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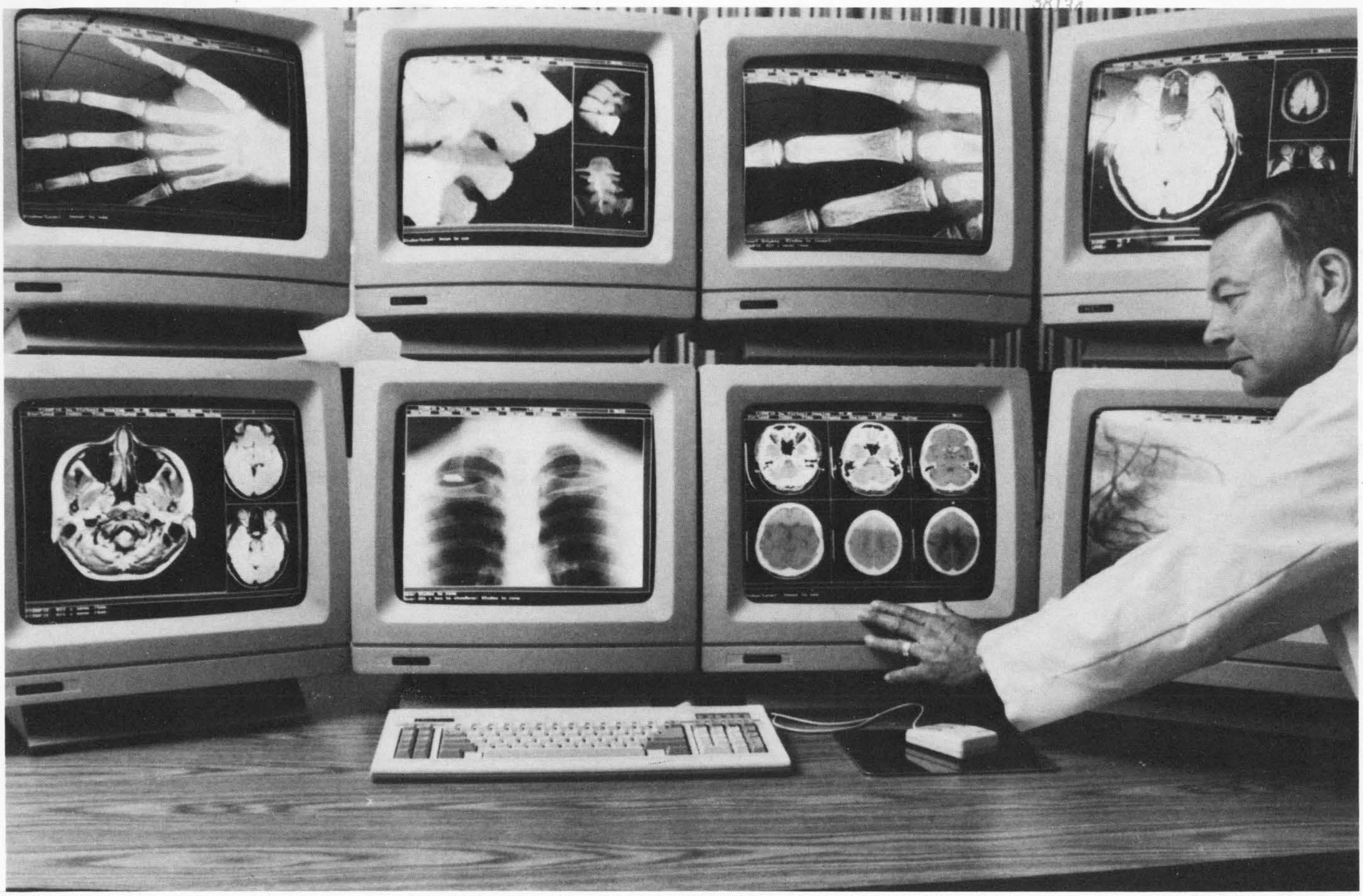

COMPUTER SYSTEM ENHANCES X-RAYS, HELPS PHYSICIANS

The Computer Almanac and Computer Book of Lists — Instalment 56

Neil Macdonald, Assistant Editor

60 TOPICS IN A COURSE "DESKTOP AND PERSONAL COMPUTER PUBLISHING" (List 871101)

Definition of the Desktop Publishing (DTP) Concept
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- Critical Success Factors

(Source: Catalog of Professional Development Seminars, August 1987 through January 1988, issued by Control Data Corp., Institute for Advanced Technology, 1450 Energy Park Dr., St. Paul, MN 55108)

14 VERY FAMOUS NUMBERS (List 871102)

These fourteen numbers are the chief numbers which over the course of tens of thousands of years have caused human beings to think, to ask themselves questions as a part of studying the external world, and to derive answers. The period of time over which the thinking occurred is certainly longer than 12,000 years and may be longer than 100,000 years. Actual archeological evidence of naming and identifying numbers and thinking about them is indirect, but is related to the interpretation of religious practices, music, art, ceremony, and other ancient elements of culture.

Number	Definition
0	zero, the quantity of nothing, recognized as a number by the Hindus and the Arabs long before it was recognized by the Romans and the Europeans; the

start of the X axis of positive real numbers running to the right; the middle of the X X' axis of positive and negative reals running to the right and the left

1 — unity, one, recognized as a number before the dawn of history; the difference between "boy" and "boys," "thing" and "things"; the concept "singular" recorded in Greek and other languages

2 — two, recognized as the number after one, and giving rise to the dual number in Greek and other languages; recognized as a number in prehistory

MANY — an indefinite number, with at least two meanings "more than one" and "more than two"; the concept "plural"; recognized as a number in prehistory

-1 — the negative of one; minus one; one unit to the left from 0 (the origin, zero) on the X X' axis of positive and negative real numbers; recognized as a number in the 1500s

i — the unit of imaginary numbers; the square root of minus one, $\sqrt{-1}$; the unit of measurement on the Y axis up and down (at a right angle) from the X axis; recognized as a number in the 1800s

1.4142... — the square root of 2, identified by the Pythagoreans about 300 BC as an incommensurable number (irrational number), a number that cannot be the quotient of one whole number by another whole number; the first irrational number recognized

2.7183... — the number called e, the sum of the exponential series (1 + 1 + 1/2 + 1/6 + 1/24 + 1/120 ...); the base of "natural logarithms"; recognized in the 1500s as a profoundly important number in the computation of powers and logarithms

3.1416... — the number called pi or π ; the ratio of a semicircle to its radius; recognized as a number by the Ancient Greeks; a subject of the Tennessee legislature at one time, when it passed a law that π should be equal to 3 and 1/7 (3.1429...)

5 — the number of fingers on one hand; in many languages the word "five" and the word "hand" are closely related; recognized in prehistory

10 — the basis of the decimal system of notation of numbers; the number of fingers (digits) on two hands; the scale of notation invented by the Arabs (the Arabic numerals); also the basis of some forms of the abacus, a machine based on counters and locations on a board, or beads and strings on a frame; recognized as a number in prehistory

29+ — the number of earth days from one new moon to the next new moon, and basis of a calendar "moonth"; recognized as a number in prehistory

365+ — the number of earth days from one vernal equinox to the next vernal equinox; the basis of the return of the seasons; the basis of the calendar year; recognized as a number in prehistory

∞ — infinity, the limit of 1 divided by X as X becomes smaller and smaller and smaller approaching zero as a limit; a number that is greater than any given number; in a computer the largest number that that computer can represent in a storage location within that computer, such as 10 to the 63rd power times .9999999999; associated with some special provisions for overflow and stopping the program; used especially to prevent a computer trying to execute "infinite loops" such as "add 1 to the running total S"; recognized as a number in the 1600s

(Source: from "The Computer Book of Lists and the 1st Computer Almanack" by Edmund C. Berkeley, published by Reston Publishing, Reston, VA, 1984)

(please turn to page 28)

Vol. 36, Nos. 11-12
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computers and people

formerly *Computers and Automation*

The magazine of the design, applications, and implications of information processing systems — and the pursuit of truth in input, output, and processing, for the benefit of people.

Announcement

The 1986-87 Computer Directory and Buyers' Guide, the 28th edition, has been published and mailed to all subscribers with a code *D on their address imprint. If you should have received this edition, but have not yet, please let us know.

We thank our subscribers for their patience while we prepared this *Directory*. Future printed editions will be more regular. In the meanwhile, since we are updating our database of names and addresses continually, we are now offering the following service to all *Directory* subscribers:

> If you are looking for information about an organization (with more than 10 employees) before you receive our next printed edition, write or telephone us and we will gladly give you what information we have.

Correction

In the September-October 1987 issue, on page 2, we mistakenly printed an old address for the Computer Security Institute. The correct current address is: 360 Church St., Northborough, MA 01532. We regret this error.

Front Cover Picture

The front cover picture shows a group of patient x-rays that can be made available to physicians in hospitals or their offices via a computerized radiology system called I/PACS (integrated picture archival and communications system). The system's voice-to-text capability allows for faster transcription and distribution of radiologists' reports. Computer enhancement of x-ray images helps doctors to better diagnose and treat patients. For more information, see page 24.

Computer Field → Zero

There will be zero computer field and zero people if the nuclear holocaust and nuclear winter occur. Every city in the United States and the Soviet Union is a multiply computerized target. Radiation, firestorms, soot, darkness, freezing, starvation, megadeaths, lie ahead.

Thought, discussion, and action to prevent this earth-transforming disaster is imperative. Learning to live together is the biggest variable for a computer field future.

Signals in Table of Contents

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Editorial

The Religion of Computers

Edmund C. Berkeley, Editor Emeritus

Is there a religion of computers?

For a religion to exist, there needs to be a group of "believers" and a doctrine in which all (or nearly all) of them believe, a set of statements to which they agree. Ordinarily, this doctrine is attributed to decrees or "truths" coming from "divine" origin, persons (or forces) real, historical, ancient, or imagined, who have asserted the statements in past centuries. These statements are declared to be "true" and any denial of them regularly causes a "believer" to be rejected from the group.

