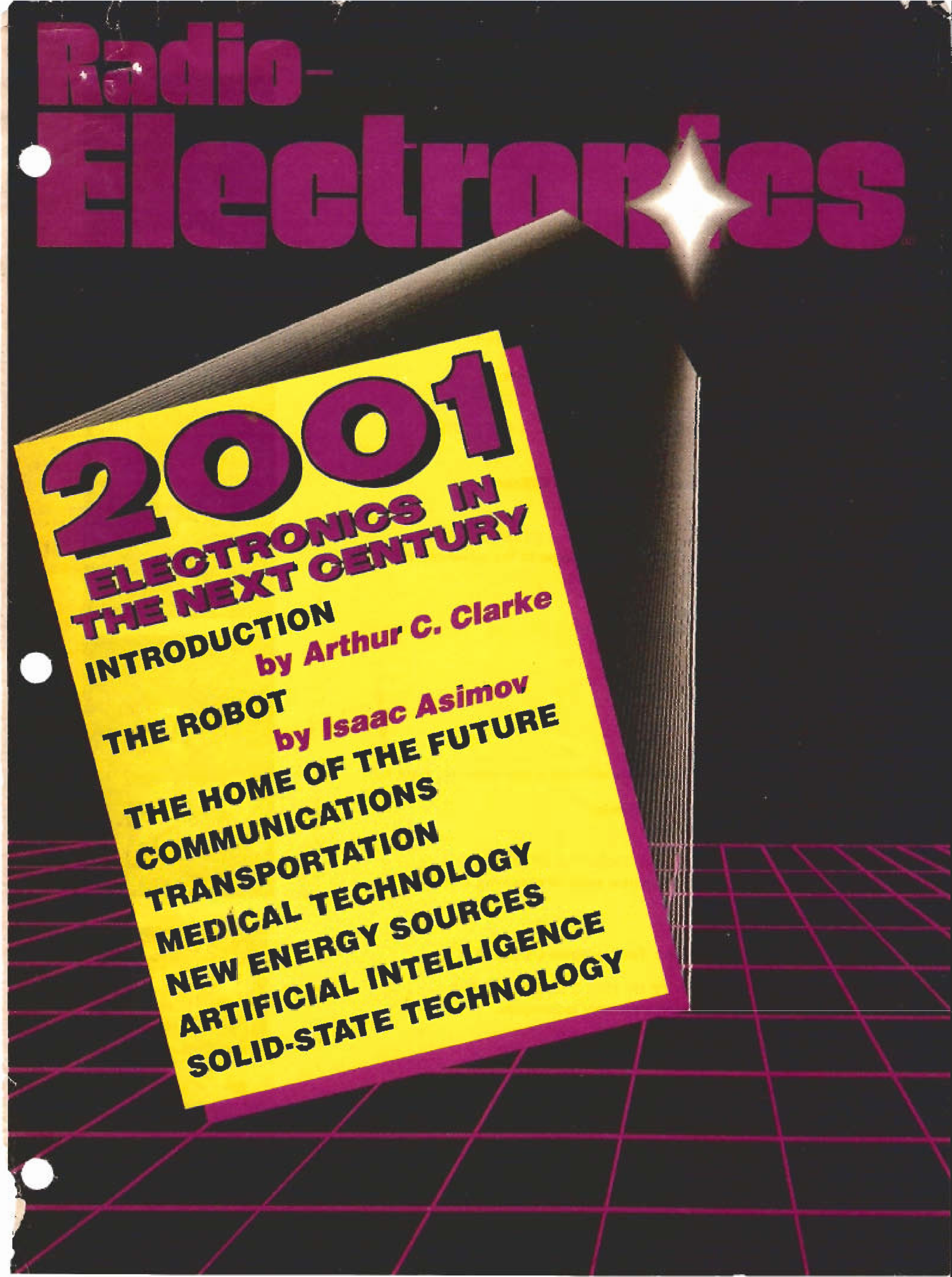
Radio-Electronics



2001
ELECTRONICS IN THE NEXT CENTURY

INTRODUCTION
by Arthur C. Clarke

THE ROBOT
by Isaac Asimov

THE HOME OF THE FUTURE
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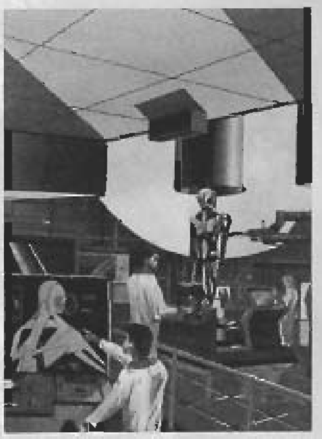
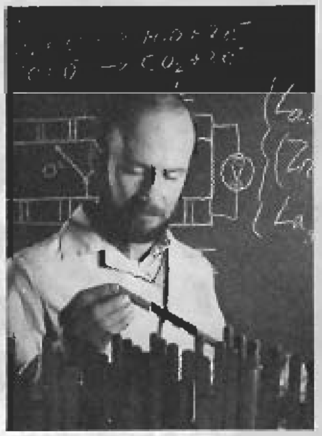
ELECTRONICS IN 2001

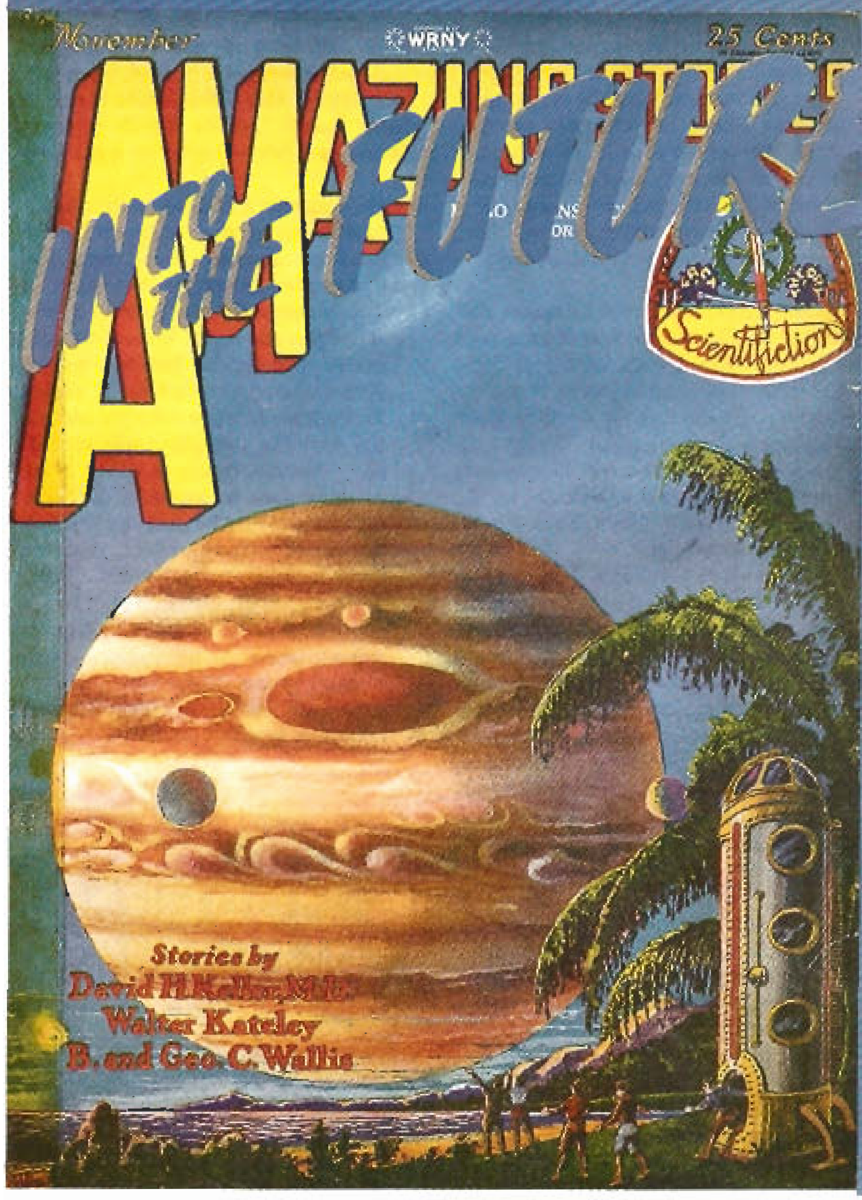




THE HOME OF THE FUTURE

Hugo Gernsback had a special talent for anticipating forthcoming technology. This special section, written by today's experts, pays tribute to that talent, as we anticipate the role electronics will play in our lives as the next century begins.

LOOKING INTO THE FUTURE



ARTHUR C. CLARKE

THIS SPECIAL ISSUE OF THE MAGAZINE he founded gives me a chance to pay tribute to the memory of Hugo Gernsback, who was a major influence in shaping my life. And not only mine—there must be thousands of engineers and scientists all over the Western world whose careers he boosted into orbit.

The very first science-fiction magazine I ever saw was the November 1928 issue of Gernsback's *Amazing Stories*, and the magnificent cover by Frank R. Paul has haunted me ever since. It shows the planet Jupiter, dominating the sky of its largest satellite, Ganymede. The main feature was the Great Red Spot, but what was truly amazing about that painting was the depiction of minor atmospheric details—eddies and cyclonic storms—which no Earth-based telescope could have shown in 1928. They were revealed almost 50 years later by an almost miraculous feat of electronics, when the *Voyager* spacecraft radioed back the first detailed images of Jupiter and its satellites. Gernsback would have been delighted, but not surprised.

It is difficult to think of any technological development in the field of electrical or electronic engineering that he did not anticipate, in countless articles, but above all in his serial *Ralph 124C41+*. This story of "Thrilling Adventures in the Year 2660" ran from the April 1911 to March 1912 issue of *Modern Electrics*, a remote ancestor of this journal, and the neat pun in the title applies perfectly to Gernsback himself.

The tale's most remarkable forecasts is this careful description of radar:

> It has long been known that a pulsating polarized ether wave, if directed on a metal object, could be reflected in the same fashion as a light ray. … If, therefore, a polarized wave gener-

> ator were trained towards the open space, the waves would take a direction as shown in the diagram, providing the parabolic wave reflector was used. By manipulating the entire apparatus like a searchlight, waves could be sent over a large area ... from the intensity and the elapsed time of the reflected impulses, the distance between the Earth and the flyer is then accurately calculated...

As the diagram referred to makes perfectly clear, Gernsback had leaped over the whole 1935-40 era of meter-wave radar, going straight to today's microwaves! No wonder that my *Profiles of the Future* bears the dedication "To my colleagues in the Institute of Twenty-first Century Studies, and especially to the memory of Hugo Gernsback—who thought of everything."

Well, almost everything. I am a little surprised that he did not invent communications satellites, though I am sure that he touched on them somewhere—perhaps in the delightful mini-magazine Christmas cards he sent out every year to his friends. He certainly had a considerable influence on Bell Lab's John R. Pierce, the father of ECHO and TELSTAR. As John records in his memoir *The Beginnings of Satellites Communications* (San Francisco Press, 1968):

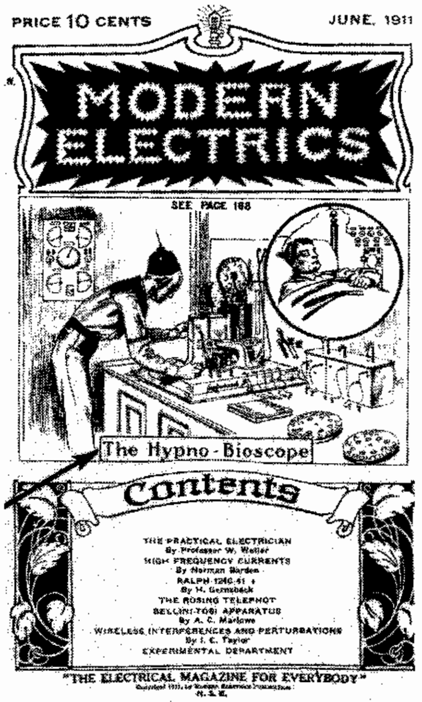
> In my teens I plunged into space when I turned from Tom Swift to the science fiction stories that Hugo Gernsback published in *Science and Invention*, and later in *Amazing Stories*, the first science fiction magazine... I became so involved ... that I wrote a few stories myself. The first, "The Relics from Earth" won second prize in a cover illustration story contest; it was published in Science Wonder Stories in March 1930.

Gernsback was already 21 when his hero, Jules Verne, died; they had both been lucky in their times of birth. Verne was the prophet of the Mechanical Age, and brilliantly extrapolated its dawning technologies to predict aircraft, submarines, and space-guns. But Gernsback was just in time to take advantage of the newly discovered electron, radio waves, and the energies of the atomic nucleus. He had a far wider stage—with far more props—than Verne, and he used it to the full.

According to his biographer and one-time editor Sam Moskowitz, Gernsback's *Ralph 124C41+* contains references to fluorescent lighting, radio direction-finders, juke boxes, tape recorders, loud speakers, television, radio networks, a device for teaching while the user is asleep, solar energy, as well as countless other ideas in fields not directly associated with electricity or radio. Except for the "sleep teacher"—which still is a long-felt want—all those are now commonplace.

So what would Gernsback predict if he was living today? Well, there is one item from *Ralph 124C41* which is not yet here—the "Menograph" or mind-writer:

> He attached a double leather headband to his head. At each end of the band was attached a round metal disc that pressed closely on the temples... The Menograph had entirely superseded pen and paper. It was only necessary to press the button when an idea was to be recorded and to release the button when one reflected and did not wish the thought-words recorded... Twenty times as much work could be done by means of the Menograph as could be done by the old-fashioned writing, which required considerable physical effort. Typewriters soon disappeared after its invention. Nor was there any use for stenographers, as the thoughts were written down direct on the tape, which was sent out as a letter was sent centuries ago.



PRICE 10 CENTS JUNE, 1911

MODERN ELECTRICS

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The Hypno-Bioscope

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"THE ELECTRICAL MAGAZINE FOR EVERYBODY"

THE HYPNO-BIOSCOPE was introduced in the June 1911 issue of Modern Electrics. Invented by Ralph 124C41 +, the machine worked like a Menograph in reverse. It transmitted words directly to the sleeping brain in such a manner that everything could be remembered in detail the next morning. In fact, it was proven that a story "read" by means of a Hipnoblograph left a much stronger impression than if the same story had been read while concious.

That passage is a fascinating mixture of foresight and naivete, for Gernsback visualized the output of the Menowriter as a paper tape covered with wavering lines like a seismograph or EEG record which "could be read by anyone—children being taught it at an early age." Why not plain text, which to us would seem obvious and far easier?

The answer is that between us and the 1911 Gernsback lies the computer, which alone would have the processing power to turn the Menograph's squiggles into printed words. He can hardly be blamed for missing that—but it is quite surprising that he imagined the final product being delivered by postman (in the year 2660!), not by telecommunications.

In one other respect, he was dead right—except in the matter of timing. We won't have to wait half a millennium for the typewriter to disappear; it will be lucky to last out this century. (Last week I found two forgotten electric portables in a cupboard, and sold them for junk...)

Already, in the combination of word-processor plus modem, we have surpassed Gernsback's vision, and I rather feel that a Menograph would be an electronic Edsel. I am fairly sure that my mental processes will never be sufficiently organized to permit direct brain-to-floppy-disk communication. But I have no doubt whatsoever that it will be feasible if desired. Mental control of simple operations has already been demonstrated in the laboratory.

Virtually all the devices in general use by the year 2001 will be little more than extensions or refinements of today's technology—which, admittedly, can now do almost anything we can conceive in the fields of communication, information handling, and entertainment. Any limitations that still exist by then will be due to economic, legal, or political factors—not technical ones. (Witness the current debate in many places: should the public be allowed to receive private broadcasts from satellites?)

There are two distinct ways of looking at future possibilities, and it may seem paradoxical to call Gernsback's (and Verne's) approach the conservative, down-to-earth one. Their method requires a good understanding of scientific principles and the latest discoveries, and the clear-sighted ability to extrapolate from them. It does not rely on new powers or forces beyond the boundaries of known science.

The second method might be called the Baconian one, after Friar Roger Bacon (circa 1214-1292). Roger (not to be confused with the much later Francis, who also dabbled in science-fiction) visualized flying machines, telescopes, automobiles, submarines—all at a time when there was no theoretical basis for their achievement.

Gernsback said: This is what we'll be able to do with what we've already got. Bacon asked the open-ended question: What would we like to do?, confident that

GERNSBACK'S VISION OF A SLEEP-LEARNING MACHINE is one of the few that have not come to pass—at least it hasn't been perfected yet. Records, kept in a central exchange could be deliverd to the subscriber automatically.

eventually the technology would come along. Both approaches are valuable, but the Baconians usually have to wait a few centuries for vindication. I have stated their position in my well-known Third Law: "Any sufficiently advanced technology is indistinguishable from magic."

Are there any new "magics" lying beyond the scientific horizon, as unimaginable to us as radio waves and electrons would have been to the founders of the Republic? It seems very unlikely that we are the lucky generation to which Nature has revealed her last secrets. Perhaps the current turmoil in particle physics and cosmology hints at fantastic future technologies which will, once again, transform human civilization.

But it is very hard to imagine them, for surely we are reaching the point of diminishing returns. From no TV at all to our present color sets is an unparalleled quantum-jump in human communications. After that, high definition and 3-D are merely marginal "fine-tuning" improvements—nice to have, but not essential. Much the same is true in our technologies of transportation and entertainment. Frankly, I don't want to travel faster than the Concorde—and have defected back to the jumbo jets now that they have seats I can sleep in. And I still haven't made up my mind about compact discs—though doubtless I'll capitulate eventually.

But there is, perhaps, one awesomely important technology which still lies ahead of us. We now have virtually complete command of information and energy; they can be stored, converted, transmitted or manipulated in every conceivable way, as a few minutes of any music video channel will amply demonstrate. Yet we are still no better than primitive savages in our ability to handle the other member of the vital triad—*matter.* Indeed, most of our manufacturing techniques are no more than refinements of Stone Age operations—scraping, drilling, cutting...

We need the equivalent, in the universe of solid, ponderable matter, of the photocopier or the videodisc, so that any desired object can be created from a suitable bank of raw materials. That is an old science-fiction idea, of course, and has appeared under many names: Replicator and Santa Claus machine are perhaps the best known among them.

We have to go back to the invention of the printing press to find anything that would have a comparable impact on society. Our world was created by the information explosion that resulted when monastic scribes, taking years to copy single books, were superseded by moveable type. It will be destroyed—and, we hope, re-created—when the Replicator makes our present social and economic systems not so much obsolete as irrelevant.

Will that happen by 2001? No; but I suspect that the technology will be on the horizon by then. It may be based on the new discoveries in genetics and biological engineering. After all, living creatures have been doing that sort of thing for a few billion years, and are getting quite good at it at last.

Or the Replicator may operate on principles that were demonstrated in the laboratory more than a decade ago. My random access information retrieval system has just unearthed this item from the *London Financial Times* for 14 September 1977:

> **3-D COPY IDEA A MAJOR ADVANCE**
>
> Predicted in 1963 by Arthur C Clarke, but not expected by him to be feasible for many decades, equipment with ability to reproduce the most complex three-dimensional shapes simply, quickly and with high accuracy is the subject of a patent granted very recently in the U.S... The equipment uses a system of steered laser beams in a block of photo-resist material, which after exposure will resist the action of solvents... The key is that the photoresist is not affected by one laser beam, only the combination of the two at their point of intersection... An American, Wyn Kelly Swainson, began working on the idea in 1968 and the patent (US 4,041,476) has been assigned to Formigraphic Engineering Corp. Licensing is in the hands of Omtec Replication, Berkeley...

Hugo would have loved that. But hurry up, Wyn—we're more than halfway to 2001... **R-E**

Jan. 4, 2001

Dear Sue,

I'm sure glad I ran away from the Back to Basics commune—why did our parents raise us in that relic of the past? This world of the 21st century is far more challenging. Today I went to the Office Training Center. When I told the job counselor that I had secretarial experience, she laughed and said, "That's all done by expert systems in workstations. Your entry-level job these days is learning to manage an electronic office!"

The counselor sent me to a trainer, who handed me my next surprise—an electronic notebook. It looks like a pocket calculator but instead of a numeric keypad, it has a speaker, a microphone, and two keys, ON/OFF and COMMAND. You do everything using your voice and the notebook's electronic memory. Before I could try it out, the trainer dragged me to the workstation and showed me where the notebook hooks up. At first glance, that workstation looked much like those stations back at our commune. It had a monitor screen, microprocessor, copier, and laser printer. But I saw no alphanumeric keyboard—just a keypad with control keys. Then I noticed that the telephone, the rolodex files, and the dictionaries were missing. As I should have guessed, everything's electronically integrated into the workstation. A phone call is made simply by request. There's no telephone headset, but privacy's no problem because phased-array speakers focus the sound. An eavesdropper would have to lean right next to you to hear the conversation.

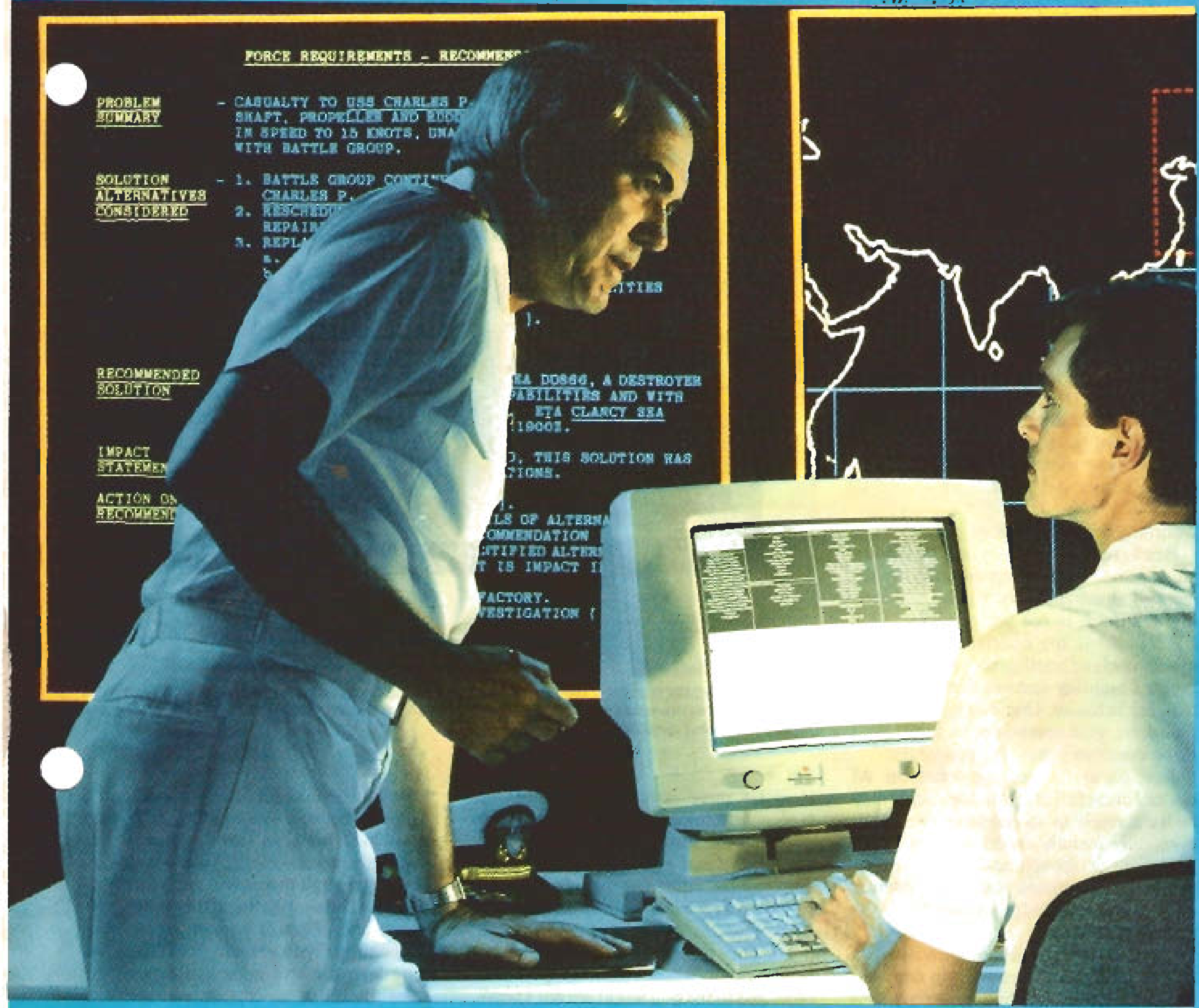
You've probably guessed that speech-recognition systems and natural-language programs have progressed far beyond the limited-vocabulary models we had at the commune. You can carry on a natural conversation with this workstation—no memorized commands. I could have simply dictated this letter and the system would have automatically sent it to you via electronic mail—that is, if you were linked to the electronic-mail network. It's just as well, though; I'm still fond of this old typewriter, and it look's like I won't have many more chances to use it.

I still wondered how people write long reports without a standard keyboard. The trainer explained that the expert report generator and expert writer make it easy. Most of the data you need is already in memory. You tell the report generator who you need to write to and what about. It asks you questions, you answer, and it generates your report for you. The only people who still use keyboards, the trainer said, are professional writers and editors, who polish and tailor documents for special audiences.

After seeing how much the workstation could do, I asked what they needed an office manager for. The trainer told me that, in spite of all the advances in expert systems, the brainy workstation of 2001 is still dumb when compared to a human. The office manager must review the reports that the expert system churns out, answer the expert-system queries, and make the decisions that only humans can make—decisions requiring judgment,creativity, and empathy. I learned to operate the workstation in a day. The hard part will be learning to think like a manager. But aren't challenges what life's all about? Why hide back at that commune, Sue? Come join me in the 21st century.

Love,

Hedy



THE FUTURE OF ARTIFICIAL INTELLIGENCE

GEORGE HEILMEIER

Computers so clever that they appear to think like humans will revolutionize the ways in which we solve problems.

