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LIGHTNING RESEARCH USES COMPUTER NETWORK

The Computer Almanac and Computer Book of Lists — Instalment 51

Neil Macdonald, Assistant Editor

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(Source: Volume 29, No. 5, May, 1986 "Automatisation", received November 17, 1986, published by SNTL-Publishers of Technical Literature, Krakovska 8, 113 02 Praha 1, Czechoslovakia)

20 CHALLENGES TO ARTIFICIAL INTELLIGENCE (List 870102)

Meaning	Example
1. get into one's possession	take a book from the table
2. seize, capture	they took Verdun
3. catch	he took 3 salmon
4. grip	he took the trunk
5. select	take a number
6. accept	take a bribe
7. wed	take a wife
8. receive	she took the news hard
9. gain for money	he took the box at the theater
10. subscribe	he took "Newsweek"
11. exact as compensation	he took revenge much later
12. swallow	he took the pill
13. undergo with equanimity	he took the punishment like a man
14. enter into	she took a vacation
15. carry off	the burglar took the jewel
16. end	he took his own life
17. subtract	take 2 from 5
18. carry with one	she took her notes
19. transport	we took them on the bus
20. get on board	take the train at half past three

(Source: Neil Macdonald's notes)

(Note: In a good dictionary there are listed more than 120 meanings of "take". The challenge is to determine the meaning from the context.)

22 APHORISMS (List 870103)

How forcible are right words!
Speak to the earth and it shall teach thee.
I am escaped with the skin of my teeth.
Oh that my words were now written! Oh that they were printed in a book!
The price of wisdom is above rubies.
I was eyes to the blind, and feet was I to the lame.
Great men are not always wise.
He multiplieth words without knowledge.
Hard as a piece of the nether millstone.
He heapeth up riches, and knoweth not who shall gather them.
The words of his mouth were smoother than butter, but war was in his heart.
We spend our years as a tale that is told.
I said in my haste, All men are liars.
The stone which the builders refused has become the headstone of the corner.
Put not your trust in princes.
If sinners entice thee, consent thou not.
Wisdom is the principal thing; therefore get wisdom and with all thy getting, get understanding.
Go to the ant, thou sluggard; consider her ways and be wise.
Can a man take fire in his bosom, and his clothes not be burned?
Hope deferred maketh the heart sick.
A soft answer turneth away wrath.
Pride goeth before destruction, and a haughty spirit before a fall.

(Source: Old Testament, Book of Job and Book of Proverbs, King James version, 1612)

Ω

Computing and Data Processing Newsletter

SCIENTISTS DESIGN COMPUTER CHIPS THAT MIMIC HUMAN BRAIN CELLS' FUNCTION

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Experimental computer chips that may mimic the way some brain cells retrieve stored information and solve problems are being tested by AT&T Bell Laboratories scientists working to devise new computer architectures. The researchers hope to create specialized machines that are able to "recognize" and "remember" by association -- tasks that living organisms now perform much faster and more efficiently than computers.

The new chip designs, called electronic neural networks (ENNs), are compact and highly interconnected networks of many simple components such as resistors and amplifiers. Like their living counterparts, these artificial "neurons" function continuously and collectively to obtain quick answers. The most complex chip thus far -- 256 electronic neurons -- is still to be tested. It contains about 25,000 transistors and more than 100,000 resistors, all on about a one quarter inch square of silicon. Previous chips have had a few dozen "neurons."

The basic elements in the circuitry of the chips are the resistors, the possible electrical equivalent of simple synapses (the regions of contact between neurons across which nerve impulses are transmitted in one direction only) in nature. The matrix of resistors interconnects amplifiers (neurons). When the neural network is used for memory storage, information is distributed over an entire network, not at specific sites as in conventional computer memory. When the memory is interrogated electrically, answers are as if from a team of neurons, not from individual players.

Researchers expect ENN chips to retrieve information in about 400 nanoseconds (billionths of a second), much faster than biological neurons. The scientists plan to explore use of certain chips as specialized image processors to extract significant features from a picture or a set of characters. The associative behavior of the network would allow it to recognize distorted features and classify them correctly.

The chip research was inspired by work in the Molecular Biophysics Research Dept. of AT&T Bell Laboratories. Scientists there have been studying information processing in single nerve cells and simple organisms, and have devised mathematical models for neural networks to solve optimization problems and memory problems.

Neural networks permit greater chip density because resistors occupy a fraction of the space and require fewer layers of lithography than transistors used in present day computer memory chips. These memories are more powerful than conventional memory chips because the data can be recalled by association. In addition, researchers, using electron beam lithography, have been able to fabricate test chips with features as small as one tenth of a micron (four millionths of an inch), in contrast to 1.25 micron features in current computer memory chips.

Neural networks have other characteristics that distinguish them from the function of today's digital computers:

- ENNs can process information in analog (continuous values) rather than just the digital form that today's computers use.

- The entire circuit, instead of only a fraction, is engaged in computation at one time, so "good" answers to certain hard problems may be available more quickly.

- An ENN circuit can simultaneously retrieve and process information, so an erroneous or incomplete input query can elicit a complete, "closest match," response.

- Since information is stored globally, no single crosspoint is critical. The network is fault tolerant (i.e., will still execute properly even though parts may fail), as in massive biological systems where neurons die each day but processing and recall functions go on. Ω

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

Announcement

The Computer Directory and Buyers' Guide

The names, addresses and descriptions of over 3500 computer field organizations are still being updated in our computer data base for the next Directory edition. Production of the photooffset master for printing has been delayed. We hope that we will have this, the 28th edition, ready for mailing to subscribers early in 1987.

Meanwhile, any current subscriber to *Computers and People* who also subscribes to the *Computer Directory and Buyers' Guide*, and who does not already have the 1984-85 edition, may on request to us, receive a copy of that issue, so long as the overrun lasts.