Religions attract people. It is easy, comfortable, and natural to grow up within a family and neighborhood and to accept from family and neighborhood the neighborhood religion. But great contenders of the neighborhood religion are science, industry, and government. These institutions of society require change, changes as time goes by in all kinds of statements. The test of a scientific statement is experience and experiment: if the experiment works, it is provisionally true; if not it is provisionally false. The test of statements by industry and government is again "Does it work? Does it happen?" These tests are a trouble to religious people who "believe" in an unchanging "sacred" or "divine" world. They are regularly unable to change (or update) their religious beliefs.

A large number of people now "believe" in computers. For computers perform activities which never previously were possible. Most people are convinced that computers do actually perform these activities; but most people do not understand how computers accomplish these "magical" acts, and their common everyday viewpoint is a combination of "They work, and sometimes I can use them, but they are completely mysterious to me." So they have a rather profound religious quality.

For example, part of the religious aspect of computers is the common statement "Garbage in, garbage out." This refers to the fact that if you put wrong information into a computer (either a machine or a person), you are very likely to receive wrong information out of it. But if you think over situations in the real world, you observe that adding a tiny amount to a big amount often results in the big amount unchanged. 10,000 miles plus 1 mile is practically the same as 10,000 miles. Another famous example is that for over 200 years the physical and geometric description by Isaac Newton of the motions of planets in the sky was accepted as the truth.

And so we come to a rather surprising conclusion:

1. There is a religion of computers.

2. It consists of a small number of facts and true statements.

3. It consists of a large number of beliefs and mysteries.

As we all become more and more involved with a computerized civilization, we become less and less able to use the common sense and wisdom of past civilizations.

Ω

The Steam Engine and the Computer: What Makes Technology Revolutionary

Herbert A. Simon
Prof. of Computer Sciences and Psychology
Carnegie Mellon Univ.
Pittsburgh, PA 15213

"The point is that when technology reshapes society, it is not the result of a single invention but of a host of additional, completely unanticipated inventions, many of them of the same order of magnitude as the first one in the chain."

It may seem absurdly anachronistic to be reflecting about the steam engine in a conference devoted to the role of computers in higher education. But it's often been said that computers have triggered a second industrial revolution, so perhaps there are some lessons to be learned from the First Industrial Revolution, the one that was triggered by the steam engine -- lessons that might have some bearing on what we can and should do with computers and on what computers might do to and for us.

The First Industrial Revolution

We think of revolutions as being sudden events, producing far-reaching changes in a very short period of time. But the revolution launched by the steam engine took, by any reasonable account, 150 years. The invention that started it was Thomas Newcomen's "atmospheric" steam engine, which appeared in about 1711. Newcomen developed his engine primarily because his coal mines were being flooded and he needed more powerful pumps than were currently available to get water out of the mines. James Watt made some important improvements on the engine in 1769, in the course of trying to repair one of Newcomen's engines. Two generations had already gone by, and one could hardly speak of a revolution yet. The aims and aspirations of these "revolutionaries" were distinctly limited.

In order for the steam engine to produce genuinely revolutionary change, there had to be a whole series of subsequent inventions, none of which were -- or could have been -- contemplated by its originators, and these took still another generation, reaching well into the 19th century. The steam engine was adapted for use in transportation, giving us the steamboat and steam locomotive, and in industry, the power loom. Perhaps even more important were a number of complementary inventions that were initially quite independent of the steam engine but that were harnessed to it to produce further changes. The most notable of these was the dynamo, which used the steam engine to generate electricity. (To convince you of how long this revolution took, let me remind you that there were many rural areas in the United States that didn't have electricity until about 50 years ago.) Then there was another series of what it is fair to call "derivative" inventions -- the internal combustion engine, the automobile, the electric light bulb, the airplane, the telephone. The point is that when technology reshapes society, it is not the result of a single invention but of a host of additional, completely unanticipated inventions, many of them of the same order of magnitude as the first one in the chain.

More Than "Technological" Change

Conversely, what we sometimes call technological change actually permeates society, affecting it in far more than merely "technological" ways. Before the automobile, one of the most important skills of a physician, certainly the one he used the most, was the skill of driving a horse. For a while, that was replaced by the less-time consuming activity of driving an automobile. Now, physicians don't even have to do that; their patients come to them. We don't ordinarily think of the steam engine as changing medical practice, yet it did; it certainly altered the physician's time budget. The creation of the suburbs is another example. And -- though again it seems surprising at first -- one of the largest migrations in human history was brought about by air conditioning, which transformed what many people thought of as uninhabitable parts of our country into the very attractive sunbelt. The invention of air conditioning is usually dated at about 1911, and no one at that time could have anticipated that, as a result of it, a large part of the American population was going to move from one part of the country to another. As one more example, the burning of coal to produce steam for the generation of electricity had a number of adverse consequences, leading us to look for other fuels that could be used for the purpose. As a result, we opened that Pandora's box known as nuclear power.

Lessons Drawn from the First Revolution

I've already alluded to one lesson to be drawn from all this, and that is the lesson of unpredictability. There are no crystal balls that can tell us what the consequences of a fundamental technological change are going to be. A genealogical chart of the First Industrial Revolution would encompass about six generations. Parents all come to understand the impossibility of foretelling how their children are going to turn out; how much more futile it would be for them to try to imagine what their great-great-great-great-grandchildren will be like.

A second lesson, also alluded to, is the extent to which the ramifications of any one technological change depend upon the stimulation it provides to other inventions, and the links that are made from it to inventions that may be independent of it, as steam was linked to electricity.

A third lesson is the importance of what we might call "education by immersion." Most Americans, after all, did not learn to drive automobiles in driver-education classes. Instead, they learned to drive because there was a Model T on the farm, or maybe a tractor, and there was something or someone that had to be moved from here to there -- so they got in their cars and figured out what all those levers and pedals did, and they also learned, out of necessity, how to take the car apart and put it together again. None of this was planned ahead of time; nobody sat down and figured out the kinds of courses that would be needed in order to teach people how to use these new contraptions. We educated ourselves about them because they were all around us.

A final lesson to be drawn from this history is the lesson of generality. In the last analysis, the reason that the steam engine and the associated inventions proved to be revolutionary is that they didn't do anything specifically. Rather, they allowed us to move in innumerable directions. They replaced and augmented human and other forms of animal muscle by the muscle of engines, thereby completely transforming the nature of that major input into everything we produce -- energy. No single-purpose device is going to bring about a revolution, however convenient or useful it may be. Revolutionary significance lies in generality.

Applying Those Lessons to Today

How are these lessons applicable today? If we were to make a genealogical chart for the second industrial revolution, it would of course be far less elaborate than the one for the first, because computers have been around for only about 40 years. Though there have already been a number of derivative inventions, most of them are still fairly closely related to the original conception of the computer whether it is solid-state hardware, time sharing (now almost outmoded), higher-level languages or methods of non-numerical computation of various sorts, primarily means of making the computer faster and more powerful. At most, there have been two generations so far. It is true that people in the hardware business like to say that they are now in the fifth generation, but that's a little like asking us to accept child marriage. I think it's more accurate to say we're now in the third generation, and even that one is at most in its adolescence.

Elements of the Third Generation of Computers

This third generation is identified by several elements. One is the appearance of minicomputers and microcomputers. Their significance is not in the opportunity they give us to play games at home or to keep the family accounts, but in the fact that they open up the possibility of computer education by immersion. Today, for the first time, we can say that a very large proportion of the American population has had hands-on exposure to a computer (and the event is recent enough to be still very vivid in the minds of most of us).

Another element is the development of computer graphics and of new kinds of workstations. Still another is computer-aided instruction. Of course, computer-aided instruction has been around in some form for almost as long as computers have been. We have had an instructional management game in operation at the business school of Carnegie

Mellon University since at least 1960. Nevertheless, computer-aided instruction is still rather primitive and has had only a very modest effect on the way education takes place in this country or anywhere else.

Robotics, expert systems, and cognitive science are also part of the third generation of the second industrial revolution. And finally, computers are beginning to form links with other parts of technology, in particular with our systems of communications and information transfer. Networking is one example of this -- the creation of a system in which computers no longer stand alone but can talk not only to us as individuals, but also to each other, in a great variety of ways.

What Computers Can't Do vs. What We Can Get Computers to Do

Surely, the second industrial revolution is just as unpredictable as the first one was -- and the second has barely begun. We are closer in time to the first computer than James Watt was to Thomas Newcomen. There is a lot of solemn talk about what computers can't do but that's not a very interesting subject. Computers today are doing a lot of things they were "known" to be unable to do a while ago, and what they can't do today they may very well be doing tomorrow. Besides, our task is not to decide what computers can't do but to look ahead for the very short distance that we are capable of and to think about what we can get computers to do, what we would like them to do that they can't do right now. Each year we see more impressive computer systems for handling natural language. Still, most of them are limited to particular domains of discourse. I know of no computer program today that can enter into a general conversation with you about anything you want to bring up. There is plenty of room for developments of that kind without worrying about whether there are ultimately some things that computers will never be able to do.

It is sometimes said, by way of demonstrating the superiority of human beings, that computers cannot be imprecise, even when the situation demands imprecision. I'm not sure that this is a shortcoming -- how much have humans really gained from their ability to be imprecise? -- but anyone who has had much experience with computers is not likely to believe that they cannot be imprecise. More and more, we are using computers in tasks where the exact course of action is not determinate at each moment. A problem solving program, an expert system, is an organized but highly flexible way of making sure of information that is incomplete and imperfect and that comes to it in a variety of forms and sequences. A capability for imprecision no longer marks the boundary between what computers can and cannot do.