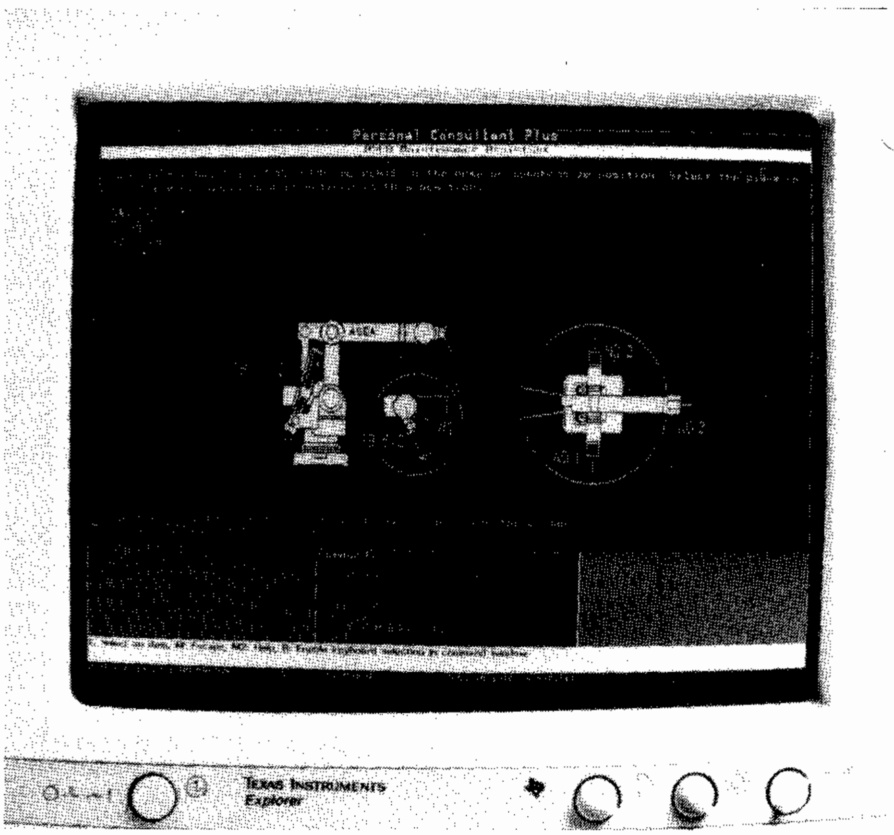
As I recall the futuristic predictions of a quarter century ago, by 1987 we were all to have a few family helicopters in our backyards, ready to waft us to work or play. I sometimes think back to those prognostications while fighting my way to work through freeway traffic at 20 miles an hour.

I've devoted much of my career to predicting and developing technologies that will be needed ten or fifteen years in the future. Early on, I learned to predict not what *should* be, but what is *likely* to be. If Artificial-Intelligence (AI) technologies were still in the laboratory—as they were for about 25 years—I would have serious misgivings about outlining their future in the workaday world. Just a few years ago, however, real-world applications began to proliferate.

We know of several hundred applications that have been performing vital functions in commerce and industry for a year or more, and we have reason to believe that another three or four thousand applications are in development. Almost 50,000 people attended Texas Instruments' Artificial Intelligence Symposium-by-Satellite in June, 1986; any time a seminar on a technology can attract as many people as a rock concert, you've got to believe it's real.

Given the broad base of applications already in everyday use in forward-looking organizations, given the powerful hardware and software already available from substantial companies, and given the potential of the AI technologies to influence many aspects of our society, we can be safe in extrapolating our experience of recent years. Just allow me a lot of blank space for uses yet undreamed of. I've often wondered whether the initial developers of lasers predicted that more lasers would be built for entertainment purposes than for all other applications combined.

But first, let's examine the current state of AI. As you'll see, it's as though we had been using that family helicopter to commute during the last few years, and now we only have to devise ways to go more places, farther and faster.



FOR SOPHISTICATED USERS, ***Personal Consultant*** **for the** ***Explorer*** **takes advantage of the extensive common Lisp environment of the** ***Explorer*** **workstation for extremely complex problem solving and rapid prototyping capabilities.**

Defining the indefinable

Because AI is enjoying headlong growth and is branching out in many directions simultaneously, a good and lasting definition is not yet possible. As a science, AI is the understanding of the mechanisms of intelligence. As engineering, it's building systems that exhibit intelligent behavior. One wag has called AI "what we give computers so they won't make dumb mistakes like people do."

Here's a useful working definition: AI is a tool chest full of technologies that may be used singly or in combination; it will eventually include expert systems, natural-language speech and image understanding, intelligent planning systems, automated knowledge-acquisition systems, and robotics.

Each of the sub-technologies listed in that definition has been used in conjunction with conventional computers, but AI brings dramatic new levels of capability. Since expert systems are the most highly developed of the tools at this time, let's focus on them.

Conventional hardware, unconventional software

Computers that are used today to develop or deliver expert systems aren't remarkably different in appearance from conventional computers: they have a keyboard and a display, and black boxes in between. They use hard disks and floppies, RAM and ROM. In fact, if you have a fairly powerful personal computer, you can probably find software, like *Personal Consultant* from Texas Instruments, that will let you both develop and deliver expert systems on your PC. You'll need at least 756K of RAM, and the RAM is controlled and organized in a non-conventional way, but no special hardware is required.

The big differences are in the software. Here are three essential differences between conventional data-processing software and the software of expert systems:

- *Conventional software represents and manipulates data, but knowledge-based software represents and manipulates knowledge.*

For our purpose here, "data" are isolated symbols whose relationships to each other and to the real world are not known. "Knowledge," on the other hand, consists of facts that are related to each other and to the "real world" well enough to serve as a basis for intelligent action.

In a conventional computer, for example, "914" might represent a home address. But it carries no characteristics of a home. In an expert system, the symbol "home" represents a home and everything that the computer operator says it stands for. The concept "home" will be manipulated through processes of symbolic logic, along with other facts, to produce logical inferences and interrelationships about the "home."

- *Conventional software can use only algorithms, but expert-system software can use both algorithms and heuristics.*

An algorithm is a rigid mathematical relationship or equation. Here's a simple algorithm: X + Y = Z. On the other hand, a heuristic is best thought of as a rule-of-thumb. Here's a simple heuristic that might be used by a carpenter: X and a little bit + Y and a little bit = Z and a little bit, because I can always sand them down to fit, but I can't sand them up to fit.

Heuristic knowledge, which is gained largely through thoughtful analysis of experience, is what distinguishes the experienced and effective human expert from the beginner with a head full of theory. At long last, the technology of expert systems allows us to capture and use that invaluable heuristic knowledge.

- *Conventional software uses repetitive processes, but expert-system software uses inferential processes.*

Ask a conventional computer to add 3 and 2, and you'll get 5 as the answer every time; a million times a second, if you like. Now, ask an expert system to add 3 lions to 2 lambs, and, assuming you've told it something about the habits of lions, you'll get "3 animals." Or the answer might be "2 animals," if you've told the expert system about each lion's hunger thresholds, fighting abilities, and the like. Expert systems already have the ability to carry out long chains of inferential reasoning, and that capacity is growing fast.

Other traits of expert systems

Those three differences are the essence of an expert system. In addition, however, most expert systems have other characteristics in common. It is these capabilities that make expert systems seem less like mindless number crunchers, and more like helpful colleagues:

Explanation facility: Most expert systems can explain how they arrived at their conclusions, either by citing the rules they used, or by displaying a part of the inferential chain, or both. During the development of a system, that gives the developers a quick and easy way to detect and correct faults. When a system is in operation, it gives users greater confidence in the results by clarifying the rationale behind the recommendation.

Meta-knowledge: Mastering words like that can make you rich and famous. "Meta-knowledge" simply means the knowledge a system has about its knowledge. Such knowledge, in expert systems now in development, allows them to adjust their explanations to the interest or level of knowledge of the user, to correct and amplify their own rules as more is learned, or to rank diagnoses in order of probability when more than one diagnosis fits the available facts.

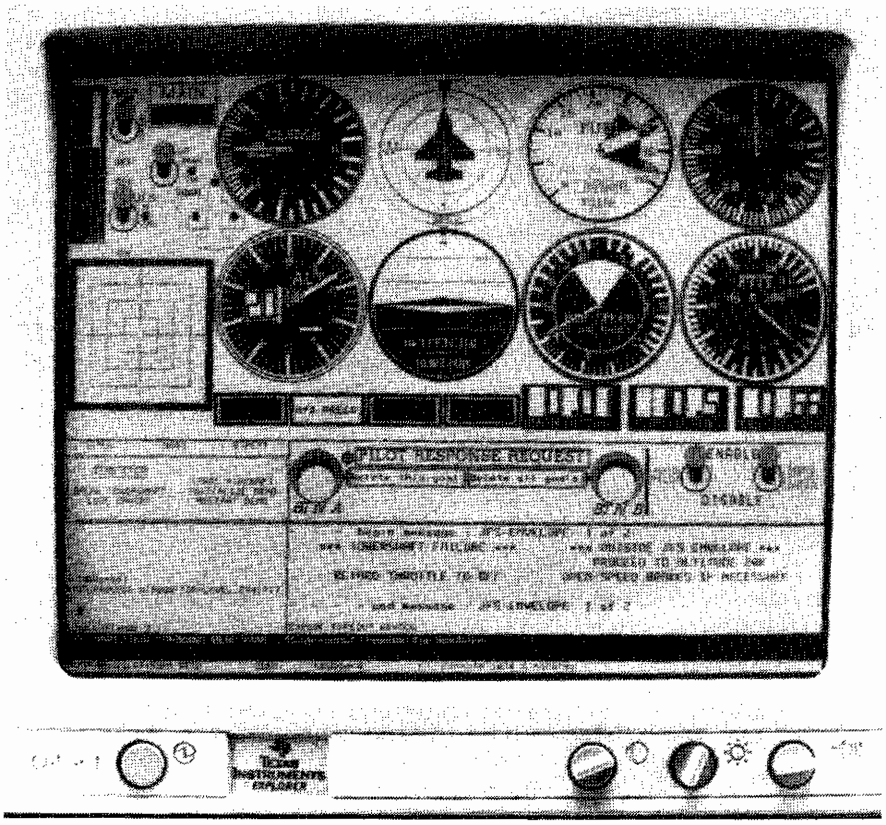
Assistance in formulating problems: Much of the value of a human expert lies in helping clients to "ask the right questions." A system designed to assess the impact of the 1986 Tax Reform law on a company's depreciation, for example, might accept inputs about the class of property, its cost, end-of-life value, and the like, then offer the optional treatments under the new code, and run out year-by-year dollar figures for comparison.

Access to databases: Many expert systems are still limited to the relatively small databases that are programmed into them, but that will change. Texas Instruments, for example, was the first to introduce a system that incorporates both a numeric processor (a conventional computer) and a symbolic processor (an AI computer) in one integrated machine, the *Explorer LX* computer system.

The near future will certainly see expert-system computers tied into worldwide corporate computer systems, to give the user quick access to information throughout the organization.

Multiple representations of data: That is a "near future" capability now in the works. Conventional database systems don't deal well with data represented in maps, X-rays, photographs, diagrams, and the like. Yet a physician, for example, may need to read a patient's history, study his chest X-ray, and relate that information to his electrocardiogram. We're working on object-oriented database management systems that will help solve that problem.

Dynamic environments: Expert systems work beautifully on problems that "hold still" for at least a few minutes, but they don't comprehend dynamic environments. Yet some of the most promising areas of application, like emergency procedures in aircraft, and dynamic industrial automation, demand facile "quick thinking" as conditions change in seconds. We're working on expert-system toolkits that accommodate such dynamic environments.



THE EMERGENCY PROCEDURES EXPERT SYSTEM, developed by TI, can either interact with the pilot and perform low-level flight operations or assume control of the aircraft and communicate directly with its automatic control systems until the pilot can regain control of the plane. Here, a simulated F-16 panel is shown on the screen of an *Explorer* computer. It is typical of the type of information that could be provided in an emergency situation.

The past is a prelude

Now that you're armed with a bit of background about what expert systems are, you're in a good position to understand what they're doing in the workaday world. More important, you're primed to extrapolate from today's systems and their uses, to the incredibly capable systems we will have in 2001.

In general, today's expert systems can do the following: diagnosing, monitoring, interpreting, controlling, predicting, selecting, designing, training, planning, testing, and dispatching.

Today's systems are at work in almost every field of endeavor: diagnosing bacterial infections and controlling treatment of patients in intensive care for Stanford; interpreting hydrophone data to identify ship types for the Navy; predicting airline seats sales for Northwest Orient Airlines; designing computer-system configurations for DEC; planning bombing missions for the Air Force; monitoring the Space Shuttle's computers for NASA; selecting among capital-investment proposals, training sales engineers in selecting metallurgical materials, testing electronic circuit boards at Texas Instruments; and scheduling manufacturing at Westinghouse.

That's a very small sample. It's safe to predict that the expert systems of the future will find potential applications anywhere that human thought is required.

That includes cars and homes. Quite powerful expert-system development tools are already well within the economic reach of home-PC owners. I wasn't among the enthusiasts who predicted "a PC in every home by 1985," and I don't expect more than a few percent of homes to get involved in developing expert systems. What I *do* foresee, however, is the widespread *imbedding* of expert systems in automotive systems and home appliances, just as microprocessors are already widely imbedded in a wide variety of products.

Today's applications

To challenge your imaginations, I'll describe what a few expert systems have been doing for the last year or more. Later, I'll describe a few systems that we're developing for the Department of Defense; they'll be ready for field trials within a few years.

- Campbell Soup Company is using an expert system to help diagnose and correct malfunctions in their hydrostatic sterilizers (otherwise known as "soup cookers"). A typical cooker is a gadget seven-stories high, crowded with intricate can conveyors and heaters, capable of turning out 700 cans of perfectly sterilized, cooked soup every minute. Campbell has cookers at its plants all over the world. Local maintenance people can correct minor malfunctions, but on occasion a knotty problem requires calling in their one real expert, a man who had helped design the cookers years ago. Unfortunately, his future availability to Campbell is questionable as he is close to retirement age.

Texas Instrument's knowledge engineers worked with the expert to identify the clues, impressions, and thought processes he uses in diagnosis. Together, they converted all of that to a system of rules, using a Texas Instruments PC to develop the expert system.

Now, instead of sending a human expert, Campbell sends a floppy disk to each plant with a cooker, long before trouble occurs. When it does occur, local maintenance people sit down at their PC, spend a few minutes in dialogue with the expert system, and get the system's recommendation for corrective action faster than they could have placed a long-distance phone call.

- The University of Illinois uses an expert system called *PLANT/cd* to predict insect damage to crops for farmers throughout the Midwest. It takes into account the insect populations of prior years, winter temperatures, rainfall amounts and timing, and other breeding and survival factors. Then, interrelating those facts much as a human entomologist would, by applying both theory and heuristics, the system recommends spraying schedules that will achieve optimum results. Several pecan growers in Texas use a similar expert system.
- Decision Focus Inc. has developed an expert system, now in use at several electric utilities, to aid long-range planning by calculating the probable effects of many different scenarios involving changes in fuel costs, changes in demand, and changes in efficiency. Multi-variable problems like that can be solved using decision-tree analysis, an operations-research technique taught in MBA courses, but little-used because it's so cumbersome and time-consuming. With just a few variables, the many combinations of possible futures soon create trees with hundreds or thousands of branches, each the outcome of a specific scenario. The probability of each scenario must be calculated, from the probabilities assigned to each branching point along the route to each final twig. Done manually, it's a nightmare. Using *Arborist* decision-tree software from Texas Instruments, the system constructs the tree and calculates all the probabilities without difficulty.

From cooking to entomology to finance, those three examples only begin to suggest the vast scope of applications.

The near future

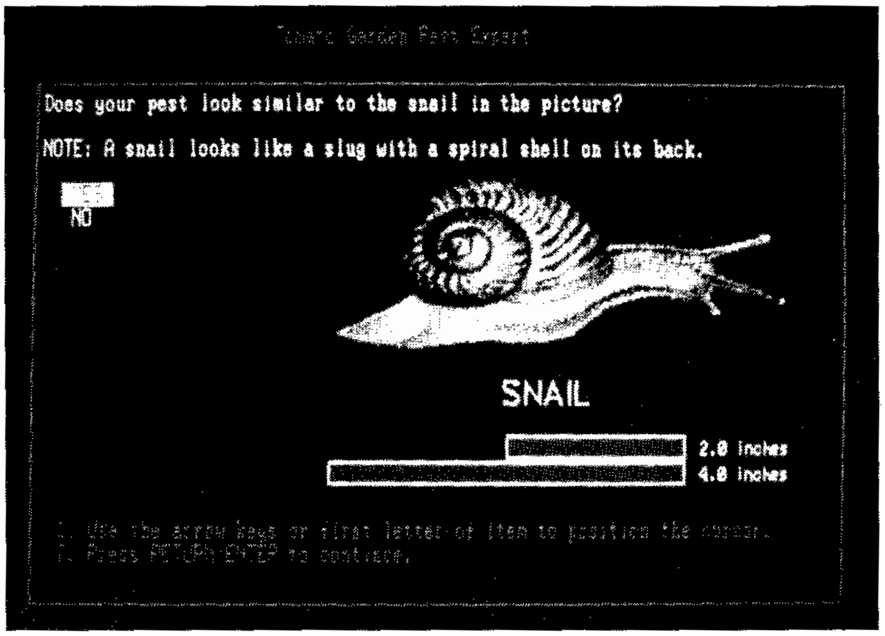
In 1983, the *D*efense *A*dvanced *R*esearch *P*rojects *A*gency (DARPA) recognized that AI technologies could improve the effectiveness of many military systems while making them safer. DARPA has chosen the AI Lab of Texas Instruments' Defense System & Electronics Group to pursue a number of ongoing AI projects. Among them are:

- *Pilot's Associate:* We're developing an AI system that will tie into an aircraft's operating and control systems, as well as its radar and weapons systems, to help the pilot gather information, evaluate it, and make fast decisions. Advanced versions will perform complex tasks beyond the capabilities of a human pilot, like the instant planning of the best tactics for attacking several enemy planes that are threats, even though some of them are beyond his visual range.

There's no need to wonder about how we're going to jam a large computer into the cockpit alongside the pilot. We're designing a VLSI device that is capable of performing all of the functions of a large 32-bit computer running LISP; LISP is a computer language that was designed specifically for AI applications. We believe that device to be the most complex integrated circuit ever designed.

- *Enhanced Terrain Masking Penetration:* Several expert systems will be tied into the aircraft's systems to help guide it in low-level flight and to select the safest flight paths. The systems will take full advantage of the masking effect of hills and buildings to avoid enemy-radar tracking, will avoid known anti-aircraft missile launching sites and other threats, will provide for safe clearance of obstructions, and will still get the aircraft to the right target at the right time. The systems will also be able to re-plan the flight en route, control radar power to minimize enemy detection, position the radar antenna for safe terrain avoidance, monitor fuel consumption, and perform other vital functions on demand.
- *Force Requirements Expert System:* Less glamorous than their use in combat aircraft, expert systems are also at the heart of systems for the Battle Management Program. The Phase-I system we're completing for the Navy will be one of the largest expert systems designed to date. The system will detect changes in the readiness of an entire fleet of ships, help assign replacement ships, and help military operations staffs to determine a fleet's capability to undertake various operations, considering current battle operations and ship types available.
- *Autonomous Vehicle:* A military vehicle without a human aboard, and without a human operator back at base, could obviously perform many important functions in combat without risking troops. DARPA is developing expert systems to control such a vehicle. When development reaches an advanced phase, the vehicle will be able to decide its own routes, drive down roads, cut across fields, hide from the enemy, carry out its missions at the right time, and return to base.

Let me say it again: Those last four examples are not "Blue-Sky" projects on some futuristic wish list. They're a sample of several projects that are undergoing development *today*.



Does your pest look similar to the snail in the picture?

NOTE: A snail looks like a slug with a spiral shell on its back.

1. Use the arrow keys or first letter of item to position the cursor.
2. Press RETURN/ENTER to continue.

EXPERT SYSTEMS are widely used in agriculture, by commercial growers and amateurs alike. Here, a pest-identification system takes the first step toward identifying a snail species.

Streamlining the interfaces

The Autonomous-Vehicle program obviously depends on development of a powerful expert system, but it depends on even greater breakthroughs in three other sub-technologies of artificial intelligence: machine vision, pattern recognition, and robotics. Most of that work depends on creating software to help a computer understand the unfamiliar things that it's looking at.

We've already had considerable success in helping computers to understand familiar objects. For example, for several years, vision-aided robots in Texas Instruments' calculator-manufacturing operations have watched calculators come down a conveyor belt, have picked them up after orienting their robotic fingers to the random placements of the calculators, and have oriented the calculators properly for the next operation.

In the installation of surface-mounted integrated circuits, and other devices, on printed-circuit boards, we're using vision-aided robots to see the orientation of the board, to rotate the device to the correct orientation, and then to place the device accurately on the board.

It's certainly a long leap from today's machine vision and pattern recognition to the recognition of unfamiliar and unexpected objects like roads, rocks, and cliffs, but we're progressing nicely.

In addition to those "world-machine interfaces," we've made progress in easing man-machine interfaces. In plain language, we're helping computers to understand and speak plain language.

Most readers are already familiar with speech synthesizing devices that have made possible "talking cars," "talking microwave ovens," and Texas Instruments' talking learning aids that drill children in spelling, math, and music. The integrated circuitry is already remarkably dependable and inexpensive. Expert systems that speak English (or Swahili, Tagalog, or Esperanto) are just a short chip-shot away.

Natural-speech input is a bit more complex, however. For several years, Texas Instruments has offered a speech-recognition system that can be trained to respond to nine groups of 50 words or phrases. That 450-word vocabulary is more than enough for the specialized applications that the system is used for today:

- An executive who doesn't care to learn how to type, retrieves information from a personal computer just by speaking into its microphone.
- A quadraplegic operates his ham radio, dials a telephone, types letters, and is training himself to do a paying job.
- An inspector of printed-circuit boards, though both hands are occupied, records the location and nature of defects without touching a keyboard.
- An inspector of carpeting observes it as it comes from the machine in thousand-foot lengths, detects defects, and verbally notifies a computer so it can decide where to cut to create smaller rolls.
- An inspector of integrated circuits maneuvers the slice with one hand, adjusts the microscope with the other, and records lot numbers and types of defects and their locations, by speaking.


WITH THE AID OF A VOICE-RECOGNITION SYSTEM, Jim Ickes of Redondo Beach CA, can handle a word processor, a telephone, and his ham radio.

Those examples may sound like something out of Buck Rogers, but they're commonplace today. Just two primary obstacles prevent today's speech-recognition systems from finding widespread, generalized use: They're speaker dependent, and they handle small vocabularies. "Speaker dependent" means that the speaker must teach the computer each word and phrase that will be used by speaking it several times, and then the computer will respond only to the speech of that person. Such is the wide variability of human speech that it may take many years to solve that problem. Vocabulary size, like the power of algorithms and heuristics, is largely dependent on the power, speed, and price of existing integrated circuits. And that brings us to the driving power behind developments in all the fields of artificial intelligence: integrated circuits.

Computational plenty

In 1960, Texas Instruments supplied transistors for the first solid-state computers, at roughly $16.00 per transistor. At that price, just the transistors to build a 256K RAM today would cost more than $4 million. Instead, a 256K RAM, ready to plug in, sells for a few dollars.

The fabled ability of the semiconductor industry to jam more and more computing power onto a tiny chip of silicon, is the key, not only to the ever-increasing power of expert systems, but to the simplicity with which they communicate with us.

Here's why: When you type the word "integrated" into your computer, it takes just a few dozen bits of RAM memory to translate those keystrokes into computer-digestible data. But when you *speak* "integrated" into the computer's microphone, converting those sound waves into computer-digestible data, and then recognizing the word by comparing it with stored vocabularies and by considering it in the context of words that come before and after, can take tens of thousands of bits of RAM.

Fortunately, we've entered the era of "computational plenty." Back in the 1960's, we had to devote almost 100% of our computational resources just to do the number crunching. By the 1990's, perhaps 10% will be devoted to that; 90% will handle the interfacing.

Earlier, I mentioned that we're developing a single IC that will perform the essential functions of an AI computer (called a Lisp machine). In 1986, Texas Instruments announced the world's first 4-megabit IC—an IC that can hold and manipulate four million bits of information. Three of those IC's can be placed side-by-side on a dime without covering all of it.

That's the kind of computing power—complex, compact, dependable, and inexpensive—that we have at our disposal today to create expert systems as easy to deal with as human experts.

Think of it: No more "computerese" to master, no more frustrating protocols, no more wading through incomprehensible operating manuals. Just sit down and start talking, then sit back and listen. Imagine having a computer tell you "You don't have to do it my way, I'll be glad to do it your way." By the year 2001 I think it will come about.

Then, Arthur C. Clarke's dream of HAL the Computer will be a working reality—minus, of course, HAL's one serious flaw.

Toward the unknown

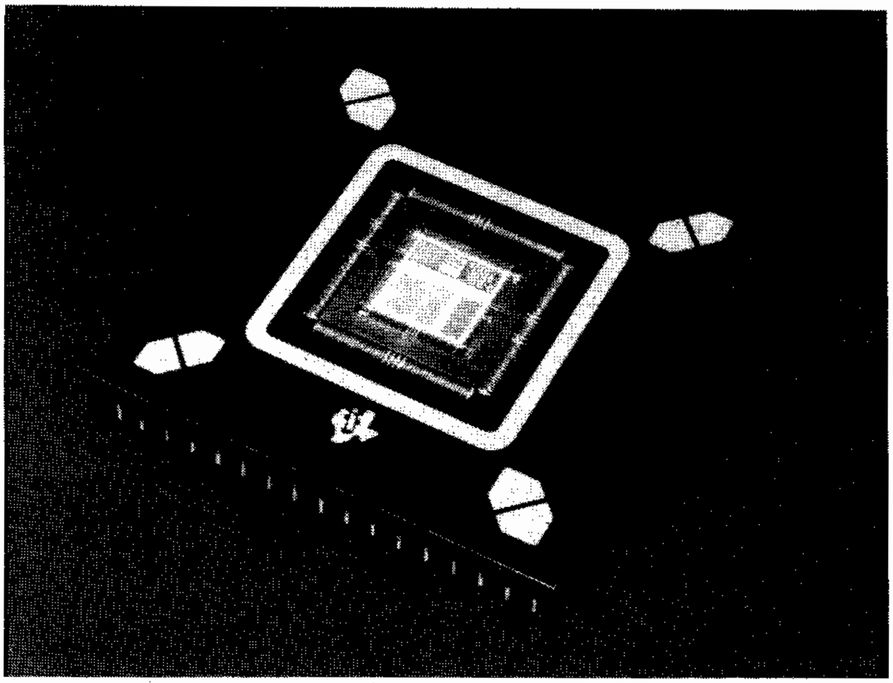
Alan Turing, the great computer pioneer, was once asked whether computers would ever be able to think. He answered "I compute so."

My answer is different: "Absolutely not; but they'll be so clever you'll think they're thinking."

In truth, whether computers will ever be able to think is a philosophical debate, not a scientific one. The important thing is that we have already conclusively demonstrated—in hundreds of applications—that computers can help humans think more effectively.

