

COMPUTERS OF THE FUTURE

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Editor's note: Anita Weston received the 2004 Exemplary Faculty Award from the BYU-Idaho Faculty Association and gave the following address at a Major Campus Forum on 15 July 2004.

It is good to be with you today. I can't think of anything more enjoyable than to discuss with you possible future happenings in the computer area. Let's take a few minutes to talk about Moore's Law and how it relates to the Petaflop Imperative. Then let's touch on the area of Quantum Computers and the tremendous need our country has for mathematicians and physicists to possibly help make it become a reality. A newer application called RFID, which stands for Radio Frequency Identification, is currently being implemented in the business world. It can be a form of wireless communication.

I will be using three terms that are almost beyond our imagination—let alone our ability to understand. I thought if I talked about them first, then used them in context, it would be easier to follow at least part of what I am talking about.

First, the word teraflop refers to the ability of computers to process information. A teraflop means a trillion operations per second. I've tried to come up with some kind of analogy that would make understanding this type of speed easier. If I were able to talk at teraflops speed, you would go home with libraries—not one but many—of information from today's forum.

The ordinary person speaks at about 150 words per minute. Dividing 150 words by 60 would give me about 2.5 words per second. I then need to determine how many seconds I will be speaking so I can multiply 35 minutes by 60, which is about 2100 seconds. Two and a half words per second for 2100 seconds will result in approximately 5,250 words during this forum time. That's nearly eight pages—single spaced—of information. That's normal speaking. If I were to shift gears into teraflops, I would need to present 2100 teraflops (2100 trillion words) of information. As I've done my math, I think you would be taking home several billion books from just 35 minutes of time. Aren't you glad I'm not shifting into teraflops speed?

The next step up in speed is a petaflop. A petaflop is a thousand trillion operations per second. Another way of saying this is one quadrillion mathematical computations per second. A nanosecond is one billionth of a second. Currently, many computer operations, such as the speed of memory chips, are measured in nanoseconds. You are always hearing

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people respond when asked to hurry, “Just a second.” Can you imagine how fast they would come if they could travel at nanosecond speed?

I wish we had time to discuss some of the fun gadgets that are being developed, such as InfoCharms¹ (sometimes referred to as “wearables”), new mouse capabilities, and contributions in the computer area made by science fiction authors. I can’t think of a career or profession in this day and age that doesn’t use computers and take advantage of their capabilities. As a result, there are, of course, as many future computer applications as there are careers. Artificial intelligence, virtual reality, Global positioning systems (GPS), and so on are all topics that probably should have been addressed as well. There is no way, however, in the time we have today to touch on all of these areas. The future of computers encompasses the world and interacts with just about everything in the world.

Since the development of the first computer, refinements have been made. The first major change in computer technology was when we moved from vacuum tubes to transistors. However, the same procedures and processes were used. With each succeeding generation, computers have become faster, more economical, and more powerful. Technologically, however, we are basically doing the same thing that we did with the very first computer.

MOORE’S LAW

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In 1965 Gordon Moore, a co-founder of Intel, observed that the number of transistors per square inch on integrated circuits had doubled every year since the integrated circuit replaced the vacuum tube. Moore predicted that this trend would continue for the foreseeable future. In subsequent years, the pace slowed down a bit, but data density has still doubled approximately every 18 months without additional cost. Since this doubling phenomenon has continued from the time Moore made his observation, it has been referred to as Moore’s Law. Most experts, including Moore himself, expect Moore’s Law to hold for at least another two decades (approximately 15-20 years) but feel that eventually we will not be able to miniaturize any further—that something new must be invented if the trend toward faster, more powerful, and more economical computers is to continue. We are told that:

Engineers no doubt will continue wringing performance gains out of silicon chips. But the computing industry knows it can’t keep shrinking the size of the electronics on those chips forever. As components approach the nanoscale, power leakage and heat start to hold back performance.²

Currently the world’s five fastest supercomputers, according to a new survey, are:

- First, the Earth simulator, which is a 35.9 teraflops machine. It was created by NEC and is housed in the Earth Simulator Center in Tokyo, Japan.
- Second, the Thunder supercomputer runs at 19.9 teraflops. It was made by Digital Corp., and can be found at the Lawrence Livermore National Lab located in California.
- Third, the ASCI Q computer can calculate at the speed of 13.9 teraflops. It was made by Hewlett-Packard Company and is used by the Los Alamos National Lab in California.
- Fourth, Blue Gene/L is an 11.7 teraflops machine made by IBM. It can be found at the Watson Research Center in New York.
- Fifth, the Tungsten computer operates at 9.8 teraflops. It was created by Dell computers and is used at the National Center for Supercomputing Applications in Illinois.³

A *teraflop* refers to a *trillion operations per second*. Tera is a prefix indicating 10 to the power of 12, which is a trillion. FLOPS are floating-point operations per second. The Earth simulator in Japan today handles almost 40 teraflops per second—40 trillion operations per second. Since Japan’s Earth Simulator supercomputer shocked Washington two years ago, there’s been a sense that the United States could lose its lead in many areas just as it did in climate science.