What People Can Do vs. What Computers Can Do

Human beings are also said to possess "intuition." That's a term we use when someone looks at a problem and doesn't at first know the answer, but a minute or two or even just a few seconds later, does know the answer, and knows it without any awareness of the process by which the answer was found. When we see someone coming down the street, we may not know who it is at first, but if it's a friend we are likely to know it long before we know how we knew it. But if that's what intuition is, then it can be said that computers have it, too.

An important part of the anatomy of an expert system is a database, indexed by a set of cues that the system can recognize. When one of those cues appears, the system retrieves relevant information from its database. A medical diagnosis system, for example, can be presented with a few symptoms, and it will "intuit" what the ailment is. Of course, like any prudent diagnostician, it doesn't entirely trust its intuition, so it goes on to request that certain tests be made, and with the additional information, it confirms or refines or alters the diagnosis. Unless we deliberately want to make a mystique out of human thinking, and sometimes it seems that we do because it makes us feel better about ourselves, we have to conclude that what's going on in such a system is exactly what we call intuition when a human being does it. Once again, the supposed contrast between what people can do and what computers can do doesn't fit the facts of computation in the modern world.

When we're especially impressed by an intuition, we are apt to call it "insight," and beyond that we begin to talk about "creativity." Here too, however, there are computer programs that can do things that would be regarded as "insightful" and "creative" if they were done by humans.

Theorems in mathematics and logic have been discovered and proved by computers unaided by human hands or minds. Some of my associates and I have been working for six or eight years on a program that we call

BACON. We have given it, for example, the data that Kepler had available to him at the time he made his discovery of the third law of planetary motion or that Joseph Black had available when he proposed his theory of specific heat, and we found that the program is able to rediscover the law or the theory. /1/ We can conclude that we don't have to postulate any kind of mysterious processes, any kind of fundamentally unknown -- much less unknowable -- processes to account for what in humans we like to call creativity. Hence, we can't establish the creative process as an Iron Curtain that limits what computers can do.

Computing by Immersion

The first computer we acquired at Carnegie Mellon was an IBM 650. When we got it, in about 1958, we didn't have any idea what we were going to do with it. The electrical engineers didn't want to be associated with it because they were afraid they would have to maintain it; the mathematicians didn't want to be associated with it because it seemed beneath their dignity. So we put it in the basement of the business school, but we were very careful not to put a lock on the door. What happened was that the students swarmed all over it, just as previous generations had swarmed over the Model T. It was then that the faculty began to learn about it, to save themselves from embarrassment. What was happening was education by immersion.

The same phenomenon could be seen in industry. In those early days, a business executive would decide that his company ought to have a computer, often merely because one of his colleagues at another company had just gotten one and he wanted to be progressive and up-to-date. On occasion, I was called in to advise in such situations, and my advice was usually, "Before you buy a computer, decide what you intend to do with it, and then plan your installation around those intended uses." That was terrible advice, and I probably ought to return the fees I got for giving it. Fortunately, my advice often wasn't taken, because the motivation for getting the computer was not to use it but just to have it. But then it arrived, and when I observed what happened afterward, I realized that the best advice was, in fact, just to have one around, for that's the only way a company or a university, or anybody else, is going to learn what to do with it. You have to make friends with it, talk to it, let it talk to you. Hit the keys and see what happens. The computer will tell you about itself, and it tells you probably better than the instruction book. Immerse yourself in the technology. I don't mean we shouldn't have classes about computers -- after all, I work for a university -- but they are not going to be the major educational force. One of the most impressive things about a computer is its capacity, by virtue of its power and the flexibility of its responses, to be its own instructional device.

Computers and Education

Besides helping us learn about themselves, computers can play a role in helping us learn about other things as well. We are indeed a long way from knowing what computers can do for education. In our university, we certainly don't have a detailed blueprint for what our campus is going to look like with a network, or with all the things a network will bring about. We are engaged in an exploration, an adventure.

At Carnegie Mellon today, we have a computerized campus mail system. It's a great convenience, and I think students find it so, too. I'm much more accessible to them now than I was ever able to be before. They can write me a note, without having to go through a secretary, and what's more, I often answer it, and promptly, because it's so easy to do. A fair amount of my correspondence is conducted that way now. It has obvious advantages even over the telephone, because you don't have to be there when the call is made, and the sender doesn't have to be there when you return the call, so information is actually transferred more quickly than is often possible by phone. That's the kind of modest change computers have brought so far to our campus. Change of this kind is hardly revolutionary.

Before the computer and all the associated devices can have any great impact on the educational system, there have to be major developments in our understanding of what the educational process is. Up to now, particularly at the university level, we have operated on what I call the "infection theory" of learning. This theory holds that if you assemble a large number of people in a room and spray a large number of words at them, some of those words will be infectious and will stick with some of those people and perhaps affect their future behavior. (Another form of the theory is that people are infected if they spray themselves with words from a large number of pages of print.)

A different theory might be called the "Mr. Chips" theory, according to which students learn by being treated with tender loving care. But, while tender loving care may be important for students as it is for patients in a hospital, it is no more adequate as a theory of learning than it is as a theory of curing disease.

Technology has helped to implement the infection theory in a modest sort of way. It has provided the means for broadcasting the words, using microphones and loudspeakers or headphones, and for putting the professors on film. (Sometimes I think that it's only the economic self-interest of professors that demands that they be there live at all.) Though some people believe that technology actually interferes with Mr. Chip's ministrations, I think the contrary is true, as I've already suggested in describing our campus mail system. The idea that having a lot of screens and boxes around makes human beings less interested in talking to each other, or doing all the other kinds of things that human beings do, just isn't borne out by the facts. At Carnegie Mellon, the Computer Science Department has been saturated with networked computers for a dozen years, yet it is the most social and sociable department on campus, both at work and at play.

A Revolution in Education

On the other hand, an improved technology of infection still does not amount to a revolution in education. If computers are to have real educational significance, there will have to be a major advance in what's now called cognitive science. We must gain a much deeper understanding of what it is that a student learns, what it is that a student should learn in order to become capable of exercising particular skills, and how that learning comes about. The theory we need does not so much concern the electronics we have available as it does the human component in the system that does our thinking and our learning. A good deal of progress has been made toward that theory, or at least its foundations, in the past 30 years. Now we are just getting to the point where researchers are beginning seriously to apply it to actual educational procedures.

It seems equally obvious to me that computers will not revolutionize education until there are massive changes in the organizational and administrative structure of the educational system as well. There must first of all be a redefinition of the teacher's role. Perhaps we'll never reach the point of having a completely professor-free university, but at least the professors will have to abandon the theory of infection. Secondly, we have to develop new conceptions of the production and marketing of software. There is no more sense in having each university prepare all its own instructional programs than there would have been in having each one publish its own textbooks. In general, for every megabuck we spend in hardware and systems software, we will need to spend another megabuck for research on effective learning and development of modern learning environments in the schools.

By way of conclusion, let me say that, as I hope the examples of the steam engine and the computer make clear, new technology is simply new knowledge; and as such, it resides not in machines but in the human brains that invent them, develop them, and use them. Even though the machines can help us learn about their characteristics by our use of them, still, in the last analysis, we have to think about technology in terms of human knowledge.

New Possibilities for Human Learning

Knowledge confers capabilities, but capabilities, like knowledge itself, can be used for good or ill. Prometheus brought us indispensable knowledge, while Pandora brought us mischievous knowledge. Yet, without denying all the problems that we face in contemporary society, some of which are admittedly an outgrowth of our knowledge, I think that most of us would rather be living in the 20th century than in the 13th. Technological revolutions are not something that "happen" to us. We make them, and we make them for better or for worse. Our task is not to peer into the future to see what computers will bring us, but to shape the future that we want to have -- a future that will create new possibilities for human learning, including, perhaps most important of all, new possibilities for learning to understand ourselves.

Reference

/1/ Langley, P., H. Simon, G. Bradshaw, and J. Zytkow. "Scientific Discovery." Cambridge, MA, MIT Press, 1986.

Based on the keynote address of EDUCOM '86, as printed in *EDUCOM Bulletin* of Spring 1987, Vol. 22, No. 1, published by EDUCOM, 777 Alexander Rd., Princeton, NJ 08540. Reprinted with permission.

Ω

Computer Intimidation and Anxiety —Part 2

Dr. John Shore
c/o Viking-Penguin Inc.
40 West 23rd St.
New York, NY 10010

"Fear, almost always, springs from ignorance."

(Part 1 appeared in the September-October, 1987 issue of "Computers and People".)

Computer Anxiety

Our dependence on computers is broad, deep, and intensifying. This fact causes anxiety -- anxiety about using computers ourselves, anxiety about dealing with the computers around us, and anxiety about the effects of computers on our society.

Many people want to use computers to improve their personal and professional lives. Some of these people dive easily into the computer mainstream. Others want to get into it, but they hesitate to take the plunge; they're afraid that computers are too difficult, too technical, and too unfamiliar. Still others have these same fears, and they're not at all attracted to computers; unfortunately, they're being pushed.

Many people notice that they get more mail from computers than from people, and they don't like it; they feel victimized by junk mail, credit cards, utility bills, other examples of computer-controlled commerce. If they disagree with a bill or balance statement, they feel overwhelmed by the effort required to object, and they feel unprepared to do so effectively. They worry about the effects of computers on society. The computer is seen as an adversary.

Computer anxieties are real. They add psychological and sociological dimensions to the spread of computer technology.

Keyboard Paralysis

To those who've never experienced it, "keyboard paralysis" sounds like a joke. But it's a real problem for many people, both those who want to use computers and those who'd rather not. The symptoms are obvious: a vague discomfort when asked to sit in front of a computer terminal, a conscious fear when asked to press some keys. The victims ask themselves:

"Will I break it?"

"Will I destroy some information?"

"Will I feel foolish?"

"Will I look stupid?"

"What if it beeps?"