Artificial intelligence is helping us break out of the narrowly restricted world of conventional computing. Conventional computers are really giant calculators that solve problems with blazing speed, provided that humans have thoroughly structured the approaches to the problems, have provided unambiguous rules, and have input precise and certain data. Conventional computers deal wretchedly with unstructured problems, ambiguity, and uncertainty. A conventional computer can be thrown into chaos if you tell it "maybe," "probably," "my best estimate is...," or maybe "I'll supply that bit of data later."

Yet most of the important thinking humans do is based on imperfect structures, ambiguity, and uncertainty. Clearly, all planning for the future is beset by those characteristics. Expert systems are already helping us handle such problems with great power. Other facets of AI, such as natural-speech input and output, will soon make that powerful help available to everyone.



THE *EXPLORER* "MEGACHIP"—arguably the most complex IC ever developed—replaces several cubic feet of Lisp machine circuitry. It's the key development that will permit the use of expert systems wherever they're needed, including in jet and helicopter cockpits.

It has been estimated that conventional computers are presently doing the work of five-trillion people. Since the population of the world is about 5 billion, each of us has an average of a thousand servants working for us somewhere. If you've ever had hassles about a miscalculated bill, you've probably concluded that a few of your servants are idiots, but that's a small price to pay for all the other good, low-priced help.

AI computers, including millions of small ones imbedded in useful products, may never supply that *quantity* of help, but they'll supply help of a much higher *quality*. Conventional computers made us more efficient, but AI computers will make us more effective.

It's the fashion, in articles like this, to end with a detailed picture of the future wonders that will arise from the new technologies. I'm not going to do that. Instead, I would like you to spend some time dreaming of the possible wonders that AI might bring. Those future wonders will take many forms and shapes, each of which will be tailored and adapted to the user's level of intelligence, knowledge, needs, and wants. If you would like, you can consider this a challenge, or perhaps a thought experiment.

Most of the building blocks are available today. Some of those are embryonic, a few are awaiting birth, and others are in their adolescence. Your challenge is to extrapolate the power of those technologies into the future, add your own vision, and assemble your own wondrous intelligent colleagues.

After all, it will remain forever the province of humankind to dream greater and greater dreams.

An epilogue

Years ago, when people still felt it their duty to illustrate the computer's lack of common sense, the following story made the rounds:

A new user told the computer: "I have two watches. One is erratic, and runs as much as a minute fast or slow. The other won't run at all. Which should I use?"

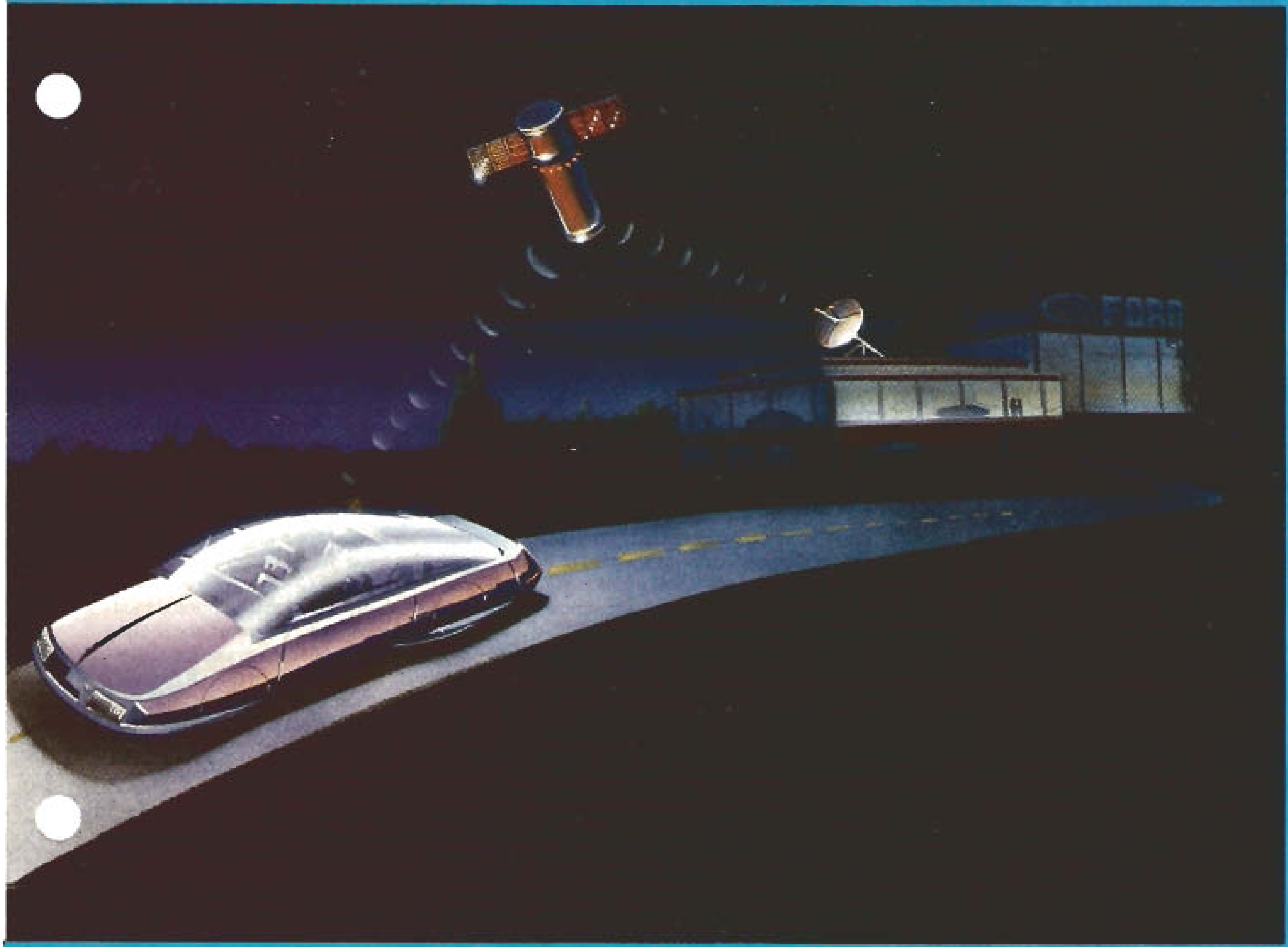
The computer answered "The one that is stopped."

Puzzled at that answer, the user asked a human expert the grounds for the computer's decision.

"Obviously," said the expert, "you can never be sure the erratic watch is correct, but the stopped watch is precisely correct twice a day."

In a few years, if you give the same problem to an AI system, it will give you the better answer, explain its rationale, offer to fix the stopped watch and adjust the other, and suggest six improvements in their designs.

The new age has already dawned. I hope you look forward to it as enthusiastically as I do. **R-E**



THE AUTOMOTIVE WORLD OF THE 21st CENTURY

You're invited to test drive Ford's new 2001 model

Donald E. Petersen

ANY ATTEMPT TO DESCRIBE THE FUTURE is a hazardous exercise at best. By definition, it's an excursion into a world of fantasy. But fantasy can range from chimerical nonsense to a commonsense projection of a rational vision.

What follows here is the latter: a reasonable extrapolation of current automotive trends and technologies reaching out 14 years; a vision of the future of the automobile firmly based on technologies now emerging. Product planners and creative thinkers at Ford Motor Company have devoted considerable energies looking beyond conventional planning horizons—and into the 21st century.

When you think about it, 14 years ahead is not all that distant. Consider the fact that 14 years back was 1973—the year of the first OPEC-inspired energy crisis. To some of us, that doesn't seem very long ago at all.

Based on what we've learned since that time, however, it's safe to make one all-important prediction about the future: The businesses that survive into the 21st century will be the ones that have become obsessively customer-centered. We will realize the importance of producing products that meet the customers' demand for quality and supply their precise needs. We will learn, more skillfully than ever, to tap the remarkable reserves of talent, energy, and unique ideas that the people who work in our plants and offices can bring to their jobs. We will discover new and more productive ways to energize that crucial resource and use it.

In the process of looking ahead, teams of Ford futurists have identified dozens of technologies that can be applied to our future vehicles—to their designs, to their onboard features, to the materials used in them, and to the way that they are manufactured. The technologies can provide automatic navigational guidance, security-alert protection, and adaptive peripheral vision systems.

For the driver, those technologies would mean on-board, direct-to-satellite communications links with dealer service departments allowing automatic diagnosis of any developing problems; high-efficiency air-purification systems; automatic passive-restraint systems; electronic light-emitting surfaces; auxilliary electrical power systems using photovoltaic cells integrated into the roof; and special glass coatings that reduce vision distortion from rain, repel dust, and retard formation of condensation.

Our vision of the future features modular construction of the automobile—using modules that can be easily reconfigured for urban use, for family vacations, or for long-distance travel.

But rather than just listing the features of the future car, let me invite you to imagine what it would be like to enter the showroom of a Ford dealer featuring the newly introduced 2001 model.

A future vision

As you enter the showroom, your first glimpse of the car conveys its strikingly aerodynamic appearance. As you move closer, you notice that its appearance results from more than just the "clean" basic shape. There are no apparent door handles, rear-view mirrors or antennas. The glass, which comprises all of the vehicle above the belt line, is flush with the lower body and shaped with compound curves to conform to the car's smooth aerodynamic form.

A Customer Information Specialist (CIS) introduces herself and explains the vehicle's overall Airflow Management System—which includes such automatic features as variable ride-height control, variable skirts and spoilers that cancel all induced lift, and variable air inlet/outlet ducts—all under the coordinated control of a central electronic command system.

She points out the wide tires that blend into smooth, disc-like, body-colored wheels and explains how the tire-reinforcing cords are continuous with, and flow into the molded plastic wheels, resulting in a perfectly balanced, light-weight, high-performance integral element.

As you stroll around the car, you wonder at the apparent lack of turn-signal indicators, side marker lamps, or tail/brake lights. The CIS explains that all of those functions are now accomplished by electronic light-emitting surfaces, which have been integrated into the glass and selected body areas, and are almost invisible unless they are lighted.

When lighted, the areas become highly visible and vary in intensity, color, and shape to clearly communicate the driver's intent and the vehicle's operating condition, such as its rate of deceleration or acceleration. She illustrates her explanation by activating the left turn signal. Instantly, you see a large, bright, flashing yellow arrow appear on the bottom left region of the rear window area.

To open the car door, the CIS demonstrates the Keyless Entry feature, which is activated by a coded sequence of touches to sensitive areas on the side window. In response to the proper code, the door automatically opens; an exterior handle is no longer needed.

Now that the door is open, the CIS invites you to slide into the driver's seat. The seat momentarily feels alive as it automatically adjusts to conform to your body, like a fluid-filled bean-bag chair.

She continues by explaining that the Automatic Total Contour Seat is part of an overall Individual Occupant Accommodation package that also provides individually selectable climate control and audio programming for each occupant.

The CIS points out that in place of rear-view mirrors, there are multiple electronic cameras that are individually programmable for the best direction and size of field. Those cameras are small and "look out" through the glass, so they are almost impossible to detect.

They display on a 3-segment screen located on the upper rim of the Driver Information Module and portray the environment behind and to both sides of the car. There are absolutely no blind spots, and the system senses non-visible infrared radiation; it works equally well at night and during inclement weather.

She points out that the same technology also operates a forward-looking infrared system that provides driver vision during heavy fog, rain, or snow conditions in the form of a heads-up display on the windshield where driver attention focuses.

The CIS now invites you to watch a short video presentation that illustrates some of the car's construction details.

Modular construction

The holographic video show introduces the automobile as a breakthrough in the development of modular construction. You watch as 3-D representations of the vehicle's basic building blocks appear out of nowhere and slowly rotate into correct positions, while a voice explains the advantages of that modular assembly.

You learn that the basic vehicle module is an occupant-protecting "cage" constructed of heat-treated alloy steel preforms that are bonded together with structural adhesives to form an incredibly strong and resiliant structure. The narrator states that two-, four-, and six-passenger modules are available.

Front and rear-end modules attach to the central occupant cocoon with what appear to be about a dozen bolts. The integrated engine/transmission powertrain is itself a sub module that can be installed in either a front or rear module. For applications where 4-wheel drive is required, or where "dual power" is considered an asset, a powertrain module may optionally be installed in both the front and the rear.

Required tailoring of parameters such as suspension rates, damping characteristics, and brake proportioning is accomplished by appropriate programming of the central electronic control system.

The steering is also under electronic control—which automatically orchestrates complex 4-wheel steering responses to completely normal driver inputs. That effectively extends the performance range of the vehicle during any radical maneuvers.

The video show concludes by showing how the completed assembly of modules—which is basically a drivable vehicle—is skinned by large plastic panels which are corrosion-proof, damage-resistant, and easily replaced if required. A full-length, smooth plastic underpan reduces air turbulence under the vehicle and provides some drag-free "ground effects" road handling.

The CIS points out that additional modules will be introduced from time to time as market research uncovers new consumer needs. She emphasizes that all modules will be readily interchangable, and it is even possible to rent a module and temporarily reconfigure the vehicle for short-term purposes such as vacations.

Flying the simulator

The CIS suggests that you spend a few minutes in the dealer's vehicle simulator which will demonstrate the operation of various features. She explains that the simulator is based on aerospace flight-simulator technology.

Upon entering it and closing the door you are amazed at how life-like the experience is. The CIS joins you on the passenger side and gives you an operator authorization code that's needed to activate the simulator.

Of course, the conformable seat has already adjusted to you, but you've experienced that earlier. You adjust the Adaptive Peripheral Vision sensors and the sound system to your preference. You notice that the sound system couples low-frequency response to your body directly through your seat, greatly enhancing the realism.

The CIS explains that you can now make several more personal-preference adjustments. The first is Climate Control. You select a temperature of 68° F, whereupon she reaches for her individual Occupant Accommodation control pad and selects a temperature of 72° F for her side.

Now you begin to "drive" the simulator while the CIS uses a special control to call up a range of road surfaces. As you begin to acquire a feel for the "vehicle," she suggests that you experiment with the driver-preference controls which determine effective suspension-spring rates and damping characteristics. Also, you experiment with the controls that program the steering effort, steering sensitivity, and simulated road-feel feedback. You converge on a combination of settings which feels best for you.

Since you are now "driving" the simulator in a more spirited fashion, the CIS asks if you would like to experiment with the instrument format. You sequentially review each of the 12 basic pre-programmed information formats as they appear on the colored flat-panel display of the Driver Information Module. Ultimately, you opt for an electronic representation of a few basic analog gauges augmented by a variable color bar-chart which graphically displays that all of the vehicle's critical systems are operating within their normal range.

As you really extend yourself at simulated high speed along a twisting road, you feel the conformable seat grip you tighter. Also, the instrumentation display simplifies to an easier-to-read, less-distracting format.

After several minutes of that, you do manage to find the limit and spin-out. You shut off the simulator and remark to the CIS how useful that experience was to you. You had no previous idea that a "road car" could be stably controlled at such high rates of lateral acceleration. You mention that you will probably now be a better driver should an emergency situation arise. She agrees and explains that the simulator has been used effectively for advanced driver training. But now it's time to try the real thing.

INSIDE THE CAR OF THE FUTURE. Navigation screens will keep you from getting lost, and satellite telephone hookups will put you in touch with the outside world from the start to finish of every journey.

21st-century automotive serivce

On your way to the parking area where the demonstrator vehicle is parked, you pass by the dealer's service area and the CIS introduces you to the service manager. He describes the recent changes that have occurred in his department.

First, the new vehicle's central control-system contains a self-diagnostic feature that pinpoints the source of virtually all problems. Because of the car's highly modular construction, the preferred repair technique is to replace the offending module. In most cases, that can be accomplished in a couple of hours. The modules that are removed will be repaired either at the dealer's facility or at regional service centers, or they will be returned to a factory where they will be completely remanufactured and reissued.

Continuing his explanation, the Service Manager informs you that redundant systems and "limp home" features make it highly unlikely that the vehicle would ever break down on the road. If it should occur, however, its on-board direct-to-satellite, two-way communication system will automatically contact the nearest dealer. The dealer system will analyze failure data and determine whether the problem can be fixed in the field using replacement modules in inventory.

If the problem is not field-correctable, a service van will drop off a loaner vehicle and transport your car back to the dealer's service department for repair.

When the Service Manager finishes his explanation, you ask about the "two-way satellite communication system" and "on-board navigation system"—two features you had not heard about before. The CIS assures you that the demonstrator contains both systems and that they will be explained during the test drive.

Driving the demonstration vehicle

As you slide into the driver's seat in the demonstrator, the CIS hands you the driver ID card that she programmed in the simulator. That card also contains the authorization code for this vehicle. Inserting the card in a slot in the Driver Information Module, you start the engine while all driver-adjustable systems automatically adjust to your preference.

It's a cold fall day—well below the 68°F setting of your Individual Occupant Accomodation control, and you're aware that you are being bathed by a gentle stream of warm air. The CIS explains that that is a Quick Heat feature, which uses energy from an auxilliary electrical power system that generates electricity using photovoltaic cells integrated into the roof glass. It stores that power in a high-energy-density solid-electrolyte battery.

As you pull out of the dealer's lot, the CIS begins to explain the communication and navigation systems. She informs you that the demonstrator you are driving has automatically established contact with a geosyncronous orbiting satellite.

She switches on the navigation system, and a map of the dealer's neighborhood appears on a flat-panel display on the right side of the Driver Information Module. A flashing dot indicates the exact location of your car. As she dials-down the resolution, the neighborhood map "zooms" to a full-city map; but the position of your car is still readily apparent. She points to the map and suggests that you head for a nearby freeway.

She then programs the navigation system to guide you to the freeway entrance by using audible commands, and a pleasant voice instructs you: "Turn right at the next intersection and move into the left-turn lane for access to the freeway entrance ramp." The same instructions appear on the screen, superimposed over the map display.

You also learn that navigation is only one function provided by the satellite link. She pushes another button and the map is replaced by a display of local information topics including: hotels/motels, restaurants, route selection, amusements, museums, and local events.

The CIS continues by explaining the Security Alert feature. You learn that sensors integrated into the window glass and in other key locations can detect any attempt to break into or steal the car. When the sensors are stimulated, the communication and navigation systems will automatically link up with a central Customer Security Services facility operated as a customer service. The police department closest to the car will be notified and given the car's exact location. The system can also be activated manually for any necessary emergency assistance.

By now you have reached the freeway-entrance ramp. As you accelerate to the 70 mph speed limit, the CIS introduces you to the Automatic Guidance feature. You learn that this feature uses the navigation system in conjunction with data from on-board sensors to provide totally automatic vehicle guidance on certain of our interstate highways.

This particular highway has been "mapped," so the CIS shows you how to engage the guidance feature while continuing to explain that within a few years, a complete interstate "grid" of highways will be "mapped" and reserved exclusively for automatic-guidance-equipped vehicles.

As the automatic system takes over, you release the controls and observe that the demonstrator vehicle tracks smoothly down the center of the lane at a constant 70 mph. As you gradually close in on a slower-moving car ahead in your lane, the demonstrator automatically signals for a lane change and pulls smoothly to the left, passing the slower vehicle.

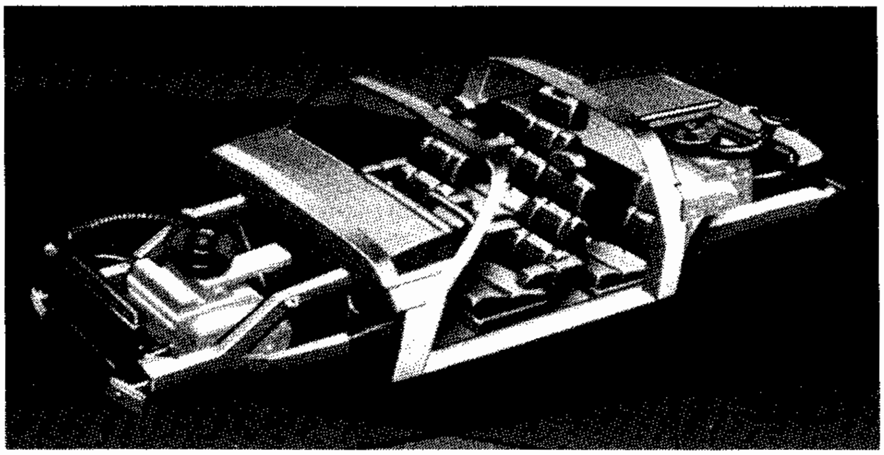
The CIS explains that even when the vehicle is not being automatically guided, constantly operating features of the guidance system will prevent unsafe lane changes and passing maneuvers. The system will also detect upcoming road hazards, such as an ice patch, and help the driver to respond appropriately. In an emergency, that constantly operating system will take over so that it is almost impossible for the car so equipped to hit another object.

Your demonstrator completes its pass, signals for a lane change and pulls into the right lane while smoothly avoiding a piece of truck-tire tread lying in the road between lanes. The CIS suggests that you take the upcoming exit ramp, so you switch off the automatic guidance system and notice that it does not relinquish control until you conclusively demonstrate that you are back in command.

The road back to the dealership is lightly traveled and twisting so you engage in a mild version of the performance driving you enjoyed in the simulator. The demonstrator confirms all of your simulator impressions. You try to skid to a stop, but your car refuses to lock its wheels. It just stops rapidly, but smoothly, while maintaining your full steering control. You try to spin the wheels on gravel when accelerating away from construction at an intersection, but you can't do it. The car just accelerates smoothly, automatically determining the maximum rate it can attain.

Nearing the dealership, you pass a road-repair crew generating a cloud of dust and spreading hot tar on the road's shoulder. As you pass this scene, you realize that you did not detect the expected odor of tar. "The air-purification system filtered it out," the CIS explains. You also remark that no dust stuck to the windshield even when you stopped momentarily in the dust cloud. "It's electrostatically repelled," she explains, and she also mentions that the windshield has a special coating inside and out which reduces vision distortion from rain and greatly retards the formation of any condensation on the glass surfaces.

As you near the dealership, the CIS explains that this car can electronically communicate with others. Soon, all new vehicles on the road will have that feature. That capability also functions as an adjunct to audible horns and sirens, and is a particularly useful way for emergency vehicles to warn near-by drivers, particularly in urban areas where sirens are used less often.



MODULAR CONSTRUCTION will allow your car to be custom built and upgraded as new modules are introduced. You'll also be able to rent modules to temporarily reconfigure you car—to take a family vacation, for example.

Placing your order

As you return to the showroom, the CIS accompanies you to an interactive Vehicle Specification Selection and Order Coordinating Terminal where you work out the exact combination of features and options you wish to order.

She helps you to consider the relative virtues of the various powertrain options. You select a higher horsepower unit for rear module/rear drive installation. That basic engine adapts to various fuels—including gasoline and alcohol. You select gasoline, since that's the prevalent fuel in your area.

The CIS mentions that a hydrogen-fueled powertrain with high-performance capabilities is in the final stages of development and suggests that you may be interested in trading in your gasoline-fueled powertrain and upgrading to the hydrogen unit in a couple of years.

When you finish the specification process, the CIS explains that your order is now being entered, analyzed, and scheduled at the factory. Just as she finishes her explanation, the terminal displays a message that your order has been placed and your car will be delivered to your dealer—exactly 15 days from now.

After thanking the CIS for her help, she invites you to tour the manufacturing complex where your car will be constructed. The complex is only about 120 miles away, and a tour takes about half a day. That sounds great to you, and it is conveniently arranged.

21st-century manufacturing

The first stop on your tour of the manufacturing complex is a small auditorium where your tour guide explains that you will see a short film that explains some of what you'll see later. You learn that all engineering and manufacturing processing is now accomplished on an integrated, computer-driven engineering, design, processing and testing network that ties together all design and production centers. Even key suppliers are tied into selected parts of this network.

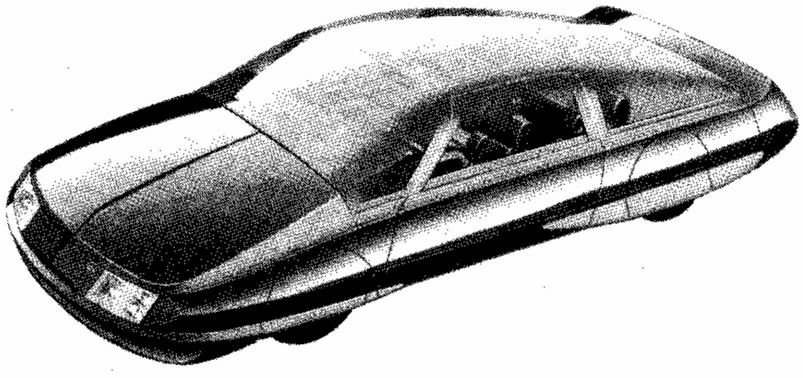
The film presents an overview of the manufacturing complex. You learn that the central Vehicle Final Assembly facility is responsible for assembling completed modules and sub-assemblies into a finished automobile. Those modules are supplied on a just-in-time basis from a ring of surrounding plants which use highly automated but flexible processes to manufacture, and remanufacture, a variety of components. Those factories are operated by a highly trained staff.

Not all manufacturing operations are represented at the complex you will tour. Engine blocks, steel structural pre-forms and major glass components are all supplied to the module-fabrication plants from central facilities. The film concludes by presenting those operations.

You see one-piece aluminum engine block/cylinder head/transmission case casting with ceramic inserts being processed by evaporative-casting techniques. You watch large pieces of thin glass being laminated to transparent plastic and molded into complex shapes which are lightweight but shatterproof.

The film's concluding sequence shows steelmaking in which plasma melting techniques are used to produce carefully controlled, high-purity alloy steel, which is cast into a thin slab requiring minimum hot rolling before it is cold-rolled into a finished sheet. Some of the sheet steel is electrolytically coated with a nickel alloy for outstanding corrosion resistance and is supplied in that form to other Ford manufacturing locations. Other sheet material is roll-formed into a structural preform which is cut to length, stretch-formed and selectively heat-treated by lasers.

The real tour starts in the Powertrain Module Factory. There you watch as robots that, in your guide's words, can "see," "learn" and "think for themselves," perform the complex task of assembling a high specific output, high RPM, internal combustion engine within a "monoblock" casting which also houses the integral Continuously Variable Ratio transmission.



THE ALL-GLASS TOP OF FORD'S 2001 MODEL is flush with the body, giving the car execellent aerodynamic performance.

The highly automated assembly process makes it difficult for you to see all of the operations, but you are able to visually confirm your tour guide's claim that many of the engine's internal components are fabricated from high performance plastic composite materials.

The guide also points out that the engine's various covers and "pans" are installed with structural adhesives and are not removable in the field.

As you study the finished powertrain modules at the end of the assembly line, you notice that they are all fully integrated units, devoid of any "hung-on" accessories. For control purposes, a single electrical umbilical is provided to plug into the vehicle's central control-system.