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PETAFL0P

“The Energy Department last month said it’s prepared to spend as much as \$200 million in the next five years to install a Cray- and IBM-supplied supercomputer at Oak Ridge National Lab in Tennessee capable of *250 teraflops... and 1 petaflop by the decade’s end.*”⁴ A *petaflop* is a *thousand trillion operations per second*. Another way of saying this is: *one quadrillion* mathematical computations per second. Researchers are attempting to again shrink current components enough to allow for this faster processing. However, the miniaturization process has run into some very difficult challenges.

Not only do we need to build the computer that will run at that speed, but:

The U.S. government is also betting big money that academic researchers and private-sector scientists will be able to write software that can take advantage of these theoretical supercomputing beasts. If they can’t, the United States is going to end up with some very expensive, very smart white elephants.⁵

According to Tom Tecco, director of computer-aided engineering and testing at General Motors Corp, “If a petaflop was delivered tomorrow,

we probably wouldn't know what to do with it." However, "By the end of the decade, we'd probably consume it."⁶

Just how could and would we use such a computer? Well, "a petaflop machine could help engineers virtually prototype entire cars and planes without building costly models, weather forecasters could zero in on storms with crackerjack accuracy, traders would be able to instantly predict the ripple effect of a stock-price change throughout its sector, and doctors could biopsy tissue samples for fast decisions while a patient still lies on the operating-room table. It would help research physics, biology, global warming, and nanoscience." The biotech industry needs the kind of performance that IBM and Cray are building into their next-generation supercomputers to deliver useful products. "We want to be able to model cells, tissues, and organisms," he says. "*A petaflop won't do that, but it's a start.*"

Blue Gene, a computer line of IBM's, was conceived of as a computer to simulate protein-folding, a mysterious bodily process that could shed light on disease formation if it's well understood. A small version of Blue Gene/L can run one protein simulation 12 times faster than IBM's popular SP supercomputers.⁷

The Dreamliner will be Boeing's first airplane whose assembly will be modeled on a supercomputer. Software that can plot the location of every part and tool and on the factory floor is becoming so sophisticated that a petaflop computer may soon be necessary to run it." Donofrio, a senior VP who joined IBM in 1967 says, "We know the petaflop is a high-water mark, and I want it done." He goes on to say, "We'll achieve a petaflop in 2005 or 2006. We're that close." Other scientists think it will take longer and predict we will see a petaflop computer by the year 2010. "Later this year, IBM plans to deliver a version of its experimental Blue Gene/L supercomputer capable of *360 teraflops—a third of the petaflop mark*" and much faster than Japan's 35.9 teraflop machine. "A follow-on machine called *Blue Gene/P could reach a petaflop in three years*, people at Livermore say."⁸

The Blue Gene line was designed from the get-go to break the petaflop plateau, and they're currently shooting up the list of the world's 500 fastest computers. IBM has poured \$100 million into Blue Gene's development. Says Irene Qualters, VP for research information systems: "The petaflop in and of itself isn't enough to gain our enthusiasm." "It has to be sustainable architecture we can invest in over the long haul. In many cases traditional wet-lab instruments yield cheaper, better results than computer simulations," adds senior computing director Jeff Saltzman. "Blue Gene is a long-term investment with an uncertain probability of success."⁹

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QUANTUM

There is, however, on the horizon a different technology that is being researched. It is referred to as the Quantum Computer. This computer, would be faster, lower priced, and more powerful than today's fastest computers and could, theoretically, exist inside a coffee cup. "One technologist on Wall Street says a shift as big as the one from electronic to quantum computing—no matter how technically feasible—would require massive amounts of work to fit into the private sector."¹⁰

"Quantum computing is harder to justify than most, since practical uses seem so far off—and far out." Most of the research done on Quantum Computers seems to have occurred in the late 1990's and the first year or two of 2000. However, because of the tremendous possibilities of using quantum physics (as far as speed and accuracy go) as well as once again becoming more competitive with Japan, the government has decided to fund research on this computer to the tune of \$2.8 billion. This amount is in addition to the funding being given to Petaflop research. Quantum computing is largely theoretical. If it works, quantum computing could provide such enormous computing power that it would make today's encryption and other information-security systems obsolete. "Even if successful, quantum computing is likely a decade—or, more likely, two—away."

