5 *Big Plans*

Hey, pal, how do I get to town from here?

And he said—
Well, just take a right where they're gonna build that new shopping mall,
go straight past where they're gonna put in the freeway,
and take a left at what's gonna be the new sports center,
and keep going till you hit the place where they're thinking of building that drive-in bank—
—you can't miss it.

And I said, this must be the place. [1]

Like Laurie Anderson's protagonist in "Big Science," we are so obsessed by our big plans for the future that we can hardly communicate in terms of the present. We are fascinated with digital technology. Imagine—a machine can be made to do almost anything! The systems we can build with this! A hardware engineer now graduating from college may *never* build a machine without a microprocessor in it. We are ambitious.

But projects absorb more resources than expected, and the systems we build will not always work. Sometimes a lot is at stake when they don't.

Introducing new systems introduces social risks, even if the technology does its job with well-oiled precision, as the expression used to go in a mechanical world. New technologies do not spring fully formed into a vacuum. Every system we propose will change aspects of society we have taken for granted for centuries. We might want to stop and think about this first:

- Seeing may mean believing even less than it does now. Digital video means that videotape will be easy to fake, for example. How much further can we undermine direct experience before we drive ourselves nuts?
- We are already losing our private lives. Our whereabouts, our habits, our pleasures and our problems are increasingly matters of public record. How far do we want this to go?

- Society may fragment further: human contact may no longer be needed to satisfy an increasing number of human needs. We will all have different experiences. We will be able to assume little common knowledge.
- Computers may be delegated some seriously inappropriate jobs: standing vigil over prisoners, caring for the old and sick, making life-and-death decisions in hospitals. Do we really want to end our days being tended by a program in an understaffed nursing home?
- Mechanisms by which we have for years regulated ownership and copyright will have to undergo significant changes. No one is quite sure how to set up a system of incentives that will sustain the production of new books, programs, or even works of art.

And that's if things go the way they should. But accidents will happen, and then we face graver risks. The failure of some of these systems could have serious consequences. What if a robot surgeon slices someone in the wrong place before a human surgeon can stop it? When cars on a rush-hour freeway are under central computer control, a computer failure could wipe out as many people in a freeway accident as might ordinarily die in a jet crash. With commercial air traffic likewise under central computer control, the failure of an air traffic control computer could involve as many jets as a freeway accident involves cars. Companies could go bankrupt because of the silent failure of information management systems. We could watch the disappearance of coastal lands all over the world because an overly simplified computer model led to a disastrous decision about permissible atmospheric carbon dioxide levels.

We really ought to discuss all of this first. Trouble is, events move at incredible speed in this field, and it's hard to pin down a moving target. But we may as well try.

We hear a lot about the benefits of proposed systems, and many of them are beneficial, certainly. But we seldom hear what we are risking or get an accurate picture of the cost. Public discussion tends to be sparse and one-sided, often dominated by those thrilled to breathlessness by the thought of building these systems, or collecting the profits from them. They tend to describe benefits in glowing, unrealistic terms.

Some of these systems will indeed bring benefits—digital technology has some impressive strengths. But some of these systems are not worth building. They will be ruinously expensive and the risks will outweigh the benefits.

The number and variety of proposals put forward in recent years is stunning, but society's resources are finite. Let's evaluate them first, instead of committing resources on the basis of who's waving the best flags. We can't build them all.

You may wish to read the following discussion in the spirit of a game called Find That Risk.[2] I hope you don't find it unrelievedly gloomy. But I say, enough with the "gee-whiz" already.

Information in Digital Form

When we put a microprocessor into a machine, we have decided to digitize the information that machine deals with. What are the consequences of this decision?

No matter what it represents, all digital information has certain characteristics in common. It is all equivalent and interchangeable zeroes and ones as far as the machines are concerned. This can be handy or amusing or a pain. Interchangeability fosters integration of systems: a number of different microprocessor-based machines can be connected into one big integrated system. Integrated systems have artistic, psychological, and social ramifications that have as yet to be appreciated.

Digital information is easy to spread, copy, and change. Computers connected in a network can exchange information constantly. A modem opens the network to other modems. It is easy to access information and hard to restrict such access. This can be good or bad, depending on the situation. A ride-sharing bulletin board, traffic information system, or online professional discussion benefits from the nearly effortless and instantaneous way digital information can spread. Other applications present problems for privacy, individuality, copyright, and ownership.

Digital information is nearly as easy to modify as it is to copy. Anyone knows this who has spent hours tinkering with a report or spreadsheet or picture. It is hard to detect traces of the modifications, though—which can have psychological or legal consequences.

Easy to Access: Disseminating Information

As faxes and email have shown, one of the things that computers do best is disseminate information quickly. This isn't always a good thing, but often it is. For example, sometimes information disseminated in traditional ways travels too slowly; a research report that might save lives can take up to a year to make it into a medical journal. So we now have "The Online Journal of Current Clinical Trials," jointly published by the American Association for the Advancement of Science and the Online Computer Library Center. The first medical journal in electronic form uses computers, modems, and phone lines to send information about cancer, heart disease, and AIDS research to subscribers all over the world. Information will arrive months sooner than it used to—a clear boon.[3]

Spreading traffic information has clear benefits, too. If drivers can get frequent, updated traffic reports, they can then plan their trips to avoid the congestion. Such negative feedback introduced into the system stabilizes it. Broadcasting such information is cheap, so why not? Sensors built into the roads themselves allow such systems to be automated: the city of Chicago broadcasts automated traffic reports on AM radio based on information received from sensors beneath the asphalt. The traffic reports are updated every ten minutes, interspersed with a tape recording detailing construction projects or other events that affect traffic flow.[4]

This relatively simple system has one fascinating characteristic: it fails utterly at the worst possible time, and it is still better to have it than not. When traffic is at an absolute standstill, no cars travel over the sensors. The computer detects nothing and reports no traffic. But the worst case doesn't occur very often, and when it does, common sense might tell those familiar with this quirk that the main expressway out of town is unlikely to be empty at 5:00 P.M. on a Friday before a holiday weekend. The Chicago traffic information system practically defines a benign system: its worst failure has no consequences worse than its absence.

Traffic information systems are being developed or deployed in many cities that experience chronic traffic jams. In London a driver can subscribe to a system called Trafficmaster. For about $33 a month, the system displays traffic snarls on an electronic map. A network of radio transmitters is being expanded in Berlin to provide a similar function.[5] And traffic information systems are part of a comprehensive solution proposed for the Los Angeles area.[6]

Traffic will continue to be a problem, however, as long as everyone insists on driving him- or herself everywhere. Systems that might get some cars off the road might be more helpful. In recognition of this, a network for spur-of-the-moment ride-sharing has also been planned for the Los Angeles area. It's supposed to decrease the number of cars in a downtown area. A network of terminals linked to a central computer can pair drivers and riders at a moment's notice, providing an incentive for people to leave their cars home, where they needn't pay for parking. The trip-planning computer would allow a carless individual to dial up and get the bus schedule or request a ride from a driver going in the same direction. Such a system might decrease traffic congestion and promote social cohesion in many cities, but I find it an odd system for Los Angeles. I suspect it would work better somewhere with a higher level of trust and a lower level of private gun ownership than the Los Angeles area has at present.

Anyway, a high-tech approach to ride-sharing is unnecessary. For example, in the San Francisco area, a lot of commuters are to be found at the east end of the Oakland Bay Bridge every morning, where they catch rides with drivers wishing to travel in the faster, carpool-only lanes into the city. In the evening, they are at the west end, helping drivers leave faster. The hitchhikers improve their chances by placing themselves near the incentive—the carpool-only lane—and also by allowing themselves to be looked at, thus allowing drivers to make their own risk assessments.

Easy to Copy: Some Thoughts on Handwriting

In spite of all the recent hype about multimedia (using voice recordings to annotate documents, playing video and music in windows, and such stuff), text and numbers are still the main reasons we use personal computers. They're still the main problems as well. A lot of people don't like typing; some of us like to write with a pen. Pen-based computing is on its way; close to a dozen different companies have announced offerings. Personal computing may now become accessible to the keyboard-averse.

To use a pen-based computer, you hold an input device made to feel and act like a pen. You place the pen against the screen (the "paper") and write. Your writing appears on the screen. The result of this used to be just a pattern of pixels, meaningless to the computer, but pen-based computers will be able to interpret your loop-and-stick as the letter d and your loop-and-curve as the letter g. They will convert handwriting to ASCII,[7] the representation of text that most computers use today. This will be handy.

Even without a pen-based computer, you can design a typeface that looks just like your handwriting and use it on your present PC. For about a hundred dollars, you can pay someone else to do it.[8] However, digitizing your handwriting exposes you to fraud. You are giving anyone who can use your computer the ability to print out documents that look as if you wrote them. That may be fine. Then again, it may not—digitizing your signature makes it easy for others to get, keep, and use. What can a fax with your signature commit you to?

You don't even have to own a computer to get into this kind of trouble. If you've received a UPS package lately, you probably signed your name with a computer "pen" on a liquid-crystal display. A digitized copy of your signature now reposes in the UPS database forevermore, available to anyone who wants it badly enough to break into their system.

Soon signatures will no longer mean what for centuries we have assumed that they mean. How are we going to replace them? There are other ways to indicate consent to a contract. The Japanese use *hanko*, for example. Due to the characteristics of their writing system, Japanese signatures are not necessarily idiosyncratic. So they buy specially made stamps showing the Chinese ideographs of a name carved in a unique way. *Hanko* can be forged or stolen, and might not work well for us. What would?

Easy to Modify: Undermining Direct Experience

In popular parlance, trusting your senses is tantamount to sanity. Our senses evolved to enable us to perceive the world, and the effects of millennia of evolution are powerful—people are swayed by the evidence of their senses. We used to be able to believe what we saw, but photography, film, and especially television have undermined our faith in direct experience. The consequences for our hearts and minds have yet to be appreciated.[9] To this modern problem, digital technology adds a whole new dimension—digital media is easy to alter convincingly.[10] Once photographs, documents, or videotape are commonly kept in digital form, the ease with which they can be altered is likely to further undermine direct experience.

The plasticity of digital media is terrific for artists. Ted Turner's portrait on the cover of *Time* (he was *Time*'s "Man of the Year" for 1991, his head surrounded by a globe made up of television images) consisted of forty-four exposures combined with a computer.[11] The photographer, Greg Heisler, handed an electronic cassette to his client, not a print or a slide.[12] Computer imaging has a lot to offer professional photographers, and they are aware of both the potential and the risks. One photo lab that produces images using digital technology clearly labels them: "Electronic image manipulation by Meteor Photo."[13] That's laudable and good for business, too, but not everyone is going to be so scrupulous.

Altering data can be done without leaving a trace. It can be just like telling a lie, only harder to detect. A child who was never in Ohio can be placed there in a picture, with the rich October evening light falling on her just as it falls on the others. Or a man who *was* there can be deleted, and the pattern of the chairs or the leaves or the sky in the background can be filled in just as the camera would have recorded it in his absence. Film or video can be modified in the same manner; it just takes longer and costs more. Pretty soon, a videotape such as the one showing the Los Angeles police beating Rodney King will no longer be admissible as evidence in a courtroom. It will be too easy to fake, and too hard to detect the fraud. In a few short years, videotapes may go from being the most persuasive possible evidence to the least persuasive, as access to digital video editing equipment spreads.

Sounds, too, can be snatched, stored, sliced, replayed. Timbre can be altered, an ordinary voice can sound spacey or spooky, speech rhythms can be changed, an everyday phrase can be made to sound ominous. It is easy to produce a tape recording of your voice saying something you never said.

If Stalin had commanded this technology, what couldn't he have done with it?

Easy to Access, Copy, and Modify: Copyright Problems

So far, it isn't falsification that's caused legal trouble, though—it's art. Digital sampling has already prompted one copyright infringement case. Snatches of previously recorded music can easily be woven into new music using digital sampling technology. The music thus produced is like a collage containing snippets of photographs, such as the *Time* cover discussed above. This is just the sort of thing that artists love to play with, but rap artist Biz Markie had to go to court for it. His album *I Need a Haircut* was pulled from stores after a judge ruled he should not have sampled a snippet from Gilbert O'Sullivan's 1972 paean to self-pity, "Alone Again (Naturally)."[14]

This ruling is easier to enforce than the license to use only one copy of a software program: organizations such as EMI Music Publishing now pay people to listen to records and detect samples so that clearance is paid for. For the moment, therefore, the ruling has had an inhibiting effect on digital sampling in music.

It's too bad. Michael Green's quirky book *Zen & the Art of the Macintosh* shows that a more open attitude is possible. The book is about Michael Green, a graphic designer who falls in love with his computer while producing the book. The pages get wilder and wilder. Each is beautiful. At the back of the book, Green talks about the hardware and software and techniques he used to do it. Then he writes "On the philosophy of Digitizing:"

> Digitizing captures an *idea*. And when you finish playing around with it, what you have (if it's still recognizable) is an *homage* rather than a rip-off. In keeping with this, let me go on record as saying *anyone who wishes to digitize any of the images in this book is welcome to do so*. May a hundred flowers bloom! emphasis his][15]

Data in digital form has real advantages. You can hunt for phrases, jumping around with more freedom than is provided by a table of contents or index. These advantages lead people to proclaim that some day, all the world's data will be stored on compact disc. But how will it get there? Who is going to volunteer to type in the Library of Congress?