Their hands hesitate; depressing the first key is an act of will. The main reason for this hesitation is the uncertainty of the result. And this uncertainty, this sense of unpredictable consequences, causes anxiety. I've watched people suffer through keyboard paralysis, and I've talked people through it, but only recently did I taste it myself.

It happened when I was shopping for a word processor on which to write this book. For years I've used computers in my work at the Naval Research Laboratory, not just as research tools, but as tools to help me write everything from scientific papers to bureaucratic memoranda. Indeed, I depend on computers to help me write faster and better. When I decided to write this book, I wanted a personal computer at home to support me in the style to which I had become accustomed. About this time there became available a number of personal computers that essentially were scaled-down versions of the relatively large systems I knew well. This was an exciting development, and, as I began my search, I assumed that I would buy one of them. In the end I didn't. Instead, I bought something different -- an Apple Lisa, which was then a brand-new product.

The Electronic Mouse

I first saw the Lisa at an hour-long demonstration in a local computer store. I went expecting to leave with a long list of things the Lisa did poorly or not at all, but I left with a short list. I was impressed. About a week later I went to see the Lisa again and to talk more with the people selling it, this time at a "computer show" at the Washington Coliseum. A few days after that I returned to the store and read the Lisa's manuals. The following week I went back again to see a final demonstration and to sign a purchase order. At this point I was well informed about the Lisa, but I hadn't actually used one myself. I had definitely wanted some "hands-on" experience -- I couldn't imagine buying a new computer without it -- but somehow it hadn't worked out. There was only one Lisa in Washington, and the salespeople didn't exactly encourage every prospective customer to hang around and play. At the final demonstration, however, I had my chance, and of course I took it. The salesperson left the room for something, and without even a furtive glance around, I reached out. But then the unexpected -- for a small but acutely self-conscious moment, my hand hesitated. Keyboard paralysis.

It was the mouse's fault, sitting there quietly next to the Lisa. Mouse? I refer not to some unwelcome desktop rodent, but to a palm-sized, box-like object with a button on top, a rolling ball underneath, and a wire connecting it to the Lisa. A wonderful invention, the mouse is used to interact with the Lisa in a relatively natural and efficient manner that supplements use of the keyboard. When you move the mouse around on the desk, a corresponding mark on the display screen moves in concert. As a result, you can use the mouse to point to something and you can then press the button on the mouse as a means of issuing commands.

What bothered me about the mouse? Was it the confrontation with a radical, unfamiliar innovation? Not exactly. Although the mouse wasn't common in personal computers when the Lisa was introduced in 1983 (for example, Apple's Macintosh had not yet been bred), the Lisa is hardly the first computer with a mouse. Indeed, mice -- the legitimate plural of a perhaps illegitimate noun -- are old by computer standards. Mice were invented about twenty years ago by Douglas Englebart and William English at the Stanford Research Institute (now SRI International) and have been used enthusiastically ever since by many in the R&D community. Nor was the Lisa the first computer to use a mouse in a commercial product that achieved widespread use; that distinction belongs to the Xerox Star. So mice had been around for quite a while. And I had known about them for a while -- I knew their history, how they work, what they're used for, and their advantages.

Despite this knowledge, I still hesitated. Why? Simple: I knew all about mice, but I had never used one! Intellectually I knew what to expect, but I didn't have the assurance that comes only with direct experience. In this respect, using a computer is like cooking a soufflé, driving a car, hang gliding, and having sex.

Keyboard paralysis is widespread. The phenomenon is recognized as a significant problem by people who sell computers, train new users, or design training programs. Often it comes with a first -- the first time you use a computer, the first time you use a new computer, the first time you use a new computer program. Keyboard paralysis decreases with experience, because experience improves the ability to predict.

Computer Anxiety at Work

The severest cases of computer anxiety occur on the job, where computers are wrenching the status quo. Whether workers face office automation or factory automation, they see their own obsolescence and they're uncertain about their ability to adapt. Also, as more jobs require the use of a computer, fewer of those people who are susceptible to computer anxiety can avoid being exposed. For years, computers were used only by those who were drawn to them and took to them easily. Not anymore.

People are confronting computer technology throughout the work force -- shopkeepers, lawyers, secretaries, clerks, accountants, doctors, restaurateurs, assembly-line workers, and managers of all types. Many of them have to deal with computer professionals, but they have no computer training themselves -- they feel ill-equipped, intimidated, and insecure. Others are choosing to use computers themselves, or are being pressured into doing so, but they have trouble getting started and they don't get far. Whether or not they suffer initially from keyboard paralysis, once they start typing they become frustrated and annoyed. They keep making mistakes, and they don't understand what they're doing wrong. They have trouble controlling the computer.

A common example of computer anxiety occurs when word processors are first introduced into a traditional office. For secretaries in such a situation, there's considerable pressure to master the new machine. Whether the word processor is seen as an obligation or an opportunity, many are unsure of their ability to master it. What if they fail? Will they lose their jobs? And even if they succeed, will they lose their jobs anyway -- not to people who are better-trained, but to a next-generation word processor? These feelings can be intense, with dramatic results.

In 1975 I was responsible for a small group of people engaged in computer science research and development. Around this time word-processing technology had reached the point where it made sense to introduce it into an office such as ours. I proceeded to do so, despite my secretary's implacable skepticism. When the machines arrived, I gave my secretary the responsibility of redesigning the office layout -- I asked that the word-processing terminals, the printer, and the other equipment be put in appropriate places -- and I left. When I returned, a terminal was near my secretary's desk; but it hadn't displaced the typewriter, which remained, poised for use, on top of the desk. Being a clever technologist but a not-so-clever manager, I switched the positions of the typewriter and the terminal. My secretary retreated, in tears, to the head administrative officer of our division.

I was surprised by this reaction, but I've since found out that it could have been worse. Other reactions to computer anxiety have included hyperventilation, vomiting, and attempts to destroy the offending machine. I was even more surprised by the longevity of the reaction. I knew that there was anxiety and skepticism, but I was confident that the word processor would enthrall my secretary quickly. Wrong again; it took almost a year. To me, the word processor was a predictable, efficient tool that provided elegant solutions to numerous office problems. There were a few "glitches," but these could be explained easily, and they were no more inconvenient than various typewriter-associated inconveniences we lived with comfortably. It was obvious that the word processor would not only make my life easier, but my secretary's as well. To my secretary, however, the word processor wasn't predictable, efficient, and elegant; it was threatening, capricious, opaque, and clumsy.

Computer Anxiety at School

At school, there's pressure for educational computing -- teaching about computers and with computers. The pressure comes from parents, students, school administrators, public officials, and some teachers; much of it arises from the assumption that "computing" will soon be a necessary basic skill, just like reading, writing, and arithmetic. Although the importance of "computer literacy" is sometimes overdramatized, it's a valid educational goal. As Robert S. McNamara wrote in 1968:

> A computer does not substitute for judgment any more than a pencil substitutes for literacy. But writing without a pencil is no particular advantage.

Additional pressure arises from the computer's tremendous potential to serve as an effective tool for teaching other subjects. The overall pressure is intense. One indicator is money: educational computing is the one area of the school budget where additional spending is favored by practically everyone concerned.

Spending money for educational computing is one thing; spending it wisely is another. Given the money, most schools proceed happily down the path of least resistance: they buy some computers. They do so without adequate planning for how the computers will be used and without adequate planning for teacher training. Such planning raises tough problems, and there are few readily available, tested solutions. But there's relentless pressure to do something, and everyone knows how to go shopping. The results are predictable: intense anxiety for teachers and ineffective educational computing for students. Successful educational computing cannot be achieved merely by placing computers in every classroom, like Gideon Bibles.

During the summer of 1982 I began participating in the planning for an educational computing program at my daughter's elementary school. When I first became involved with the planning group, they were doing the usual thing: surveying the market and deciding what to buy. Thanks to a small group of recalcitrants, we stopped the market survey and began formulating a more comprehensive plan. We did not finish quickly. We wrote position papers and proposals for external funding. We debated endlessly -- vocal evidence of the power of anxiety-fueled opinions over facts. Moreover, the debates were among parents, teachers, and administrators -- three forceful groups with different concerns and different anxieties. These groups rarely agreed, even among themselves, and progress in the debates, when it occurred, seemed to be random.

A year and a half later we were done. We had an approved plan, not only for buying equipment, but also for teacher training and curriculum modifications. It was a reasonable plan, but it was shamefully modest compared to the time and effort involved in preparing it; if you read it, you might guess it had been produced in a week or so. After another six months, even this plan had been abandoned. Owing to committee fatigue, generous gifts, and a resurgence of the shopping instinct, computers were put into most of the classrooms, while teacher training and curriculum modification were left to evolution.

Our failure attests in part to the difficulty of the problems, to the lack of well-tested solutions, and to the inefficiencies of volunteer committees. But mostly our failure attests to the power of the anxieties involved. I came to realize just how intense and reasonable were the teachers' anxieties. They were being asked not just to accept computers for their own use, and not just to allow their students to use computers -- they were being asked to integrate computers thoroughly into their classroom activities. Like professionals in other fields, teachers feel threatened by the technology, and they are uncertain about their ability to master it. But in other fields people need only learn enough to use the technology -- teaching requires a deeper level of understanding. Teachers know this, and it multiplies their anxiety. To make matters worse, children are quite without computer anxiety and in many cases already know more about computers than do their teachers.

Anxiety for Society

Computers affect us whether or not we use them ourselves. On the sinister side, people worry not about their ability to master computer technology, but about the ability of computer technology to be used in mastering them. They also worry that the public safety may depend too much on computers. They ask questions about computer crimes, electronic vandalism, invasions of privacy, political power, military power, and the possibility of computer-instigated disasters. Will the biggest robberies of all time be accomplished by breaking into vaults, or by breaking into computers? Will the worst military mistakes of all time be made by generals and admirals, or by computer programmers? Will the worst disruptions of everyday life be caused by natural disasters or by computer failures? Will history record that the most effective manipulations of populations used mass media to broadcast to everyone, or mass memories to record data about everyone?