The fundamental idea of quantum computing is that a particle—a quantum bit, or qubit—can represent both a 1 and 0 at the same time, so the number of calculations scales exponentially with each quantum-computing bit, compared with linearly in an electronic computer, where each bit must be either a 1 or 0. So a quantum computer using 14 calculating atoms, which is twice as large as what's been assembled thus far, could perform more simultaneous calculations (16,384) than the fastest supercomputer in the United States.¹¹

Darpa's (Defense Advanced Research Projects Agency) proposed program, called Focused Quantum Systems, or Foqus, aims to build a quantum computer capable of factoring a 128-bit number—a common method today of online encryption—in 30 seconds, with 99.99 percent accuracy.¹² Can you imagine how easy it would be for identification theft and other fraudulent activities to take place with such power? We have enough of these kinds of problems today without this kind of capability.

Darpa describes Foqus only as a possibility. A bid for scientists to participate will likely come "sometime in the near future," a spokeswoman says. She continues: "The agency is interested in quantum computing for its potential to help understand ultra-secure communications and superaccurate calibration." "Everything at the moment is very rudimentary, but they're the key steps in building something more complicated," says

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Carl Williams, chief of the atomic physics division at the National Institute of Standards and Technology, which sets U.S. measurements and timekeeping standards.”¹³

The notion of constructing a computer that behaved according to the laws of quantum physics arose in the early 1980’s, when the late Richard Feynman, a Nobel Prize winner at the California Institute of Technology, postulated that the only way to simulate a quantum mechanical system—one in which particles can spin clockwise and counterclockwise at the same time—was with a computer that itself behaved that way. A big breakthrough came in 1994 when Peter Shor, a researcher at AT&T’s Bell Labs in New Jersey, showed in an algorithm how a quantum computer theoretically could quickly find the factors of large numbers. Since the codes that protect military and financial secrets are based on the inability to do that, government money began flowing into quantum-computing research.¹⁴

There’s no agreement about the best way to build a quantum computer. Experiments by Isaac Chuang and Neil Gershenfeld at MIT and David Winland at NIST use atoms or charged ions in an electro-magnetic trap, while IBM is testing superconducting materials that can generate quantum bits. Researchers estimate it would take a quantum computer of 100,000 calculating atoms to perform work that’s beyond the reach of today’s most-powerful computers, such as breaking the 128-bit codes used in encrypted e-mail and other internet data in a reasonable amount of time.¹⁵

Qubits possess the strange properties of the sub-atomic realm, where electrons and photons appears to occupy more than one place at once and exist in indeterminate states. Quantum computing is difficult in part because those states exist at speed-of-light velocities, within unimaginably short distances, and at extremely low energy levels. Experiments at MIT and the National Institute of Standards and Technology are conducted at fractions of a degree above absolute zero, at which all molecular activity stops.¹⁶

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Mathematicians have proven that a quantum computer with thousands of atoms could find quickly the factors of numbers hundreds of digits long, a feat that would take *conventional supercomputers billions of years*.¹⁷ The most advanced quantum computers have not gone beyond manipulating more than seven qubits, meaning that they are still at the “1 + 1” stage.¹⁸

Quantum objects, such as electrons and other subatomic particles can be thought of as existing in multiple states simultaneously, ‘up’ as well as ‘down,’ ‘1’ as well as ‘0.’ This idea of existing in multiple states simultaneously is a property known as “*superposition*,” and opens the way to a completely different approach to computing. In this approach, one

quantum bit enables you to manipulate two values at the same time. As you string together more and more qubits, the power grows exponentially. If you link two qubits together, you can work with four values at the same time. Three qubits can work with eight values, and so on. If you can get up to 40 qubits, you could work with *more than a trillion values simultaneously*.¹⁹

Essential for quantum computing is a bizarre characteristic called *entanglement*. Two quantum objects can be linked together so that if you observe the result of an interaction with one of the objects, you can figure out what the state of the other object is as well. The entanglement holds even if the two objects are *widely separated*. This makes possible an “action-at-a-distance” phenomenon often called *quantum teleportation*—a term that often leads people to think of “Star Trek” transporters. In reality, what’s being teleported is information about a quantum object, not the object itself. Two people could encode information, trade it back and forth, and reconstruct the information using entangled quantum systems. Even if eavesdroppers intercept the coded information, they couldn’t read the message because they wouldn’t be part of the entangled system.²⁰