As it happens, some people are signing up to do it, one book at a time. Michael Hart, a systems analyst and zealot in Urbana, Illinois, has been typing since 1971. About forty volunteers have been helping him for a while now. The goal of Project Gutenberg, as he has dubbed the enterprise, is ten thousand books in digital form by the year 2001. What Mr. Hart yearns for is a world in which you enter the library with a blank diskette and leave with a diskette containing the books that you want. You would not have to return anything. You might not even have to go anywhere; the "library" could be a computer that you dial up with a modem.[16]

Project Gutenberg avoids the difficult issue of copyright by scrupulously typing in only books in the public domain. Heaven knows those are many, but it's only a matter of time before the issue has to be faced. If you can go to the library and walk off with a book on a diskette that you will never have to return, then who will buy a book at a bookstore? And if no one buys books anymore, what incentives will authors and publishers have to produce new ones?

Digital media thus has the potential to break the economic mechanism that produces books. The music industry has been facing this problem since it went digital: technology enables anyone to make a perfect, crystalline copy of a digitally recorded compact disc. Musicians, music publishers, and record labels have fought for laws to keep digital cassette tape recorders out of people's homes, fearing the economic effects of widespread, perfect, homemade copies. The advantages of the technology for recording were undeniable. So the music industry identified a choke point—the easy availability of digital tape recorders to home consumers. It halted production of the machines until an economic remedy and a technological fix could be introduced into the system: royalty fees were built into the cost of the machines and their tapes, and the machines themselves will be artificially limited to produce only first-generation copies.[17] The music industry picked the right moment to fight the technology. After the machines became commonly available to consumers, the music business would never have been the same. Print publishers will be facing this issue soon, and it is unclear what approach will best serve everyone's needs.[18]

Because information in digital form is easy to alter as well as to copy, other problems crop up—problems similar to those that software developers must grapple with. When programmers write software, they use a word processor to write lines of instruction in a programming language such as C or FORTRAN or BASIC. The file they create this way is called *source code*. They take the source code file and run it through a compiler, and the compiler spits out a file called an *executable file* (because the processor executes it). Most software is sold as executable files. Programmers do not like to sell source code because it can be read and modified, albeit with difficulty. This puts the vendor in an impossible position. If a bug is found, whose bug is it? Who should be responsible for fixing it? What happens if the vendor releases an update with new features, and one of the new features collides with one of the custom modifications? It opens the door to endless problems, which most vendors avoid by selling only executable files.

A book is both source and executable; it is source when it sits on the shelf, and it is "executed" when you read it, and the author's mind speaks to yours. If books are distributed on digital media, we risk breaking the link between the mind of the author and the reader. What is to prevent someone from giving *King Lear* a happy ending, or slipping a pornographic passage into the *Book of Mormon*? Forty subtly different versions of *Moby Dick* will circulate. How are we going to tell which is the original? Will we support a bureaucracy to certify books?

Interchangeable: The StereoVideoFaxPhonePC and HouseController

As a child, I went to the 1964 New York World's Fair and stood in a long, long line to use the world's first picture phone. I had plenty of time to consider that the neighbors I was calling did not also have a picture phone, but it didn't occur to me. I was disappointed to sit in the futuristic, egg-shaped booth and only hear voices, just as always. Soon after, AT&T put the picture phone on the shelf: it was difficult to install and cost $9 per minute in 1964 dollars.[19]

It's now the early 1990s, and the long-awaited picture phone is here at last. The interchangeability of digital data means you can send pictures down the telephone wires along with sound. You can also send video or weather maps or medical Xrays; it's all just ones and zeroes to the computer. You can put a little television tube into the phone. You can put a computer in there, too. You can put a computer in the television. (A television is already part of the computer—it's the screen.) Some computers have built-in modems. Some modems have built-in fax machines. Why have separate machines? Why not just have one ultimate all-purpose machine to do it all?[20]

With this mythological computer, you could send a fax, talk to a friend, do your word processing, listen to music, watch television, look at the pictures you took of last year's summer vacation, and record any of it. Consumer electronics are going to change.[21], [22]

And grow. We can take the all-in-one computer and tie it to every appliance with a microprocessor. Then you can teach your house to run itself; a few prototypes have already been built.[23] A so-called "smart" house (I think we should ban this use of the word "smart" before we're sorry) could save energy and keep down utility bills. It could wake you up if it detected smoke, intruders, or a noise in the baby's room. No harm in this when it works, unless you count as "harm" becoming too lazy to turn off the lights when leaving a room.

Science fiction stories about smart houses have often focused, for some Freudian reason, on the problem of a house that is too motherly or overbearing. The scenario usually goes something like this:

HOUSE :	You'd better wear your boots, it's raining outside.
GROWN MAN:	Open the door, I'm in a hurry.
HOUSE:	Not until you put on your boots.
MAN:	Grrrr!

If you take those scenarios seriously, you might ensure that your integrated house control system has no voice. A more likely problem, though, is a flaw in the house controller that causes bizarre interactions between various subsystems. Integrated systems can be quite complex, because many different kinds of interactions among the components are possible. The bugs could be interesting: using the garage-door opener might turn the dishwasher off. Clever software might allow a broken house controller to call a repair technician. What if it called spuriously? What if it dialed the wrong number? Repeatedly? Integrated systems are complex; they can be challenging to troubleshoot. Repair technicians will need quite an education. Their services will probably not come any cheaper.

But suppose it all works just as it should. Cocooning goes electronic. We watch movies at home with the VCR, we use the home shopping network, we pay bills by phone, we work from home with our modems, we satisfy our needs for companionship with computer bulletin boards. Want interaction? Thanks to any of several proposed technologies, you will soon be able to interact with your television set. Play along with the game show. Request the special $2-off pizza coupon (probably in exchange for having your name and address enter yet another database under the labels "pizza-eater" and "Friday-night-TV-watcher"). Live like Vashti, the heroine of E.M. Forster's story "The Machine Stops," cozy in a little cell, horrified at the thought of actual face-to-face contact. That's one way to cope with urban overcrowding.

Okay, I'll lighten up. Data interchangeability also opens the door to new art forms. Imagine dialing up the library, downloading Shakespeare's sonnets, and reading the resulting file into a program that generates music. The program takes the ASCII character codes for the text and interprets them as musical notes instead, thus creating a "melody" (it is sure to sound weird, especially at first) to go along with the poetry. The human talent for perceiving patterns being what it is, at least one of those sonnets will end up with a song that some critic will describe as "haunting and fraught with significance."[24] Then someone will take a video recording of a conversation with Aunt Maeve and run the audio through the music program and the video through a color graphics program, and the fun will really begin.

An Unexpected Bonus: Digital X-Rays

Sometimes the effect of digitizing information can be hard to predict, because the particular characteristics of the system using it can make a big difference. For instance, digital technology improves dental Xrays. Dentists can place an electronic sensor inside your mouth and see the resulting image only seconds later on a video screen. The images are detailed and magnified, enhancing the dentist's diagnostic abilities. Your exposure to radiation is reduced by 90 percent.[25]

And the bill goes up: the new technology costs about five times as much as the old. There's no such thing as a free lunch.

Moving Lots of Information Fast

These consumer electronics toys presume the ability to move a lot of information—voice, pictures, books, shows, music, and more—all over the world, very fast. Conventional copper-based telephone cable is not up to the job. *That* will require fiber optic cable, which can carry a vastly greater amount of information. In the

United States, plans for the Integrated Service Digital Network (ISDN) call for building the data equivalent of the interstate freeway system. After the telephone companies, cable companies, utilities, and government finish squabbling over who gets to build this fiber optic network, homes and businesses will be linked in an ambitious communications infrastructure that makes what cable companies have done to connect city-dwellers look paltry by comparison.[26] Our present system trickles data to us, and ISDN will be a firehose.

But as we've seen before, advantages and weaknesses go together. When ISDN is a boon to every household, *a lot* of services will be disrupted when one backhoe operator has a bad day.

The ability to send huge amounts of data quickly over the phone lines allows new sorts of information to be sent, such as X-rays or other medical images (those taken with magnetic resonance imaging technology, for example).[27] It is undeniably safer to move the image than the patient under certain circumstances. If we grow to depend on this technology, will we concentrate the required facilities into fewer and fewer big-city hospitals? When the phone lines go down again, what then? Like so many other things, it's a tradeoff. Which risk is worse?

A subtler risk is the possibility of missing some critical detail in the process of digitizing the image. Unlike analog images, which consist of details smoothly shading into each other, digital images are of a finite resolution—the picture, like a newspaper photograph, consists of only so many tiny dots per millimeter. What if, in the process of turning the data into these dots, a tiny but critical detail happens to fall into the cracks between dots, and is thus not visible in the digitized image?

Compressing digitized data poses another risk. Compressed data can be transmitted faster. Using compression schemes, telephone companies now bundle many telephone conversations and send them across the country together. If the compression scheme used causes a small problem here and there, it's no big deal: human language is so redundant that speakers are likely never to notice.[28] Compressing and decompressing medical images, however, could be riskier, as altering even the smallest detail could affect diagnosis and treatment.

ISDN's huge increase in capacity erases the distinction between broadcast and cablecast television.[29] Instead of watching or taping shows when they're broadcast, you will be able to choose from a menu of offerings at any time. Dial up a film library and download the movie you want to watch. Get a news broadcast tailored to your own local area—this may encourage people to learn more about local problems on which they could actually have an impact. Tailor the news to suit yourself. Get a deeper look at a story that interests you. But don't take it for granted that you and your neighbors share much common knowledge when you tackle those local problems you are now eager to solve.

Interactive television news permits people to retain pristine ignorance about any aspect of the world they decide not to care about. Sports junkies can forget that international politics exists until a war converts their country into a team they can root for. Bigots can choose to ignore all news coming from communities they disapprove of. Will this augment the already frightening fragmentation of society?

Utility companies are developing meters that send information on utility usage from the consumer's home or business to the utility company's computers. This information can be used to decrease the need for new power plants by allowing more sensitive projections of demand. Of course, the same lines that send information out can send it back. For a small rebate on your electric bill, would you sign up for a service that would turn off your hot water heater at times of peak power demand? Would you pay for a service that would turn off all but essential appliances when you were gone on vacation?

This has privacy ramifications as well:[30]

> Once an intelligent meter is linked via sensors to home appliances, "we're going to know every time someone in the house turns on a toaster or an egg-beater," Mr. Weinberg [manager of research and development at Pacific Gas & Electric Co. in San Francisco] says. "Market-research guys would love that information. We have to be very careful or we'll look like Big Brother."

InfoMarket

The champion Orwellian technology, though, is the information market. It's no longer news that, as we go through life using credit cards and ATM machines and checks and medical insurance and car insurance and driver's licenses and marriage licenses and mortgages and mail-order catalogues and airline reservations and rental cars and even supermarket coupons, we leave a trail of electronic bread crumbs for credit agencies and direct-mail marketing organizations. Our electronic personae grow more well-rounded daily. Given the extensive amount of data that is available electronically about each of us, some people fear we will lose our privacy, or have already done so.[31]

Data as a Commodity

Some data is collected for us for purposes we choose. Our names are in the database of the Department of Motor Vehicles because we want to own a car and drive. If we take a class, our academic transcripts are kept to determine our eligibility for a degree. In order to care for us properly, health care providers keep records of our medical histories, and pharmacists keep records of our prescriptions.

This system has been in place for decades, originating in a time of paper records. The responsibilities of each party are clearly defined: the data subject wishes to purchase a service (electricity, vehicle ownership); the agency declares a need for certain of the subject's data; the subject provides the data. Both parties need accurate data and assume certain responsibilities for maintaining its accuracy: the subject provides updates as necessary, and the agency acts on those updates. It is not a bad model; so far, it has worked for us.

Incentives and capabilities are distributed in quite another way with agencies, such as credit-reporting and direct-marketing organizations, that collect data on us for their own purposes. Data as a commodity is a relatively new phenomenon, and it's unique:

the producer does not own it; the collector—the agency—does. Yet errors in the data do not reduce the value of the commodity, nor otherwise harm the owner, because they are so difficult to detect. Instead, they harm the producer, the data subject. Correcting errors, however, benefits the data subject and costs the owner. The owner has little incentive to correct errors, and the data subject has little power to do so. As the residents of Norwich, Vermont, found out, it is not an ideal arrangement.

So far the data agencies have had it all their own way. Any information they could wheedle or trick people into revealing was fair game. UPC bar codes, for example, can be used to determine your buying habits.[32] In one instance, a television commercial for an allergy-relief medication advertised a toll-free number that allergy sufferers could call for "a pollen count in your area." When called, the number used the newly implemented Caller ID feature of the phone system to capture the phone numbers of the callers. Various directories allowed the marketing organization that dreamed this up to get names and addresses from the phone numbers, thus obtaining a nice list of people who had telephones, televisions, and allergies.[33]

Scams like the allergy ad described above are not transactions that both parties agree to. They are not even transactions that both parties are aware of. The data subject is duped into giving something valuable away for next to nothing, and on top of that, allowing it to be used for purposes he or she may find objectionable.