On the social side, people ask about employment, education, and economics. They worry that computers will take jobs away from people. They wonder if children must learn about computers in order to make it in tomorrow's society. Will computers enlarge the gap between rich and poor? Will the advantages of computers bypass the disadvantaged?

And on the personal side, people ask about their intellects and their relationships. As we depend more and more on computers, will our minds grow dull? As we turn more to electronics, will we turn away from each other?

As consumers, we can choose to participate or not in certain aspects of the computer revolution. But as citizens, our choices are fewer; we feel less in control, a feeling that itself heightens our anxiety about the effects of computers on our society.

Dealing with Computer Anxiety

Ralph Waldo Emerson said: "Fear always springs from ignorance." While this is hardly true in general -- it would not, for example, be convincing if affixed to my dentist's spotlight -- it does apply to keyboard paralysis and related anxieties. Information about how computers work can ease the anxieties associated with using them.

Unfortunately, new users often don't get enough basic information because veterans underestimate how important that information can be. Experience insulates veterans. We take for granted all sorts of skills, intuition, and information; we overlook how often we use them, how hard it can be to acquire them, and how hard it can be without them. Such oversights on my part contributed to my secretary's problems with the word processor. I relied on inadequate manuals, sporadic and sparse explanations, occasional visits by "customer service representatives," and psychological pressure. I should have insisted on a systematic training program.

Information can calm fears about using computers. But fears about the effects of computers on society are a different matter. Some of these fears also spring from ignorance, but many do not. On the contrary, some of them are apparent only to the well-informed. This just means that information is important for a different reason -- not to eliminate the fear, although that may happen, but to illuminate the cause.

In both cases, however, information isn't enough. You have to start using computers, and you have to form your own opinions about the effects of computers. But information can make your actions easier and your opinions educated. Whether you welcome the computer revolution or fear being one of its victims, information can help.

Computers and Sex

Many people recognize that information can help, but they wonder about who can learn. For example, the subject of computer anxiety is tinged with traditional prejudices about the role of women in science and engineering. Arising as a modern blend of mathematics, machinery, and microelectronics, computers arrived with a masculine aura. Traditional stereotypes suggest to some people that computers are harder for women (high tech, don't touch).

Given the legacy of traditional female roles, it could be true that women are more susceptible to computer anxiety than are men. But whatever their initial feelings about computer technology, there's plenty of evidence that women can learn about it, use it, control it, and contribute to it. Large numbers of women operate comfortably at every level of technical expertise in computer technology.

In 1980 there were more than 3,000,000 scientists and engineers in the United States, including computer specialists. Only 13 percent of the scientists and engineers were women, but 27 percent of the computer specialists were women. Moreover, the proportion and number of women in computer science and engineering are increasing rapidly: In 1972-73, only 14.9 percent of the bachelor's degrees in computer science were earned by women; in 1980-81, the figure was 32.5 percent.

Participation is one thing, remuneration is another. A 1978 salary survey of "experienced scientists and engineers," defined as those scientists and engineers who were already in the labor force at the time of the 1970 Census, reported that women in the computer specialties had an average salary that was 90 percent of the average male salary. This is not equal pay for equal work, but the 90 percent figure is larger than that for any other science and engineering category covered by the survey -- including engineering, psychology, life sciences, mathematical sciences, physical sciences, and social sciences.

Why are women more successful in computer science and engineering? The most likely reasons are that computer technology is relatively new, arriving in the 1940s less tinged with prejudice than its predecessors; that women have been involved with computer technology from the beginning; and that the technology exploded from the 1960s to the 1980s, during a time of increasing female participation in the work force and increasing attention to feminist issues.

Women are fully capable of dealing effectively with computer technology. Lots of women are doing it, and they're doing it well.

Computers and Age

Perhaps you worry that you're too old to learn about computers and too old to use them. After all, it's often said that the time to learn foreign languages, mathematics, and practically anything else is when you're young. Don't worry.

Consider one example: the world's leaders in the fields of computer science and engineering. Suppose you made a list of the ten most distinguished, respected people working in these fields today, and suppose you looked into the backgrounds of the people on the list. You would find that most of them are, insofar as their computer knowledge is concerned, largely self-taught. Their formal education was in other fields, and most of it occurred before their involvement with computers.

Fifteen years ago it was unusual to meet an accomplished computer user, unless you happened to be "in the business." Today there are millions of accomplished users and it's no surprise to meet one, no matter what business you're in. For most of these users, their first computer experiences took place well past their formative years. They did it, and so can you.

Much Easier Than It Seems At First

It really is. Most people can understand the basic principles behind computer technology, and most people can learn how to use computers successfully. Many doubt their ability to succeed because their anxieties

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Computers and Solving Global Problems: Buckminster Fuller's World Game

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"...The World Game was based on assumptions of potential abundance, the possibility of solutions where everyone wins, and 'enemies' that consisted of such conditions as starvation, drought, and illiteracy – not other countries or people."

In 1967, Buckminster Fuller, the ebullient philosopher of geometry, architect, and global visionary, completed what many consider his masterpiece. The United States Pavilion at the Montreal World's Fair, Expo '67, was a 250-foot-diameter geodesic dome (a light, domelike structure which combines structural properties of the tetrahedron and the sphere) of epic beauty. The revolutionary structure won for Fuller almost every architecture award that there was to win and brought him to the cover of "Time" magazine and international acclaim. But, unknown to most people, this stunning accomplishment was only a hollow shell of what Fuller proposed.

Computerized Game for Solving World Problems

In addition to being the architect for the United States Pavilion, Fuller proposed the exhibits as well. He proposed that the United States build a "great logistics game" that would be played in the dome by world leaders, researchers, students, and the general public. The Expo '67 dome would house a giant map of the world that would be connected to an equally large computer. The computer would store an inventory of the world's resources, human trends, needs, problems, and opportunities. The big map would display these vital statistics for the public and world to see. Different teams or individuals from around the world would then use this database to develop and evaluate alternative strategies for solving world problems.

Fuller envisioned policy and decision makers from the Soviet Union, United States, China, Europe, Africa, South America, and the rest of the world competing against each other to develop the best strategy for solving a world problem. Instead of war games, the "world game" would be a tool for figuring out how to rid the planet of illiteracy, starvation, lack of health care, inadequate energy supplies, etc.

In Fuller's vision, the first week of The World Game at the Montreal World's Fair might be focused on food. The first team or individual that could demonstrate how humanity could eliminate starvation and malnutrition, using only known resources and technology, would be declared the "winner" of round one. Round two would be won by the team that could do it even quicker, or by using less resources, or doing it less expensively, or by doing two things at the same time -- such as providing clean water as well as food. The next week, The World Game would focus on energy, then illiteracy, health care, housing, and eventually come back to food for another go-round.

The Possibility of Solutions

Whereas war games are based on the assumptions of scarcity, the need to control scarce resources, and defeating the enemy, The World Game was based on assumptions of potential abundance, the possibility of solutions where everyone wins, and "enemies" that consisted of such conditions as starvation, drought, and illiteracy -- not other countries or people.

The World Game views the whole earth as the "gameboard"; all the world's resources, technology, and problem-solving know-how as the "game pieces"; and a "player" as any person concerned with life on earth and interested in developing new alternatives and opportunities for humanity.

The World Game was intended as an apolitical peace "game" that would allow the leaders of the world to test out their ideas for international cooperation, regional development strategies, or even local tactics that could synergetically interact with the rest of the world. The World Game was to be a tool for making visible the earth as a whole system with vast resources, capabilities, and opportunities that do not reside in any of the world's "parts," but rather in the interactions among those parts. It was a tool -- a "macroscope" -- that would allow us to perceive patterns, relations, and the synergies of global interaction and to use these in constructive ways for the elimination of local poverty and the expansion of global well-being. It was, in addition, by making all this information available in understandable ways to everyone, a profoundly revolutionary tool.

It was also rejected by the United States Information Agency as too expensive and not appropriate for Expo '67. But Fuller decided that The World Game was too important to be left to politicians and too crucial to be left unattended to. He began to build it himself.

Spreading the Idea

Fuller set up the office of "The World Resources Inventory, Human Trends and Needs" at Southern Illinois University in Carbondale, Illinois, where he taught. A staff began assembling the database that The World Game would need. In 1969, Fuller held the first of many World Game workshops. Speaking with his incredible energy and zeal at over 500 colleges and universities on some 47 circumnavigations of the globe, Fuller spread the idea of The World Game.

Fuller was convinced that the greatest challenge to humanity was "how to get the most people 'in the know' about their world, its problems and possible solutions as quickly as possible." When people have the information they need to solve their problems, the need for centralized decision makers decreases. Here was the crux of the revolution Fuller was fostering.

In 1971, after his budget was drastically cut, Fuller kept The World Game going by funding the effort out of his own pocket. It did not take long for him to get alarmingly in debt. After being convinced by friends that he could not continue as he was without ruin, Fuller reluctantly all but eliminated his staff. World Game efforts were kept going by some of Fuller's students and colleagues at a small, nonprofit research and education organization in New Haven, Connecticut.

In 1975, after Fuller moved to Philadelphia, "Energy, Earth and Everyone" was published. This was the first book to comprehensively examine the world's total energy situation. It inventoried 30 different energy sources and presented a detailed plan for providing everyone in the world access to enough energy to have a standard of living equal to that of New Zealand -- all from nondepletable energy sources. In 1979, "Ho-Ping: Food for Everyone" was published. It dealt with the world food situation and presented a plan for the elimination of starvation and malnutrition from the world.

In 1978, The World Game became the sole endeavor of the nonprofit education and research organization, World Game Projects, Inc. Fuller remained creatively active in developing The World Game until his death in 1983.