Your next stop is the Greenhouse Fabrication Factory where you watch large formed-glass pieces being unloaded from trucks onto a line for Magnetic Vacuum Sputter Deposition. That process, your guide explains, is used to deposit multiple thin films of exotic materials to insulate the car's interior from the sun.

That, you are told, allows smaller/lighter air conditioning systems and prevents degradation of the car's interior materials from ultraviolet radiation. The coatings also impart cosmetic color to the glass, control glare, and reduce the tendency to fog. In other operations, various sensors and antennas required for features such as keyless entry, intrusion detection and satellite communication are integrated into the greenhouse structure.

You next visit the Exterior Panel Fabrication Factory where large panels are injection-molded from high performance thermoplastics or formed from reinforced thermoset plastic composites with finished color gel coats in large presses.

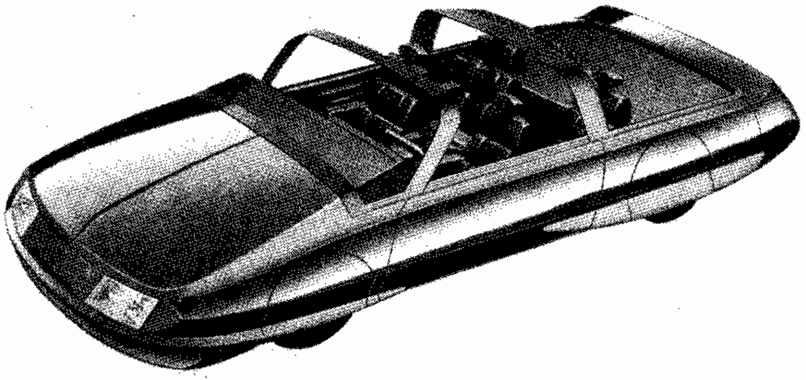
Your tour also includes stops at the Suspension Module Assembly plant and the various structural module fabrication plants where you watch robots apply fast-curing structural adhesives to bond elements into an integral structure.

All modules leave their various assembly plants complete with all sensors, actuators and control electronics and a single electrical power-distribution bus.

Your tour ends at the Final Vehicle Assembly plant where all modules arrive on a coordinated, just-in-time basis and are assembled by robots, with minimum human assistance, into a completed vehicle. A comprehensive computer-directed final checkout procedure completes the manufacturing process.

On your drive home from the plant tour, you think about the seven days remaining until you take delivery. You can hardly wait! **R-E**

Well, there you have it. A look at 21st century transportation technology, materials, and manufacturing processes as we at Ford Motor Company now anticipate them to be. To me, it's a fascinating prospect. But getting from here to there will be even more fascinating. While I expect to be happily retired and playing golf in Palm Springs when 2001 comes around, what we do for the remainder of this decade and into the 1990's will determine whether or not this scenario comes anywhere near reality. And, as I noted at the outset, how we treat our customers and how we treat our own people will make all the difference.—Donald E. Petersen



THE INTERIOR OF FORD'S FUTURISTIC automobile is revealed in this photo by the removal of the glass top.

Apr. 4, 2001

Dear Sue,

I'm still glad I left the Back to Basics commune, but I admit that being raised there does have some advantages. Although I may struggle with today's technology, at least I know how to read and write! That, along with my experience on the commune newsletter, got me my new job: researcher for *Telecommute*, an electronic magazine.

When I say I'm a researcher, I don't mean I run around town visiting libraries. I sit at my office workstation, tell the expert-system researcher what information I need, and let it dig out the data from the online databanks we subscribe to.

Although *Telecommute* is transmitted electronically, the editor designs it to be read as hardcopy rather than videotex. Subscribers scan the magazine on their home terminals and print out only the articles they want to read more closely.

Such on-demand printing is common. In fact, books printed on printing presses are considered antique curios, of interest mainly to rare-book collectors. (That library of books at the commune may be worth a lot of money some day!) High-speed laser printers can print out full-color illustrations and double-sided copy, then adhesive-bind the pages.

The editor told me that when high-resolution screens displayed type as clear as print on glossy magazine stock, many people said that paper books and magazines would vanish altogether. That still has not happened —certain types of communication, such as those requiring analysis, can be more easily read and understood as hardcopy. Even for casual reading, many prefer it to book disks that are read on portable book screens.

My first research assignment was to dig up background for an article on bootleg TV-art. Subscription TV-art displayed on high-resolution flat-screen TV's has become popular. A TV-art reproduction—French impressionist—hangs on my wall at home. The quality doesn't match that of the original, of course, but it's about the same as the print reproduction; it doesn't need to be mounted or framed, and I can change it whenever I want to just by requesting another selection from the catalog. Video artists found a new market selling to the subscription art services. But now, because hackers have downloaded popular artworks onto optical disk and sold bootleg copies, some artists are demanding improved safeguards.

Doing research on that article gave me my first taste of how the expert-system researcher works. One feature I particularly like is the databank guide. I request information from the guide, and give it search parameters, and it becomes an instant librarian: It designs a search pattern, then collects, catalogs, and electronically "shelves" the results. It can search international foreign-language sources and run them through its translater. I found that sources originally written in Japanese, Russian, Chinese, Arabic, and Swahili can give a broad perspective.

I can learn more in one week researching electronically than in months researching in library books. Sometimes I complain about information overload, but then I remind myself what life was like back home. With electronic research, printing on- demand, and art broadcast on TV, 2001 offers plenty of mental stimulation. Sue, admit it—don't you find life in your Back to Basics commune just a little dull?

Love,

Hedy

SOLID STATE TECHNOLOGY IN THE 21st CENTURY

One gigabit in three dimensions.

B. L. GREGORY

FOURTEEN YEARS AGO THE INTEGRATED-circuit industry introduced the 1-kilobit MOS Dynamic *RAM* (DRAM). Although the DRAM has reached the 1 megabit level—a tenfold increase—it took five generations of development since 1973 to get there. In retrospect, each step in the development of 1-megabit DRAM's is obvious, yet few people in 1973 would have been able to chart the advances in both the processing and the equipment that made the progress of the last 14 years possible.

What made it difficult, back in 1973, to see 14 years into the future is that prognostications are really limited by what we already know. It's relatively easy to predict the next generation of technology because it's usually based on existing knowledge and production equipment: The problem of getting there is largely one of execution. It's predicting the third generation that becomes difficult because key pieces of technology or equipment normally do not exist, or at best we surmise what direction technology will take based on what is already known. Beyond the third generation, predictions become very inexact; at their best they are *guesstimates* that must be solely based on extrapolations of past rates of progress.

What does the extrapolation process show us about the future? Between the late 1950's and early 1970's, chip complexity doubled every year; a pace that was difficult to sustain. In the early seventies it slowed to a factor of four increases every three years. Indications are that, as we approach the existing technical limits, the rate of change will slow even further in the decade of the nineties. But even with slower progress, extrapolation predicts that in the year 2001 it will be possible to fabricate a 1-gigabit chip (1000 million bits) having a minimum feature size of less than 0.25 micron and an area approximately ten times larger than today's largest chips.

Another approach to prediction is to identify fundamental limits. This can take the form of limits in feature size due to lithographic or other patterning constraints. It can take the form of practical limits on the thinness of gate oxides necessary for high reliability. The limit can become even more fundamental and relate the energy involved in a semiconductor device's switching action, or the charge stored on a storage capacitor, to the fundamental thermal noise present in the device's elements; or the energy might be related to the charge produced spontaneously in a device when it is transisted by a high-energy particle. For example, without the shielding effect of the Earth's atmosphere on cosmic rays, we would not be able to use our present complex integrated circuits because of induced logic and memory upsets.

We can attempt to predict the evolutionary equipment that will set the major limits in future manufacturing processes. If, for example, we knew the capability and availability of future generations of optical lithographic (photographic) equipment we would eliminate a major unknown in our predictions—assuming that optical systems will still be used for manufacturing chips.

But there is hazard in that kind of thinking, because it is based on the existing technology that uses an optical process to improve two-dimensional (2-D) chip density by making the features smaller. The existing 2-D technology might easily be superseded in two generations. For exam-

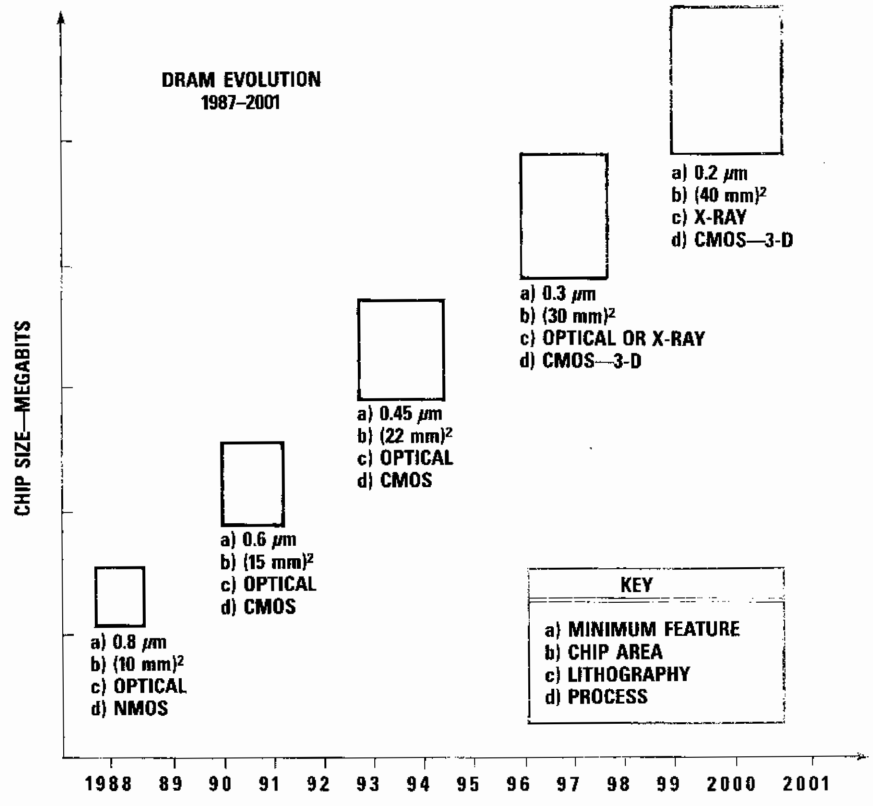


FIG. 1—THE PROJECTED EVOLUTION OF DRAM to the year 2001. The major breakthrough is expected to occur when the chip structure can be made three-dimensional.

ple, the introduction of three-dimensional (3-D) technology would allow us to work within the depth of a chip (in connected layers, so to speak) so that the overall active density of the chip would be increased without requiring smaller features. Or, the chip might contain its own testing system capable of bypassing faulty memory circuitry, thereby permitting larger chips to be built at greater yields—meaning fewer and fewer rejects caused by faulty memory.

But enough said about the difficulties—on to the predictions! The most complex chips in 2001 will be DRAM's. NMOS (negative-channel MOS) technology, which is used for both DRAM's and CPU's, will have given away to CMOS for a variety of reasons, among the most important being lower power requirements and improved submicron performance. Although new architectures will reduce CMOS power to minuscule levels, the higher density of the 1-gigabit chip will nevertheless concentrate what little heat there is per individual cell, so new, more efficient, concentrated cooling techniques will be employed to provide for the power dissipation required in a 1-gigabit chip.

The chip itself will have 3-D circuitry, employing both horizontal (2-D) and vertical (3-D) devices, multilevel 3-D devices, and several layers of electrical and optical interconnections. In a sense, the chip will resemble a modern commercial building having some office complexes on a single floor (2-D), others occupying several floors (3-D), horizontal raceways for communication wiring (2-D), and vertical raceways or the elevator shaft (3-D) for interfloor wiring. To the process engineer of 2001, the processes of 1987 probably will appear as primitive as a 10-micron metal gate and a high-threshold PMOS appears to us today.

Referring to Fig. 1, from what it is possible to conceive from present technology, we have extrapolated the limits, processes, and equipment that are likely in the evolution of DRAM's from the present to the 1-gigabit chip of 2001. Because it is a density-related 3-D system, we expect that X-ray lithography (synchroton source) will be required in the late 1990's in order to continue DRAM evolution.

Other silicon products

The DRAM is a high-volume, cost-sensitive product. Decisions made concerning its technology are not automatically relevant to low-volume, high-value ASIC (*A*pplication-*S*pecific IC) chips. An ASIC chip is an ultra-high-density device containing a complete system made to order for a specific application. Stretching the imagination, one ASIC chip might comprise all the electronics of a personal computer system: the CPU, DRAM, and support systems. More likely, an ASIC might contain the entire electronic system for an automobile: Everything from a voice synthesizer warning that the doors aren't closed to the computerized ignition system. Similarly, one or two ASIC's might comprise a complete cellular telephone, something that presently takes a bagful of components, of which many are already multi-function integrated circuits.

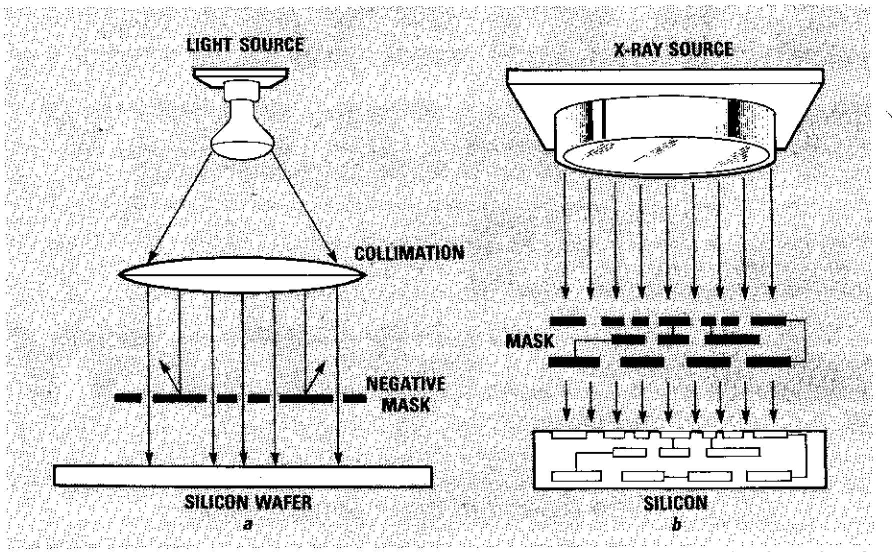
Even today a schism is developing between the technologies used to manufacture DRAM's and ASIC's. Although the DRAM process is continuing on an optical-lithography path, high-performance high-density ASIC's, called VHSIC's, are being produced by direct-write E-beam lithography. Other techniques for manufacturing ASIC's and VHSIC's that are still in the early stages of development include laser-assisted deposition/etching, and focused-ion beams. The advanced ASIC line of 2001:

a) will not use any form of mask or reticule.

b) will use a combination of E-beam, laser and ion-beam processing.

c) will depend on extensive computer resources for design, simulation, processing and testing.

d) will be designed using innovative techniques to achieve high levels of tolerance against both hard and soft faults.



MULTILAYER, OR 3-D PROCESSING will sharply increase the active area per chip. As shown in *a*, in conventional optical procoessing a mask provides the surface pattern for a silicon chip. In 2001, 3-D processing, such as the X-ray system shown in *b*, will result in a multilayered chip having individual elements interconnected by metallic and/or optical paths.

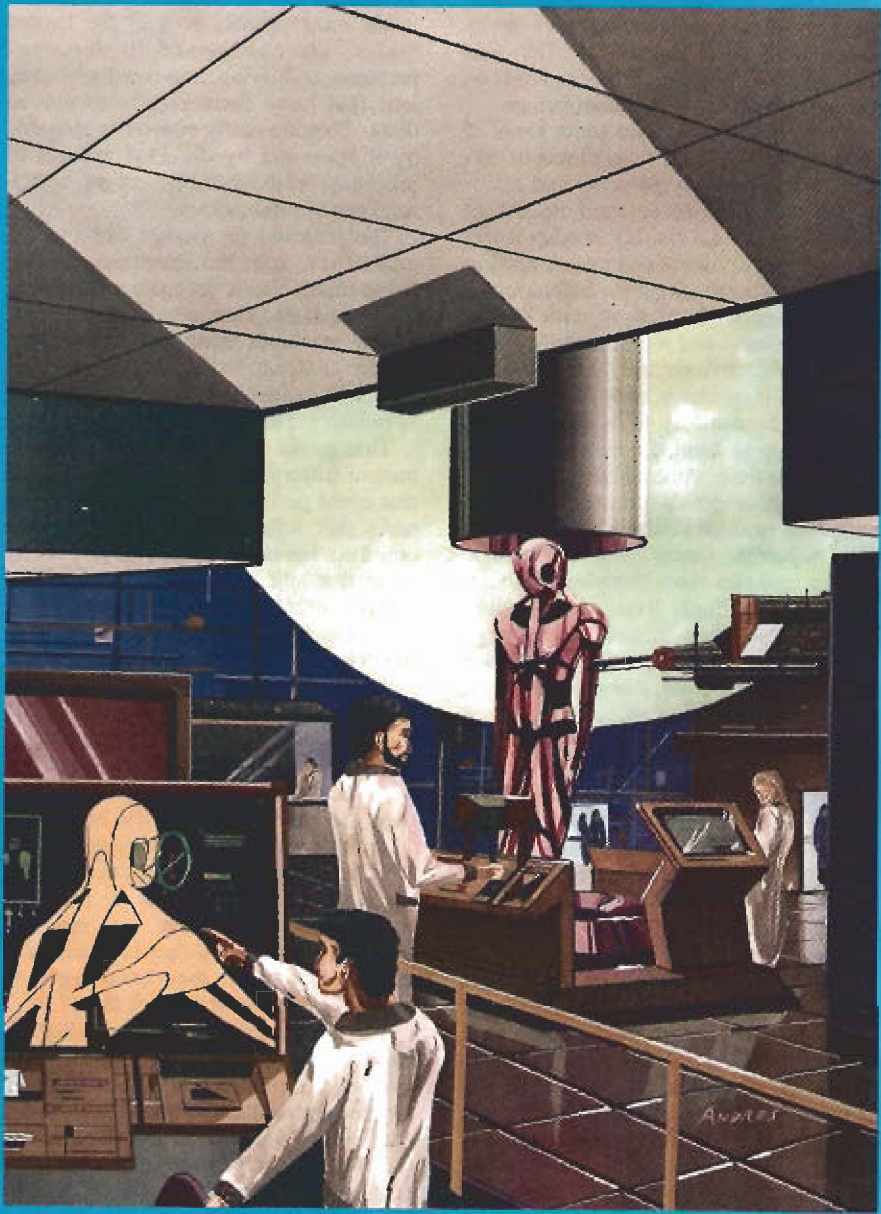
New materials

Because compound semiconductors provide greater speed, and because speed is the key to performance in VLSI (*V*ery *L*arge *S*cale *I*ntegration) circuits, it is more than likely that 2001 won't be a silicon world. Right now, new classes of synthetic compound semiconductors are being developed in research labs and universities around the world. In particular, there is a great deal of effort going into improving the materials-technology of gallium arsenide (GaAs), which is considered by many to be the most mature of the compound semiconductors. By 2001, the compound semiconductors will be extremely fast, and single-gate switching in just a few picoseconds will be possible.

Although it would normally be difficult to take advantage of such speed in complex IC's due to the parasitic resistances and capacitances present in large chips, the shorter paths of three-dimensional structures will maintain the higher speed by reducing the signal delay between devices (because they will be within the same structure).

In 2001, the major impact of high-speed compound semiconductors will be in devices that successfully combine optical and electronic signal processing; devices that combine ultra-fast analog-to-digital conversion with digital signal-processing to make possible digital video transmission and reconstruction at greatly reduced bandwidth. Also, compound semiconductor devices will be standard in monolithic circuits, in integrated optical arrays of various sorts, and in high-performance communications. However, compound semiconductors will not have succeeded in the semiconductor memory market. There, silicon will continue to be the unquestioned leader, although the current wasteful approach to memory fabrication will be eliminated in 2001—we throw away approximately one-half the silicon we make due to defects. In 2001, on-chip fault-compensation will allow us to use *all* the chips.

Although we anticipate that silicon will still be the material of choice for memory, the search for different, higher-density memory materials will continue. Should a new memory material be created, the predictions in this article will most likely prove to be too conservative. **R-E**



ROBOTS IN THE YEAR 2001 may take on a more human appearance, and act as personal "servants." We'll still be covering new technology then—you can bet on it.

THE ROBOT IN THE 21ST CENTURY

At present, robots are simple, computerized arms with limited capabilities. That will change as the 21st century begins.

ISAAC ASIMOV

At present, robots (which may be difined most briefly as computerized machines) are extremely simple. They are, essentially, merely computerized arms performing very few motions over and over again.

Research is under way, however, to add to the capabilities of such robots—to give them the equivalent of visual, auditory, and tactile senses—to let them modify their behavior according to what they see, hear, and touch—to make them responsive to spoken orders and to let them speak in return—to grant them mobility.

By the year 2001, it might well be that at least some of those characteristics will have been imparted to robots, so that they can perform tasks of increased complexity. Robots will improve not only in their capacity, but they will certainly increase in numbers as well. There may be well ten times as many robots in action in 2001 as there are today.

The social impact of robots

Today, robots are used almost entirely in factories; they are "industrial robots." However, attempts are being made to design robots of vaguely human form that would be able to do tasks in the home, acting essentially as servants, since they will be running the household appliances, and even greeting visitors. Such "personal robots" may well exist by 2001.

But robots do not exist in isolation. They are accompanied by social and economic problems. If, in 2001, there are many more and much better robots in existence, then it is reasonable to suppose that the social and economic problems will intensify enormously.

The most obvious problem is that arising from the fact that robots will replace human beings in many kinds of work. They are doing so now, but they will be doing so to a much greater extent in 2001. In fact, the economic dislocations that may result, and the popular resentment that will grow, may be an important factor in inhibiting the entry of robots into society. Robots might not increase in numbers or in ablilities as rapidly as they would if human suffering did not have to be taken into account.

Since the advantages of robots are so great that the pressure for their use will be overwhelming, society will have to make that use more nearly possible by attacking the problem of human displacement and unemployment. By 2001, social concerns, in that respect, will be as prominent a part of the human scene as the robots themselves are.

It might be asked, of course, whether robots are really so necessary that it is worthwhile disrupting society for their sake. What are the advantages of robots that are so great?

For one thing, robots may be used in jobs that are too dangerous for human beings—under conditions of considerable heat or cold, or in environments where poison gases or radioactive contaminations are a possiblility. They can also do work that is too filthy or unpleasant to be popular with human beings.

Then, too, they can do some kinds of work more efficiently than human beings can. When properly powered and maintained, robots do not get tired, do not get bored, do not take dislikes to other workers or to supervisors, and do not need to take coffee-breaks, visit the bathroom, or stop for lunch. They work with greater meticulousness and reproducibility.

All that is obvious, but there is another point that is, perhaps, easy to miss.

Throughout history, human beings have sought help in doing the heavy labor that needs to be done. Animals were hitched to the plough or set to turning millstones, dragging carts or chariots, and carrying human beings. Levers, wheels, inclined planes, and ever more complex combinations of those simple devices were devised to do work more easily. Sources of energy other than human and animal muscle were looked for—the wind, flowing water, and, most of all, burning fuel.

However, when all that could be done in the way of the use of animals and machines was done, there still remained jobs that, because of their complexity, had to be done by human beings. Yet a great many of those jobs, although too complex for animals and machines, were far too simple to make use of the full potential of even ordinary human brains.

The repetitious work done in factories and offices, the endless tightening of bolts or filing of papers, the alphabetizations and hammerings, had to be done by human beings under conditions that did not engage the brain except to a most limited extent. The brain, largely unused, loses much of its capacity, as unused muscles will. A brain that has no occasion to think, becomes unused to thinking, and ends by being unable to think.

It was customary in pre-industrial times to think of the peasants and serfs, who made up at least 90 percent of the human race, as sub-human and brutish, little better than the animals they lived and worked with. To some extent, that was justified—but the serfs were not born so; they were made so by the nature of the work they did all their lives, work that never engaged the mind.

In today's industrial time—in the United States, for instance—we are far less inclined to despise the "lower classes." We attempt to educate everyone to some extent, and we maintain the belief that since all human beings are human beings then everyone has an opinion that ought to be considered. It follows that opinion polls merely present numbers and have nothing to say about the quality of thought behind the opinions. It also follows that we allow every human being an equal vote in political contests.

Yet most people, even in the United States, are condemned to those repetitious, stultifying, non-mind-engaging jobs that leave them largely unable to think. They are easily swayed by slogans, by illogic, and by distorted appeals to prejudice and emotion—all of which weakens our democracy.

The potential for change came in the mid-1970's, with the developments that led to small, cheap, yet enormously capable computers. That meant that computerized machines could be made sufficiently compact and affordable, and yet sufficently capable to be profitably used in industry. The robots had come!

That meant that, for the first time in human history, there existed a machine that could perform the dull and reptitious tasks that hitherto only human beings could do. For the first time, the possibility arose that human beings might be freed from the necessity of doing work that stultified the human brain and made it so much less useful than it could be.

After all, is it not plain that work which is so dull and repetitive that a robot can do it is beneath the dignity of human endeavor? If a human being is forced to do it, you make a robot out of him or her. Robots, then, can free human beings to be human.

Put that way, it sounds very good—but it is not that easy. Those human beings who are replaced by robots are precisely those whose brains have been rendered flaccid by unuse; and they may have lost the capacity to turn their brains again to use. What are we to do with them?

We might argue, of course, that advances in technology that wipe out jobs have always created new jobs in numbers far greater than those that had been wiped out. There's no reason to suppose that that won't be true of the coming of robot technology too. The work involved in designing, manufacturing, maintaining, and coordinating robots will require vast numbers of qualified people.

Re-educating society

The key word, however, is "qualified." It will be insufficient to tell those who have lost their jobs to robots simply to take one of the new jobs that have become available. They are not qualified. There will arise the absolute necessity of an expensive program of retraining and re-education. And for those who are too old or too damaged by the life-work that has been forced on them, there must be the task of finding work they can do or of giving them financial assistance.

The age of robots, which will be well along in the year 2001, will therefore, as a direct result, be also an age of huge educational projects designed to correct the harm done human beings by a non-robotic economy and to create the people who can fill the jobs that have been opened by the robotic economy.

It is clear, however, that that problem is a transitional one. It belongs only to the period of the change-over from a non-robotic economy to a robotic one.

Presumably, the new generation born to a robotic economy will, from the start, do only work that robots cannot do, work that engages the human brain much more fully than hitherto. It should be a thinking generation, rich in creativity.