Data collectors use, sell, or trade data like baseball cards. Data collecting agencies proliferate, and so do exchanges between the computers on which the databases reside. But these agencies have not been forward about assuming responsibility for the accuracy of their data. Inaccurate data can cause serious damage; people have been thrown in jail—and kept there—because keepers of databases have been unresponsive about correcting data they knew to be erroneous.[34] If data agencies cannot be trusted to use their property responsibly, people may soon demand to own their data themselves. It won't be easy to figure out how to structure such a system.

Risks to Privacy: Medical Records and DNA on File

Medical records are a special kind of data. They are kept for us and we pay for the service. They can be quite complex and heterogeneous—words, images, and probably audio and video someday soon. Most important, their privacy is privileged; they are nobody's business but our own and that of the professionals concerned.

At the moment, most medical records exist on paper, with the consequent problems of bulk, inconsistency, and unavailability familiar to almost anyone who has worked with vast quantities of information on paper. In response, the inevitable solution has been proposed: online medical records.[35] The chief obstacle to this proposal may be doctors themselves: they reportedly hate typing, and it is difficult to tell them what to do. In HMOs, doctors are mere employees, so a few HMOs are now trying online medical records.

The system is touted as solving a number of problems that it actually does not solve: the problem of missing information, for example. Yes, doctors sometimes forget to record the patient's age or chief complaint, or for that matter, their diagnosis. They can be just as forgetful with a computer as with pen and paper; whether they are or not depends on factors only marginally related to the media.

Information can be lost or unavailable because another specialist has the paper records, because someone mislaid them—or because the computer is down. Maybe the network is flaky. Maybe an upgrade scrambled the database. A well-designed online system might improve matters; it could certainly cut down on bulk. But it might not cut down on waste paper: if it is easy to push a button and print the patient's entire file, that is what people will do.

If the system turns out to be reliable and available, it may enhance communication between various specialists, several of whom may wish to view the same record while they discuss it over the phone. It could help patients who move and want doctors in their new towns to have immediate access to their records. But online systems pose problems for privacy and confidentiality. Computer systems are notoriously insecure and vulnerable to break-in. Sufficiently motivated, anyone will be able to read your medical files without the risk of physically breaking into your psychiatrist's office.

Your prescription records, in fact, have most likely already been scrutinized by a total stranger. Most doctors may not keep their records online yet, but many pharmacists do.[36] Pharmaceutical companies provide them with state-of-the-art computers and software to do so at nominal cost. The drug manufacturers are not exactly altruists; the systems include a modem and software for them to upload prescription records. In this way, drug companies learn which doctors prescribe their products and which prescribe their competitor's. They claim they delete patient names, but who is able to check? "In fact," says an article describing the situation, "certain data-collectors that pledge total confidentiality sell drug companies the age, sex—and an ID number—for individual patients." Other companies include patients' social security numbers.

Once again, the incentives seem distributed to ensure an unresponsive system. If your privacy has been breached, what can you do about it? If you sue, the whole world gets to hear your private concern.

Some proposed databases pose serious risks even without security breaches. Imagine a database holding your genetic information. Its mere existence changes the rules.[37]

Imagine the uses to which such data could be put. Health insurance companies could require screening for genetic diseases or predispositions to certain conditions before agreeing to insure you. *Everyone* has such genes. It would open the door to arbitrary decisions for which some might have no recourse. So far, U. S. health insurance companies have given us little reason to think they will be generous about extending benefits to the "unfit."[38]

DNA samples allow biologists to infer paternity. Under some circumstances, this is useful; under others, it can be disruptive. Lives of relative peace and contentment are not to be destroyed lightly. Who will decide when a paternity search is to be made? Who will have the power to block it?

How might this technology change the process of applying for a marriage license? Will both partners have to undergo a routine genetic screening? If both carry the same potentially lethal recessive gene, will their license be refused? Will it be granted only under the condition that one partner be sterilized? What if the gene isn't lethal, just undesirable?

The proposal for the DNA database comes from the United States Army, which wants to keep a database of genetic information on its soldiers in order to identify battle casualties. If you're geared for wholesale slaughter anyway, I suppose it's practical and humane to identify casualties quickly and surely. But what mechanisms can ensure against misusing this data? Let's think this through carefully before we pull the cork on this technology. This genie will be tough to rebottle.

Risks of Connectivity: BigBrotherNet

In July 1990, Thailand inaugurated a giant central database for the government to keep tabs on all 55 million Thai citizens, and the Smithsonian Institute gave them an award for it. No kidding. Each person receives a PIN and a computer-readable card. "The system will store date of birth, ancestral history, and family make-up and was designed to track voting patterns, domestic and foreign travel, and social welfare. Eventually 12,000 users, including law enforcement, will have access by network terminals."[39] For some reason, an official body of the U. S. government thinks this system is just great.

At almost the same time Thailand was implementing its National Big Brother Network, a debt collector in Australia proposed a functionally similar system:

> "Tomorrow's credit grantor will be extending credit in a perfect market with total knowledge of the debtor," Mr Owens [former president of the Institute of Mercantile Agents and head of a debt-collecting agency] asserted. "The credit grantor in the future will have access to all the debtor information. This will be made available through linked data bases in the manner of George Orwell's 1984."[40]

And Singapore seems to have adopted the master database as a national mascot. Everything in the country is going online, from building blueprints to property surveys to records on every citizen.[41] It's a trend, so no one should be surprised that some folks in the United States are also hearing the siren song of perfect information. Also in July 1990 (the summer of 1990 is beginning to sound dire), the U. S. Justice Department proposed spending $60 million to create a national drug intelligence center.[42] Although the attorney general attempted to calm the fears of such groups as the ACLU and Computer Professionals for Social Responsibility, saying "It's not 'Big Brother'" (a mandatory allusion for these discussions, I guess), he also mentioned that cooperating agencies would include the Customs Service, the Coast Guard, the Immigration and Naturalization Service, the FBI, and possibly the Defense Department. Sounds like quite a database.

The problem with such databases is not the information they store. All the information is already stored elsewhere, as proponents will point out. In fact, our present data system has some of the characteristics of a hologram: because it has so much redundancy, any small local failure allows virtually all data to be reconstructed—in theory. But in practice it requires effort and purpose to do so. Putting it all together changes the system characteristics; connectivity makes the system as a whole different from its parts. Having all the data about you in one place eliminates the effort needed to collect it. It's so easy, the system creates its own purposes. It allows a nimble human mind to notice patterns, infer, conjecture, extrapolate. So much information about an individual in one easily accessible place paints a detailed, comprehensive picture.

Proponents of such systems often argue: if you are doing nothing wrong, what do you have to fear? This puts the onus on individuals to explain why such data should *not* be kept. That is not where it belongs. Proponents need to explain to the rest of us why the data *should* be kept. No one wishes to live under scrutiny. Criminality is not the issue: the distinction between our private lives and our public personae is crucial for our sanity. Our privacy is as vital—and as fragile—as the fuzz on the wings of a butterfly.

Modeling the World in Bits

Anyone using a spreadsheet can now become an instant statistician. In its popular Excel spreadsheet program, Microsoft has included a facility it touts as "the ability to forecast trends."[43] The spreadsheet uses a specific sequence of instructions to make its forecast. Are these the instructions you would have used if you had done it by hand? Is the spreadsheet answering the question you are asking? How can you tell for sure? If the simple spreadsheet is going to get sophisticated, we had better be equally sophisticated in the way we interpret its results. Statistics can be dangerous in the wrong hands.

When statistics are incorporated into spreadsheets, the spreadsheet becomes a kind of computer model of some aspect of the world. Computer modeling takes myriad forms—for example, expert systems, simulations, database query systems, or virtual reality. All are a game of "what if." Users supply initial data, which is transformed according to the rules programmed. When NASA measured ozone levels in the 1970s and 1980s, for example, they measured them with software programmed to reject readings below a certain level. So the computer, unable to tell us what we wanted to hear, threw out the results and told us nothing. Computer models seem to show you something objective, but all the while you are looking in the mirror, your biases and preconceptions coloring the questions you ask and the way you perceive the answers. In order to use models intelligently, we have to understand this.

Computer models are necessarily limited. As digitized information, they require a finite resolution. Only so many characteristics can be considered, only so many details factored in, the result carried to only so many decimal places. Models may be crude or subtle but they are always cruder than infinitely complex reality, in which each detail enfolds seven or seventeen others, no matter how closely you look. When you model a phenomenon, you can only hope you have abstracted the essential information you need for a meaningful result. You won't always be right. And you won't always know if you were right or not.

It is pitiful when you hear of a company going bankrupt because its managers took the reports they were getting from their information systems as oracular pronouncements. Did they understand what their programmers were doing when they coded the system? Did they try to get any information from another source to see if the results reflected what was actually going on? Did they ask themselves if common sense supported the answers they were getting?

The computer is *not* an oracle; it doesn't know anything that we don't. Its value lies in being able to apply rules quickly and consistently to far more data than any human would have the patience for. If the results are going to be of any use, you must first ask, "How can I tell if I ought to believe this?" Depending on what you are modeling, the question can have economic, legal, political, psychological, or ethical ramifications.

Ethics of Expert Systems in Medicine

Expert systems represent an attempt to use a computer to store and apply the knowledge of an expert. They have been tried extensively in medicine, especially for diagnosis and prognosis. Expert systems for physicians have been developed to aid diagnoses of skin disease, blood disease,[44] bacterial infections,[45] and some forms of cancer. The tools can be useful, but they have glaring drawbacks. For one, they are constrained to view the world in terms of the narrow niche they know about. In the PBS special "The Thinking Machine," for example, artificial intelligence researcher Doug Lenat tells of describing his rusting 1980 Chevy to a skin disease diagnostic system for a lark. It concluded that the patient had measles,[46] and it hardly seems fair to laugh at the poor thing.

Such systems can also be difficult to maintain. To incorporate new knowledge about the causes or symptoms of a disease may require extensive rewriting and retesting—almost a brand new development effort each time.[47]

Medical personnel may find the tools useful anyway. Simple diagnostic systems have even been made available to patients directly.[48] In Bedford, Massachusetts, an experiment has put terminals in the homes of 150 health plan members with either chronic illnesses or young children. Patients dial up the database and type in symptoms. The system responds with questions; depending on the answers, the system either recommends a treatment or an appointment with the doctor. Reportedly, patients love it, and it is certainly easy to see the appeal to the HMO, which receives the same monthly fees whether doctors' time has been used or not. The wrong recommendation could lead to a lawsuit, of course. I suppose the issue can ultimately be dealt with—if we decide such a system is worth it, we just have to agree ahead of time to settle disputes another way.

Systems for prognosis are more problematic. Such systems draw on an extensive database to project the likelihood that a given treatment will help a patient, or they state the statistical probability (carried somehow to two decimal places) that a patient arriving in an intensive care unit will die. Tools such as these are helping doctors decide what treatment to offer or whether to withhold treatment. An editorial in the *Washington Post* focused on a system called APACHE used at a hospital in Michigan.[49]

Statistics, as we ought to know by now, are extremely easy to misunderstand and misuse.[50] As the editorial points out, "a person with a 95 percent chance of dying under a procedure is not the same thing as a person whom that procedure cannot help, or a person from whom care can be withheld with no compunctions."[51] Indeed, as one contributor to *comp.risks* has pointed out: "Even if [the] data is 100percent correct, it still leads to positive feedback which will further skew the output data."[52] That is, if a system advises a doctor to withhold treatment on the basis that a patient is unlikely to survive, the patient goes untreated and is therefore even less likely to survive. The system adds one more case with a negative outcome to its database and produces an even gloomier assessment next time.

Still other prognosis tools are used by governmental agencies who wish to measure the quality of care provided by specific hospitals. Hospital administrators now fear that bureaucrats will use the resulting information to pressure hospitals to "restructure" their care. In 1991, an article and accompanying editorial appeared in the *Journal of the American Medical Association* to assess the technology and discuss the associated problems.[53]

A fundamental problem with prognostic systems is that, as far as users are concerned, their pronouncements are opaque and mysterious. Many systems are proprietary, so users cannot know what operations are performed on the data they supply. Yet even small omissions or errors can have large repercussions for patients. The system examined in the JAMA article, for example, was found to have significant statistical biases in the one area the doctor was able to research thoroughly.

Even if the source code for the system is open to inspection, to assess such systems requires significant knowledge of complex statistical formulas. No standards require that such systems be safe and effective, as the magic FDA incantation has it, and it is practically impossible to test them rigorously and thoroughly. They are difficult to refine if they prove to be inaccurate, or when understanding of their domain deepens. And they could alter medical practice, just as schools sometimes react to standardized tests by altering the curriculum to "teach to the test." But a better score on such a system may bear only a vague relation, if any, to better care as perceived by doctors, patients, or patients' families. Computer-assisted triage may not be our best response to rising health-care costs.

Politics of Environmental Simulations

The scientific method is supposed to proceed by carefully comparing the results of controlled experiments. But sometimes it is impossible to perform a controlled experiment. In the absence of a duplicate planet, how can we understand the effects of humanity and its activities upon the earth? How can we untangle the factors that affect the atmosphere, its ozone layer and greenhouse gases, oceans, weather, and climate? Simulations offer the only way to experiment in these arenas.