Largest Map of the Whole Earth

One of the last artifacts that Fuller was involved in developing was The World Game edition of his Dymaxion map. Called the "Big Map" because of its basketball-court size, this map was conceived by Fuller and built by World Game staff. It is the world's largest and most accurate map of the whole earth.

Not simply a "Guinness Book of World Records" oddity, the Big Map plays a central role in The World Game's assorted workshops. With 100 people on the map, each representing 50 million people or 1% of humanity, exactly where humanity is located around the planet, participants become part of a living scorecard as the workshop process reveals the facts of world food and energy production and consumption, literacy, military expenditures, and -- in a horrifying display of one possible future -- the combined destructive power of the world's 50,000 nuclear weapons.

Resource Distribution in Perspective

Participants get a feel for the patterns and dynamics of global resource distribution, problems, and possible solutions. Standing on their world at the height of about 2,000 miles, with the tallest mountains the height of a nickel laid flat and with the space shuttle going into orbit at their ankles, participants see and feel the whole earth as they have never, unless they are astronauts, seen it before. Relationships of the parts to the whole become tangible.

Twenty-five people crowded into China put in perspective the notion of "doing more with less" and the accomplishments of modern China. Six individuals spread out in North America represent that region's vast consumption of the world's resources and outlay of military expenditures. Their counterparts in consumption and military outlay are in the Soviet Union.

These educational events vary in length from one hour to a week. Workshops and presentations have been held for such diverse groups as the United States Congress, U.S. State Department, United Nations, Malaysian Economic Society, and over 100 universities, high schools, primary schools, and corporations. Over 15,000 people have participated in World Game events.

A World Game workshop designed especially for government leaders in the developing world is currently under development. It will provide leaders with access to The World Game's database and its problem-solving software, but it will have the added feature of being focused upon the specific country and its region -- sort of a country-level World Game.

Another workshop being tested is aimed at grade-school children in the United States. This workshop uses a new map called the Little Big Map. Less than half the size of the Big Map, it will accommodate grade-school children while giving them a unique and exciting introduction to the world, geography, the earth's resources, current events, and the connection between themselves and the planet. Like all the workshops, these events will be used as a research tool.

The World Game Laboratory

Wars are planned and conducted out of war rooms. Peace, being of more importance to more people on the earth, ought to have a similar facility, but focused on developing peace. The World Game Laboratory (or "Peace Room") is intended as the prototype for the World Game facility originally envisioned by Buckminster Fuller. It won't be housed in a giant dome, but the actual workings that Fuller envisioned will be there. It will contain the World Game database and the software that will improve the abilities of individuals or teams to solve the problems they are concerned with. Perspective will replace information overload, and the ability to test "what if?" strategies will replace expensive and often disastrous trial-and-error methods and mere reactions to emergencies. The World Game Laboratory will be a prototype facility that can be duplicated in every country to enhance local problem solving.

The foundation of The World Game is the enormous database being developed and steadily expanded. In time, it will be the world's most comprehensive inventory of world and local resources, production capabilities, human trends, needs, and opportunities for sustainable development. Like the Big Map, it will be coupled to some powerful problem-solving software that will empower everyone from the researcher and policy maker to the high-school student to recognize, define, and solve global problems and local problems in a global context.

"Global Data Manager" is one of The World Game's early computer software efforts. Currently available in IBM, Macintosh, and Apple II formats, it contains approximately 100 different variables for every country in the world for population, food, energy, health, the military, etc. The computer user can sort or rank countries, compute any variable per capita, change the units of measurement, derive new information, and a host of other things.

Opportunity for a Computer Network

Now, 20 years old, The World Game is coming of age. And so is the technology that is needed to make The World Game a practical reality. The mainframe computer envisioned for the 1967 version of The World Game is about as powerful (but not as flexible) as today's desktop computers. The software and hardware that are available today make The World Game something that can be in every classroom, office, or home -- not just in a centralized location.

A World Game computer network, where students, researchers, and policy makers all have access to the same data and compete or cooperate in gaming situations to develop their ideas about making the world work, is now much more possible than in 1967. The database of the world's resources, human trends and needs, production capabilities, technology, problems, and options is fully available. The methodology for putting all this together into a useful tool is also ready. There is even a sizable body of trained researchers who could use The World Game in even more sophisticated ways, thanks to the ecological awareness boom of the early 1970s.

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Computer Reliability and the Fault Tolerance Approach

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"As computers are used in more and more crticial functions than ever before, techniques for dealing with computer malfunction are increasingly important."

"If something can be wrong it will certainly go wrong at sometime or other"
- Murphy's Law

Very high reliability and uninterrupted operation of computer systems are vital in a variety of applications -- manned/unmanned spacecraft, aircraft flight control and landing systems, nuclear power plants, rapid transportation systems, chemical industries, telecommunications, transaction processing and biomedical equipment.

As computers are used in more and more critical functions than ever before, techniques for dealing with computer malfunction are increasingly important. Rapid progress in microelectronics has brought down the cost and size of computer hardware, as well as enhancing the capabilities and performance. Fault tolerance, an approach in which programs or systems still operate properly even though parts may fail, now assumes greater significance and can be achieved without much penalty.

Duplicate Systems

Other approaches do not offer the same reasonable solutions to computer malfunctions as fault tolerance. Earlier solutions to avoiding breakdowns involved having hot-standby computers, fully redundant, which would immediately take over when the primary systems failed. This, of course, was an expensive proposition since the duplicate system was not in use except when a fault brought down the primary system. Later on, refinements were introduced which avoided the need for 100 per cent duplication of the hardware by using special software techniques. But in all these solutions, the basic disadvantage remained that whatever redundancy was incorporated was put into use only when the primary system failed. It did not pull its weight during the normal course of processing.

Fault Avoidance Method

In the fault avoidance approach, higher reliability is achieved through conservative design and fabrication practices such as improved designs and system configuration, use of high-reliability and burnt-in components, refined fabrication techniques, careful signal-path routing, intensive testing and periodic maintenance.

Even with the most careful system design and fabrication, faults can still occur due to physical, chemical and external stresses, resulting in the total system failure. Failures are inevitable and there is a limit to the reliability that can be achieved by this method.

Redundancy Techniques

The fault tolerance approach, on the other hand, accepts the inevitability of failures and counteracts their effect through some form of redundancy. Redundancy is used to provide the information necessary to negate the effects of failures. It is a "fault-management" technique.

Animals and human beings are equipped with two kidneys, because waste removal is critical to life. The kidneys work in parallel, each processing half the load. If one kidney fails, the other takes over most of the full load and the animal/human beings survive.

The basic concepts of fault-tolerant computing are as old as the first calculating machine. About 150 years ago, in 1834, Dr.

P. Lardner in his article on "Babbage's calculating engine," wrote "the most certain and effectual check upon errors which arise in the process of computation is to cause the same computation to be made by separate and independent machines; and this check is still more decisive if the machines make their computations by different methods." Functional redundancy may be achieved either by repeated execution (temporal) or replicated hardware and software modules (physical).

Fault-tolerant systems automatically maintain correct operation of the system, despite failures, without human intervention. Fault-tolerant systems provide features such as on-line maintenance, fail-safe operation, and continuous availability. These systems are also attractive for unattended facilities, where nobody is on hand for repairs or restarts.

Designing Fault-Tolerant Computers

Reliable operation of a computer system requires not only properly functioning hardware components but also correctness of its software modules. In practice, fault-tolerant computer design is more complex than it appears at first glance. The challenge facing designers is to meet the requirements of fault tolerance and high reliability in the face of "real-life" constraints on synchronous operation of redundant systems: cost, throughput (computing power), weight, volume, power consumption, and the length of design cycle. At the same time, the designer has also to satisfy the requirements of response time (in case of real-time applications), flexibility (ease of change) and maintainability.

Classification of Errors

All computation errors are caused by faults -- deviation of system behavior from its intended behavior. Faults can be classified according to their source, nature ("soft" or "hard" failures) and duration (permanent or transient).

Hard failures are those which continually demonstrate the same failure condition; they are also known as substitutive failures; examples: stuck-at-ZERO or one output of logic gates, valves stuck at open or close.

Soft failures are those which cease to exhibit failed state upon re-examination/re-execution; example: change in state of memory cells of read/write memory due to radiation and subsequent correction with rewriting.

Intermittent failures are the ones which randomly alternate between failed and operational states.

Transient failures exist for a short duration and then disappear.

Some faults, known as "latent faults," however, do not harm the normal operations, but exist in the resource as a potential cause. Example: change of data in the unused portion of the memory.

Hardware Fault Tolerance

The key ingredient in all fault tolerance techniques is redundancy. Redundancy is simply the addition of information, resources (hardware and software) or time beyond what is needed for normal operation. Information redundancy is used in a variety of error detecting (and correcting) codes such as single-bit-parity check, M-out-of-N coding, Hamming error correcting codes, single precision or double precision checksum, Honeywell checksum and arithmetic codes.

In hardware redundancy -- the most commonly used technique in a fault-tolerant system -- the physical hardware of the system is replicated to provide alternative paths to system activities. It is used to tolerate random component failures and certain malfunctions caused by environmental disturbances.

Time redundancy (retry, repeated execution) can be used to distinguish between permanent and transient failures. The processor performs the computations one or more times after detecting the first error; if the error disappears, the hardware is considered "healthy". But the main difficulty with time redundancy is ensuring that the processor has the same data to manipulate each time it redundantly performs a computation. Also, by performing the same computation more than once and comparing the results, some transient failures can be detected.

Software Fault Tolerance

As software has become more complex -- and hence more error prone -- and critical for operation of many computer-based systems, there is a need to tolerate even the software errors/faults. The replicated copies (modules) of a software, however, have the same software errors/faults in each copy. Hence, replication of software, as is done in hardware, fails to provide tolerance to software faults.