But is that possible? Might it not be that cleverness, ingenuity, and creativity are but rare properties and that most human beings are, after all, only fit for the kind of dull jobs a non-robotic economy would afford them? We can't tell until we try, but at least there is historical precedent in favor of the fact that we may be underestimating the capacity of human beings generally.

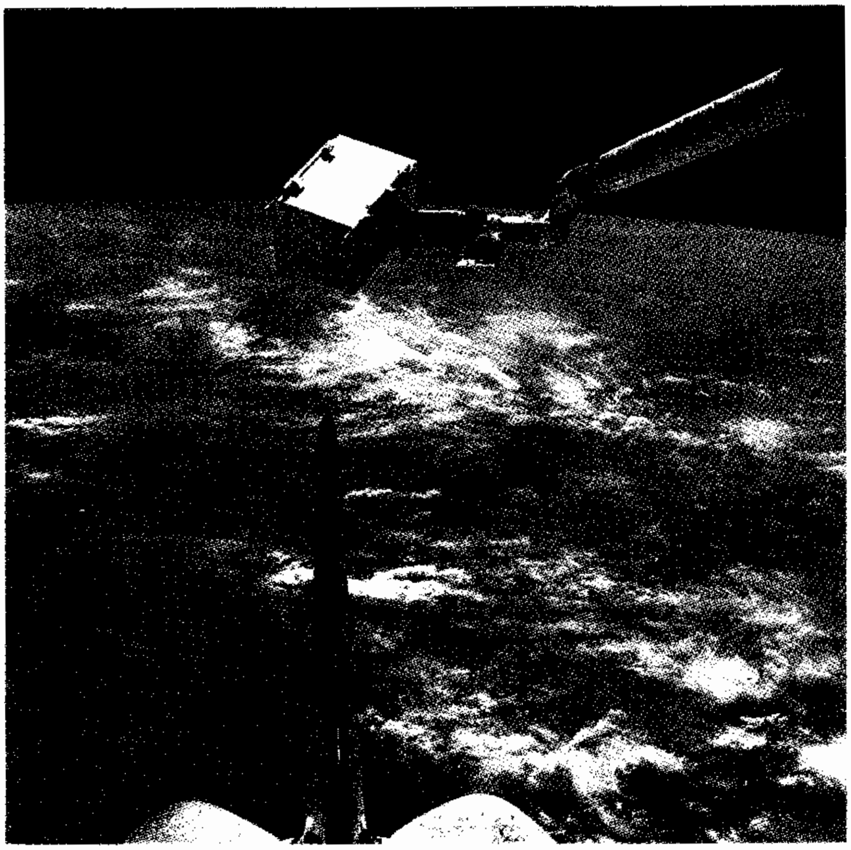
In ancient and medieval times, the ability to read and write belonged only to a very few people—philosophers, scribes, merchants, and so on. Most people did not have the opportunity to learn how to read and write and it was generally thought that they could not do so, even if one attempted to teach them. Literacy was a rare faculty.

But as the world grew industrialized, it became more and more important for people, generally, to be literate. Industrial nations established the principle of universal education, and built free public schools for the purpose and, behold, most people in such nations are literate as a result. Almost all of us can read and write with some facility. Those of us who cannot suffer more from an imperfect education than from innate lack of ability.

So it may well be that the generations brought up in the 21st Century into a robot-economy will display widespread creativity, more widespread than we, with our experience of a non-robot economy only, are likely to credit.

To be sure, it means that in the year 2001, we will be struggling with the establishment of an entirely new philosophy of education. Until now, the notion of mass education has meant one teacher for many students (since it is all too difficult to find capable teachers). It has also meant a standardized curriculum in which everyone learns in the same way at the same speed. No allowance is made for individual differences, with the result that most students are either confused, bored, or resentful of the learning that is forced on them.

Fortunately, the coming of a robotic economy means the coming of a generally computerized economy, for robots themselves are the products of computers. Libraries will be computerized and the computer outlet, which may be present in nearly every home by 2001, will make it possible for people generally (adults as well as children) to satisfy their curiosity in any field.



PERHAPS THE WORLD'S MOST FAMOUS ROBOT. The Space Shuttle's remote manipulator system holds a monitor to detect contaminants around the orbiter's cargo bay.

We all love to learn, if we are given a chance, provided that the learning is in a field in which we are interested. After all, the human brain is particularly proficient in learning, and anything for which an organism is well adapted is pleasant to do.

Therefore, in addition to school where basics are learned, and where students learn how to deal with human interactions and those subjects that require such interaction, there will also be time at home where youngsters can pursue their own inquires and explore his or her own interests and potentialities. In a sense, each child (and adult, too) will have a private tutor in the form of an advanced and interactive computer that can guide curiosities, supply answers, and even suggest new avenues of questioning.

In 2001, then, we will be looking forward to a world in which human beings will, almost automatically, find themselves delightful ways of life, some in science, some in art, or music, or literature, or government, or industry, or show business.

We will be looking forward to a far richer and happier world, and we will be learning to be grateful to the faithful, hard-working robots who will have taken the weight of all the dreadful hack-work from our shoulders and our minds, and will be doing the dull work of the world in order that we might do the interesting work.

Humans vs. Robots

But will the robots stay where they are put? Surely, they (and computers in general) will continue to be improved, will continue to be made more versatile, and given additional powers. They will be able to take over more complex jobs.

Will humanity be engaged in a hopeless race; climbing the mountains of complexity and creativity, with the inexorable robots always close behind, until we despairingly reach the highest peak of all, only to be pushed off by the robots? In other words, will robots and computers finally replace human beings altogether, simply because they will become more intelligent and capable than humans?

I don't think so. Such fears are based on the assumption that intelligence is a rather simple thing, a unitary phenomenon; that all objects that show intelligence show an identical kind of intelligence, so that direct comparison is possible.

That can't be so. Intelligence comes in various varieties and the greatest geniuses, transcendent in one way (Einstein in physical concepts, Mozart in music, Shakespeare in writing) may be quite ignorant, or even foolish in other fields. It is not enough, then, to say "intelligent," one must say "intelligent in this or that way."

It seems to me, then, that robotic intelligence is widely different from human intelligence. If we measure intelligence simply by the ease with which we solve mathematical problems, then the simplest pocket commputer is already far more intelligent than we.

But, then, the human brain is not adapted for number crunching. We can't possibly do any but the simplest arithmetical operations in our head. For anything else, we use our fingers, or an abacus, or Arabic numerals written on paper, or a slide-rule, or a computer.

THE TROIKABOT can carry out complex three-dimensional assembly tasks. We might see this Westinghouse robot in a future space station.

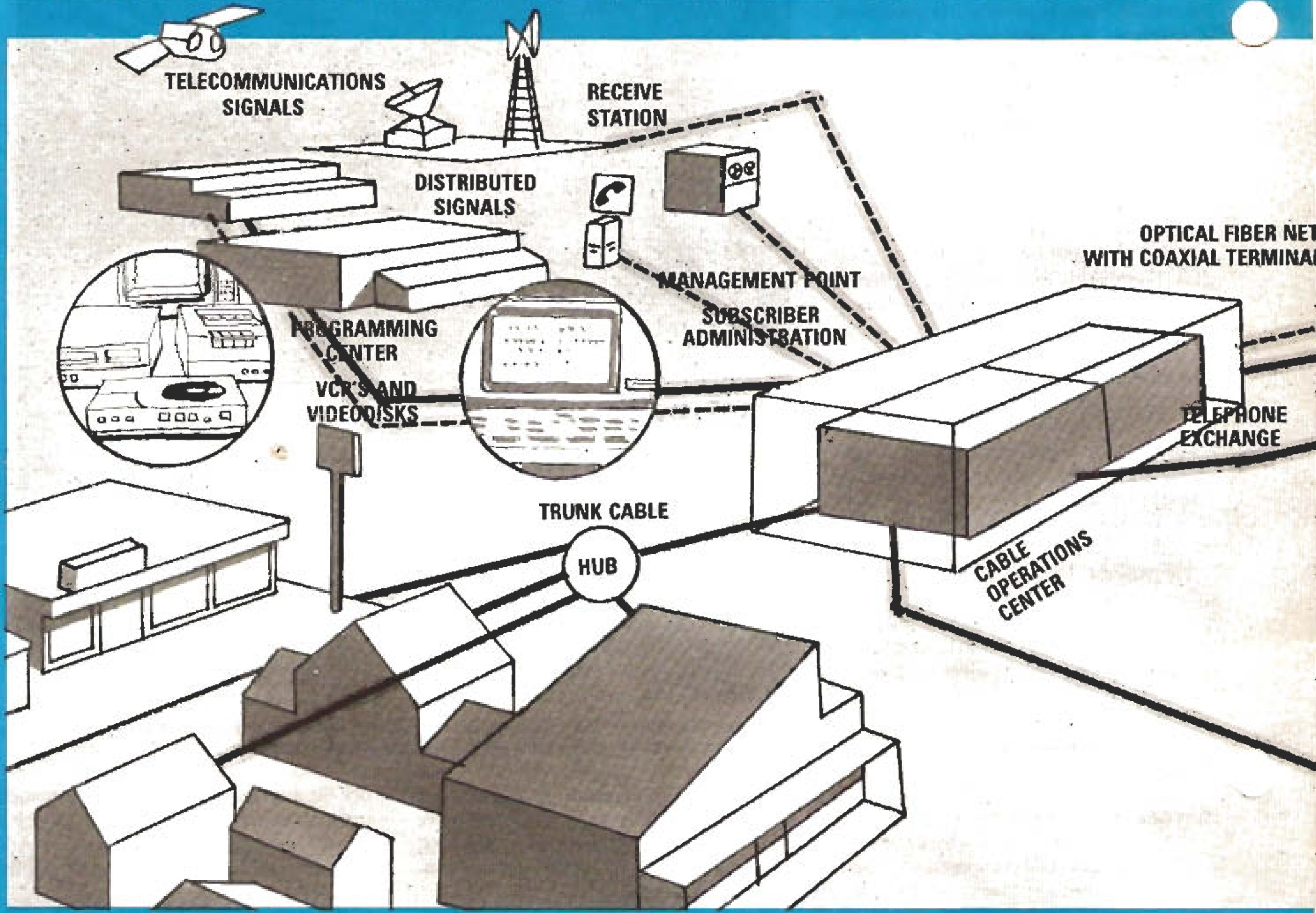
What the human brain is good at are such things as insight, fantasy, imagination, and creativity. The human brain has the ability to look at a problem as a whole and guess the answer. It can take insufficient data and work out the probable result. (I can write an essay such as this one at top speed without ever stopping for conscious thought over the problem of which word comes after which word, or how to structure a paragraph.)

Can we teach robots those human ways of thought? Probably we can't, because we don't know how we think. (I don't know how an essay comes out of me without conscious thought, so I can't program a robot to do it. What directions can I possibly give it?)

Even if we learned how to program robots to think humanly, why should we? We have humans to think humanly. What we want are robots who think robotically, who have capacities that we don't have.

In short, in 2001, we will be looking forward to a world in which robots and humans, two different varieties of intelligence, will cooperate, rather than compete. Together we will advance far more rapidly, than either of us could, separately. R-E

COMMUNICATIONS IN 2001 -



Interactive VCR's? Movies on demand? They're coming—soon!

CHARLES N. JUDICE

IMAGINE YOURSELF IN THIS SCENARIO: You'd like to switch jobs, and, to learn more about companies in the area that need people with your expertise, you type "companies within 50 miles employing physicists" into your TV. In two days, an hour and a half of video programming describing seven local corporations is downloaded to your VCR automatically.

Or suppose your daughter has a thyroid problem. Her pediatrician recommends a local surgeon, but you would like comments from former patients. You type "former patients of Dr. Wellbeing who have had thyroid disorders" into your TV. In five days it informs you that "the material you requested on thyroid patients has arrived."

Or suppose you're a young mother taking care of your newborn son and studying for your master's degree in electrical engineering. While the baby sleeps, you are taking Lesson 12 of the digital signal-processing course being taught at Princeton. Your VCR recorded the lesson last night. In addition, your questions regarding DSP chips were received by Professor Billings this morning.

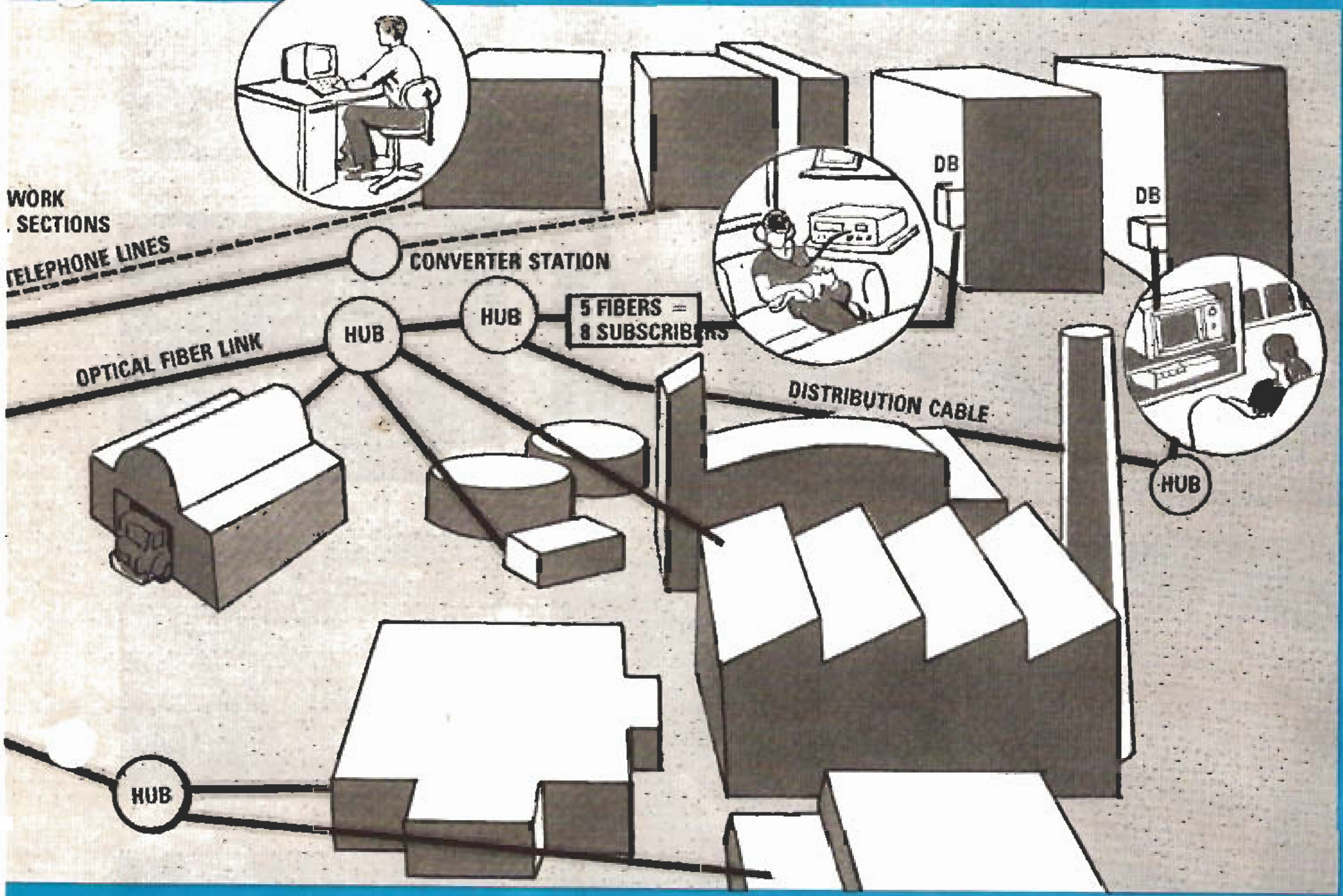
Each of those scenarios is likely to be realistic in the Third Age of Video—a time in which television audiences might very well consist not of groups of 20 million watching one program, but of groups of ten or fewer watching 20 million programs. Advertising, rather than being the province of relatively few of America's half a million corporations, will be accessible to virtually any company. We are talking about "Video Power to the People"—a time when most anyone can be a producer as well as a consumer of video—and it's about as close to realization as personal computing was in the early days of the first personal computer, the MITS *Altair*.

Bellcore research

Scientists at Bell Communications Research (Bellcore) have been researching the devices, systems, and services we envision for the Third Age of Video. We want to understand what role telephone companies, as distributors of information, might play. That there will be a role—and an important one—can hardly be doubted. Even pessimists predict that within 20 years, it will be no more expensive to build high-speed fiber-optic telephone-switching systems than it is to build our current systems. However, the new systems will handle many times the volume of information that our systems do today.

The fiber-optics based communications network of the Third Age of Video will have the information-carrying capacity of cable-TV networks, as well as the telephone network's ability to connect any node in the network to any other node. In fact, experiments in Europe, Canada, and Japan are already being conducted to explore the possibilities of such wideband communications systems. In Biarritz, France, for example, 1500 telephone subscribers have video-telephone service, video-library service, and other advanced features provided through a fiber-optic distribution system.

The Third Age of Video



Third-age prototype

To test the feasibility of those ideas, Bellcore engineers developed an experimental machine that delivers the type of integrated video services that we believe will be important to consumers. We wanted to give the viewer as much control over what he watched on TV as he now has over who he talks to on the telephone.

So we built a machine called a *Video Resource Manager* (VRM), and installed it for three months in my New Jersey home. One of the most useful services experimented with was what we called the "intelligent VCR." It comprised an up-to-date list of TV programming available on a particular day, and for the next month. From any of four television sets, my family could either watch the current program, or, by pressing a button, have the VRM record the show for later viewing. (See Fig. 1).

Playback required only a selection from one of several on-screen lists. All of the usual VCR functions, such as fast-forward, freeze-frame and search, were available from the keypad as well. We multiplexed the output of a *Touch-Tone* telephone pad onto an RG59 coaxial cable that also carried the audio and video signals from the VRM to the remote TV set. Key presses were de-multiplexed and interpreted at the VRM independently for each of six users. Every action taken by the VRM was then recorded for later analysis in our ongoing evaluation of the service.

In addition to the intelligent VCR, users had a movies-on-demand service that allowed them to browse through listings of movies organized by title, subject, and rating. Although that particular service was not as conveniently implemented as the intelligent VCR, at that time, it suggested a new approach to introducing videotex into the home.

In fact, until now, videotex has been a solution looking for a problem. But by integrating a database service with entertainment video, we believe we may have found the path leading to the Third Age—that is, Moviebrowser, a natural photo-videotex application.

Still-image composer

Researchers in the United Kingdom and Japan have been experimenting with the notion of photo-videotex. And engineers at Bellcore have been busy, too. We have built a still-image composer that can snap pictures of ordinary video images and place them at arbitrary places in arbitrary sizes on a composite screen. Such capabilities can be provided over cable-distribution facilities by adding a frame buffer to the home videotex system.

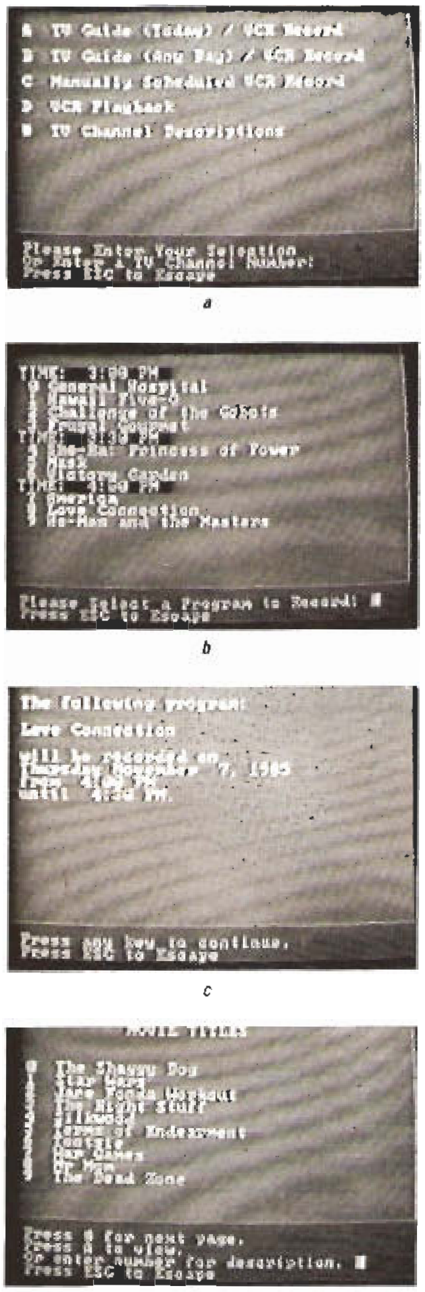
In addition, we built a system that allows you to create slide-show like sequences; each frame may be associated with an audio sequence. The system is multi-user, and uses Winchester-type hard disks to store digital audio whose quality matches that of the compact disc. The technologies are here today and can be made available inexpensively in sufficient volume to be economically viable.

TV production

The obstacle to that sort of proliferation of television production has not been a lack of ideas, but of access to the tools of the trade. Until recently, video production has been restricted to professionals, due to the cost of the necessary specialized equipment. However, simple VHS-format editors are now sufficiently inexpensive that high-school curricula include video

THE VIDEO RESOURCE MANAGER (VRM) was installed in the author's home for three months for testing. It allowed us to share video resources among four TV sets via remote control. The remote controllers were based on *Touch-Tone*-like keypads.

FIG. 5—DEMOCRATIC TV (DTV) MUST BE EASY TO USE, unlike current Videotex systems. Developers are working on new ways of getting information from the system, including the Macintosh-like interface shown here.



```
A  TV Guide (Today) / VCR Record
B  TV Guide (Any Day) / VCR Record
C  Manually Scheduled VCR Record
D  VCR Playback
E  TV Channel Descriptions

Please Enter Your Selection
Or Enter A TV Channel Number:
Press ESC to Escape
```

a

```
TIME: 3:00 PM
 0 General Hospital
 1 Hawaii Five-O
 2 Challenge of the GoBots
 3 Frugal Gourmet
TIME: 3:30 PM
 4 She-Ra: Princess of Power
 5 Mask
 6 Victory Garden
TIME: 4:00 PM
 7 America
 8 Love Connection
 9 He-Man and the Masters

Please Select a Program to Record:
Press ESC to Escape
```

b

```
The following program:
Love Connection
will be recorded on
Thursday November 7, 1985
from 4:00 PM
until 4:30 PM.

Press any key to continue.
Press ESC to Escape
```

c

```
MOVIE TITLES
 0  The Shaggy Dog
 1  Star Wars
 2  Jane Fonda Workout
 3  The Right Stuff
 4  Silkwood
 5  Terms of Endearment
 6  Tootsie
 7  War Games
 8  Mr. Mom
 9  The Dead Zone

Press # for next page.
Press * to view,
Or enter number for description.
Press ESC to Escape
```

d

THE VRM COMBINED VIDEOTEX-LIKE SERVICES with remote-VCR control. From any location we could, using on-screen guides, choose one of several television services (*a*), obtain a listing of current shows (*b*), set up for delayed recording (*c*), and obtain a listing of current movies (*d*).

production as an elective along with photography. Special-effects processors that mix multiple video streams are being researched at Bellcore, to determine the extent to which microelectronics can reduce the cost of such components.

For example under study is an RGB video-image combiner that can take four NTSC or RGB inputs and combine them into a single high-definition or 525-line RGB composite-video output. With sufficient demand, cost could be reduced to the point where the equipment would be affordable by semi-professionals.

In the fourth edition of the *Video Source Book*, there are more than 35,000 listings of video material categorized by business/industry, children/juvenile, fine arts, general interest/education, health/science, instruction/how-to, movies/entertainment and sports/recreation. The Third Age of Video will change our habits from shopping for one title out of several thousand in the local video store to requesting that one of several *hundred thousand* titles be downloaded to your VCR. The technology is available today and could compete as an alternative to video-store shopping.

Democratic TV

Consider a new service that we call Democratic TV (DTV). How would it work? You turn the TV set on and select a DTV service. Your videotex controller connects you to a computer in the cable head-end. The ensuing dialogue would depend on the sophistication of the service offered. It might proceed as follows:

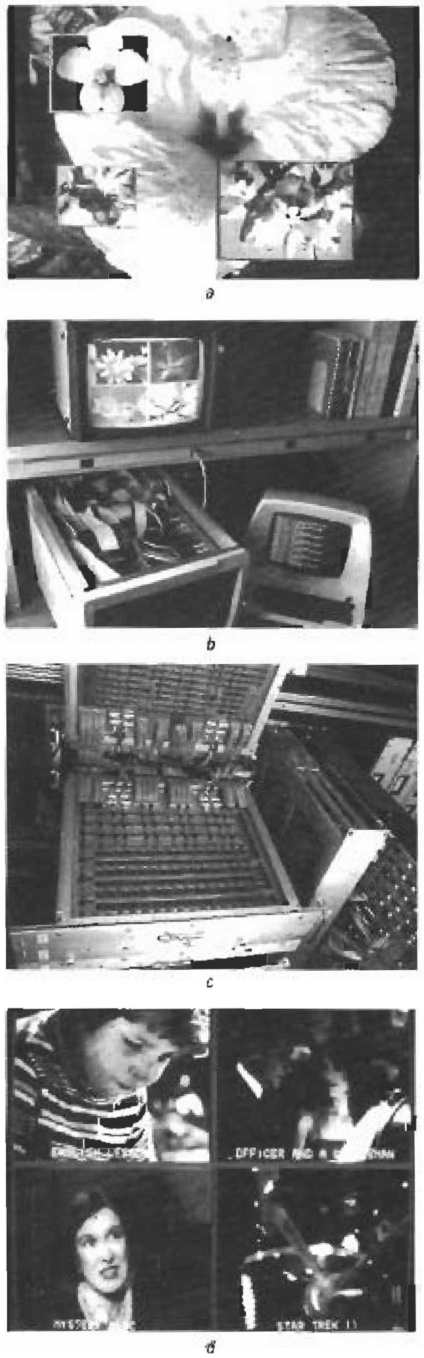
DTV System: *Thanks for calling. Select a subject category.*

Subscriber: *Baseball.*

DTV System: *Select an event.*

Subscriber: *Last night's little-league game.*

DTV System: *Currently being offered not later than 10 pm on Friday at $3.50 to 17 other subscribers. We do not expect sufficient interest to permit earlier broadcast.*



STILL-IMAGE VIDEO EDITING is another application of third-age video technology. For example, various images can be superimposed (*a*) on one another. A standard video terminal can be used to browse through an electronic "book" of video "snapshots" (*b*). Semi-professional TV production using equipment like that shown here (*c*) can be used to combine several video signals into a single output (*d*). The input signals may be either NTSC or RGB; the output may be in either the standard 525-line or the upcoming high-definition format.