We must research the questions, for we need the answers. But we don't have them yet. Climatologists cannot even get their models to predict what we know has already occurred. This understandably causes skepticism about predictions of the effect of greenhouse gases on global warming, a skepticism only exacerbated by the numbers of different predictions those models have so far produced.[54] At present, computer models provide a shaky basis for public policy, as little progress has been made on environmental questions.

Perhaps we are asking the wrong question. Perhaps we should take the hint and, for the moment at least, ask a humbler question: Given our ignorance, our present circumstances, and the high stakes, what is a prudent holding position?

Psychology of Simulations in Court

A report full of numbers is easier to view dispassionately than a video clip showing a car accident. Using computer graphics and animation, you can simulate accidents or other events and create cartoonlike videos to show juries during trials.[55] Computer animation is so expensive that it is used only in cases in which a lot of money is at stake. Truly lifelike computer animation is even more expensive, so simulations still look relatively crude. It will get cheaper, though. Before it does, let's consider the comparative effects on a jury of a page of numbers, a one-minute cartoon, and a five-minute re-creation of an accident complete with facial expressions and bright red blood.

In a news report on courtroom simulations, lawyers seemed embarrassingly frank about the benefits of entertaining the jury.[56] Said one, "75–80 percent of all the information people get is through television." Why buck a trend? Simulations can be valuable to a jury trying to understand a lot of complex material, but only if they are understood for what they are. They should be presented along with the assumptions that went into them and the rules used to transform those assumptions into the information shown. If this cannot be done clearly, they should be viewed with skepticism; without additional evidence, they are just another TV show.

Virtual Reality

Computers show us alternate worlds. They can show you what you'd look like with lilac hair, or what the kitchen would look like with a lilac breakfast nook, or what the bathroom would look like with lilac wallpaper, or what your yard would look like with lilac bushes.

Virtual reality is the most extreme form of the whatif game. As presently envisioned, *virtual reality* is a technology by which the user can enter the world the computer creates. Put on special glasses, and the computer projects its display in front of your eyes. Put on a special helmet, and the computer adjusts its display when you've turned your head. Earphones built into the helmet play sounds. A special glove permits the computer to distinguish your gestures. The computer can respond by moving you or some other object in the simulated environment. Eventually, a full body suit may allow you to move through a simulation normally; it could even include full sensory feedback (though I'm hard pressed to imagine the olfactory interface). This will require many more computations per second than we can presently achieve, but computations per second is one of those numbers that have been rising swiftly and steadily since the computer was invented.

Full virtual reality isn't always necessary, though. It might be nice to walk through your imaginary landscaped yard, but seeing it on a screen can give you a pretty good idea.[57]

Chemists and drug researchers need more than a two-dimensional picture of a molecule. To guess how it might interact with other molecules, they need to understand its three-dimensional structure. Remember those 3D movies in which you wore special glasses to see monsters floating out of the screen at you? A similar principle allows three-dimensional displays for computer-aided chemistry. The molecules appear to pop out of the screen; they can be rotated and made to interact with other molecules.[58] Virtual reality adds to this process, and researchers are presently using it to help them learn about new molecules and design new drugs. They claim the process is "revolutionary."[59]

Using virtual reality to help design buildings seems like another great idea. Before the building is built, you can walk through it, see what it will look like, feel how it will feel.[60] As long as the new technology is not used as a substitute for rigorous engineering analysis, it seems bound to save money and produce pleasanter buildings. In Tokyo, a showroom allows people to remodel their kitchens in virtual reality. Reportedly, this sells more kitchen renovations than traditional methods.[61] Maybe virtual reality is persuasive. Maybe clients have already invested a nontrivial sum just to get the demo. Maybe they design a kitchen they really want.

VPL Research, pioneers of virtual reality technology, have been exploring its uses in surgery, structural inspections, and financial analysis, too. Using virtual reality in surgery is particularly intriguing. With the aid of a virtual reality computer system, a surgeon in, say, Toronto might perform an operation on a patient in the remote Northwest Territories.

Obviously, this is going to be a safety-critical application; a bug could kill the patient. But what if the patient could not survive without the operation, nor could be physically moved to Toronto? What if the medical personnel at hand cannot save him or her unaided? Why not take the chance? What have we got to lose? Well, for one thing, the system is bound to be extremely costly, both to develop and to operate. Will it be available to the ordinary patient or to millionaires only? Is it reasonable to spend enormous sums on exotic technologies while millions lack access to basic medical care? Would it be cheaper to provide financial incentives for doctors to serve in remote areas instead?

The most accessible virtual reality applications so far, though, are just exciting, expensive shoot-'em-up games. Two video-arcade games are already on the market (at prices considerably steeper than a quarter), and more will follow soon.[62]

Where violence is, can sex be far behind? People have naturally been speculating about virtual pornography. With more computational power and a full body suit, high-tech masturbation may enable those who can afford it to hoist anchor and sail away forever from the frightening and forbidding Dark Continent of the opposite gender.

Tracking and Monitoring

Business travel is a pain, but sometimes it must be done. Armed with my key, I headed out to the car rental parking lot. The car was programmed to respond to the key—the display lit up with a map of the airport area. "Your motel reservation has been entered into my database," said the car, n a strange Scandinavian accent. "Would you like to check in now?"

"Later," I said, and told it my client's address.

The map zoomed out over the greater metropolitan area, panned north-northeast over the landscape, and zoomed in a bit to show the airport and my destination in one tightly framed rectangle. A red arrow painted itself along the route, scrupulously pausing at traffic lights. "Proceed to the exit and turn left," said the car. As I drove, the prepainted route faded to pink. I shifted my gaze between the road and the display, watching the red arrow which was now replaying the route for me in real time. I hate traveling on business, but at least I wasn't going to get lost.

Navigation

Okay, I freely admit the above is a fantasy—I'd get lost anyway. But maybe you wouldn't, and a navigation system in your car could come in handy, especially in a strange town.

If you lived in Japan, you might already have a car navigation system—over 400,000 people do.[63] The 1991 Mitsubishi Diamante sold in Japan, for example, included a television set mounted on what used to be called the dashboard. It shows broadcast television programs when the car isn't moving. When the car is moving, it has "a compass display and a CD-ROM-based navigational system that shows vehicle position against a road map." The Mitsubishi system uses a compass and the vehicle's odometer. The compact disc contains the addresses and telephone numbers of about 20,000 service stations, golf courses, hotels, department stores, art galleries, and amusement parks.[64]

The Mitsubishi Diamante proves that the odometer, a built-in compass, and a compact disc are enough to know where you are. Nevertheless, others are designing systems that will use U. S. military satellites—the Global Positioning System (GPS). GPS technology was developed to help the military know exactly where all its soldiers are, and to make sure that they get where they're supposed to be, even when crossing hundreds of square miles of trackless desert.

If you know your location with respect to three reference points, you know where on earth you are. To supply the required reference points, a receiver containing the ubiquitous microprocessor receives signals from GPS satellites 11,000 miles above the earth. These satellites have incredibly accurate clocks. They send their identification and precise time codes to GPS receivers that remember where each satellite was before. The receiver actually requires signals from four satellites to figure out where it is—the redundant fourth signal helps check for errors. The GPS system isn't complete yet; the twenty-fourth and final satellite is scheduled to be launched in 1993. When it is, any GPS receiver anywhere on earth will be within range of four satellite signals at all times. In theory, no one need ever be lost again.[65]

After they have all been built and launched, the satellites will require maintenance. Either commercial users will take over the expense of maintaining them, or they will have to depend on the military to keep them running.[66] There's a lot of commercial interest. GPS navigation systems are already in use in some airplanes and ships. Cities are using surveying equipment with GPS receivers. Trucking companies are considering combining GPS receivers with radio transmitters to track freight.[67] For about $1000, you can order your very own GPS personal navigator from a catalog. GM and Motorola are planning to spend $35 million to test a program called Advance that will equip 5000 cars near Chicago with navigation gear.[68]

In order to be useful, a car navigation system needs more than a GPS receiver. The system also needs maps, a communication interface, and some smarts about driving. Maps are required in digital form, with information about restaurants, motels, gas stations, and so on. Betting that advertisers will find digital maps an excellent medium, Rupert Murdoch, the publishing magnate, has bought Etak, Inc., a small maker of digital maps.[69]

A car navigation system also needs a way to accept input from its driver—and a keyboard just won't cut it. A system called TravTek that Avis is testing allows drivers to press menu items on a touch screen. In response, the system speaks in "a computerized male voice with a Scandinavian accent."[70] The technicians call it Sven. (You thought I was just kidding about the accent back there, didn't you?)

In addition to its maps and a database of travel information, the system also has to understand certain aspects of driving. As usual, this is trickier than it looks. In a test drive reported in *Business Week*, TravTek warned of an impending right turn with a mere ten yards to go. The driver was in heavy traffic in the wrong lane. This mishap is the result of an unstated requirement in the spec, or more likely, several. As usual, the activity being modeled—driving, in this case—is more complicated than anyone thought it was at first. You can't think of everything, can you?

TravTek has been installed in seventy-five cars in Orlando, Florida for a yearlong test. It uses GPS satellites, sensors buried beneath intersections, and video cameras. It is supposed to navigate, warn of traffic congestion, and provide information in case of emergency. But the test drive turned out to be disappointing; in addition to issuing directions with too little warning, its database was incorrect.

Tracking

Knowing where you are is handy; having everyone else know might not be. There's no denying that tracking, either using GPS or other systems, could be a boon to spies and police departments. Various antitheft devices have been proposed. Location data can be commercially useful for tracking stolen items such as cars, so we may soon be tracked whether we like it or not. Already an insurance company has refused to insure a car for more than half its value unless its owner installed a tracking device—a device reportedly so accurate that it can determine driving speed.[71] I cannot believe an insurance company has the right to demand this. How else will this information be used? What privacy protection does the driver have?

Foiling car thieves can be done another way. A company in the United Kingdom has announced it will market a system of owner-encoded microprocessors, small chips that you can hide inside your car, motorcycle, or other items of value. The system, call Datatag, requires registering your chips with the police, who will have special equipment to read the chips. The police can then check the registration database to determine if an item is stolen.[72] A similar system called TeleTrace has also been proposed in the United States. Such systems aren't foolproof either—thieves can still dismantle the car and sell its parts, often a more profitable activity. But at least it doesn't track the driver all over the continent.

The concept of electronic tagging has been extended in a number of ways already, and almost certainly more will come. A 1991 advertisement by Samsung touts a computerized monitoring system to determine the location and direction of travel of victims of Alzheimer's disease. Presumably, tracking devices could also be used for potential kidnap victims, pets, or mountain climbers.[73]

The telephone system provides other opportunities for paranoia about tracking. When they enter a new cell, cellular phone users are greeted with a phone call welcoming them to the new area and informing them of available services.[74] The data gathered from tracking cellular phones can be accurate to within an area of about a square mile (a "sector"). A court order is required to tap someone's phone or use the results of such a tap. It is not clear whether data gathered from cell phone tracking is afforded the same civil protection. If cellular phone users truly wish their whereabouts to remain private, they may have to turn off the phone.

Soon you won't need a cellular phone to face this issue. AT&T has announced that a phone number (prefix 700) can now be yours for life. Using a 4–digit PIN, you call your personal phone number and specify the regular phone number to which your calls should be forwarded. Naturally, the record of which calls were forwarded to you at which numbers and at what times constitutes a record of your whereabouts—perhaps a very detailed record. The phone company will have to keep these records for billing. What happens to them? What is their legal status? Can the police review them simply by asking the phone company, or will they need a search warrant? What about people who break into the phone company's computers?[75]

Automated Billing

A transponder in your car provides yet another way to track you. Some agencies are pushing to install transponders in cars in order to ease traffic congestion. The California Department of Transportation (CalTrans) wants Automatic Vehicle Identification (AVI) transponders to automate the process of collecting tolls. Roadside transmitters will send a signal to the cars driving by, whose AVI boxes will respond with a coded number. In theory, fewer toll booths will allow more traffic to flow unimpeded, while drivers are billed for the highways and bridges they used.[76]

Initial plans call for the system to be implemented in a manner allowing individual motorists to remain anonymous, but it looks as if there will be no legal way to turn the transponders off.[77] Ominously, a relatively late version of the CalTrans spec left the door open to further uses later. One possibility mentioned was tracking individuals by the Drug Enforcement Administration or the Immigration and Naturalization Service,[78] prompting one concerned software professional to write:

> "We ought to stop now and think. Do we want to set up a bureaucratic mechanism that can turn out automatic tracking schemes on an assembly-line basis, hoping that we can hold the line on privacy and other civil liberties by keeping careful enough track of this process? Or should we...get this entire process to be suspended long enough for a proper public debate?"[79]

Monitoring

Some jobs are so distasteful we want to automate them. At first blush, they seem good candidates for automation. Computers can serve as nursemaids, for example. A system for monitoring Alzheimer's victims is being developed in Sweden, where a computer watches over Gunnar, a 77yearold man suffering from senile dementia.[80] The computer is programmed to play prerecorded voice messages if it senses certain situations. At night, it tells him to go to bed; if it detects smoke, to leave the building. The man does not understand that he is a guinea pig in this technical and social experiment.

There have been a few technical glitches: after the system had been in place for some time, it was discovered that in the event of a fire at night, the computer would have told Gunnar to go to bed. But I find the social problems more troubling yet. Do *you* want to end up being tended by a computer?