Researchers at the Los Alamos National Laboratory have demonstrated a quantum cryptography scheme that works over 30 miles of optical fiber.²¹ Gary Fitzmire, an employee of Boeing, has been pursuing the possibilities of Quantum computing. “When we want to send data wirelessly from an F-18 or AWAC’s [Radar-surveillance plane], we think there’s some promise inside quantum computing to boost our information assurance,” Fitzmire says. “We don’t want these signals jammed or eavesdropped on.”²² Peter Shor, an award-winning mathematician at AT&T Labs, says it may be possible to develop a 30-qubit computer within the next decade—but that would be just the start. It would take hundreds or thousands of networked qubits to solve problems beyond the capability of classical computers.²³

Quantum information has a tendency to “leak” into the outside environment, in a process known as decoherence. Thus, the quantum system has to be isolated from outside influence as much as possible. Quantum operations are inherently “noisy.” How do you correct for errors? It turns out that you can adapt classical error-correcting techniques to quantum systems to make them fault-tolerant.²⁴ You can see that there are a lot of possibilities in the quantum information area. There is also still much work that needs to be done in order to see if a Quantum Computer would even be a reasonable option to pursue further.

RFID

I decided to include RFID in my talk as an introduction to a technology that is currently being implemented. The pedaflop computer is a down-

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the-road possibility. The Quantum computer is an idea that needs to be explored to determine if it is even a viable alternative and whether additional research is a good idea.

RFID is the acronym meaning radio frequency identification. It refers to the technology that uses devices attached to objects that transmit data to an RFID receiver. These devices can be large pieces of hardware the size of a small book like those attached to ocean containers or very small devices inserted into a label on a package. RFID has advantages over bar codes such as the ability to hold more data, the ability to change the stored data as processing occurs, does not require line-of-sight to transfer data, and is very effective in harsh environments where bar code labels won't work.

A typical RFID system consists of a tag, a reader, and some sort of data processing equipment, such as a computer. The reader sends a request for identification information to the tag. The tag responds with the respective information, which the reader then forwards to the data processing device. The tag and reader communicate with one another over an RF channel. In some systems, the link between the reader and the computer is wireless.

Only a small number of consumers are aware of radio-frequency identification technology, even after privacy groups have raised questions about its use. A survey of 1,000 consumers by Capgemini Group and the National Retail Federation found that 77 percent were not familiar with RFID. Of those that were, 42 percent had a favorable impression of the technology and 31 percent had no opinion. Still companies such as Procter & Gamble aren't taking chances, "We realize RFID is a concern for consumers," said Sandy Hughes, P&G's global privacy executive last week at the Federal Trade Commission's RFID Forum. P&G is pledging to treat all RFID data the same as it does other customer data.²⁵ Let me give you some examples of its use:

Misrouted baggage costs Delta Air Lines about \$100 million per year—enough for the company to allocate \$25 million to automate much of its baggage-tracking functions with radio-frequency ID tags by 2007. The tags will be embedded in the luggage labels the airline uses to identify a bag's origin and destination. The labels will be scanned during check-in, loading, and unloading, giving supervisors the ability to quickly find any given piece of luggage. The passive tags it plans to use cost about 25 cents each, but Delta expects that price to drop to about 5 cents by the time it's ready to implement the project.²⁶

Radio-frequency identification devices in toll lanes are part of a system that will be transforming life in California. Millions of commuters are using the E-ZPass services. Cars can zip through the toll booths. Information from their E-ZPass tag is sent to a receiver that, in turn,

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charges that individual's account for the amount of the toll. People, however, may sometimes forget that their movements are recorded by the radio-frequency identification tags on their windshields. Authorities can get that data with a court order—and solve crimes. The FastTrak system monitors vehicles as they travel through the region. Overhead detectors log the location and time of FastTrak tags on passing vehicles. The data is encrypted to protect it from hackers, and fed into a centralized computer system. The information helps keep traffic flowing and is used to update real-time maps on the Web. An important safety use of RFID tags is likely to be on tires. After faulty Firestone tires were tied to dozens of accidents, regulators are developing a plan to require soft-tire warning systems on future vehicles. RFID based systems could alert drivers about underinflation. By giving each tire its own radio signature, the tags might also be useful in the event of a recall.²⁷

