like alcohol and water in a vodka bottle: if you want higher proof, the only way to put more alcohol in the bottle is by first taking out some of the water.

But *applied* and *basic* are not opposites. The opposite of *applied* is *unapplied*. Since we don't use *unapplied* in English, we ought to use *academic* instead.

In my view, research ranges from academic to applied, as well as from short-term to long-term (see the exhibit below). For example, for someone at Pfizer to study the metabolism of a hamster would be long-term applied research. At Bell Labs, I would put the transistor in that category. People in these two quite different businesses might disagree about whether a particular activity ought to be considered applied or not, but both sides would agree on the long-term vs. short-term nature of a project.

The Research Portfolio

	Academic	*Applied*
Long-term	*High-energy physics*	*The transistor*
Short-term	*Space lab*	*Joint projects*

High-energy physics is clearly a long-term academic undertaking, since no industrial company I know of cares about it. But the results of research in high-energy physics will interest the scientific community for many years to come. At the same time, however, exploring the effects of weightlessness on astronauts is like asking, „What are the effects of rock music on bartenders in discos?“ This answer is of interest primarily to the people who happen to be doing the job in question. So I’d call that short-term academic research.

As I see it, modern research managers shouldn’t have to choose between applied and basic research. To build for the future, we must make sure that the research we do is – like the transistor – both applied *and* basic.

Arno Penzias, who was awarded the 1978 Nobel Prize for Physics for his part in the discovery of evidence supporting the „big bang“ theory of the origin of the universe, is vice president of research for AT&T-Bell Laboratories and has recently joined the Board of Directors of Arthur D. Little, Inc. This Viewpoint article is based on a presentation made by Dr. Penzias in June 1992 in Boston at a conference on the business implications of technology sponsored by Decision Resources, Inc., and Management Centre Europe.