Nursemaid isn't the only distasteful job being handed over to computers. Jailors, too, wish to distance themselves from their charges. Prisons in the United States are becoming quite overcrowded, and one response has been to place certain categories of offenders under house arrest. Various schemes use some combination of computerized polling, telephone calls, voice recognition, Caller ID, and electronic anklets to attempt to ensure that the detainee remains at home. Results so far are mixed.

Voice recognition technologies are slowly coming into their own, and at present, systems are available that take dictation, fill out forms, control PCs, and deal with people over the telephone, such as AT&T's automated long-distance operator service.[81] These systems can cause economic dislocation—AT&T caused some fuss when it announced the number of operators it was going to lay off, for instance. However, the best of these systems can provide a flexible and natural interface to a computer, enhancing the machine's utility.

When you use voice-recognition technology to monitor people under house arrest, though, the system has a different and more difficult job. Users are not trying to help the system, but to foil it.

House arrest schemes are apparently cheaper than prison—about $13/day versus $67/day, according to one source.[82] Sending people to overcrowded prisons does not seem like a good idea, nor does releasing them early. People don't want to pay for building more prisons. Why not house arrest?

Security is a difficult requirement. Voice recognition, electronic anklets—whatever you use, there will be holes that prisoners can exploit, and they have. Existing systems have so far seen two escapes. One fellow escaped repeatedly to rob gas stations on weekends when he learned that the system's monitors worked an ordinary fortyhour week. Another fellow committed murder because of an unstated requirement, a questionable design, and an odd user interface. He escaped by removing the rivets holding his electronic anklet together. The computer dutifully printed his name out with an asterisk next to it, on a display on which seven hundred names move constantly. No one noticed, because for some reason the real monitoring effort ran on another computer. The first computer placed the anklet on "tamper" status and called the computer that people were actually monitoring. It got a busy signal. Having marked the anklet as tampered with, and having called the other computer to say so, the first computer proceeded to drop the subject. Nobody said the phone call actually had to get through.[83]

The house arrest system that was so easily defeated was designed by Digital Products of Florida. In the wake of the murder, the New Jersey Senate Law and Public Safety Committee decided they ought to shop around and look at other systems. They will probably find a system that doesn't have these problems. If they decide to switch, they can learn about the problems of their new system, instead.

Security is indeed a tough problem. After a few postings describing house arrest systems and escaped prisoners, the software professionals who read the online news bulletin board *comp.risks* rose to the challenge. One brave soul described the best system he could design and asked if anyone could find a problem with it. In less than a week, experts in computer security matters found seven ways for the prisoner to escape from this theoretical system: six technical solutions and one psychological strategy.[84]

Verb-by-Wire

Real-time process-control presents another set of tough requirements. Previous chapters discussed several examples, notably fly-by-wire systems wherein symbolic, electronic connections replace direct, mechanical connections between pilot's gestures and aircraft controls. The computer controls the process of flying the plane, responding quickly to pilot inputs. If the system responds in error, the airplane can crash. If the system responds correctly but t

oo slowly, the airplane can likewise crash. Process control does not give you a second chance.

Not all real-time process control software is safety-critical. Systems to muffle noise by canceling sound waves are usually not, for example. But many are, and such proposals are proliferating. Software to operate on you, sail supertankers, and drive your car are all examples of real-time process control systems wherein safety is at risk. They may be asking too much of the technology.

Hush-by-Wire

The electronic muffler is a relatively simple system: a microphone sends the sound waves to a microprocessor. The microprocessor directs a speaker to produce sound waves that mirror those it received. If the microprocessor works fast enough, the two sound waves cancel each other out, and the result is blissful silence. In addition to doing a better job reducing engine noise, electronic mufflers for cars are also supposed to increase horsepower and fuel efficiency, because no muffler chamber builds up exhaust to create back pressure on the engine.[85]

The worst failure mode one can imagine for such a system can be fixed with an OFF switch. If the microprocessor gets badly out of phase somehow, the system is noisier instead of quieter, since you now hear the speaker as well as the engine. In this case, turning the system off may not leave matters much worse than they were before. When it works, the increased fuel efficiency may even partially compensate for the power that the system will consume.

Noise canceling technology isn't limited to cars, of course. Right now, you can buy (expensive) headphones that do the same job. Operators of noisy machinery, such as helicopter pilots, can save their hearing by wearing them. Perhaps factories will use this technology to responsibly dispose of their noise pollution someday. (When the price of electricity goes way down, like they said it would back in the 1950s.)

Cut-by-Wire

At least three groups are presently working on robots that can perform surgery: a group in Britain is developing robots for prostate surgery, a group in the United States for hip surgery, and a group in France for brain surgery. There are benefits: the quicker and more precise the cut, the more quickly the patient will heal, and a robot may be steadier and quicker than a human surgeon.

The risks are obvious; we all know enough to be chilled at the thought of a robot with a scalpel poised directly above our skins. So everyone's taking a lot of precautions: the robots are designed to be easy to interrupt, and a human surgeon is supposed to be there to finish the job if things go wrong.[86]

Sail-by-Wire

Some folks in Japan are reportedly developing systems to automate the sailing of enormous unmanned supertankers that transport oil across oceans.[87] I hope that reports are wrong. What about the other, smaller ships and boats they meet? Will they be able to get out of the way in time? Will they expect to be able to communicate with a human captain? How will these unmanned tankers respond to another ship's distress signal?

Yes, accidents can happen—and have—because of the actions of human captains and crew. But to eliminate such accidents, you have to provide a system that human beings cannot override. Is this wise? The ocean has a lot of water, but there are limits to how much oil and filth it can absorb. The trickiest situations are apt to occur near coasts. We have seen how fragile are the complex and beautiful ecosystems found along coastlines. Is it really that much cheaper to dispense with supertanker crews? What are we risking here?

Drive-by-Wire

The military pioneered fly-by-wire aircraft, and a couple of decades later commercial jets are plying the air with digital flight controls. They're easier and cheaper to manufacture, they weigh less, and, their designers feel, they can be made safer by building in such functions as envelope protection, functions that require software to implement.

For all the same reasons, the advent of drive-by-wire has been creeping up on us piecemeal for the past decade or so. As of the early 1990s, hardly an aspect of driving has not been under the control of a microprocessor. Some cars integrate several driving functions under the control of one microprocessor, and some cars have four or five microprocessors. We are within a gnat's eyelash of having all driving functions integrated in one master control program. The reasons given are all the same—the vehicle is easier and cheaper to manufacture, it weighs less, and it can include built-in safety functions.

Drive down the road. The fuel injection system determines the best time to squirt fuel, and how much. The ignition spark controller decides when to create the spark to ignite the fuel. If you hit a bump, the active suspension system reacts within milliseconds to firm the shock absorbers so you won't feel it. Your intelligent cruise control system adjusts your speed to that of the car ahead of you. Another car gets a bit too close, so your collision avoidance radar buzzes at you. As you accelerate around a curve, the transmission shifts to give you the extra power you require, while traction control ensures that you won't start to skid. The electronically controlled four-wheel steering responds to a tiny twitch of the joystick. If you start to drift over the center line, the heading control system nudges you gently back to the center of your lane. The antilock brakes ensure that you stop precisely and smoothly at your destination. The only parking spot you can find looks barely big enough, so you get out of the car and let it park itself.

So far, no car you can buy includes all these features, but you can buy many of them, and the rest are at least in the prototype stage. Fuel injection and "spark management" systems have been in use for years, as have antilock or antiskid braking systems. Cadillac, among others, has already sold cars (such as the Allanté) with active suspension systems. The Cadillac Allanté also includes an electronically controlled transmission that anticipates when the driver will require a gear shift—aggressive drivers will feel the Cadillac stay in gear a bit longer to maintain acceleration, while the car shifts earlier for sedate drivers in order to improve gas mileage.[88] City buses and school buses also have electronically controlled transmissions these days, to which manufacturers can add such safety features as routines that ensure the bus cannot shift into gear if the door is open. And the radar-based collision avoidance system is being installed in Greyhound buses to buzz at the driver in stressful moments, which will no doubt have a helpful, calming effect.[89]

Electronically controlled transmissions can be designed to save the engine, by reading wheel speed or engine rpm and shifting up if the vehicle is moving too quickly for the gear that the driver selected. Such a feature has been implicated in a school bus crash on July 31, 1991, outside of Palm Springs, California. The bus, which was carrying sixty Girl Scouts and their chaperones, was headed down a steep, winding road from the Palm Springs Aerial Tramway when the driver lost control. It slipped off the road and down an embankment, overturning as it fell. Seven people died, including the driver, and the rest were injured, some seriously. Like most accidents, this one had multiple causes—the brakes were later found to be bad, and the hapless driver (who is easy to blame, being dead) was at first accused of having selected the wrong gear for the steep descent. The California Highway Patrol examined the bus wreckage and found the bus to be in third gear, too high for compression braking. But the driver had a clean driving record and had been instructed on how to handle a bus going down mountain roads; his instructor had been pleased with his performance. His instructor did *not* tell him that the electronic transmission would upshift automatically, because the instructor himself was unaware of this feature. During the investigation that followed, "Stephen J. Bayt, a supervisor with Allison Transmission Co., which built the transmission, testified . . . that even if [the driver] had tried to shift to a lower gear, a mechanism designed to keep the engine from over-revving would have automatically shifted it back up into a higher gear."[90] And the bus transmission didn't even save the engine when it sacrificed the Girl Scouts.

Over-revving prevention doubtless seemed like a good idea at the time. Electronic control allows you to dream up skillions of ways to make the system "safer" under the circumstances you envision. Safer or not, though, the transmission has one clearly awful feature: it ignores or negates a direct driver action, apparently without giving the driver a clue that it has done so. This is not a well designed user interface.

Some of this stuff may be motivated by safety, but I can't help suspecting that some of it is there just for the whiz-bang-wow factor. To judge by the ads and the panting articles in car magazines, a lot of people get breathless over high-tech cars. "When three microprocessors talk to each other, what do they talk about?" asks an ad for a 1992 Lincoln Continental—a pointless question that contains the magical phrase "three microprocessors." According to the ad, the Lincoln includes an electronic engine controller that handles fuel injection, ignition timing, and coordinates with the electronic transmission; computerized suspension; antilock braking; and "computer-regulated speed-sensitive power steering."

The award for the most digital technology crammed into one presently available frame goes to the Mitsubishi Diamante.[91] In addition to digital engine and transmission control, active suspension, and antilock brakes, it includes the navigation system described earlier and an "intelligent cockpit" that puts the seat, steering wheel and mirrors into the positions you have specified when you unlock the car. This sounds handy, and I suppose it is when it works. When it doesn't, can you position things manually, or have they blithely discarded the backup system?

The Mitsubishi's real contribution to the technology race is its traction control system. It is really two systems, slip control and trace control, and each can be turned off independently. Slip control monitors wheel speed and steering-wheel angle; if the system senses a loss of traction it will ease off the throttle. Trace control is a nervous-passenger-in-a-box. The system has a table that relates vehicle speeds to steering wheel angles, and eases off the throttle if the driver exceeds the predetermined values. "The effect is uncanny," writes a test-driver. "You head into a tight turn with your foot planted and, next thing, the car loses power."[92] They want me to pay for this? What if the day comes when I prefer to drive into a ditch rather than hit the child on the bicycle?

Like Lake Wobegon's children, most of us think we are above average; we pride ourselves on our driving. I suspect that most drivers will react to trace control as did the test-driver quoted above: "Personally, I think I can live without trace control, but I'm willing to admit it might be a handy feature...for those occasions when the car is being driven by a valet parking attendant or by a friend or family member whose driving isn't entirely trustworthy."[93] Any bets on his Aunt Ethel's opinion of her own driving, and on how long it takes her to figure out how to turn off trace control? Technological breakthrough or not, trace control code may require little testing, simply because it may almost never be executed.

Saab has a traction control system, too, as you'd expect from a car designed by engineers who often drive on ice and snow. If you buy a Saab 9000 Turbo in Europe, you can include an optional "traction control system incorporating brake, ignition, and fuel injection controls, a virtual drive-by-wire system wherein the accelerator pedal is linked not just to the throttle of the fuel injection system, but also to a computer system. The computer decides how much spark advance, how much fuel, and how much brake application will achieve the best balance for maximum traction, even at full throttle on snow and ice."[94]

Since they're over halfway there already, it's no wonder that Saab has built its first steer-by-wire prototype. They don't expect to sell cars with steering joysticks for another twenty years or so, but they anticipate incorporating some digital steering technology into cars with conventional steering wheels much sooner.[95]

The heading control system mentioned above also comes from Europe. BMW has built a prototype that includes a camera peering ahead to track the lines painted on the center and side of the road. "If a driver gets too close to either marker, a small electric motor integrated into the steering system is activated to put things right. Later versions will gauge road conditions and differentiate between broken and solid lines, so the computer can tell such things as whether it's okay to pass. Drivers being corrected might feel a tug on the wheel. But they can easily override the computer..."[96] A number of questions spring to mind. How does the computer behave on roads with no lines painted on them, or nonstandard lines? How much will it cost to paint the required lines on all roads? Do I really want to feel a tug on the steering wheel just as I'm finally ready to pass that triple-trailer truck? Most important, if I can't steer the car, why am I driving?