Just a few weeks ago the 108th Boston Marathon was run. Race organizers wanted a way to track and accurately time individual runners, as well as share their place on the course with spectators. HP's solution was to tie radio frequency identification chips into the shoelaces of registered runners. Each chip contains a unique ID assigned to that a person, and when he or she runs over special RFID-receiving mats on the raceway, the system logs the runner's location into a database. With that information organizers can track the progress of racers and, by comparing the time difference between when they hit various mats, estimate their speed and predict when they'll finish.²⁸

HP makes that information available in several ways—to organizers and the press on-site, and also to friends and family. On the course, 75 volunteers armed with wirelessly connected iPaq PDAs can answer questions and provide location information to spectators. The service proved to be very popular. More than 180,000 alert messages were sent this year, and the Web site served up more than seven million page views during the race. "We didn't have any major issues, and the Web site worked flawlessly," said officials of this race.²⁹

The first part of May, Wal-Mart stores Inc. and eight manufactures began shipping and receiving a limited number of cases and pallets tagged with RFID labels, marking the first real-world implementation in Wal-Mart's RFID trials. The trial—involving Gillette, Hewlett-Packard, Johnson & Johnson, Kimberly-Clark, Kraft Foods, Nestle Purina PetCare, Proctor & Gamble, and Unilever—is a step toward Wal-Mart's requirement that top suppliers have RFID tags on cases and pallets by January 1. It involves just 21 of more than 100,000 products carried in a typical Wal-Mart Supercenter. Tagged pallets are being delivered to Wal-Mart's Sanger, Texas, distribution center, where RFID readers at the

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dock doors scan tags and alert Wal-Mart teams and the suppliers that the shipments arrived.³⁰

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Though the Wal-Mart trial focuses on pallets and cases, there will be some individually tagged products. By the end of the year, HP expects to use RFID tags on 80 to 85 percent of its cases and pallets bound for retail sale. The most pervasive challenge is reading tags accurately. “It seems like read rates [on average] are close to 70 or 75 percent. Wal-Mart is working to improve read rates, having run into problems with liquid and metal products, says Simon Langford, manager of its RFID strategy.³¹

HP gets 100 percent accurate reads on cases and pallets, but the company had to change how it puts pallets together to achieve that. Accuracy is more difficult when tagging individual items. Readings on ink-jet cartridges were often inaccurate because the liquid inside absorbs RF signals and metal on the cartridges can short out RFID readers. HP solved that problem by putting a material between the cartridge and the tag. Colorpoint LLC, a \$7 million-a-year greenhouse that supplies Lowe’s, CosCo, and Sam’s Club, has 99.5 to 99.75 percent accuracy, up from 75 percent last year. The company solved some problems by replacing shipping-and-receiving dock readers—eight times. It also needed new tuning equipment to define the radio frequencies. The multiple readers in the warehouse disrupted each other when two or more tried to send signals simultaneously.”³²

Boeing Co. and Airbus S.A.S., the world’s largest airplane makers, plan to require more than 2,000 of their suppliers to begin tagging aircraft and engine parts with radio-frequency identification technology by this time next year.³³

These are just a few ways that the RFID tags are being used. Businesses are finding that they can be more accurate, handle materials faster, cut costs, and please customers. The tags are expediting the supply chain and helping to tie businesses and suppliers closer together. Customers will also be a big part of this chain soon. Individuals will be able to enter the store, pick up the items and products they want, and swipe their card as they leave—there will be no need to individually scan or itemize products. As a person leaves the store, the tags will send product information to the computer, which will tie the products taken to that person’s account.

SUMMARY

Technology is making life easier and safer, but at what cost? New tools of the digital age add to our convenience, efficiency, and instant gratification, but there’s a trade-off: The more progress we achieve, the more of ourselves we expose. Wherever we go now and whatever we do, someone—or something—is probably watching. One of the biggest

privacy issues may be how much of the data gathered is available to third parties.

People love the convenience and ease new technology brings. They don't seem to mind that money can be automatically deducted from their account for toll booths and speeding tickets. They don't seem to mind that they can be followed to work through traffic, but they don't want others to know that at night they might drive to a strip club.

During these few minutes, I've really only talked about three possibilities to consider in the computers of the future—petaflop speed, quantum computers, and RFID. In the near future, RFID tags are going to eventually impact every one of us. Many suppliers and retail stores are attempting to set-up and follow standards that will allow them to track every item they handle from its inception to manufacturer, retailer, and eventually to the customer. Within the next few years this technology will be firmly in place.

In the next two to ten years, we will see computers working at petaflop speeds and adding capabilities to do things that were never possible before. Even further down the road—in the next 10-20 years, there is the possibility that Quantum computing will become available and developed to the point where there will be a major shift in how information is handled. ∞

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