Do you still wish to subscribe?
Subscriber: *If by Wednesday, yes. If not, any baseball game will do.*
DTV System: *Conditional order taken. Anything else?*
Subscriber: *Display movie listings.*

The basic idea is to use software and hardware technologies to take maximum advantage of existing limited-distribution networks. Movies would be distributed on the CATV network; control signals would be transported on the telephone network.

A key element of the architecture is the VCR. It is important because the capacity of CATV networks is limited, and more so if you attempted to provide video-on-demand service to a typical system of 5000 subscribers. The reason is that most people watch TV at the same time (7–10 pm), and if half of a 35-channel CATV system were devoted to DTV service, only 18 people would get to watch what they wanted. However, with intelligent VCR's (to which programs could be down-loaded during off-peak hours) 180 people could watch their program choice with at worst a one-day wait from the time it was ordered.

DTV technology

Exactly what do we mean by Democratic TV? To begin with, your TV set would be interfaced to a controller that makes using the service easy for the subscriber and manages all the electrical signals needed to make it work. We believe that earlier attempts at a service like that failed because the user interface was poor.

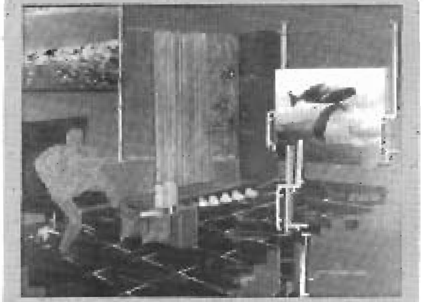
Furthermore, electronic home information (videotex) experiments in this country have been generally unsuccessful. At home, people will not pay much for information—they're used to getting it free. However, people will and do pay for entertainment, as evidenced by the popularity of VCR's, cable TV, and stereo equipment and programming. Democratic TV couples videotex with an entertainment service to give people more control over their viewing choices. That control is the key to launching the Third Age of Video—and in a sense it has already begun; Impulse Pay-Per-View schemes are under trial nationally.

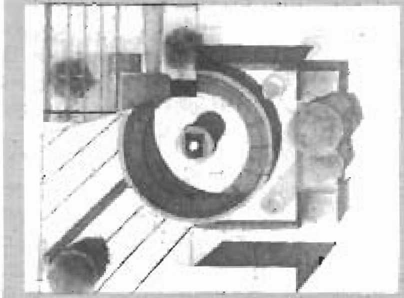
After a delivery system for still-image and full-motion video is made available at the community level, more people will have the opportunity to produce video programming, including, for example, the fifteen-minute sermon by a local rabbi or minister, excerpts from the town-council meeting discussing hazardous waste sites, a visit to the high school by one of NASA's astronauts, and a walk through a local park. The difference between the scenarios described and today's cable systems is in the scale of viewer options and their control over them.

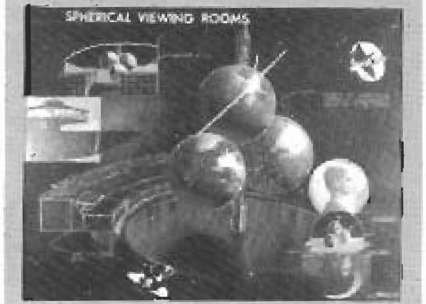
The technology for the Third Age of Video exists and awaits deployment—admittedly a large task. But it seems overwhelmingly likely that, by 2001, the strikingly superior quantity and quality of audio and video transmissions available through fiber-optic cable will have generated so great a demand that the Third Age will not only be upon us, it already will have become commonplace. **R-E**

As the preceding article makes clear, the way we use video communications in the twenty-first century will be quite different from the way we use it today. Technology will also dramatically change the video we watch and the way we view it. What are some of the possibilities?

Large hang-on-the-wall screens will finally become a reality. We'll see multi-image projection rooms with 360-degree viewing screens and holographic displays. We'll also have spherical viewing rooms that will let us experience video like we never have before. They will take advantage of new video tape that contains computerized codes for the rooms master control system—to vary room temperature, aromas, vibration, etc. to enhance the realism of what we view.







July 4, 2010

Dear Sue,

Your letter posed a tough question: How has the technology I've been describing affected people's lives? I know you feared the worst—I remember those horror stories we were raised on in the Back to Basics commune, about individual liberty being destroyed by computer integration. You thought that my enthusiastic letters meant I had been brainwashed, right? I admit the technology of the 21st centruy dazzled me. I saw instant-information, and it seemed that instant information meant instant solutions.

I no longer expect instant solutions. But I still believe that the technologies I've written you about—integrated electronic offices and electronic information access—offer the average person increased opportunities. Here's what I've discovered.

First, the integrated electronic office: Office automation shifted people's attitudes toward work in several ways. Back in the early 1990's, automation caused rough times for white-collar workers, with massive layoffs, similar to the blue-collar layoffs of the 1980's. Public pressure forced government and industry to establish free retraining centers, like the one I trained at when I first left the commune. Today, people and companies plan on changes in jobs and careers. Such changes often demand continuing education. Industry leaders increased support to community colleges and continuing education programs. Tax laws now allow deductions for any education expenses.

Next, electronic access to information: Ease of access poses a subtle danger because now people are more easily informed, but not necessarily more knowledgeable. With information so easy to get, people take its accuracy for granted. Hand someone a copy of Mein Kampf with a biography of Hitler on the back cover and they'll likely take one look, then toss it in the garbage. They can see from the context the writer's prejudices. Show that same person an out-of-context extract from the book in a databank—how are they to guess the author was a deranged fanatic?

But people are finding answers to that problem, too. Schools now train students to analyze data for the degree of accuracy. And to discourage those who might deliberately plant lies in databanks, a new law requires databank publishers to disclose the source and entry date for all information.

The benefits of electronic information access outweigh the hazards. Scientific and technological research is thriving. Geography is no longer a barrier. Because people can access translations from all over the world, they learn to understand other cultures better. Will we someday understand each other enough to solve our disagreements with reason instead of force? On a personal level, when people get the information they want faster, they think faster, make decisions faster, and act faster. People find fewer barriers between their dreams and their goals.

Speaking of which, I've got to go now. My home workstation just arrived and my neighbors have gathered to welcome me to the ranks of telecommuters with a terminal-warming party. Sue, I think you really wanted to ask, "Have the new technologies isolated and diminished people or made them mere chunks of data in gigantic databanks, as our parents feared?" I hope I've shown you that, instead, people have found new ways to come together, to broaden their interests and skills, and to better understand each other and their world.

Love,

Hedy

ENERGY TECHNOLOGY IN THE 21st CENTURY

A look at five new technologies that may dramatically effect the ways we generate electric power as the 21st century begins.

Dr. STEPHEN B. KUZNETSOV

OVER THE NEXT DECADE AND A HALF, several dramatic changes will occur in the ways that American households obtain electric power. Those changes will come about because of the development of practical, commercially-feasible small power-generating systems for consumer use.

The technology is being developed now. When that development is complete, millions of consumers will have access to resources that will allow them to generate their own power efficiently and reliably.

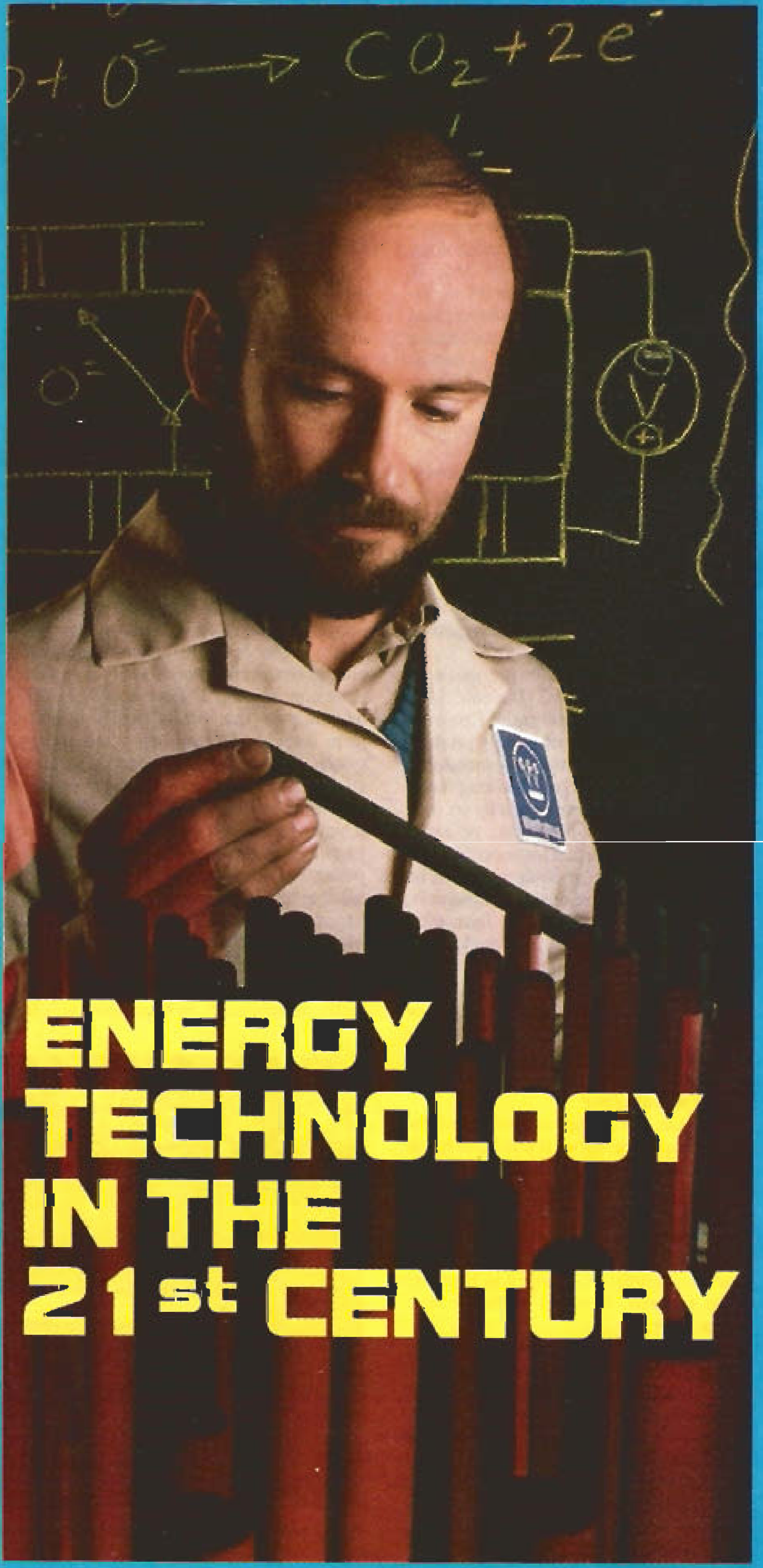
In this article, we will examine five new power technologies that could be in mass production by 2001, profoundly affecting our everyday lives. Three of the technologies generate DC and AC electric power; a fourth conditions the electric power produced by the consumer for practical use; and the fifth is one of the most efficient energy-storage inventions known to modern civilization.

Private power production

The inventions and technologies described here are ones truly designed for a new age as they are used to produce rather than consume electric power. Further, the generators we'll describe here all use renewable energy sources in performing their tasks. Finally, their installation, use, and maintenance in a home/consumer situation requires no specialized skills or additional training.

For the consumer, there will be many incentives for turning to self-generated electric power. In the past, the government has encouraged the use of solar, geothermal, and wind energy, and it is likely to do so in the future. For example, since 1978, owners of home power-generating equipment have been guaranteed a fair selling price for the electricity they produced. Utilities are required to purchase any excess electricity, up to a limit of 80 megawatts, at the prevailing rate. By 2001, that rate could be $0.12 a kilowatt-hour, or more, potentially making private power-generating systems a very attractive investment.

The energy-technology industry is undergoing explosive growth. Almost 4000 new manufacturers spring up in this coun-



try every year; and if current trends continue, that rate is likely to triple by 2001. Unlike traditional energy-equipment manufacturers, which have concentrated on large-scale power generation exclusively, the new manufacturers are concentrating on technologies that are suitable for small-scale applications. Many are appropriate for use by individual home owners.

One key to making home power-generation practical is to make the technology less intimidating. That can be done in part, by using microprocessors. With microprocessor-controlled systems, you won't need to be an engineer to maintain a small generating unit. Instead, a microprocessor—perhaps aided by voice-recognition and speech-synthesis systems—can guide you through most maintenance and repair operations.

Many consumers already have turned over the operation of some home energy-generating equipment to microprocessors. That equipment ranges from hot-water boilers to automatic fireplace lighters. In most installations, however, all equipment is controlled by a single, central processor—that is, the personal computer.

By 2001, we will be in the midst of what is called the DIRAC (*D*ecentralized *I*ndirect-*R*adiated *A*utomatic *C*ontrol) era. Then, each piece of energy-producing equipment, be it a rooftop generator, a basement storage-unit, or a hidden power-conditioner, will be controlled by its own microprocessor. No fiber-optic or hardwire link will be needed for coordination, because each piece of equipment will be able to react autonomously to conditions for peak performance. Some have even speculated that, by 2001, each wall socket in the home will be equipped with microprocessors that will monitor all appliances and control the distribution of power in the room following voice instructions and sensor information.

A new vocabulary

Man has always speculated about the future. In past centuries it was fashionable among scientists and others to consider the changes that might come about in 100 years. As the pace of technological advance quickened, perceptions altered and visionaries began thinking in terms of 50 years for significant changes in lifestyles to be realized. Now, 15 years, or less, seems safer.

With the dramatic changes in energy technology will come a new language of sorts. In particular, five new "words" will become familiar to everyone from age 2 to 92 (the anticipated life expectancy in 2001). Those words will be:

- LIMPET—*L*inear *I*nduction *M*achine *P*rogrammed *E*lectric *T*urbine
- SUPERSEA—*SUPER*conducting *S*elf-*E*xcited *A*rmature
- CAVET—*C*losed-cycle *A*dvanced *V*apor *E*lectro-*T*urbogenerator
- FC—*F*uel *C*ell
- PC—*P*ower *C*onditioner

If you doubt that to be true, think about the blank stares that the terms microprocessor, personal computer, RAM, ROM, or even LCD would have drawn from many in 1972, and the knowing smiles they now generate.

LIMPET—a linear generator

Roughly 15 years ago the *L*inear *I*nduction *M*otor (LIM) was introduced as a replacement for conventional electric motors in high-speed mass transit. LIM-powered trains built in the U.S. achieved record-breaking ground-transportation speeds of over 250 miles-per-hour in 1974. At present, the world record is 320 miles-per-hour for a linear-induction levitated train. However, it is predicted that by 2001, the greatest use of linear induction may be for electric-power generation for homes and farms.

The LIMPET is a relative of the LIM of the 1970's, although the mechanics behind the technique originally were conceived by Leonardo da Vinci in the 14th century. The device uses wind energy, a classic renewable-energy source, to generate continuous AC electric power at 60 hertz in a way that's dramatically different from current conventional wind-energy systems. Currently, wind-energy systems all use rotary-turbine motion and a rotary generator in one form or another. Two schemes are commonly used: Either the generator is directly attached to the propeller, or alternately, it is geared to the blading through a long shaft, allowing the generator to be mounted on the ground. The result is the windmill, long a fixture in rural America.

By 2001 those windmills will have virtually disappeared. In their place will be one or more LIMPET's, like the one shown in Fig. 1, mounted on the roof of a barn or an estate house.

The LIMPET has a number of attractive characteristics. For example, its low profile (6 inches or less) means that it is unobtrusive and environmentally benign; as to other dimensions, the unit shown measures roughly 38 inches wide and 20 inches deep. Other advantages are its use of a renewable energy source and the elimination of the gyroscopic forces associated with large rotary turbines.

The principals behind the LIMPET are shown in Fig. 2. It generates electricity using a bladed "venetian blind" system mounted on a conductive movable belt. The armature consists of an array of copper coils wound on a steel core. Wind striking the blades causes the belt to move and 60-Hz electricity to be generated in a manner analogous to the way electricity is generated in a rotary system. The electricity is generated anytime the belt is moving at a speed between 1 and 25 feet-per-second.

Current prototype LIMPET's have a power density of about 50 watts/pound. That means that a unit capable of producing 10 killowatts will weigh 200 pounds. Mounting a 200-pound unit on your roof is not a particularly easy task, but by 2001 lighter units, perhaps using aluminum belts and blades, will be available. While those units will have lower power outputs, on the order of 2 kilowatts or so, for many applications that is all that is needed. If higher capacity is required, two or more units can be used.

A sea of energy

The LIMPET is just one of several power-generation technologies currently under investigation; we'll examine two others, the CAVET and the fuel cell, later on in this article. However, no matter what

FIG. 1—THIS PROTOTYPE LIMPET GENERATOR, installed on a rooftop in Maryland, is but six inches high.

generating technology is used, one of the most significant problems in making decentralized power-production practical is energy storage.

An answer to that problem may lie in the use of the element niobium—or, more precisely, a wire made of a niobium-tin alloy. That's because that wire has an extraordinary property: Its electrical resistance drops to near zero at the lower temperatures.

Over the past twenty years, scientists at the United States National Labs have experimented with niobium-tin wire. Among other things, they have found that a supercooled electromagnetic coil made of that wire can be used to "store" a DC current for up to several days. That discovery is at the heart of a technology dubbed SUPERSEA. A cross section of a superconducting armature is shown in Fig. 3. Primarily, it consists of a magnetic coil and a miniature refrigerator; there are no moving parts.

Currently, several U.S. and Canadian companies are investigating the use of superconductive energy-storage coils for residential use. Niobium-tin wire, which previously was expensive and difficult to obtain, has been produced recently in larger quantities—though it's still only appropriate for winding miniature electromagnets. Such electromagnets are of limited utility; a 2-×-3-foot electromagnet, for instance, would be capable of storing 4000 kilojoules of energy. In practical terms, that is enough energy to power an appliance that draws 11 kilowatts, such as a large electric range, for one hour. A practical superconducting armature for a typical home is expected to weigh 250–300 pounds. However, by 2001, the price of niobium-tin wire is expected to drop dramatically. If that happens, household units could cost as little as $3000–$5000.

Some have pointed out that SUPERSEA is an appropriate name for the technology as it provides for a "sea of reserve energy" sitting (in the basement of the house) and ready to leap into action when called for. When the technology is mature, the owner of a large roof-top solar array will no longer be concerned about using the energy at mid-day. Instead, 95% of the energy generated at mid-day will be available at 6 P.M. to cook, light, or entertain with. The availability of SUPERSEA technology will greatly increase the practicality of using climate dependent solar and wind technologies.

SUPERSEA has only one apparent drawback: It is capable of storing energy in the form of direct current (DC) only. In the presence of AC, the wire loses its superconducting properties. That problem can be solved through the use of a power conditioner, which can convert DC to 60-Hz AC to power all of the appliances in your home.

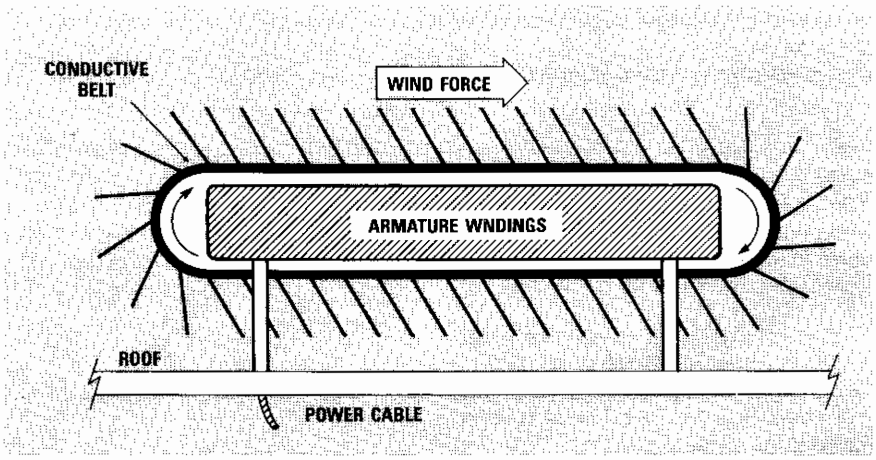


FIG. 2—ALTHOUGH LEONARDO DA VINCI first proposed the concept behind the LIMPET in the 14th century, it is expected that those devices will become an important source of energy by 2001.

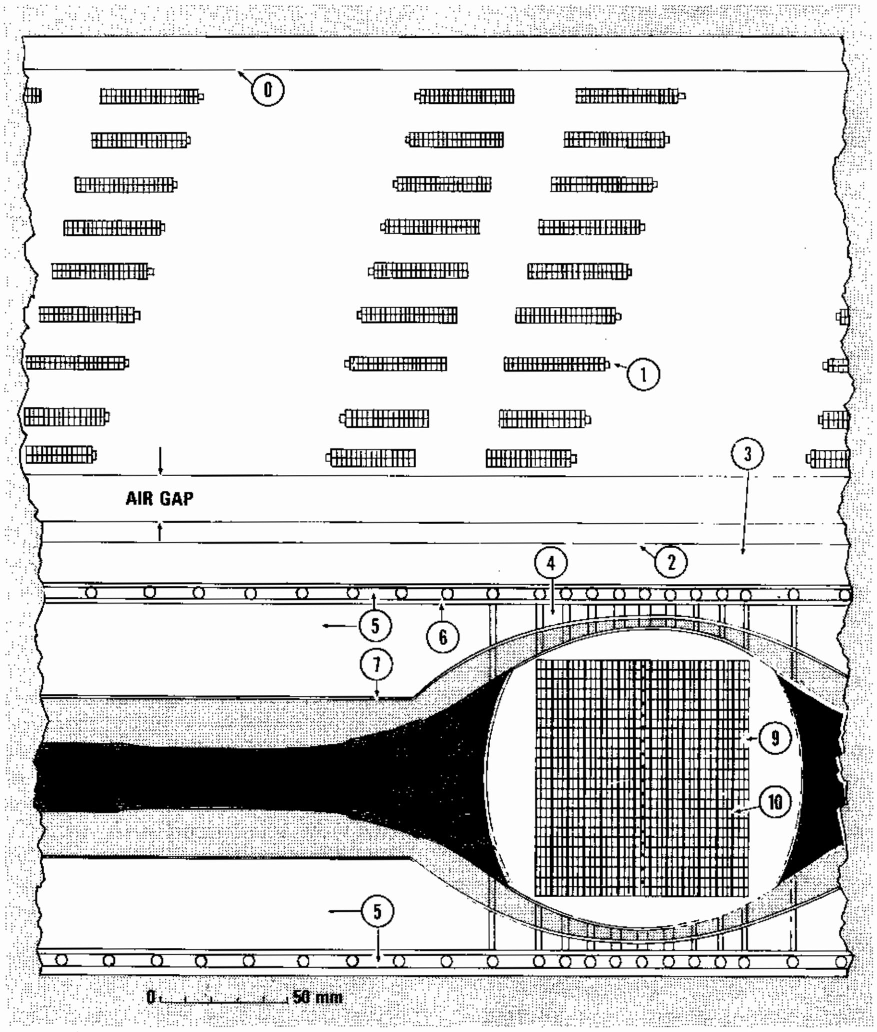


FIG. 3—SUPERSEA ARMATURE. Armature shield (0): armature conductors (1); rotor damper shields (2); ambient temperature damper (3); compression spacers (4); vacuum (5); heat shield (6); liquid-helium containment vessels (7); rotor-tourque transfer banding (8); Nb-Ti field winding (9); cooling ducts (10); field-winding containment block (11); rotor torque transfer coupling (12).

Power conditioner

All the power technologies now under investigation seem to share one common feature: they all seem to operate best at some frequency other than 60 Hz. The task of translating frequencies produced by home generating or storage equipment to 60 Hz, which will likely still be the standard for home appliances, will be handled by a PC (*P*ower *C*onditioner). The PC of the year 2001 will be able to handle three tasks efficiently and quietly:

- conversion from DC power to 60-hertz AC.

- inversion from low-frequency AC to 60-hertz AC.
- cycloconversion from high-frequency AC to 60-hertz AC.

In contrast to the power electronics of 1987, which requires completely separate units to perform each of those tasks, by 2001 it is expected that integrated power conditioners capable of performing all three tasks will become available. Advances in semiconductor technology will play a large role in making that possible.

Currently, it is possible to obtain power-handling components such as MOSFET's and thyristors in IC form. However, it is not possible to obtain different types of devices on a single substrate. That will soon change: Manufacturers are closing in on producing arrays of 6 or 12 power-handling devices of different type on a single substrate. When that has been accomplished, a complete, versatile 20-kW power conditioner may be available on a single 4-by-6-inch board. That board should retail in the $100–$150 range and be, at first glance, almost indistinguishable from a plug-in computer board. Of course, the power conditioner will handle about 1000 times more power.

By the year 2001, it is also speculated that home power-conditioner IC's will use something other than a silicon or gallium-arsenide substrate. Newer substrate materials, such as indium-phosphate, may dominate the IC industry by then. Potential advantages in using other substrates for power devices is faster power-conditioning speeds and lighter appliances.

The CAVET

These days, roof-mounted arrays of photovoltaic cells are becoming commonplace. But by 2001, owners of such installations will have discovered one of their key drawbacks: The crystalline and amorphous silicon materials that make up those cells degrade somewhat under constant exposure to the sun. Future repair, maintenance, or replacement costs can greatly offset any economic advantages offered by photovoltaic cells.

However, another solar technology, called CAVET, that may be less expensive in the long run for residential applications is under investigation. In that technology, a solar-thermal heat exchanger is coupled to a closed-cycle vapor turbine that directly drives a miniature alternator. CAVET offers the added advantage of producing high-frequency AC rather than DC. The system is shown in Fig. 4.