When the first antilock braking systems came on the market, certain macho, competitive drivers took them to the limit, delighting in their new ability to "safely" scare the daylights out of those behind whom they stopped. The same sort of people will doubtless enjoy pushing the limits with traction control and “smart” steering systems as well. Safety features can make life safer, but they can also tempt people to abuse them. Such behavior not only negates any increase in safety the features may have achieved, it also heightens everyone’s stress level.

The car that parks itself is presently a prototype built by Volkswagen of America. It has proximity detectors and can sense whether a parking spot is big enough. Then it can wedge itself into the spot with only a few inches on either side.[97] A lot of people hate parallel parking. If this application can somehow sense when a dog or cat or toddler is in the way, it could come in handy. But let’s consider the larger system, including the environment in which it operates. Not everyone is going to have cars that squeeze themselves into parking spots with only inches of clearance, at least not at first. Suppose that you own a car with two-wheel drive and manual steering. You park downtown to see a movie. You return to find yourself wedged between two of these automated wonders. How are *you* supposed to get out?[98]

You can do wonderful things with digital technology. The Cadillac Allanté, for example, allows you to drive it for a limited distance with no water in the radiator.[99] That could be a life-saver in an emergency. But real-time safety-critical process-control systems are hard to design, develop, and verify. There have been bugs; there will be more. A 1982 Mercedes 500SE with an antiskid braking system somehow managed to leave 386-foot skid marks at the scene of an accident. Brake microprocessors have been recalled on El Dorados, and Lincoln Mark VIIs were recalled for problems with their computerized suspension systems.[100]

Microprocessor-based systems are vulnerable to EMI, for example. The environment in which cars travel is rich in electromagnetic radiation: police cars, ambulances, pizza delivery trucks and taxis all have radios; cellular phones, CB radios, broadcast towers and satellite dishes are everywhere. Because of the risk to the airplane’s digital flight control system, some airlines have banned the use of personal computers with mice, because the mouse cables act as antenna and emit potentially disturbing radiation.[101] Is the shielding for automobile microprocessors really so much better? In 1990, certain cell phone manufacturers warned that their phones should not be used in cars with electronic antilock braking systems, because they might cause the system to malfunction.[102]

Yes, it’s true that the old technology isn’t completely safe, either. If the accelerator pedal isn’t connected to a computer, it’s connected to a spring that connects it to the throttle. The spring can break. But if it does, you might be able to reach down with your hand or your toes and physically pull the pedal back up in time to avoid the worst consequences. If the software has a bug, or if the microprocessor goes flooey when you get a call on your cellular phone, there is *nothing* you can do, short of shutting off the engine—and even that may not work out.

When we build a system, we should ask ourselves whether we will be worse off when it fails than we would have been if we hadn’t built it. For example, many cars with computerized braking systems will leave you with a conventional braking system if the microprocessor shuts off for some reason. As long as you’re not in mid-skid, or driving like the race-car driver from hell, you’ll probably be fine. Electronic engine control, on the other hand, is not so benign. Although many cars with electronic engine control can limp home somehow if their microprocessor fails, their performance, gas mileage, and emissions will be atrocious. Other cars just lie down in the dust.

There's another risk in drive-by-wire technology, and folks involved in software development know all about this problem. You take your microprocessor-controlled car to the dealer for its regularly scheduled maintenance. You don't know it, but the dealer has just received a software upgrade from headquarters, which the mechanic obligingly loads into your car. You had better hope the new software has been developed carefully and tested thoroughly, because you can no longer count on your car behaving the way it used to. In some ways, it is now a completely different car—and there may be nothing you can do about it. Even if you hate its new behavior, you may never be able to return to its original software.

Furthermore, your entire driving history can be maintained in the microprocessor's memory and uploaded every time you take your car in for servicing. This is apparently already the case with 1992 Saturns, for example.[103] Is it cynical to guess that it is only a matter of time before information such as this is used to save the dealer money? "I'm sorry, sir," the service manager says. "Ordinarily, this repair would be covered, but according to your engine history, you have over-revved this engine three times. I'm afraid we'll have to void your warranty."

Verb-by-Wire, Many Times Over, All at Once

In this book, I've tried to avoid stacking up computer science buzzwords like so many cars in a rush-hour freeway accident, but here they come: this section is about distributed real-time process-control software. This verbal snarl is to the point: if real-time process-control systems are tough to design and develop, distributed systems are even more complex and fragile. Every one of the areas represented by a buzzword is a topic of research by some of the world's brightest people. Many problems have yet to be solved. Even the finest developers could not implement safe and reliable systems such as these, given present software and systems engineering techniques.

Drive-by-wire systems have built on and emulated fly-by-wire systems, and have been motivated by many of the same economic considerations. The resemblance between driving and aviation goes further. Traffic in many cities is now so bad that many of the same approaches are being proposed to control cars as we presently use for air traffic control.

Present air traffic control systems use computers to advise air traffic controllers on appropriate routes, altitudes, paths of ascent and descent. The air traffic controllers relay their instructions to pilots. If two airplanes get too close, one computer warns the air traffic controller and another computer warns the pilot. Either may observe the problem and take action without waiting for the computer.

In an effort to handle increasing levels of air traffic, the proposed air traffic control system abandons this paradigm. The computer assigns routes and altitudes, transmitting instructions directly to the computer flying the airplane. Pilots and air traffic controllers become monitors, able to override the system in emergencies.

Presently, computers control traffic lights and signs in a manner analogous to the instructions of air traffic controllers to airplanes. Drivers follow instructions according to the law, their own common sense, habit, present whim or pressing need. Various ways to expand these traffic control systems have been proposed, many representing distributed real-time process control. But these systems control only traffic lights and signs; they don't take over the vehicles for us.

A proposed vehicle control system will, however. The system takes the same approach as air traffic control: a central traffic control computer is supposed to drive your car for you, transmitting instructions directly to the appropriate microprocessor(s) in the vehicle. Research is ongoing.

In both these proposed systems, a central computer simultaneously controls a large number of processes distributed over a large area. Up to now, most distributed systems were concerned with information transfer—mission-critical they may have been, but nobody died when the network went down. That's just as well, since distributed systems add a significant new layer of complexity. Using computers to control many safety-critical processes simultaneously may *really* be asking too much.

Traffic Control

Traffic control systems take an active role in managing traffic, adjusting traffic light timing or freeway signs. If traffic planners can get reliable, updated traffic information, they can sometimes improve a traffic jam. A fair number of such systems are already in place. Many cities have mounted video cameras at critical roads or intersections, allowing the traffic department to monitor flow and adjust the timing of traffic lights or the displays on traffic signs.[104]

More ambitious traffic systems are being planned. Not surprisingly, considering its traffic problems, the city of Los Angeles is in the forefront. For the 1984 Olympics, the city installed the Automated Traffic Surveillance and Control System, which uses cameras and sensors to monitor traffic on a lane-by-lane basis on certain highly traveled roads. The system acts on the information it receives, controlling traffic lights and freeway on-ramp meters. This system was the beginning of what its proponents are calling the Intelligent Vehicle and Highway System (IVHS), an overarching set of proposals to restructure the entire experience of driving from here to there.

IVHS planners want to take traffic control further in several directions: a more sophisticated, widespread traffic management system and some method of getting detailed traffic information to the individual motorist. If you had a car navigation system, wouldn't it be convenient to connect it to a traffic information service that could tell your car's computer where all the trouble spots were? The car could then route you around the congested areas. That is one kind of service IVHS planners visualize.[105]

The Chicago traffic system discussed at the beginning of this chapter automated the process of disseminating information. The Los Angeles system has automated the process of controlling traffic as well. They'd like to do it better, and are at work on an expert system that would capture the knowledge of the best traffic controllers. The knowledge of an expert in traffic control would be reduced to a few hundred rules and put to work everywhere one can bury sensors and communicate with a computer.

Air Traffic Control: The Advanced Automation System

Digital flight control systems take the responsibility for action away from pilots. Automation is taking authority to make decisions away from air traffic controllers as well.

Air traffic control computers provide more information than controllers can get from staring out of windows or peering at radar screens. But so far, they do not issue instructions. The coming Advanced Automation System (AAS) will. Under development by IBM and the U. S. Federal Aviation Administration since the early 1980s, the AAS is a massive undertaking, incorporating about 150 large, complex, interdependent projects.[106] An ambitious integration of digital flight control, navigation, collision avoidance, ground proximity warning, communication, scheduling and routing, meteorology, and conventional air traffic control systems will computerize the air traffic flow of the United States daily. A network of computers will be responsible for maintaining aircraft separation. The flight control system and air traffic control computer will exchange data directly through the transponder. Pilots and air traffic controllers are supposed to be there to override the system if necessary—a human backup system.

The original schedule called for the system to be deployed in the late 1980s. That has slipped, of course, and no one will now say when the system will be placed in service. That's smart.

AAS is supposed not only to prevent midair collisions, but also to optimize traffic flow. At present, the air traffic control system is not as efficient as it could be, because each air traffic controller sees only the situation in his or her sector. No one views the air space over the entire continent for the whole day and determines the best way to route everyone. No one could. But AAS computers are expected to coordinate air traffic on a continent-wide basis, expediting flying time and saving money.

AAS is safety-critical, and the FAA has noticed. The overall reliability goal is ambitious: "safe, full-service operation within the required response times, 100 percent of the time." Nevertheless, the system's planners know that failures will occur, and that the system will not be able to recover from all of them quickly enough. The initial backup level operates with reduced capabilities, but includes all functions necessary for safety. It may inconvenience pilots but is supposed to occur an average of only 2.1 minutes per year. The next level of backup, emergency mode, includes only the most critical services; if maintained for any length of time, emergency mode would delay a great many flights. But it is expected to be required an average of less than half a minute per year. The final level of backup involves dedicated, sweating people shuffling pieces of paper, doing the best they can; *that* is supposed to happen an average of only 3 seconds per year.[107]

AAS will be phased in slowly, after many technical reviews, small-scale tests, and larger-scale tests. It's needed; already, air traffic at the United States's busiest airports strains and occasionally exceeds the capacity of the present system, leading to incidents such as the busy day of October 14, 1989, at Dallas-Fort Worth. The computer, having more data to process than memory to process it with, crashed and remained out of service for *over 20 minutes*. Thanks to hard work, brains, and a measure of luck, no planes crashed.[108]

Air traffic in the United States is presently increasing at the rate of 2 to 5 percent per year. We have a choice: we can upgrade the present system, or we can scale back on commercial airline travel. We seem to have made our choice. What is the best way to upgrade the system? Can we do more of what we do now? Should we take this opportunity to examine the whole airspace-airplane-pilot system? Or shall we just hand decision-making to the computers? "AAS is the most complex civilian undertaking since landing a man on the moon," says Jim Harris of Portland International Airport's Terminal Radar Control, and I suspect he is not guilty of hyperbole. This system will not come cheap.

Donald Norman, author of *The Design of Everyday Things*[109] and an authority on human factors in system design, has proposed scrapping the entire system and redesigning it completely. He is studying aviation safety under a NASA grant, and an article on the subject that appeared in *The Economist*[110] moved him to respond with the following quick and informal comment on an electronic bulletin board:

> The new addition of "datalink" to the cockpit will only create new problems. Datalink is digital transmission of ATC [air traffic control] information to be received somewhere in the cockpit on a CRT display. This replaces some of the voice communication on the now overcrowded channels. In principle it has merits, but it is yet another complex piece of equipment, yet another change in procedures, yet another bandaid and ill-considered addition to cockpit clutter. I used the word "somewhere" because nobody yet knows quite where to fit the thing into the already crowded cockpit, and all the current suggestions seem to lead to foreseeable future problems. The lack of positive confirmation from pilots will also lead to other (foreseeable) problems. Basically, one cannot fix a system problem by adding local patches. In fact, that tends to make things worse.[111]

When do we listen to such voices? Before or after the money has been spent?

The Advanced Vehicle Control System

My nomination for the wildest proposal goes to the Advanced Vehicle Control System, brainchild of the IVHS planners. Upon entering the freeway, cars equipped with microprocessors would place themselves under the control of a remote computer. The computer would control the throttles, steering, and brakes with radar signals sent out 55,000 times a second. These signals will then permit "platoons of cars, separated by only a few feet, to zoom along at 90 mph while their drivers read the newspaper."[112] Right.

Entering the Santa Monica Freeway, you surrender control of your car to a computer. It platoons you three feet from other cars at a speed you would not drive yourself. Suddenly, there's a glitch in the system. You must lift your head from your newspaper and instantly retake control of a car hurtling through space at 90 mph, surrounded by other drivers who have also been reading, or chatting, or drinking, or making love, for all you know, just in time for everyone to hear the collision avoidance buzzer. I don't think so.

A system such as this one radically changes the character of freeway accidents. When they happen, they'll be like airline crashes, both in terms of the number of casualties and the lack of control on the part of the victims. A systems safety expert working on the project says, "You'll be trading 100 accidents in which a total of 105 people get killed for 2 accidents in which a total of 30 people get killed."[113] This cold-blooded analysis is wrong on two counts.