Therefore, for effective software redundancy, one has to use different programs for performing the same function. The redundant programs may use different methods, wherever possible, and are developed independently, so as to protect against common errors or "bugs". The multiple versions run simultaneously on multiple processors or sequentially on a single processor. The results are "voted" to provide a correct result. This is known as "N-version programming."

In another scheme, normally one software module will be executing the tasks; however, if a failure is detected, the redundant software module is used to execute the same task. This technique is known as "recovery block."

Multiprocessor Systems

Multiprocessor systems, sharing a common memory and data bus and also a network of distributed computing systems, can be made totally fault tolerant. Also, they can be operated in a gracefully degraded mode (at reduced levels of operation) under some failures. This calls for scheduling and reconfiguration of operating modes.

In real-time control systems, a computer acts on data received from a host of sensors which measure the process variables being controlled through its input modules. The computer, in accordance with given control laws and algorithms, controls the actuators through its output modules, thereby keeping the control variables within the desired limits. In these applications, even if the computer is fault-tolerant, the process control system as a whole may fail due to failures of sensors and actuators. In real-life applications, therefore, fault tolerance should be extended to the entire system, including sensors and actuators.

Fail-Safe and Fail-Soft Operations

In some applications, it may not be essential to completely tolerate operational (physical) failures; systems that are partially fault tolerant are adequate. In fail-safe systems, instead of nullifying (or masking) the effects of faults, the system is designed in a way that minimum inconvenience is caused by a failure.

For example, a traffic light may get stuck on red or on green. Clearly, the first failure is a safe one, while the second is unsafe. Therefore, if we design the traffic light in such a way that it is extremely unlikely for it to get stuck on green, it will be fail-safe. Similarly, in a real-time system, upon detection of failure of the system, all the outputs of the system may be forced to zero or one depending upon which is safe.

In fail-soft systems, failures are not totally tolerated. However, they are detected and the faulty portions of the system are isolated and the rest of the system continues operation in degraded mode. Such systems are sometimes called "reconfigurable systems" as they can adapt themselves to operating in the presence of faults.

A Growing Discipline

The fault tolerant technology is a rich, complex and continuously growing engineering discipline, led by the microelectronics evolution. The exponential growth in high performance, low-cost microprocessors and memories is quickly eliminating the price and technological barriers to fault tolerant computing. Dual redundancy, and even massive redundancy, is no longer cost prohibitive and they can be realized within given constraints.

There is, however, no universal and clear-cut solution to the general problem of fault tolerance. The decision on the technique(s) to be used and the level at which it is to be adopted and the degree of fault tolerance needed (the number of failures that can be tolerated) is dependent on: application; price paid by way of increased power consumption, weight, volume, cost and design and development time; and the risk one is willing to take.

Computers are going to play an even greater role in our lives in the years to come. They need to be extremely reliable and fault-tolerant.

Based on an article in *The Hindu* July 22, 1987, published by Kasturi & Sons Ltd., Madras, India. Reprinted with permission.

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Computing and Data Processing Newsletter

NATIONAL BUREAU OF STANDARDS SCIENTISTS TURN THE PROMISE OF PARALLEL PROCESSORS INTO PRACTICE

Jan Kosko
National Bureau of Standards
Gaithersburg, MD 20899

Almost overnight, in the relative timeframe of technology, a new generation of computers is dawning. Known as parallel or multi-processors, their difference is that they use more than one processor to simultaneously solve many pieces of a problem. Their promise is to make practical the glamorous, ambitious aspirations of computing such as artificial intelligence and image and speech recognition. But there are many hurdles to overcome before these aspirations become reality.

The idea behind parallel processing is to get supercomputing speed for a fraction of the cost. To achieve this higher performance, the algorithm (mathematical recipes), programming language, and hardware architecture must be perfectly matched to the application. The only way to know whether a particular combination is successful is through reliable measurements.

But the state of the art in computer performance measurement is poor for computers with one processor and much worse for multiprocessors, says Stuart Katzke, of the National Bureau of Standards (NBS) Institute for Computer Sciences and Technology. By developing new techniques and tools to measure the performance of these new computer architectures, researchers at NBS are evaluating how different configurations of processors solve particular types of problems.

"You can't measure computer performance in terms of length, or watts, or joules," explains electronic engineer Robert Carpenter, head of the parallel processing group at NBS, "and existing measurements such as 'instructions per second' or 'logical inferences per second' do not adequately express the performance of these novel architectures."

NBS researchers will be studying many aspects of parallel processors. "Before we can develop techniques to measure their performance, we have to understand many factors, such as which languages are best, how these machines can be programmed and used, and how different architectures work," says Carpenter.

Conventional computers, sometimes called serial or Von Neumann, have one processor to perform operations, such as addition, on data. (John Von Neumann is often credited with the general design upon which most of today's computers are based.) Even today's fastest serial computers solve a problem one step at a time, just as they have since the 1940s. But one-step-at-a-time computers are already beginning to approach speed limits, largely because of basic limitations in electronic circuitry.

Unlike serial computers, parallel processors use more than one processor to simultaneously solve many pieces of the problem. Theoretically, they can comprise two processors connected by a simple link or tens of thousands -- even millions -- of processors connected by a complex communications network.

Von Neumann and others of the time saw the appeal of putting multiple processors to work on a problem. But the high cost and low reliability of early computer components made the idea impractical even into the early 1970s. The advent of microprocessors, which provide inexpensive, compact, and reliable processing power on a single silicon chip, made parallel processing possible. Of course, having the capability does not mean the technology is well understood.

While parallel processors can speed the processing of data, they pose a different set of problems for users, including uneven flow of information and increased likelihood of communications bottlenecks.

In parallel processing, memory either is shared by many processors through some common access network, or each processor is given its own memory with the network passing messages and information from processor to processor. "Both forms need just the right amount of data flow or some processors will sit idle while others choke on too much data," explains NBS computer scientist Gordon Lyon.

The NBS team is developing special hardware to determine what the computer is doing and where the problems such as bottlenecks are. "Our goal is to develop measurement hardware that can be used with a wide range of parallel processor architectures," says Katzke. "The hardware will help find out where the machine is getting hung up and where it's doing most of the work. With this information, designers and manufacturers can change the architecture to become more efficient."

Another key to making these machines run more efficiently is understanding how to program them. "But," says Katzke, "we don't have a very good handle on programming parallel processors. Having more than one processor drastically changes how you should instruct a machine via a programming language to perform some task. But we don't fully understand how." Programming languages are still oriented to serial or Von Neumann machines. "But if a problem is treated sequentially," adds Katzke, "then you are not going to get any increase in productivity out of a parallel machine."

Either the language must provide a way for the programmer to decompose the problem so that it can be executed in parallel, or the compiler has to be smart enough to recognize the best approach to partitioning the computational problem. (A compiler translates a higher level programming language into instructions the machine can understand.)

While each computer architecture represents a new opportunity for solving problems, it is often difficult to know which architecture is best for which applications. To help compare the performance of machines with different parallel processing architectures, the NBS scientists are creating, collecting, and evaluating a wide range of test software known as benchmarks. The benchmarks will represent a variety of applications which could be run on multiprocessors.

Most benchmarks available today, such as the Linpack codes (a package of about 400 Fortran subroutines for solving dense systems of linear equations), measure performance for only a particular class of problems and were not specifically developed with parallel processing in mind. The NBS collection so far contains a number of programs aimed at measuring a computer's performance in areas that include fluid dynamics, artificial intelligence, image processing, and general scientific computing.

The NBS researchers will make the routines available at no charge over networks such as the Defense Department's Arpanet. This should help users decide which machines might be best for a given application because it will offer benchmark programs characteristic of a variety of problems.

Just as no one car is best for everyone, no single design of parallel processor is best for all problems; there will never be a standard for the "best" parallel processor. But over the next several years, ways will be developed to measure the performance of these machines, so that when someone asks, "Given my requirements, what should I look for?" they may be able to find an answer.

COMPUTER RADIOLOGY SYSTEM IMPROVES PATIENT CARE, SHORTENS HOSPITAL STAYS

Jodie A. Misch
I/PACS, Inc.
2225 Winters Dr.
Kalamazoo, MI 49002

Hospital radiology reports, for which patients and doctors typically waited four to 48 hours, are available instantly with I/PACS, a hospital radiology computer system developed by Borgess Medical Center in Kalamazoo, Michigan. With I/PACS, doctors have access to x-ray and other medical imaging reports moments after they are dictated by radiologists. Patient treatment begins sooner and hospital stays are shorter.

I/PACS, a picture archival and communications system, is the first developed by a hospital for hospitals. The system's voice-to-text capability instantly transcribes radiologists' reports, eliminating the time normally needed to transcribe and distribute information. In addition, I/PACS stores all types of medical images (computer-generated CT scans as well as traditional analog x-ray film) for access by physicians both in the hospital and on their office computers.

"Borgess has benefited substantially from the I/PACS system," said James W. McGee, Borgess director of medical imaging and developer of the system. "Our physicians no longer have to converge to review analog x-ray films. Any number of specialists can pull the x-ray image up on their office or hospital computers and review it at the same time. In an emergency situation, specialists can confer and treatment can begin before the doctors even leave for the hospital," McGee explained.

The I/PACS system costs approximately $1 million, depending on the specific installation requirements of each hospital. Independent research estimates that reduced patient length-of-stay can save a typical hospital this much every year. "Studies estimate reducing patient hospital stays by one-fifth of one day; with hospital stays topping $1,000 per day, the potential savings are extraordinary," said McGee. "Operationally, hospitals save money in reduced transcriptionists' salaries, reduced administrative expenses for duplicating film, processing, sorting, retrieving and duplicating information," McGee added.

In addition to the voice-to-text capability, I/PACS features include radiology information management applications and:

- Multiple resolution for digitally acquired images such as CT scans and MRI images
- Up to 2048 x 2048 resolution for digitized analog images
- 3D reconstruction
- Digital enhancements, including:
  - Grey scale manipulation
  - Digital zoom and pan
  - Windows
  - Levels
  - Reverse imaging

Simultaneous viewing of different studies and composite capabilities of a number of dissimilar studies have also been incorporated into I/PACS.