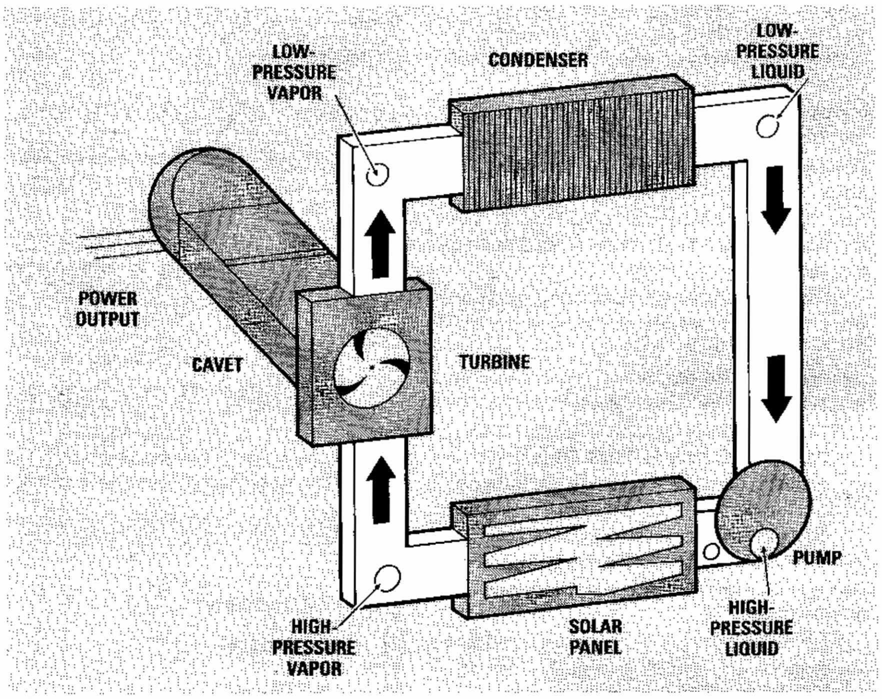


FIG. 4—LIKE SOLAR CELLS, the CAVET uses solar energy to provide low-cost electric energy. Aside from the roof-mounted heat exchanger, all of the components can be mounted within a cabinet no larger than a standard room air conditioner.

The CAVET of 2001 will be a combination heat exchanger, bladed turbine, and brushless alternator. Aside from the rooftop heat exchanger, residential units capable of generating about 20 kW will measure around 10 cubic feet; that's no larger than a standard room air conditioner. The analogy to an air conditioner can be carried one step further, since the two share many features. However, in essence, all of the functions are reversed.

Like a photovoltaic solar-cell array, the CAVET's heat exchanger is located on the roof of a house or other structure to collect solar energy. Its advantage over photovoltaic cells is that the exchanger is built from a corrosion-resistant metal, such as aluminum.

One manufacturer of roof tiles, in anticipation of CAVET technology, has already started producing roof-installation kits for new construction. The aesthetically designed house of the year 2001 could have a grid-like heat-exchanger placed on the roof support structure, above the truss layout. Above that array, special opaque interlocking roof tiles are installed as the final surface. To the casual observer, it would be impossible to determine if the house incorporated a CAVET system because the heat exchanger is hidden from sight under the roof. The vapor turbine and the alternator are located inside the attic.

Though the turbine is designed to turn at a constant rate of 7200 rpm, it is expected that it will be nearly silent. That's because, by the turn of the century, magnetic levitation bearings will be standard in all home appliances, including the CAVET. Through the use of such bearings, the shafts will be supported by a cushion of magnetic flux. Further, moving parts within the generator will be maintained in a vacuum to eliminate the friction losses caused by air.

The electrical portion of the system is a synchronous induction generator designed to output 120-Hz AC. While designed to be synchronous at 7200 rpm, on days of reduced sunlight, power generation is possible at speeds as low as 6500 rpm. A line frequency of 120-Hz was chosen because it allows for generating equipment that is significantly lighter in weight than 60-Hz equipment. A power conditioner can be used to drop the frequency to 60 Hz.

The CAVET of the year 2001 will use vanadium-cobolt magnetic steel and an inconel rotor; it is expected to have a power density of 4-kW/pound. Currently, one experimental CAVET has achieved a power density of 5-kW/pound, but at a speed of 26,000 rpm. Its rotor has no mechanical contact with bearings, brushes, etc; all linkages are magnetic.

A number of university research groups have built prototype CAVET systems. In the case of one prototype, the absence of a large roof area led to the use of sidewalk heat as the source for the solar thermal energy. Consequently, the heat exchanger was cast in the concrete, about ½-inch below the top surface. As you can see, with a little ingenuity, endless variations are possible.

Advanced fuel cells

High-temperature *S*olid-*O*xide *F*uel *C*ell (SOFC) systems show great promise for the economical production of electricity and heat in a variety of commercial, residential, and industrial applications. If that promise is fulfilled, the misconception that fuel cells are suitable only for space or military applications will be permanently dispelled.

Relying on a readily available source of heat, such as natural gas, SOFC technology is based upon the ability of a stabilized element, such as zirconia, to operate as a solid electrolyte at high temperatures. The operation of an SOFC is shown in Fig. 5. The cell conducts oxygen ions from an air electrode (cathode) where they are formed through a zirconia-based electrolyte to a fuel electrode (anode). At the anode, the ions react with fuel gas (CO, H_2, or any mixture, such as steam-reformed natural gas) and deliver electrons to an external circuit to produce electricity. The fuel cell operates at temperatures near 1000°C and is a highly efficient source of both heat and electric power that does not require the presence of a turbine or rotating generator.

Some of the advantages of fuel cells over battery- or solar-powered systems are that they are:

- air cooled—they require no cooling water.
- adaptable—gaseous or liquid fuels can be used.
- simple—they can be installed quickly.
- quiet and reliable—there are no moving parts to create noise or wear out.
- modular—efficiency can be realized in small as well as large units.
- readily sited—they can be located in populated areas, eliminating added transmission costs.

While the above advantages are generally available from all types of fuel cells, the solid-oxide fuel cell, a key contender for prominence in the year 2001, has a number of additional advantages over other fuel-cell systems. For instance, operating at temperatures of 1000°C, it shows promise of attaining higher overall system efficiency than other fuel cell systems. Furthermore, the solid-oxide fuel cell produces higher quality exhaust heat. At temperatures of about 600°C to 1000°C, that exhaust can be used to preheat incoming air and fuel, to generate steam that can be used to drive a turbine and produce yet more electric power, or to provide heating for a plant or a factory.

The high operating temperature of the SOFC makes catalysts unnecessary, simplifying fuel processing and system design. Equally important, the use of a solid-state electrolyte eliminates material corrosion and electrolyte loss.

The technology is apt to see use in areas from Alaska to Arizona for underground, roof-top, or surface-mounted systems. With added benefits of the ruggedness of the technology and the low cost of materials, the SOFC systems, when fully commercialized, could serve in a wide range of power and heat applications.

A number of U.S. firms have started investigating the commercial applications of solid-oxide technology for electric-power generation systems. Widespread commercialization will depend on developing robotic manufacturing plants that can produce relatively small size cells rapidly and at low cost. The objective is the introduction of readily-affordable residential products by the mid 1990's. Those could range from a small 1-kW energy system to a 200-kW home plant.

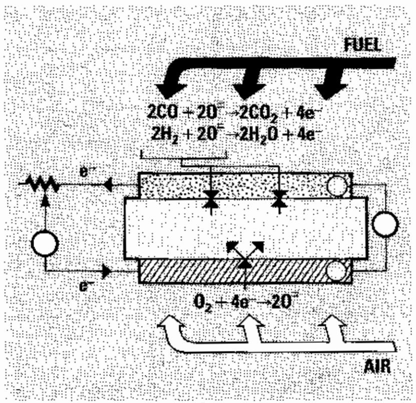


FIG. 5—IN THE SOLID-OXIDE FUEL CELL a continuous chemical reaction is used to produce electrical energy.

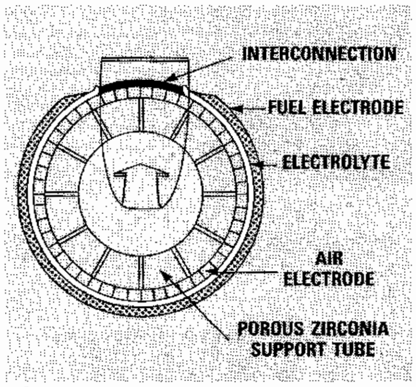


FIG. 6—STATE-OF-THE-ART FUEL CELL. Developed by Westinghouse, this cell has produced power outputs as high as 32 watts. For higher outputs, cells can be bundled in a variety of configurations.

The structure of a state-of-the-art solid-oxide electrolyte fuel cell developed by Westinghouse is shown in Fig. 6. It features a porous, zirconia 12-mm O.D. support tube overlaid with a porous air electrode of modified lanthanum maganite (about 1.0-mm thick). A gas-tight electrolyte of yttria-stabilized zirconia, about 50-microns thick, covers the air electrode, except in an area about 9-mm wide along the entire active cell length. That strip of exposed air electrode is covered by a thick (30 microns), dense layer of lanthanum chromite. That layer serves as the electric contacting area to an adjacent cell and is called the cell interconnection. The fuel electrode, a nickel-zirconia cermet, is about 150-microns thick and covers all the electrolyte surface except for a gap about 1-mm wide along the interconnection in order to prevent internal cell shorting.

With state-of-the-art units like the one shown, a peak power of about 0.2 watts per square centimeter of cell surface area can be obtained. The theoretical open-cell voltage at 1000°C is about 1 volt. Thousands of the cells have been built and tested in single-, double-, and triple-cell configurations. Testing has been done at temperatures ranging from 700–1100°C, at fuel efficiencies of 55% to 85%, and air and pure oxygen efficiencies of 25%. With air, a typical output is 0.63-volt at 26 amps; peak power is 16.4 watts. With pure oxygen, peak-power levels of over 32 watts have been obtained.

Also, a 24-cell SOFC generator has been designed, built, and tested. Peak-power levels of 384 watts and peak-current levels of 80 amps were obtained from that unit. The efficiency was 45%. The insulation package was capable of holding the average cell operating temperature above 1000°C for currents of as much as 50 amps or more; that is, the unit is thermally self-sustaining.

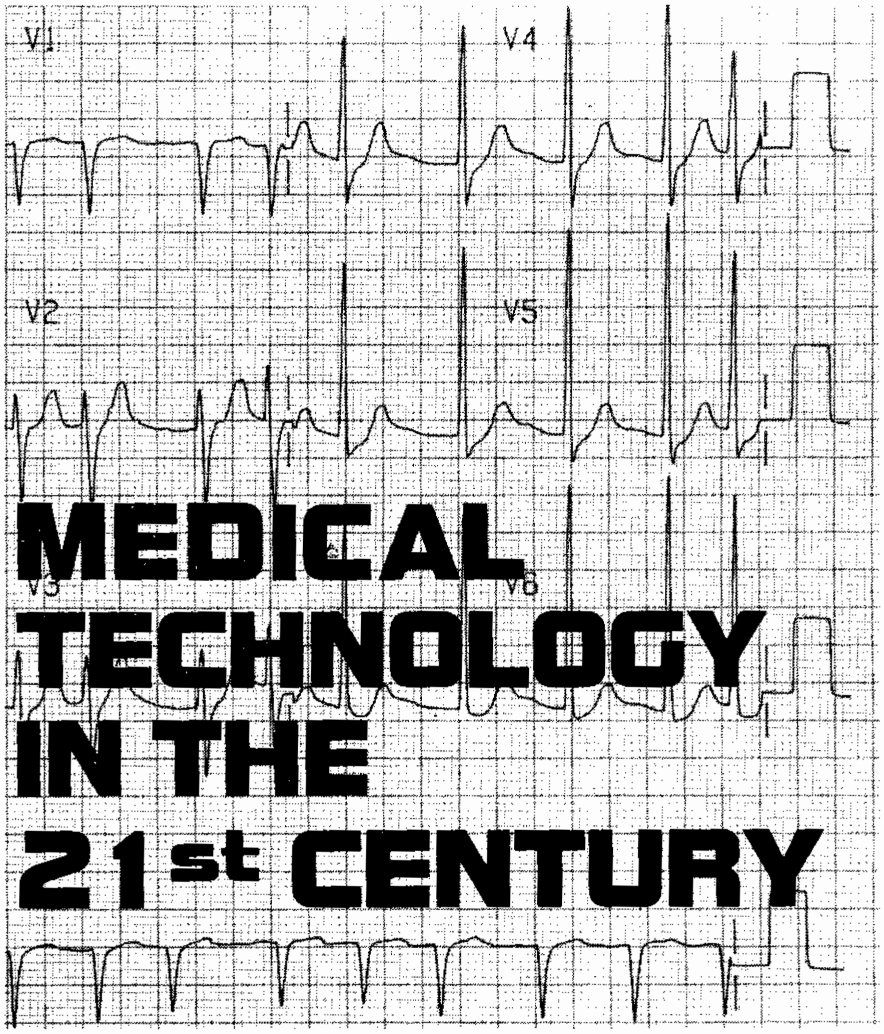
Westinghouse is actively engaged in designing, building, and testing a 5-kW generator. That unit contains 324 cells and will include design features of much larger-size generators. Over the next fifteen years, a standard fuel-cell generator will be developed that is expected to contain 500–1000 cells, with a cost of approximately $5.00 per cell.

Small experimental units are being sold to a number of customers around the world. A host of U.S. high-tech firms are currently pursuing inexpensive, larger units. Those larger units will be used for continuous power production and be custom engineered for various applications from 50–200 kW. Natural gas is expected to be the fuel of choice for most residential and commercial customers.

Widespread use of the fuel-cell units is expected to begin in the mid 1990's. A study by the IEEE Power Generation Committee estimates that 150,000—300,000 residential and light commercial fuel-cell units, using both solid-oxide and phosphoric acid, will be installed in homes and businesses by 2001.

In conclusion

In this article, we've explored some promising power-generation technologies. The LIMPET and the CAVET use classic renewable-energy sources and can be installed, operated, and maintained by the average homeowner. Coupled with a power conditioner and a SUPERSEA power-storage armature, either technology could completely fulfill its owner's electric-power requirements. Natural-gas-fed fuel cells could be used where higher generating capacities are needed to provide power for individual residences, factories, or even entire communities. They also can provide a reliable, efficient source of heat. When used in larger-scale applications, fuel cells offer an attractive alternative to more costly and more dangerous technologies. **R-E**



MEDICAL TECHNOLOGY IN THE 21st CENTURY

By 2001, the advances discussed here will dramatically affect the ways in which doctors examine, diagnose, and treat patients.

RAY FISH, Ph.D., M.D.

FOR ALMOST THE ENTIRE HISTORY OF modern medicine, the focus has been on diagnosing and fighting disease. Whether it was Dr. Ignatz Semmelweis trying with little success to persuade his peers to wash their hands before examining patients, or Sir Alexander Fleming using penicillin mold to fight the "wee beasties," the object was to keep disease out of the body, or to correct by surgery the medical misfortunes of fate.

Modern science, in particular, electronics, gives us the added tools to fight the afflicitions that slip by our defenses: those that do not respond to natural or chemically-derived drugs; those that at present cannot be diagnosed through the sensitive fingers and knowledge of a physician; those which destroy body tissue and parts.

With ever-increasing frequency we see diagnostic and surgical techniques recently thought to be impossible-to-attain become commonplace. For example, using a device known as a CAT or CT (*C*omputerized *A*xial *T*omography) scanner, we can now look deep inside body tissues without intrusion—meaning there is no surgical procedure. Also, thousands of people who just a few short years ago would die from the complications caused by defective heart valves are now literally ticking away because of a mechanical heart valve that looks not much different from a small door.

It's only a little more than 10 years since diagnostic devices such as the CAT scanner, and mechanical body-part replacements such as the heart valve, have become commonplace. But we expect progress will continue at an even faster pace—some say a logarithmic pace—and medical practices in the year 2001 will be quite different from those of today. And that will be due mainly to the advances in medical electronics.

A larger role

The steadily increasing and aging population has caused an increased demand for medical services of every kind. Complicating the delivery of those services, medical care providers must deal with a highly mobile population. For example, it is not uncommon for an elderly person with chest pain to be thousands of miles away from home, or from the hospital where he or she was last treated. The doctor treating the patient for the chest pain might find abnormalities on his or her ECG (*E*lectro*C*ardio*G*raphic report) and chest X-ray, but often no previous ECG's or X-rays are available for comparison.

In the year 2001, electronically-stored records will provide the information needed for optimum care. X-rays, electrocardiograms, ultrasound and sonar images, and even simple pen-and-ink medical records will routinely be stored as digitized records, making their access via telephone, radiophone, or satellite as easy as ordering a large pie from the local pizza parlor.

Some people will carry copies of their medical records on wallet-size digital discs having a standard format readable by any hospital computer. Others will have their entire medical history stored on a programmable pinhead-size optical memory chip that is concealed under a dental filling. In the event of an accident, a laser-scanner aimed at a bicuspid, an incisor, or even dentures will spew out the patient's medical history.

Increased abilities

If optical memories implanted in a tooth seems like the stuff of Star Wars, bear in mind that almost anything the brain can conjure is now technically feasible: In general, only excessive costs stand in their way. Often, an idea must be temporarily set aside because its cost, or what the patient must pay for its use, will be so great that agencies that control which hospital can have what equipment will simply not authorize its use, or its coverage by health-maintenance plans. However, as the average patient becomes more aware of the life-giving value of the high-technology devices, even high costs will no longer restrain their use in generally-available medical care, because once the value of a technological advance is proven, it is demanded. For example, the CAT scanner did not exist outside the laboratory before 1973. Although physicians were quick to see the value of these million-dollar machines, government cost-containment regulations prevented many hospitals from buying them. Now the technology is expected *and demanded* by both doctor and patient. Thus, the existence of new technology creates a demand for its use, regardless of cost, if the technology is truly useful and can help save lives.

Mending a broken heart

About 1.5 million Americans have a heart attack every year; more than a third of those die. By the year 2001, that figure will decrease dramatically..

A heart attack occurs when one of the arteries that supplies the blood to the heart muscle becomes blocked. Actually, the blockage of the inside of the arterial wall builds up over many years. When the blockage is nearly complete a blood clot can easily form, which results in a sudden total blockage. With its blood supply cut off, the heart muscle supplied by the artery dies in a few hours.

At present, except for a new electronic imaging technique called DSA (*D*igital *S*ubtraction *A*ngiography), we get arterial information through *catheterization*, a procedure whereby a tube is actually passed into the arterial system and the heart. While catheterization is a common procedure, there is still a small—though generally insignificant—element of risk. Unfortunately, it is not insignificant to the affected person. To totally eliminate the element of risk to the patient, by 2001 all arterial examinations will be electronic and non-intrusive, therefore risk-free.

Because arterial examinations will be non-intrusive, it will be possible to screen the population early in life—before heart problems develop—to determine those most at risk, and thereby take preventive measures—such as a special or modified diet—before heart illness strikes.

Medical imaging

When the CAT scanner was first introduced some 12 years ago, some vocal and well-publicized people said it was an extravagant plaything. In the 12 years since its introduction, it has become a necessary part of medical practice.

A conventional X-ray is literally a "shadowgraph" that gives prominance to the densest structures, such as bones. It is made by passing an X-ray beam through a body to a sheet of film on the opposite side. Softer tissues in front of, or behind a bone are overwhelmed by the image from the bone. Also, small variations in tissue density are often lost because of the amount of radiation needed to penetrate the the body and expose the X-ray film. CAT (and CT) scanners overcome the shadowing and definition problems by using a pinpoint-focused X-ray beam that rotates once around the body. Rather than exposing a flim, the energy that passes through the body is electronically detected as individual bursts of exposure, called "points," by a detector that tracks along with the source of the X-ray emissions. A typical scan might consist of data representing 150,000 or more points. A computer assembles the point data into an image suitable for display on a TV screen. The softer tissue is no longer shadowed, and even minor variations in tissue density can be seen.

CAT scanning detects tumors at an early stage, often when they can be successfully removed through surgery. On the other hand, CAT scanning also prevents unneeded surgery in cases where the indications for surgery would be unsure without the scan. For example, a person who has received a head injury in an automobile accident may have physical signs that suggest bleeding in the head, which requires immediate surgery. But the physical signs may really be due to the effects of drug ingestion (which also caused the accident). A CAT scan will prevent unnecessary surgery by showing there is no bleeding in the head.

In the year 2001 there will be additional imaging technologies and techniques that will detect and evaluate the medical and surgical treatment of many conditions which are now diagnosed and managed only with great difficulty.

One new technology sure to be in common use in 2001, but which is now in its infancy and not generally available, is MRI (*M*agentic *R*esonance *I*maging). MRI has been called NMR (*N*uclear *M*agnetic *R*esonance), but many people prefer to use the term MRI because it does not suggest the presence of nuclear radiation. Actually MRI (or NMR) places the person in mixed magnetic and radio wave fields; no ionizing or nuclear radiation is used. The magnetic- and radio-wave fields cause spinning of nuclei in the body being scanned. When a field is removed, the nuclei stop spinning and emit detectable radio waves. From those emissions both tissue density and the presence of tissues of certain chemical compositions can be determined.

In contrast, conventional X-ray devices and CAT scanners are sensitive to only the density of tissues. Thus, MRI is useful for detecting differences in chemical composition that would not show up on conventional X-rays or CAT scans. For example, the demyelination present in multiple sclerosis can be imaged by MRI.

Standard X-ray studies will still be performed in the year 2001, but they will be improved in two ways. First, the images will not be stored on bulky film negatives or microfilm. In 2001, the image itself will originate as a digital TV or a computer image and will be stored digitally, with thousands of images occupying less space than a single conventional X-ray film. Second, the image will be super-high resolution; essentially, digitally-enhanced. The detail will make today's X-rays look as if they were developed in pea soup

Artificial organs

Although the development of artificial organs is in its infancy now, by 2001 we expect that artificial organs not presently available will prolong and greatly improve the quality of life for many individuals. Such devices will include the internal artificial heart, kidney, ear, and pancreas, among others.

Because many organ functions such as the heart and pancreas are timed or quantified, they are likely be under electronic rather than chemical control, requiring some form of power that will be generated by implanted ultra-long-life batteries or rechargeable energy cells. Rechargeable internal batteries will be recharged through the skin itself by induction.

In the year 2001, electrical stimulation of various body parts will restore or improve lost functions. For example, stimulation of the diaphragm will improve breathing in persons with paralysis of the diaphragm, and many persons will regain the use of weak and paralyzed arms and legs through electronic stimulation of damaged muscles.

Computer-processed signals from intact muscles and the brain, as well as voice commands, will stimulate what were previously paralyzed limbs. In the case of brain waves, computers will carry the electrical brain waves around damaged nerves to muscle tissue, and even to artificial limbs which will be, themselves, operated by computers.

In instances where it will be impossible to stimulate unresponsive or atrophied muscles, voice commands and other actions of the severely physically handicapped will program internal computers, which will, in turn, control external and internal bionic devices (artificial limbs and organs that can "think,"or which respond to natural stimuli.)

Personal robotic devices in the year 2001 will understand and perform complex functions such as "open the door." The person will not have to give a series of commands such as "approach the door, take out the key, move the key upward, ……." A single voice command, the flex of a healthy muscle, perhaps the quiver of a finger, or even a brain wave generated by the thought, will initiate a complex series of muscle stimuli and robotics that will result in a series of pre-programmed mechanical movements by artificial limbs, whether it be extracting a key from a pocket and opening a door, or opening a frozen dinner for the microwave oven. In short, medical electronics will enable what we presently think of as totally physically handicapped persons to care for themselves, and to perform useful work.

More accurate diagnosis

Although brain waves, artificial organs, robotic limbs, and electronic muscles are spectacular and attention-grabbing, the real nitty-gritty of medicine remains *diagnosis*: the sifting and focusing of hundreds, possibly thousands of bits and pieces of information.

In the year 2001, using data gathered from a world-wide network, local on-line

A COMPUTERIZED TOMOGRAPHY SCANNING system combines an advanced X-ray scanning system with a powerful computer to allow doctors to study almost any structure within the human body. Its use often permits patients to avoid exploratory surgery or other painful diagnostic techniques.

diagnostic computers will help physicians diagnose and treat patients. For example, it is often difficult for a doctor who has never treated nor seen malaria make the diagnosis. A computer, however, can recognize the disease in possibly minutes if it can automatically search throughout the world for matching symptoms. In 2001, a touch of a button will be all that's needed to initiate a world-wide search on all forms of disease and illness.

Because computers can correlate information from X-rays, CAT and MRI scans, surgical treatment involving the precise localization of tumors and other structures, or even laser-scalpel "bloodless surgery," will be computer-aided.

The computer will even be used for conventional illnesses and treatment. In the year 2001, a typical serious illness such as a heart attack might be computer-aided from diagnosis to treatment.

While walking on a country road you feel a severe, heavy chest pain. Before losing consciousness you are able to press the medical emergency button on your personal transmitter. A satellite in space relays your location and your medical records to the nearest available ambulance. Within minutes, a paramedic starts CPR while another connects sensing electrodes to your chest. No heartbeat is seen on a monitor, so pacing electrodes are placed on the front and back of your chest. Mild pacemaker shocks cause your heart to start beating again.

The paramedics start an I-line (intraveneous) for medication, and a non-intrusive A-line (arterial) sensor for computer-aided diagnosis and observation. In the event your personal security transmitter is not programmed with your medical history, a laser-scanner aimed at your teeth by the ambulance's computer will read your medical records from the implanted optical memory. Its information, your electrocardiogram, and A-line blood chemistry data is telemetered to the hospital.

You are brought to the Emergency Department where a diagram of your heart's circulation is obtained non-intrusively through a cardiac imager.

As you awake, the physician tells you not to worry. You have started to have a heart attack, but the process can probably be reversed. A clot has formed in one of your coronary arteries. However, the clot may dissolve with suitable chemical treatment. If not, it will probably be in position to be burned clear with a laser scalpel later on.

Meanwhile, he reassures you about the twitching and pain in your chest. As soon as the blood supply is returned to your heart muscle the pacemaker will no longer be needed.

The computer display above your bed shows a continuous stream of data derived from automatic blood sampling, as well the medical history that was transmitted by your personal-security transmitter, or which was read from the optical memory concealed in your tooth. On inspecting the data, the physician says that it will not be possible to dissolve the clot because he sees on the monitor that you had gallbladder surgery a few weeks before, and the healing tissues at the surgery site are still partially held together by clotted blood. It would be too risky to put a substance which dissolves clots into your system.

The diagram of your coronary circulation showing the blockage is transmitted by computer or fax machine to a cardiologist several miles away, who determines that even a laser-bore cannot clear the clot, and that bypass surgery is needed.

In surgery, electronic monitors continually sense through your intact skin the amount of oxygen, sugar, and carbon dioxide in your blood. The electrical activity of your heart and your blood pressure are continuously recorded.

The electrical activity of your brain which results from stimuli applied to your legs is monitored to help determine the depth of anesthesia. Because you are paralyzed as well as asleep, a respirator controls your breathing. The function of the respirator is guided in part by the blood levels of oxygen and carbon dioxide measured through your intact skin.

A segment of vein from your leg, or its plastic equivalent, is used to bypass the blocked segment of your coronary artery. The blood flow through the bypass graft is measured with an ultrasound or sonar imaging, which displays a cross-sectional image of the graft. The velocity and turbulence of blood flow at each point in the graft is indicated.