No evidence exists to demonstrate that such a system would be safer in terms of the absolute number of people killed (or injured, or any other index of harm you'd care to use). Projections of the number of deaths or injuries are meaningless, based on unsubstantiated guesses and little evidence. Traveling 90 mph in platoons of vehicles with three feet of clearance between them could very well increase casualties, not decrease them. The above-quoted systems safety expert believes that the system will eliminate those accidents caused by human error. But again, that means the driver cannot override the system in any way. Given what we know of the likelihood of software bugs, the dangers of EMI or other inadvertent environmental inputs, and the staggering number of ways in which a complex system can fail, would you willingly climb into an automobile with no override capability?

But suppose that, somehow, traffic deaths go down, not up, after the system has been placed in service. Does that mean it's better? They may be wrong, but a lot of drivers like to think their superior skills will improve their chances in a bad situation. People want to control their destinies. When a synchronization glitch or a buffer overflow can be blamed for the deaths of thirty or sixty people all at once, their families will scream for someone's head. Lawyers are the only ones who will benefit.

Yet a more basic problem exists. As the city of Chicago so graphically demonstrated to us on April 13, 1992, the infrastructure of the United States is in bad shape. The tunnels underneath the city of Chicago were flooded, causing hundreds of millions of dollars of damage, because a $10,000 expenditure to repair a small leak was delayed.[114] As the "CBS *Evening News*" reported, highway bridges all over the United States are in bad condition.[115] City roads, state highways, and interstate freeways all suffer from potholes large enough to damage cars. Most water mains in the United States were laid at the turn of the century; many have not been repaired since. A nation whose entire southwest is dry loses an estimated 34 percent of its drinking water to leaks. And in fiscal 1991, the U.S. Federal Highway Administration spent $20 million on IVHS. In fiscal 1992, they are increasing this to $234 million.

Clearly, it's more fun to build than to maintain. It's more profitable, as well—for some. AT&T, Lockheed, Hughes Aircraft, General Motors, Westinghouse, TRW, Ford, Chrysler, Motorola, and Rockwell International all see the opportunity for big profits with IVHS. Money we spend on repairing the infrastructure goes to small community businesses instead. Those guys just don't pay lobbyists. But shouldn't we be taking care of the basics before adding all these frills? If traffic jams are such a terrible problem, why not build mass transit systems that run so often and go to so many places that they are actually convenient? We are going to feel awfully silly when those platoons of cars whizzing merrily down the freeway get to the place where the bridge has just collapsed. If the computer, having failed to update its model of the world recently, sends them plunging over the precipice, it will be the perfect illustration of our misplaced priorities.

Virtual Democracy

For a while now, software has been used during election campaigns to identify one's supporters for direct-mail appeals, or to comb databases for tidbits about one's opponent's heinous past. You can also use high-tech to vote, and some would like to. Schemes have been hatched to allow people to vote by interactive television, touch-tone telephone, fax machine—even computer network.

Proponents such as the Voting by Phone Foundation of Boulder, Colorado, envision voters picking up the phone, dialing a toll-free number, and interacting with a voice-response system similar to voice mail. "In the contest for Chief Dog-catcher," it might say, "press 1 to vote for Fido. Press 2 to vote for Dobbin." It's supposed to be more convenient than traveling to a polling place, and therefore to increase voter turnout. But as the voters of the Liberal Party in Nova Scotia found out, it's not necessarily that easy.

Nor is it clear why we need to vote by phone.[116] There is little doubt that voter turnout in the United States is dismal—in many elections, fewer than half of those eligible bother to vote. Is this because polling places are so difficult to get to, now that we have given up horse-drawn carriages for automobiles? Will voting by phone really bring about a groundswell of increased participation?

Is it really more convenient? People complain mightily about interacting with voice mail systems. And most of those interactions are undertaken to accomplish tasks simpler than voting in an election with national contests, state contests, local contests, and voter initiatives. The telephone interface is limited—twelve buttons and a voice. Unlike a paper ballot, a voice-mail system does not let you see what you have already done or what you have left to do. You cannot tell when you have made a mistake. You may not want an entire voter initiative read to you in tedious detail. You may wish to write in a candidate. You may even get a repeated busy signal: perhaps everyone waited until evening to perform this civic duty, perhaps an organized protest is tying up all the phone lines, or perhaps the system can't handle the load.

Assuming that we solve these problems, then what? A convenient and simple process is a good thing, but voters also need confidence that their votes will be registered as they intended and counted as registered. The voter's anonymity must be preserved. It must be difficult to alter the outcome of a contest by coercing or buying votes, using the votes of people who have not already voted, or altering or eliminating the votes of those who have. It must be possible to audit the process for reassurance and to conduct a recount in the event of a close race. How does voting by phone handle these requirements?

How can we ensure that the person voting is a registered voter who has not voted already? Voice recognition would require a database where every registered voter's voice is on file—and if you have laryngitis, you are disenfranchised. We could use PINs, as with ATMs, but PINs can be stolen or forgotten.

How can we simultaneously preserve the voter's privacy and archive votes in case a recount is needed? Those two requirements seem to be in direct conflict. What is to prevent an unscrupulous fanatic with computer expertise from breaking into the system at the last minute, determining who has not yet voted, and stuffing the electronic ballot box in the final moments?

Perhaps technical problems can be overcome, but what's the point? If we really want to increase voter turnout, it would be cheaper to make Election Day a national holiday, as it is in most European countries. Or we could hold elections over several days, including a Sunday. But most people who refrain from voting do so because they believe it makes no difference. This is a social problem, not a technological one. The real solution to increasing voter turnout is to change that belief.

The technology we use to vote is an obvious target for change. Less obvious, but more profound, is using the technology to change the basis upon which we organize representation. When the process of voting was set up, geography was the only reasonable basis for organizing large groups of people, so our representatives represent geographical communities. But this is no longer the case; nearly every day, for example, I log on to a computer and continue a discussion with a friend 3000 miles away, while in a year I've spoken to my next-door neighbor once. Computer networks allow us to consider alternatives to geographical representation. This aspect of digital technology could make democracy more representative or more chaotic, depending on your point of view.

Who but a network computing professional would suggest that we dispense with geography altogether as the basis for representation, and choose our representatives instead on the basis of ideology?[117] Instead of a U. S. Congress filled with similar politicians, this devotee of networking rightly foresees this vote-by-net scheme producing a Congress of extremists and one-issue zealots. For some reason, this prospect seems agreeable to him. "We've got the technology," he says, "why not see if we can use it?" Why not, indeed? Perhaps because the problems we face should drive the solutions we seek, not vice-versa.

Do we need the U. S. Congress at all if Americans can make their wills directly known on each of thousands of different issues as they come up? A nation can now be governed by referendum, with "electronic town meetings" as Ross Perot suggested.[118] The idea sounds appealing, but how it is going to be implemented? Public discussion of issues is necessary for democracy, and new forums for discussion are worth encouraging, certainly. But are these to be discussions? Or do we just listen to our leader's proposal and then press 1 for "yes," 2 for "no"? The ability to frame the terms of debate is a powerful position, easily abused. This system could be the triumph of demagoguery over democracy.

I have actually been to real town meetings—the nonelectronic kind. Every March in Vermont, the high school I attended trundled us onto various vehicles and sent us all over the southern part of the state to attend them. I watched neighbors stand up and discuss one proposal or another, often heatedly. The person with the gavel at the front of the room was not in a position to frame the terms of the discussion—sometimes, he or she could barely keep order. By and large, the whole town heard what various folks had to say. For those unwilling to stand up in front of everyone, remarks could be whispered in the aisles or in the halls. At midday, formal discussion ceased, but informal discussion proceeded apace over a potluck lunch with contributions from nearly everyone. Opportunity to air one's views or influence the discussion was ample. Opportunity to dominate the discussion was not.

Online bulletin boards can approach this level of involvement among their participants, but I doubt that "town meetings" using telephone or television technology can. The channel is too limited and too expensive. The person or organization paying for it frames the discussion.

As it turned out, I also participated in one of Governor Barbara Roberts's "Conversations with Oregon" in the fall of 1991. In this, one of the first uses of interactive, closed-circuit television to gauge (and shape) public opinion, the governor discussed tax policy with several thousand citizens. During my session, she was on the screen more than 75 percent of the time the system was active. Although she clearly did not mean to, she spoke far more than she listened. It's hard to resist. She called all the shots, and she's only human. Technology can help us, but it isn't going to enable us to transcend our natures. Its entry into the political process should be managed carefully and with forethought.

And More...

Proposed uses for digital technology exhibit the fruitfulness of the human imagination. Funding continues for a space station, presumably to give the space shuttle somewhere to park. Manufacturers dream of integrating the design, inventory control, and the manufacture of their goods in one computer-integrated manufacturing system. Aviation authorities are putting TCAS, yet another collision-avoidance system, into airplane cockpits. People are planning or building systems to warn us of earthquakes, automate gas stations, sell us lottery tickets with Nintendo machines, put online help systems into airplane cockpits, lock doors, teach us to play the piano, monitor how often we open a pill bottle, arm or disarm nuclear weapons in midflight, modernize the U. S. Internal Revenue Service (that one sounds fun, huh?), automatically photograph any car traveling faster than the speed limit, refer you from a national toll-free number to the pizza parlor or burger joint nearest you, and search for evidence of fraud in securities transactions. While you read that sentence, someone had another idea.

Some of these systems will be useful—relatively cheap to implement, perhaps, and worth the risk, which may be small. Others will not be—the expense or risk or both will not be worth it, except perhaps to those few who make the profit. In any case, we cannot build them all. We simply do not have the resources to throw at any and every system someone proposes. In the final chapter, I would like to suggest criteria we might use to determine which systems are worth building and which are not.

Notes

[1] "Big Science" by Laurie Anderson, 1982 Difficult Music (BMI).

[2] Contributors to the online forum *comp.risks* will recognize the game. I would like to thank them all for their insights. They have been wonderful teachers.

[3] Altman, Lawrence K. "Science Group Plans Electronic Medical Journal." *New York Times*, Sep. 25, 1991, p. A15.

[4] *comp.risks,* 10:15, Jul. 26, 1990.

[5] Schine, Eric, Mark Maremont and Christina Del Valle. "Here Comes the Thinking Car." *Business Week*, May 25, 1992, pp. 84–7.

[6] Ferrell, J. E. "The Big Fix." *Los Angeles Times Magazine*, April 14, 1991, pp. 14, 16, 18 and 38–40.

Taylor, Ronald B. "Street Smart: Testing High Tech on the Santa Monica Freeway." *Los Angeles Times Magazine*, April 14, 1991, pp. 16 and 38.

[7] ASCII stands for American Standard Code for Information Interchange, and it is the basis of text representation in all computers but a few old or exotic ones. It assigns a number to each character on the keyboard. When the computer is told to interpret a string of numbers as text, it uses the code to read the numbers and determine which character to display.

[8] "Your humble servant," *The Economist*, May 2, 1992, p. 78.

[9] For a deeper exploration of these issues, see Mander, Jerry. *Four Arguments for the Elimination of Television*. New York: Morrow, 1978.

[10] Hundertmark, Jane. "When Enhancement Is Deception." *Publish*, 6:10, Oct. 1991, pp. 50–55. Also, Durniak, John. "Camera." *New York Times*, Jan. 5, 1992, p. 19.

[11] Cover of *Time*, Jan. 6, 1992.

[12] Durniak, John, *op. cit.*

[13] *ibid.*

[14] Leland, John. "The Moper vs. the Rapper." *Newsweek*, Jan. 6, 1992, p. 55.

[15] Green, Michael. *Zen & the Art of the Macintosh.* Philadelphia, PA: Running Press, 1986.

[16] Graham, Ellen. "Plug In, Sign On, and Read Milton, an Electronic Classic: Project Gutenberg Is Sending Good Books to Computers Everywhere—For Free." *Wall Street Journal*, Oct. 29, 1991, pp. A1, A9.

[17] Reilly, Patrick M. "Electronics, Music Industries Set Pact On Digital Recording Use in the Home." *The Wall Street Journal*, July 12, 1991, p. B5.

[18] Markoff, John. "Portable electronic newspaper gets closer." *Oregonian*, July 5, 1992, p. P1.
Rogers, Michael. "The Literary Circuit-ry." *Newsweek*, June 29, 1992, pp. 66–7.

[19] Langberg, Mike. "Putting a face with voice by telephone technology." *Oregonian*, Jan. 19, 1992, pp. D1, D3.

[20] On April 8, 15, 22, 29, and May 4, 1992, PBS (the U.S. Public Broadcasting System) aired an excellent series of television shows about the computer, called "The Machine That Changed the World." The concept of the computer as an all-purpose machine was explored to great effect in that series, particularly in the first show.

[21] Schwartz, John. "The Next Revolution." *Newsweek*, April 6, 1992, pp. 42–48.

[22] Rogers, Michael. "Honey, I Shrunk the Disc." *Newsweek*, June 1, 1992, p. 64.

[23] Sichelman, Lew. "Smart houses just around the corner." *Oregonian,* Sept. 8, 1991, p. H1.

[24] Flowers, Bauvion. "Did Shakespeare Know ASCII?" *Mondo Modo*, July 1999, pp. 13–15.

[25] "Say aah: High-tech dental Xrays coming." *Oregonian*, Oct. 27, 1991, p. L12.

[26] Schwartz, John. "The Highway to the Future." *Newsweek*, Jan. 13, 1992, pp. 56–7. Also, Schulberg, Pete. "Fiber optics: the future is now." *Oregonian*, Jan. 12, 1992, p. C10.