I/PACS was developed by Borgess Medical Center and I/NET, Inc. Based on the IBM System/38 mainframe, the technology can be installed as a stand-alone system or incorporated into existing hospital computer systems.

SCIENTISTS DEMONSTRATE USE OF "HIGH TEMPERATURE" SUPERCONDUCTOR IN ELECTRONICS AND COMMUNICATIONS

Dennis Meredith
Cornell Univ. News Service
840 Hanshaw Rd.
Ithaca, NY 14850

Scientists at the University of Rochester and Cornell University have discovered that new high-temperature superconducting materials can conduct electrical pulses as short as 10 to 15 trillionths of a second (picoseconds) without absorption or distortion and at very high levels of electrical current. The shorter the pulse over a digital data line, the greater the amount of information that can be transmitted.

Thus, it is possible that superconducting digital data transmission lines could be built with far greater capacity than even optical fibers for transmitting computer data, television pictures and telephone conversations. Also, future computers could use superconducting transmission lines to move massive amounts of data rapidly among components on computer chips.

"These results represent the first application of this newly discovered, high-temperature superconductor to high-speed electronics and communications systems and could trigger a revolution in these areas," said Gerard Mourou, who directs the Ultrafast Science Center at the University of Rochester's Laboratory for Laser Energetics, and who is one of the team members. "For instance, we can predict that, over distances of miles, lossless superconducting transmission lines with 100 times the capacity of optical fiber systems could be developed."

Mourou explained that a single such superconducting data transmission line could have information-carrying capacities of a terabit, or a trillion bits, of information per second.

Such a line could transmit the text equivalent of one thousand Encyclopedia Britannica's per second, more than 15 million two-way voice conversations or more than 10,000 full-color television channels. Such a transmission line could transmit the entire 25 million books of the Library of Congress, the world's largest library, in two minutes, said Dr. Mourou.

"These transmission lines would also have the advantage of extreme simplicity due to the lack of transducers such as modulators and detectors," Mourou said. "These components are required in fiber optic systems to transform the signal from the electrical to the optical domain and back."

Superconductors are materials capable of carrying electrical current with no resistance. Last year, a new class of ceramic materials was discovered that became superconducting at "high temperatures" of up to 90 degrees above absolute zero (about -163 degrees Centigrade). Such superconductors, called "high T_C superconductors," could be cooled by cheap liquid nitrogen, which means that large numbers of practical applications of the materials are now feasible.

The Rochester scientists -- from the university's Laboratory for Laser Energetics and the Department of Electrical Engineering -- worked with a thin film of superconductor made of yttrium, barium, copper and oxygen grown on a yttrium-doped zirconium oxide substrate by the Superconducting Thin Film Group at Cornell University and patterned into a high-speed circuit at Cornell's National Nanofabrication Facility (NNF).

According to Robert Buhrman, a professor of applied and engineering physics who led the Cornell team that synthesized the material, "The ability to grow smooth, thin-film coatings of this superconductor on zirconium oxide has important economic implications for application of the material. The zirconium oxide is at present about 10 times cheaper than strontium titanate that has until now yielded the best results."

To form the superconducting transmission lines, Buhrman and his colleagues used their newly developed process of growing the ceramic by depositing vapors of yttrium, barium and copper in a oxygen atmosphere on the zirconium oxide substrate at a temperature of 700 degrees Centigrade. Previously, formation of the superconducting ceramic required temperatures of 850 degrees Centigrade or greater.

The Rochester scientists subjected the pattern of superconductor lines, cooled to its critical (superconducting) temperature, to tests in which they transmitted pulses between 10 and 15 picoseconds long.

In earlier tests, using traditional low-temperature superconductors cooled to much lower liquid helium temperatures, the scientists had transmitted picosecond pulses more than 33 feet with virtually no loss. These tests demonstrated that superconducting transmission links are far superior to optical fiber systems, currently regarded as the best way to transmit pulse-encoded signals between two points. Today, high-speed communications systems rely on generation, modulation, propagation and detection of pulses between 0.1 and 1 nanoseconds, or billionths of a second.

The Rochester research began in 1982 with a technique to study the propagation of electrical pulses through transmission links

(please turn to page 27)

Gabel – *Continued from page 19*

Greater Need Now Than 20 Years Ago

The World Game has the same goals it had when it was originated by Buckminster Fuller: to make a valuable contribution to deepening and spreading peace on earth, to help solve the pressing problems of basic human need, to empower the problem solvers of any given region in the world with the information they need to resolve their problems, to increase citizen participation in global and local decision-making processes, and to do so in a way that will be fun and accessible to the average person. The big difference is that now the world is pregnant with so many more possibilities -- both deadly and beneficent. We have an even greater need for The World Game now than we did 20 years ago.

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Shore – *Continued from page 16*

interfere with learning and make them overestimate the difficulties involved. This is a common and natural reaction; it can happen when you're confronted with any new tool -- a new car, a new camera, a new sewing machine -- but it's a debilitating reaction only if you let it be one. The reaction is due more to unfamiliarity than to intrinsic difficulty.

Unfortunately, despite claims that today's computers are "user-friendly," learning to use them effectively often requires some technical knowledge and intuition on the part of the user. Such requirements are due mostly to equipment limitations and poorly designed software. More capable equipment and better-designed software are steadily becoming available, and this trend will continue, but it's still easy for newcomers to feel intimidated and to overestimate the difficulties involved. But a little knowledge of computer jargon, a little knowledge about computer technology, and a little insight into the nature of the design failures and equipment limitations that lead to unpleasant computer systems -- all of these are easy to come by and all of them go a long way in helping the newcomer to cope.

Although the technology and its accompanying jargon are new, many of the underlying concepts are neither new nor hard to understand. As Tallulah Bankhead is said to have remarked to a companion while attending a theater performance:

"There's less in this than meets the eye."

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Newsletter - *Continued from page 26*

in the picosecond and subpicosecond range. The scientists discovered that propagating extremely short pulses without attenuation or distortion, even over very short distances, was difficult because of absorption by the conducting electrodes.

To circumvent this problem, the Rochester scientists, as well as scientists working independently at the International Business Machines Corp. laboratory in Yorktown Heights, N.Y., explored the use of superconducting materials for pulse transmission.

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CACBOL – *Continued from page 3*

7 ERRORS MADE IN DESIGNING BENCHMARKS TO RATE COMPUTER PERFORMANCE (List 871103)

No single approach to evaluating computer performance addresses the requirements of everyone who needs to measure performance. There is no universal metric of value. One of the most widely used techniques, however, is benchmarking.

Benchmarking involves running a set of well known programs on a machine to compare its performance with that of others. Benchmarking, like other evaluations, measures new computer systems either in absolute terms (will the proposed system do the job?) or in relative terms (which of several available systems perform best in a given context?) Designers use these tests to help them choose between alternative architectures and implementations; buyers rely on them while deciding which system to purchase; and users can infer from them which programming styles will lead to optimum execution of their tasks.

Although benchmarks are essential in performance evaluation, simple-minded application of them can produce misleading results. In fact, bad benchmarking can be worse than no benchmarking at all. Here are some common errors made in designing benchmarks:

Neglecting to characterize the workload (the mix of different types of programs typically run at a given worksite).

Selecting kernels (test programs) that are too simplistic.

Using programs or algorithms adapted to a specific computer system.

Running benchmarks under inconsistent conditions.

Selecting inappropriate workload measures (using the arithmetic mean vs. the harmonic mean).

Neglecting the special needs of users.

Ignoring the difference between the frequency and duration of execution of various operations.

(Source: article in July, 1987 "IEEE Spectrum," published by Institute of Electrical & Electronics Engineers, 1111 19th St., N.W., Washington, DC 20036)

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Games and Puzzles for Nimble Minds and Computers

Neil Macdonald
Assistant Editor

NUMBLE

A "numble" is an arithmetical problem in which: digits have been replaced by capital letters; and there are two messages, one which can be read right away, and a second one in the digit cipher. The problem is to solve for the digits. Each capital letter in the arithmetical problem stands for just one digit 0 to 9. A digit may be represented by more than one letter. The second message, expressed in numerical digits, is to be translated using the same key, and possibly puns or other simple tricks.

NUMBLE 8711

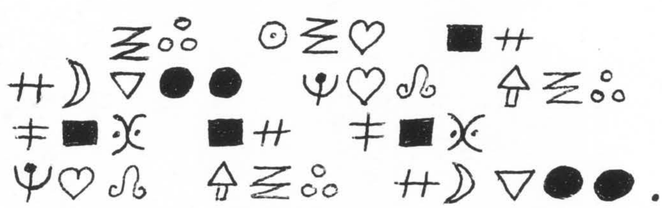
```
                P E O P L E
            *         A R E
C = R       ---------------
              O M L P P I L
            E P D O L P P
          M D C R L D C
          -----------------
        = M L P I T L I O L

          8124   9786   035
```

MAXIMDIDGE

In this kind of puzzle, a maxim (common saying, proverb, some good advice, etc.) using 14 or fewer different letters is enciphered (using a simple substitution cipher) into the 10 decimal digits or equivalent signs, plus a few more signs. The spaces between words are kept. Puns or other simple tricks (like KS for X) may be used.

MAXIMDIDGE 8711



SOLUTIONS

We regret that we did not print solutions for Numble 8707 and Maximdidge 8707 in our last issue. Here they are, as well as solutions to Numble 8709 and Maximdidge 8709.

NUMBLE 8707: Not anyone is wise alone.
MAXIMDIDGE 8707: We lose what is certain, while we search what is not certain.
NUMBLE 8709: No one knows the poor.
MAXIMDIDGE 8709: Lay the egg first, then caw, caw, caw.

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