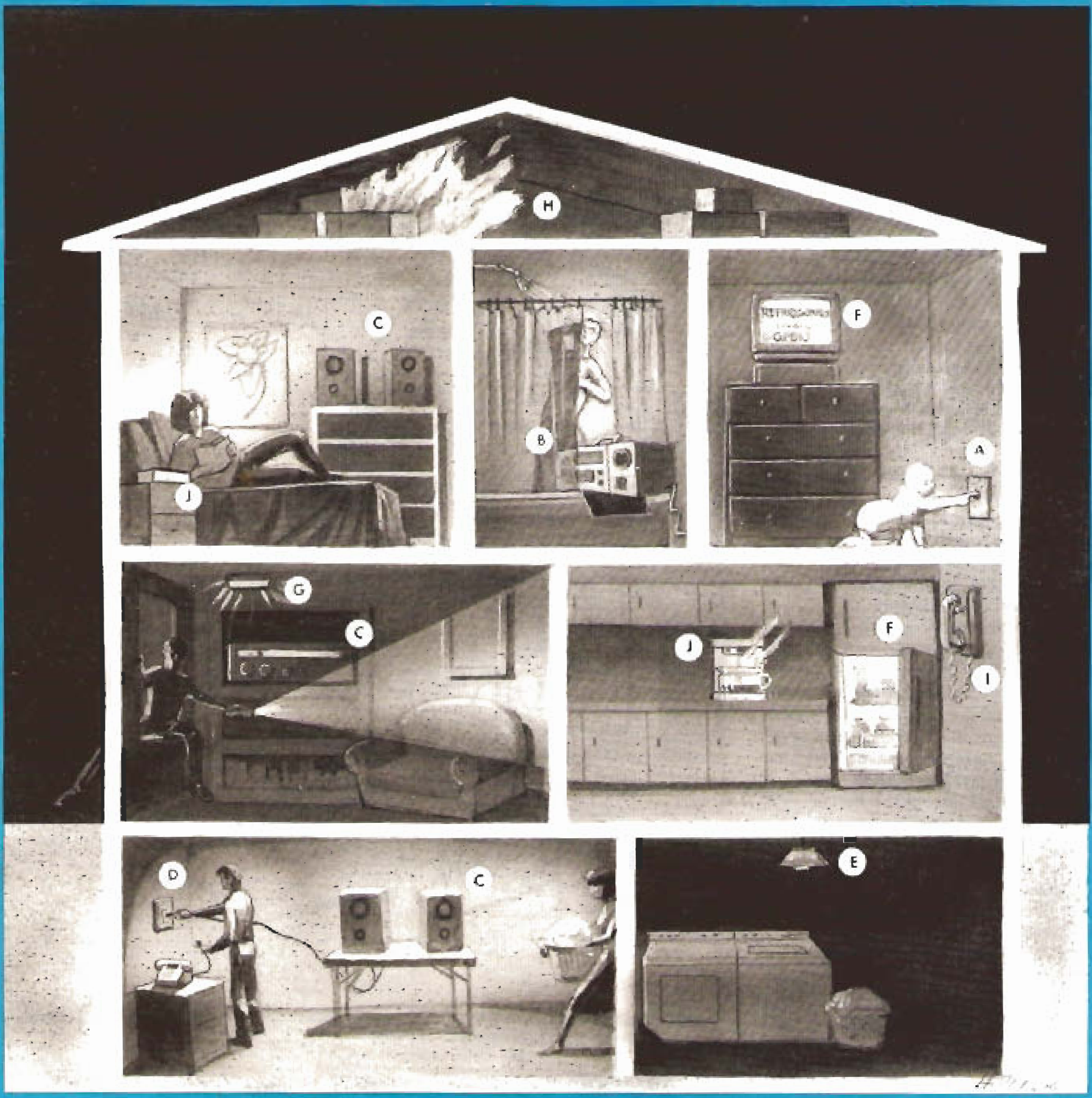
The blocked coronary artery has been successfully bypassed. Only slight damage has been suffered. Your heart attack has been undone. The pacemaker is no longer needed.

After surgery you are taken to the Intensive Care Unit. Automated monitoring of your blood pressure, respiratory rate, electrocardiogram, and mental function continues. In addition, your blood sugar, electrolytes, oxygen, and carbon dioxide are monitored. Those parameters are used to control the amounts of oxygen, fluid, and respiratory support given to you. Abnormal heart rhythms are detected and treated with drugs and electrical shocks applied to your chest. The protocol for such treatment is decided by a computer.

After a few days in Intensive Care you are ready for telemetry monitoring. Cardiac arrhythmias (fibrillation) are considered much less likely, but it is wise to provide monitoring for several more days. A few days after your surgery, you are transferred to a portion of the hospital, where you receive more intensive physical and psychological rehabilitation.

All during your hospital stay, a system of interconnected computers has kept track of your vital functions, body chemistries, medication intake, and your respiratory and physical conditions. Your psychological condition has been judged and recorded in the computer system by nurses and physicians. Your respiratory function has been evaluated by automated spirometers and respiratory therapists. Your physical condition has been judged by physical therapists. The computer system has watched for deterioration of your condition on a minute-by-minute basis, has scheduled your treatments and evaluations, has prevented drug interactions, and has charted your progress.

A month later you are walking on the same country road you were on when you had your heart attack. Your chest is sore from the surgery, pacemaker, and electrical shocks. You wonder how much further into the future it will be before science finds a way to treat heart attacks without so much pain. **R-E**



A smart house will prevent electrocution (A,B), allow the distribution of signals without running additional wires (C), using any outlet (D). Sensors will automatically turn off lights in empty rooms (E), and display the status of the house on any TV (F). Security features will protect the house from theft (G) and fire (H). The entire system can be operated remotely (I), and any device in the house can be operated from any point in the house (J).

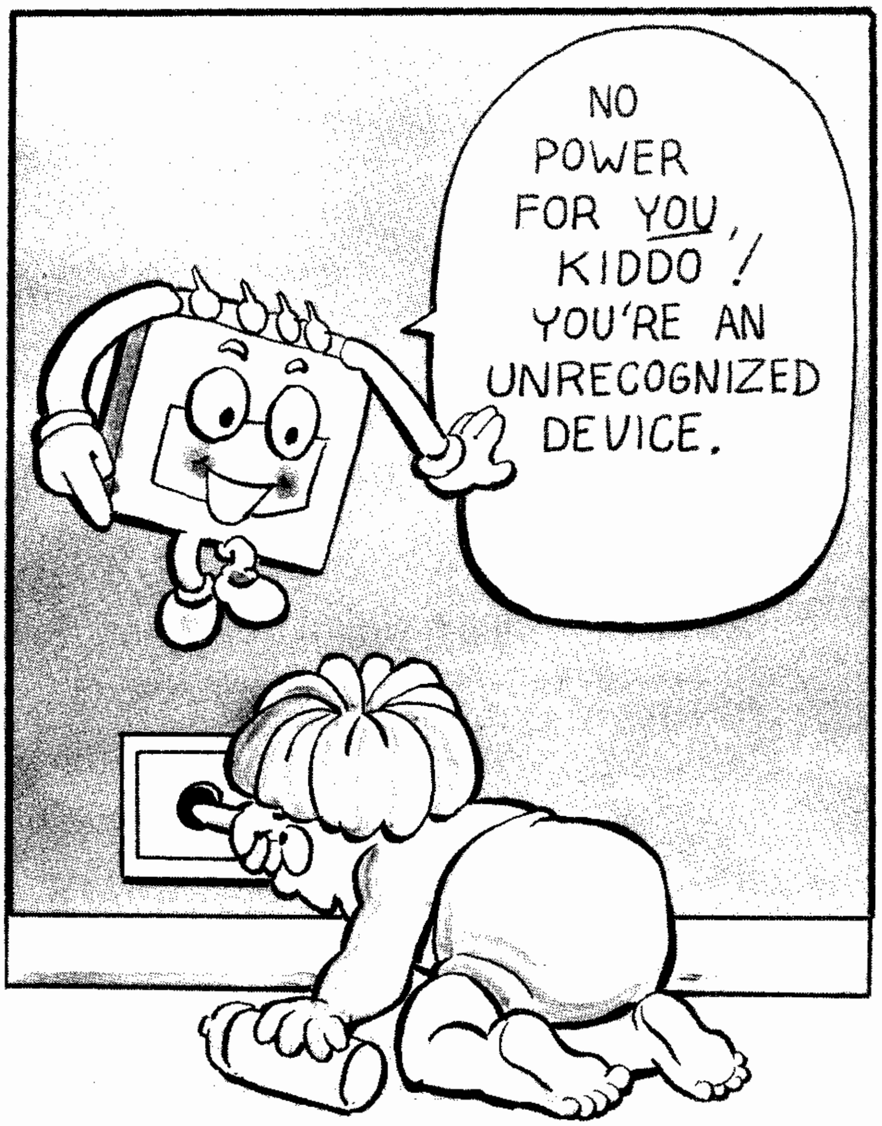
THE HOME OF THE FUTURE

Your home of the 21st century will be a Smart House.

David J. MacFadyen

THE INFORMATION AGE PROMISES TO change the way we live far more dramatically than the changes wrought by the industrial revolution. Here in 1987, we can see the leading edge of those changes and the technologies on which they'll ride. Our hardware—microelectronics, optics, and more—is advancing rapidly. The way we use that hardware—for expert systems and other artificial-intelligence approaches—is also progressing at an amazing rate.

The effects of new communications and control technologies have been seen in our factories and aircraft for more than a decade. We're only beginning to see similar effects in our cars, our high-rise buildings and, perhaps most dramatically, our offices. The mail is no longer fast enough or reliable enough for business communications. Within seconds an electronic message can be delivered across the country reliably and without error. Voice mail can provide the same speed and convenience that electronic mail has clearly established.



SMART HOUSE OUTLETS ARE SAFE. In a closed-loop power system, no electrical power is delivered to an outlet unless it is requested by an appliance.

In 1987, we're still waiting for the information age to come into our homes. It hasn't yet because much of the technology we'll need is too new. And to get it into our homes, we have to contend with the regulatory environment and the disaggregate nature of the building industry. However, the NAHB Research Foundation, a subsidiary of the National Association of Home Builders, has come up with a realistic plan for the future that allows new homes to fully accommodate the coming information age. Its *Smart House* project demonstrates how new technology can be used in our homes in the 21st century. Let's see what we can expect.

A *Smart House* will have three systems that will make its appliances—and the house itself—more "user-friendly" and efficient: a *closed-loop power system*, a *high-speed data-transmission system*, and a *logical central control system*. A *Smart House* will provide DC power as well as AC, so that new motor-driven appliances can be designed for more efficient and effective operation.

The concept of closed-loop power is not new but, until recently, we didn't have the technology to implement it. The home of the future will use it extensively. Appliances will indicate, via a communications link, how much energy they need. For instance, an electric range will tell the central controller how much current it needs to heat a burner. When the energy is supplied, the appliance must confirm, via the communications link, that the correct amount of energy is being received.

Closed-loop power systems will benefit us in three ways:

- Human electrocution will be eliminated. If an appliance cannot signal for energy, none will be provided. A finger in an electrical socket has no way of sending the electronic signal that's needed to start power flow.
- House fires caused by electrical faults and gas leaks will be eliminated. If an appliance requests a specific amount of energy, and the central controller detects that a different amount is being supplied (because of leakage between the controller and the appliance), the controller will act to ensure safety.
- Appliances can be monitored and controlled from any point in the house. A simple interface will let you do the same thing from a remote location, over the telephone lines.

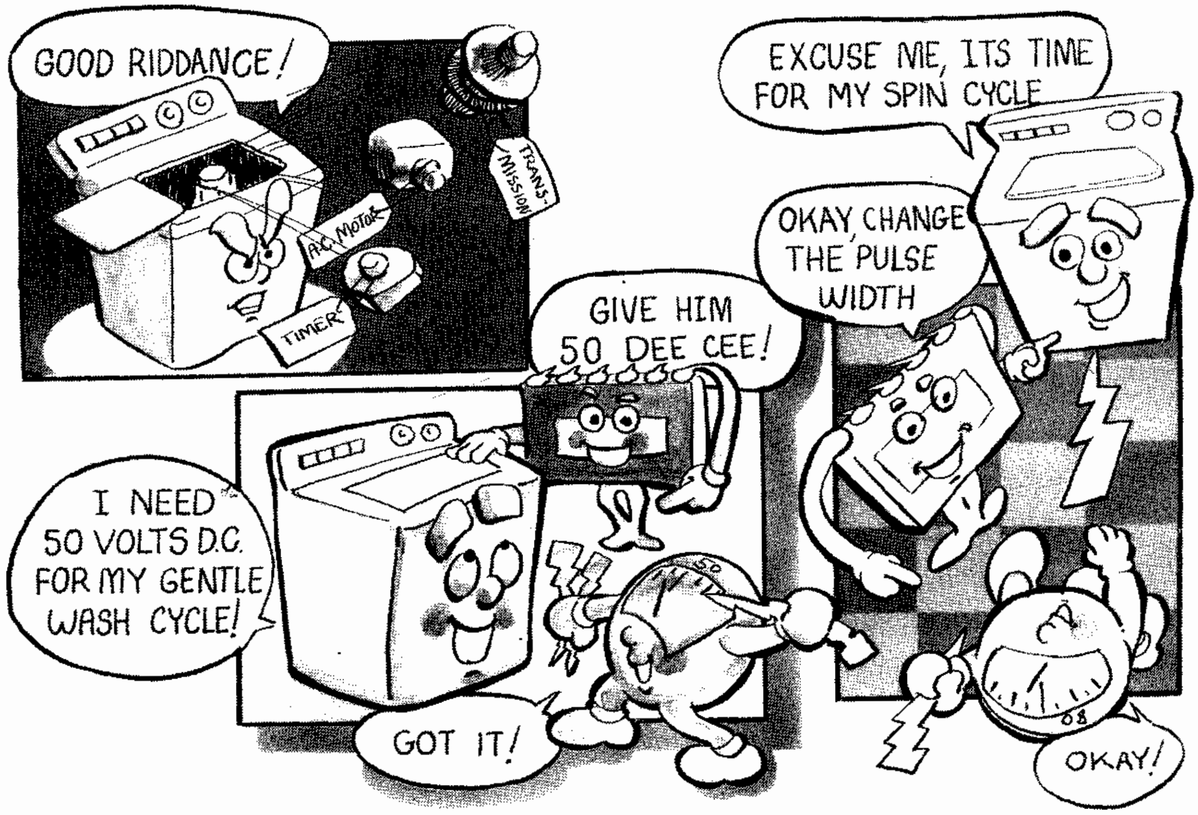
The ability to control any powered appliance at any point in the signal path will allow for *logical control* instead of the traditional hard control of devices. Wall switches will no longer physically open or close a circuit path to control the power flow to an outlet or an overhead light. Instead, they will send signals to a central controller for action. The central controller will act based on your previously programmed instructions. For example, you can tell your central controller not to turn on any lights unless it is dark in the room, the room is occupied, and the wall switch is turned on. As you can see, we won't be using only wall switches. Other devices—such as occupancy detectors, photocells, temperature transducers, etc.—will be used throughout the house to let the central controller know what's going on.

The high-speed data-communication capability in the *Smart House* will make it easy to distribute audio, video, and control signals. And instead of increasing the complexity of your home, it will make many things simpler.

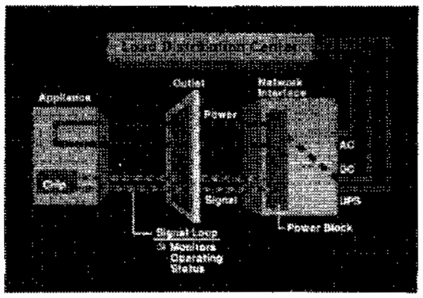
For example, it will be much easier to deal with portable devices. A single plug configuration will be used by all appliances. You'll be able to plug your telephone into any outlet. When you plug in your television set, you won't have to worry about the antenna or cable connections—they'll be made automatically through the same outlet. You'll be able to put speakers anywhere in the house and use them with a stereo, radio, television, or other audio equipment without several separate runs of speaker wire.

Using DC power

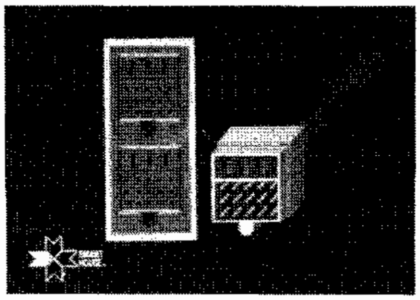
We now use alternating current in our homes, even though the vast majority of products that we use need direct current to operate. There is a good reason for using AC—it's the only economical way to transmit electric power over long distances. Unfortunately, it means that many products—radios, televisions, computers, etc.—require separate power supplies to convert AC to DC.



DC POWER WILL BE USED IN A SMART HOUSE along with AC. That will allow many appliances to be designed for more efficient and reliable operation.



THE SIGNALING LOOP is used to continually monitor the appliance interface. If any problem is detected, (such as the device drawing too much current), power to the appliance will be cut immediately.



A SMART HOUSE POWER OUTLET will also be used for distributing video, audio, power, and more. There will never be a need to run additional wiring!

When you use DC in your home, your light bulbs will last five to twenty times longer. You won't need different-wattage bulbs. You'll be able to vary the light output easily—and without flicker. The switch from AC induction motors to brushless DC motors will make your appliances more efficient and reliable, and and provide variable speed with ease.

Our heating and cooling systems will be matched to how we actually live in our homes. The *Smart House* won't use temperature sensors alone to determine how to heat and cool itself. It will know when the first person wakes up in the morning, when everyone has gone to bed at night, or if no one is in the house at all! If you go out of town for a few days, it will set back the water heater, and lower the temperatures to a safe level—and reset everything to normal in time for your expected return. Of course, if you're going to extend your vacation, you can simply phone ahead to let your house know!

You'll be able to use your TV set to display the status of any or all appliances—it will look at the signal path to determine that a light is on in the basement, that the washing machine is on its final rinse cycle, or that there is movement in the baby's room.

If you choose to add an electrical rear-door lock, you could use the TV to tell you whether the back door is open or closed, locked or unlocked. If you add a *Smart-House* compatible touch screen or hand-held remote control to your TV set, you'll be able to send commands to the lights, the washing machine, or the rear door to control them from any location where that TV set is plugged in.

Even the lowly vacuum cleaner will be redesigned to take advantage of access to the *Smart House* communications path. If the telephone or doorbell rings while you're vacuming your rugs, the vacuum cleaner will shut itself off so that you can hear. And like most other appliances, the vacuum cleaner will be designed to run on a DC brushless motor that could match the power supplied to the cleaning requirement. It will clean better, and like other *Smart House* appliances, it will cost less to operate, last longer, and need less maintenance than what you use today.

Virtually every product that attaches to the various wiring systems of a home today will be changed to take advantage of the *Smart House* technology, which will offer a vastly improved array of home products and a better way of living for all of us. **R-E**

ABOUT THE AUTHORS

ARTHUR C. CLARKE

Arthur C. Clarke, born in Minehead, England in 1917, displayed an early fascination with science, writing, and astronomy. As a youth he wrote for his school's magazine, studied and charted the moon using a telescope he built from a cardboard tube and old lenses, and was an avid sci-fi buff. Clarke transformed those childhood interests into a career as one of the world's foremost science-fiction writers.

Clarke was first published professionally while serving in the Royal Air Force in the early 1940's. In an article published in 1945, he predicted a global satellite communications system based upon three satellite stations in synchronous orbit around the Earth. Although his idea was met with skepticism by the scientific community of the time, the orbit path he described—now known as the "Clarke Belt"—is the one currently used for communications satellites.

Attending college on an ex-serviceman's grant, Clarke received a Bachelor of Science degree in physics and applied and pure mathematics in 1948. A prolific writer, he is highly regarded for scientific accuracy as well literary style. His science-fiction writing includes *Prelude to Space, Earthlight, Childhood's End*, and several short story collections. Clarke's non-fiction works on space and undersea exploration are well-respected in scientific circles. He has won several prestigious writing awards, including a *Hugo*—the science-fiction writing award named for Hugo Gernsback.

Clarke is best known, however, for "2001: A Space Odyssey" and "2010: Odyssey Two." Both films, on which he collaborated with Stanley Kubrick, were inspired by Clarke's short story "The Sentinel."

Interestingly, since the mid-1950's Clarke has chosen to make his home in the technologically backward tropical country of Sri Lanka. Seldom leaving that tropical island, he keeps up with the latest in science through journals, and depends largely upon letter-writing and shortwave radio for communications with the world at large.

ISAAC ASIMOV

Born in Petrovichi, Russia in 1920, Isaac Asimov emigrated to New York with his parents in 1923, and considers himself "Brooklyn-bred." He was accepted to Columbia University at the age of 15 and earned his Bachelor of Science degree in 1939 and his Ph.D. in chemistry in 1948.

Dr. Asimov began writing science-fiction at the age of eleven and had his first short story published in Hugo Gernsback's *Amazing Stories* in 1938. His first science-fiction novel, *Pebble in the Sky*, was published in 1950. Since then, he's gone on to write about almost every subject under the sun, ranging from math and physics to the Bible and Shakespeare.

DAVID J. MacFADYEN,
President, NAHB Research
Foundation, Inc.

Mr. MacFadyen joined the NAHB Research Foundation, in January of 1983. He has more than 20 years experience in building technology, new-product development, codes and standards, energy conservation, and research management.

Mr. MacFadyen has held many other high-level posts and has published a number of papers. He has degress from Northwestern University and the Massachusetts Institute of Technology.

DONALD E. PETERSEN

Chairman of the Board
and
Chief Executive Officer,
Ford Motor Company

When Donald E. Petersen was elected president and chief operating officer of Ford Motor Company on March 13, 1980, the *New York Times* noted that, "Not since the founder, Henry Ford, has the company had a top manager with an extensive technical background in product development." The *Times* also referred to him as "the first of a new wave of top auto executives who are more concerned about products and production systems than financial analysis."

It was, perhaps, an educational background that combined business administration with engineering that helped set him apart. After graduating magna cum laude and a member of Phi Beta Kappa, Tau Beta Pi (honorary engineering society) and Sigma Xi Scientific Research Society (natural sciences) from the University of Washington in 1946 with a degree in mechanical engineering, he went on to Stanford University where he received his MBA in 1949.

When he first applied for a job at Ford in 1949, he expressed a primary interest in what he called "product planning." At that time the auto industry had not yet formalized that function. In his early years with the company, Mr. Petersen helped establish the product-planning office.

Since becoming chairman, Mr. Petersen has devoted considerable energies toward defining the corporate culture at Ford in ways that enhance the creative process, teamwork, trust, innovation and personal fulfillment.

In the 21st century scenario that follows, Mr. Petersen draws upon the creative ideas of a number of Ford's planners, thinkers and visionaries who have constructed a hypothetical automotive world, based on a projection of today's technologies into the future. It incorporates ideas from Ford's Project "T-2008," a team effort designed to anticipate the elements of 21st century transportation.

GEORGE H. HEILMEIER

Senior Vice President
and
Chief Technical Officer
Texas Instruments

George H. Heilmeier received the B.S. degree in Electrical Engineering with distinguished honors from the University of Pennsylvania, Philadelphia, and the M.S.E., M.A., and Ph.D. degrees in solid-state materials and electronics from Princeton University.

Dr. Heilmeier has received many major awards, including the IEEE David Sarnoff Award, the IEEE Frederik Philips Award, the Secretary of Defense Distinguished Civilian Service Medal (twice), the Eta Kappa Nu Award as the Outstanding Young Electrical Engineer in the U.S., the 26th Arthur Flemming Award as the Outstanding Young Man in Government, and the IEEE Founders' Medal in 1986.

Among Dr. Heilmeier's numerous professional achievements, he holds 15 U.S. patents.

STEPHEN KUZNETSOV

Director of Engineering
Power Silicon and Monolithic
Technologies Corp.

Prior to his current position, Dr. Stephen Kuznetsov served as the Washington D.C. representative for Research and Development for the Westinghouse Corporation.

In 1984 Dr. Kuznetsov served as the Science and Technology Advisor to the Senate Subcommittee on Energy Research and Development. Since 1985, he has been Chairman of the IEEE Committee on Energy Development.

Dr. Kuznetsov holds Electrical Engineering degrees from Carnegie-Mellon University and the University of London.

CHARLES N. JUDICE

Bell Communications Research, Inc.

Charles Judice is currently division manager of the Wideband Services Research Division at Bell Communications Research Inc. (Bellcore). His division is responsible for developing new telecommications services, including multi-media teleconferencing, information and video browsing expert systems, integrated video services, and visual communications processing, among others.

The Wideband Services Division builds prototypes of advanced services and systems using state-of-the-art software and video technologies. Those prototypes will be used in field trials.

Mr. Judice holds eight patents in image processing and image retrieval and has written more than 30 papers and technical articles on those subjects. He did his undergraduate work in physics at Manhattan College, and received master's and doctorate degrees from Stevens Institute.

RAY FISH Ph.D. M.D.

University of Illinois, Urbana

Dr. Ray Fish, a frequent contributer to **Radio-Electronics**, is an Adjunct Assistant Professor of Biomedical and Electrical Engineering at the University of Illinois at Urbana. He is also a Clinical Instructor at that university's Medical School and an Emergency Physician at the Burnham Hospital Trauma Center at Champaign IL.

Dr. Fish received his B.S. and M.S. degrees in electrical engineering from the University of Illinois at Urbana. He received a Ph.D. in biomedical engineering from Worcester Polytechnic Institute and Clark University and his M.D. from the University of Chicago.

BOB L.GREGORY

Director of Microelectronics
Sandia National Laboratory

Dr. Bob Lee Gregory joined Sandia National Laboratories in 1963 as a staff member in the Radiation-Physics Department. He is a Fellow in the IEEE and has been an active participant in the annual IEEE Nuclear and Space-Radiation Effects Conference. During 1973-1974, he served as Member-at-Large for the IEEE Radiation-Effects Committee. He has served on the IEEE Solid-State Circuits Council and is a past Associate Editor of the IEEE *Journal of Solid-State Circuits* and of *Solid-State Electronics*. He is currently an Associate Editor of the IEEE *Circuits and Devices Magazine* and on the Board of the IEEE *Spectrum*.

Dr. Gregory received his B.S., M.S., and Ph.D. degrees in Electrical Engineering from Carnegie Institute of Technology in 1960, 1961 and 1963 respectively.

HEDY OLIVER

Winner, Honeywell
Futurist Awards Competition

Hedy Oliver was a technical communications major at California State University-Northridge when she won Honeywell's Futurist Award for 1986. The Futurist Awards Competition is held annually to discover how college students think technology will advance, and how those advances will affect society.

Oliver is currently a Product Informations Analyst at Unisys Inc., specializing in office automation. Oliver has resumed her studies at Northridge on a part-time basis, and plans to graduate this spring.