[27] Ramirez, Anthony. "A.T. & T. Plans to Offer Faster Data Transfer." *New York Times*, Nov. 19, 1991, p. C2. Also: Dr. Robert Beck, Biomedical Instructional Computing Center, address to Software Association of Oregon, Beaverton, Oregon, June 28, 1991.

[28] The redundancy of human language has allowed telephone technology to use a very limited bandwidth. The English sounds written as "s" and "f" differ only in their highest-frequency components. This high-frequency sound is not presently transmitted over telephone lines, but you are so good at understanding language that you may never notice in a lifetime of telephone use, until you get directions in an unfamiliar city, and can't tell whether your informant has named a street "Fable" or "Sable."

[29] Schulberg, Pete. "Please Standby." *Oregonian*, Jan. 12, 1992, p. C7 and C10.

[30] Zachary, G. Pascal. "Power Play: Utilities see the 'intelligent' meter as the hub of a new two-way communications network. No wonder some cableTV companies aren't happy." *Wall Street Journal*, April 6, 1992, p. R6.

[31] Schwartz, John. "How Did They Get My Name?" *Newsweek*, June 3, 1991, p. 40–42.

[32] Rheingold, Howard. "Big Brother, the Grocery Clerk." *Publish*, Oct. 1991, pp. 40–42.

[33] Reported by Jim Tuttle on *All About You*, television broadcast by Oregon Public Broadcasting on Oct. 2, 1991.

[34] Neumann, Peter G. "What's in a Name? Inside Risks." *Communications of the ACM*, 35:1, Jan. 1992, p. 186.

[35] Winslow, Ron. "Desktop Doctors." *Wall Street Journal*, April 6, 1992, p. R14.

[36] Miller, Michael W. "Patient's Records Are Treasure Trove for Budding Industry." *Wall Street Journal*, Feb. 27, 1992, p. A1.

[37] *comp.risks,* 12:66, Nov. 26, 1991, and 13:8, Jan. 28, 1992. Item contributed by David States, member of the National Center for Biotechnology Information. Also see "Genetic Records to Be Kept on Members of Military." *New York Times,* Jan. 12, 1992, p. 15.

[38] Quinn, Jane Bryant. "Insurance: The Death Spiral." *Newsweek*, Feb. 22, 1993, p. 47.

[39] "True Colors." *Privacy Journal*, 16:9, July, 1990, p. 1. Quoted in *comp.risks,* 10:22, Aug. 22, 1990. Also see Mercuri, Rebecca. Trip report on Computers, Freedom, and Privacy Conference, March 26–28, 1991, in *comp.risks,* 11:39.

[40] Owens, Norman. "Back to the Future for Commercial Agents." *The Mercantile Agent*. Quoted in "Sorry, you can't afford it." from the *Sydney* [Australia] *Morning Herald*, Aug. 20, 1990. Which in turn is quoted in *comp.risks,* 10:22, Aug. 22, 1990.

[41] "The World at Your Fingertips," Episode 5 of *The Machine That Changed the World*, broadcast on the Public Broadcasting System on May 4, 1992.

[42] *comp.risks*, 10:16, July 31, 1990. From "Justice Proceeds to Create Its Drug Intelligence Center," *Government Computer News*, July 9, 1990, p. 8.

[43] *comp.risks,* 13:45, April 28, 1992.

[44] "The Thinking Machine," episode 4 of *The Machine That Changed the World*, PBS, aired April 27, 1992.

[45] "Cogito, ergo something." *The Economist*, Mar. 14, 1992, pp. 5–6 of "A Survey of Artificial Intelligence—Minds in the Making."

[46] PBS, *op. cit.*

[47] Lise Storc, developer. Personal communication, July 22, 1991.

[48] Winslow, Ron. "Desktop Doctors." *Wall Street Journal*, April 6, 1992, p. R14.

[49] "The Life-and-Death Computer." Editorial,*Washington Post*, Jan. 5, 1992, p. C6.

[50] A classic book on this subject is Huff, Darrell. *How to Lie with Statistics*. New York: W. W. Norton and Co., 1954.

[51] Washington Post, *op. cit.*

[52] *comp.risks*, 13:2, Jan. 9, 1992, item contributed by Tom Perrine.

[53] Blumberg, Mark S. "Biased Estimates of Expected Acute Myocardial Infarction Mortality Using MedisGroups Admission Severity Groups." *Journal of the American Medical Association*, 1991, 265:22, pp. 2965–70. Iezzoni, Lisa I. " 'Black Box' Medical Information Systems: A Technology Needing Assessment." *Journal of the American Medical Association*, 1991, 265:22, pp. 3006–7.

[54] Easterbrook, Gregg. "A House of Cards." *Newsweek*, June 1, 1992, pp. 24–33.

[55] "Computer Animations Aiding Lawyer's Cases." *Seattle Times*, July 23, 1990, p. E3.

[56] Reported by Frank Currier on the "CBS *Evening News*," May 4, 1992.

[57] Bickford, George. "Computer landscaping simplifies garden plan." *Oregonian*, April 12, 1992, p. L24.

[58] My thanks to Joe Hubert of CAChe Scientific, Inc. for the demonstration of the 3D computer-aided chemistry workstation.

[59] Gupta, Udayan. "Designing Drugs." *Wall Street Journal*, April 6, 1992, p. R20.

[60] "The Paperback Computer," episode 3 of *The Machine That Changed the World*, PBS , aired April 20, 1992, featured a thrilling segment in which we walk through a church before and after it was built.

[61] Yamada, Ken. "Almost Like Being There." *Wall Street Journal*, April 6, 1992, p. R10.

[62] Carroll, Paul B. "Let the Games Begin." *Wall Street Journal*, April 6, 1992, p. R10.

[63] Schine, et al., *op. cit.*

[64] Winfield, Barry. "Trace control: another step toward the foolproof vehicle." *Automobile Magazine*, Feb. 1991, pp. 41–44.

[65] "Saying goodbye to 'Where am I?' " *The Economist*, Aug. 24, 1991, pp. 71–2.

[66] When fully in place, GPS receivers should be able to calculate their positions to within 25 meters. But the U.S. military can degrade this accuracy when they deem it necessary, so that civilian receivers will be accurate only to within 100 meters. Perhaps commercial users should instead take over deployment and maintenance of GLONAS, the former Soviet Union's version of GPS.

[67] "Saying goodbye to 'Where am I?'" *The Economist*, *op. cit.*

[68] Schine, et al., *op. cit.*

[69] "4˚ East, 51˚ North, and a side order of 29." *The Economist*, Aug. 24, 1991, pp. 72.

[70] "Truett, Richard. "On the Road in Orlando: My Wild Ride with Sven." *Business Week*, May 25, 1992, p. 87.

[71] *comp.risks*, 13:46, May 2, 1992.

[72] Arlidge, John. "Firm Offers 'Foolproof' Car Security System." *The Independent*, quoted in *comp.risks*, 13:48, May 10, 1992.

[73] Nicholas, Jonathan. "Some people still not getting the signal." *Oregonian*, May 24, 1992, p. L2.

[74] *comp.risks,* 13:44, April 27, 1992 and ensuing discussion in nos. 45 and 46, April 28 and May 2.

[75] Peter G. Neumann, *comp.risks,* 13:46, May 2, 1992.

[76] *comp.risks,* 11:31, March 19, 1991.

[77] *comp.risks,* 13:13, Feb. 8, 1992.

[78] *comp.risks,* 13:09, Feb. 1, 1992.

[79] Phil Agre, *comp.risks,* 13:09, Feb. 1, 1992.

[80] *comp.risks,* 12:20, Aug. 30, 1991.

[81] Keller, John J. "Computers Get Powerful 'Hearing' Aids: Improved Methods of Voice Recognition." *Wall Street Journal*, April 7, 1992, p. B1.

[82] Schwaneberg, Robert. " 'Busy signal' aided an 'anklet' escapee." *Newark Star Ledger*, May 13, 1992, pp. 1, 13.

[83] Schwaneberg, *op. cit.*

[84] *comp.risks,* 10:19, 20, 21, 22, 24, 25, 26, Aug. 10–29, 1990. It's a fascinating discussion. The subject is also discussed in 13: 38, 40, 43, 49, April 10–May 16, 1992.

[85] Hicks, Jonathan P. "Hushing an Engine, Electronically." *New York Times*, Oct. 2, 1991, p. C5.

[86] "Robodoc." *The Economist*. Mar. 14, 1992, p. 100–101.

[87] *comp.risks,* 12:10, Jul. 29, 1991.

[88] Adler, Jerry and Myron Stokes. "A Cadillac With Smarts." *Newsweek*, May 4, 1992, p. 73.

[89] Schine, et al., *op. cit.*

[90] Malnic, Eric. "Causes of Fatal Girl Scout Bus Crash Detailed." *Los Angeles Times*, Nov. 1, 1991, p. B3. Other articles with relevant information: Warren, Jenifer. "Brakes Officially Blamed for Girl Scout Bus Crash." *Los Angeles Times*, Aug. 17, 1991, p. A24; and Malnic, Eric. "Girl Scout Driver Was Unaware of Gear Feature." *Los Angeles Times*, Nov. 2, 1991, p. B6. The original accident story was Warren, Jenifer and Paul Feldman. "7 Die, 53 Hurt as Girl Scout Bus Overturns." *Los Angeles Times*, Aug. 1, 1991, p. A1 and A24.

My thanks to Mark Seecof of the *Los Angeles Times* for providing these and other references.

[91] As of early 1992.

[92] Winfield, *op. cit*., p. 44.

[93] Winfield, *op. cit*., p. 44.

[94] McCraw, Jim. "Wheels, Drives, and Dollars—The Cold Facts." *Popular Science*, Oct. 1991, p. 86.

[95] Watts, Susan. "Computer Systems Developed for Aircraft Are Being Adapted for Use on the Road." *The Independent*, U.K. Mar. 11, 1992.

[96] Buderi, Robert, ed. "BMW Puts a Backseat Driver on a Chip." *Business Week*, July 30, 1990, p. 70.

[97] *comp.risks*, 11:47, April 16, 1991.

[98] *comp.risks*, 11:49, April 19, 1991.

[99] Adler, *op. cit*.

[100] *comp.risks*, 2:12, Feb. 18, 1986.

[101] *comp.risks*, 13:26–8 and 30, March 6,7, 16, and 23, 1992.

[102] *comp.risks*, 10:15, July 26, 1990.

[103] *comp.risks*, 13:57, June 10, 1992.

[104] Mr. William C. Kloos, P.E., Signal Systems Manager, Bureau of Traffic Management for the City of Portland Office of Transportation. Personal communication, Aug. 22, 1991.

[105] This entire section draws heavily on the following three articles: Taylor, Ronald B. "Street Smart: Testing High Tech on the Santa Monica Freeway." *Los Angeles Times Magazine*, April 14, 1991, pp. 16, 38. Ferrell, J. E. "The Big Fix." *Los Angeles Times Magazine*, April 14, 1991, pp. 14, 16, 18 and 38–40. Schine, Eric, Mark Maremont, and Christina Del Valle. "Here Comes the Thinking Car." *Business Week*, May 25, 1992, pp. 84–7.

[106] For much of this information, and a lot of background, I would like to express my thanks to Mr. Jim Harris, Assistant Air Traffic Control Manager, Portland TRACON, Federal Aviation Administration, personal communication, May 26, 1992.

[107] Avizienis, Algirdas, and Danforth E. Ball. "On the Achievement of a Highly Dependable and Fault-Tolerant Air Traffic Control System," IEEE *Computer*, Feb. 1987, pp. 84–90. The quote is from p. 86.

[108] Lee, Leonard. *The Day the Phones Stopped*. New York: Donald I. Fine, Inc., 1991.

[109] Norman, Donald. *The Design of Everyday Things*. New York: Doubleday, 1988.

[110] "Wings, prayers, and prudence." *The Economist*, Dec. 1, 1990, p. 104.

[111] Norman, Donald. *comp.risks,* 10:67, Dec. 7, 1990.

[112] Ferrell, *op. cit.*, p. 16.

[113] Ferrell, *op. cit.*, p. 40.

[114] Caldwell, Bruce, and Linda Perry. "Down and Out in Chicago." *Information Week*, Apr. 20, 1992, pp. 12–3.

[115] "CBS *Evening News*," May 21, 1992. Story reported by Frank Currier.

[116] For this entire discussion of voting by telephone, I am indebted to Peter Neumann and the online *comp.risks* forum, especially 10:60, 61, 64, 67, 70, 72, 73, 78, 81, 83, and 11:1, covering the period from Nov. 14, 1990 to Feb. 4, 1991; and 11:75, 76, 77, 78, and 80, covering the period from May 29 to June 4, 1991.

[117] Haight, Timothy. "Can network computing save the nation?" *Network Computing*, Feb. 1992, pp. 59–60. The quote is from p. 60.

[118] Turque, Bill, Howard Fineman, and Clara Bingham. "Wiring Up the Age of Technopolitics." *Newsweek*, June 15, 1992, p. 25. Also: Stroud, Michael. "Perot's Bold Techno-Populism: Electronic Forums Could Be Abused, Critics Fear." *Investor's Business Daily*, June 11, 1992, pp. 1–2.