Front Cover Picture

The front cover shows a picture of lightning, a commonly experienced yet poorly understood natural phenomenon. Atmospheric scientists at the State University of New York, (SUNY) in Albany are using a network of over 25 electronic sensors to detect and study lightning patterns throughout the eastern U.S. The sensors are linked via modems and telephone lines to a central computer in Albany, NY, where that data is displayed, analyzed, and recorded for further evaluation. The sensors locate lightning by identifying the unique magnetic "fingerprint" that each flash produces when striking the ground. Started in 1982, the network can detect and record virtually every ground-based lightning event that occurs throughout the detection area. Data collected by the network is being used in weather research and to warn airplane pilots of quickly developing thunderstorms.

Computer Field → Zero

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

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

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Editorial

The Educational Quality of a College Undergraduate Education

Edmund C. Berkeley, Editor

A recent report of the Carnegie Foundation for the Advancement of Education written by Ernest L. Boyer, president, says that:

1. Scrambling for students and driven by marketplace demands, many colleges have lost sight of their purpose and mission.

2. All college seniors should write a thesis and defend it in a seminar with classmates.

3. College sports have many shocking abuses, and the budgets for sports are often outrageous.

4. Part-time faculty members should be less than 20 percent of faculty, not 25 and 30%.

5. Seven broad areas should all be covered: language; art; cultural heritage; the web of social institutions; nature; work; self-identity.

6. Not all college professors should devote themselves predominantly to research, and the rank of "distinguished teaching professor" should be established widely.

7. Students should assess professors, and faculty seminars should assess students.

8. Residential living of students should be better guided, and zero faculty responsibility should be replaced by sensible responsibility.

9. Alcohol (not cocaine or marijuana) is "overwhelmingly the drug of choice and the drug of greatest damage".

Is this verdict confirmed by what I know, have read, and observed? Yes, to a great extent. I first started in business as Edmund C. Berkeley and Associates (one secretary and myself) in 1948, main activity actuarial consulting. I have now had 38 years experience as main owner, publisher, assistant janitor, typist, lawsuit defendant, writer, maker of mistakes, and at least 20 more roles. Largest number of employees, about 8; smallest number, about 1 and 1/4. I must have interviewed over 100 persons for prospective employment. They seem to know less and less. They type worse and worse. Their vocabulary seems to be more and more limited.

I think the main causes are (1) watching television passively, (2) busier parents, both mom and pop working, (3) the steady lowering of school standards, and (4) the withdrawal of teachers and school administrators behind grade norms and "teacher knows best". (Because if you can mystify and confuse the attacking parent, you don't have to be right, you don't even have to change, or question the incorrect dogma you have been taught by educationists.)

Can microcomputers help in this distressing situation in the colleges, which the current Carnegie report explains with a bright light?

Of course. But computers have to be used with imagination, intelligence, and love of students -- in order to really assist the human professor. One example that I have advocated for many years at several colleges and public schools is computer-assisted point-grading of long freely written answers from large classes. (Details on request). Other examples in the literature are computer-assisted: drill; spelling; vocabulary expansion; letter writing; language translation; and many many more.

A human professor can do far more than a machine. But machines to help him can triple his accomplishments with young people. And well-taught young people are likely to love and admire him to the end of their days. Ω

Astronomy, Instruments, and Computers —Part 1

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"Bold new telescope designs have been proposed . . . But they could not be designed, built, or operated without computers."

Based on an important article in *Mosaic*, Vol. 17, No. 2, Summer 1986, published by National Science Foundation, Washington, DC 20550. Reprinted from this magazine in the public domain.

In 1609 Galileo Galilei raised one of the world's first telescopes to the sky and discovered objects never before seen by the keenest eyes on earth. There were craters on the moon, moons around planets, and millions of individual stars making up the familiar glowing bands of light across the sky.

Larger, More Powerful Telescopes

Since then, optical astronomers have effectively continued what Galileo began. Using progressively larger and more powerful telescopes, they are still finding astonishing objects -- quasars, gravitational lenses, and hints of planets around distant stars -- that emit energy in the optical and near-infrared portions of the electromagnetic spectrum.

For more than 350 years the techniques of building optical telescopes have gone through major, evolutionary stages. Moreover, the history of astronomy reveals that whenever one generation of astronomers pushes existing technology to the limits, the next generation devises a new technology to expand astronomical horizons.

The earliest telescopes, called refractors, used lenses to collect photons. Such telescopes were built larger and larger until it was found that lenses more than 100 centimeters in diameter would sag under their own weight, distorting light passing through them. Telescopes grew prohibitively.

Reflecting telescope mirrors impose far looser requirements on material homogeneity, can be made thicker and hence more rigid, and can be polished to deeper curves and faster f ratios. Thus larger telescopes become practical. But reflectors, too, in recent decades, have reached physical limits. Mirrors over 5 meters across are so heavy and flexible that supporting them against weight-induced distortion has become a major engineering challenge.

Going beyond this size is now perceived as necessitating new advances in mirror design, new ways of dealing with gravitational effects on the large supporting structures required. Having found the limits of mid-twentieth-century technology, astronomers are preparing the next step in telescope fabrication. No longer able to scale up existing designs, they have turned to electronic engineers to help them build the next generation of instruments. Such telescopes, in the eyes -- and arcane vocabularies -- of many young astronomers, will be sophisticated front-end peripherals for the computer-run systems and electronic components that already collect and process some astronomical data and that may well be the ground-based astronomy of the future.

Photon Gathering

Telescopes perform two basic tasks: the collection of photons and the resolution of, or telling the difference between, objects that are very far away and very close together. In addition, like cameras, they make images.

The objects of interest to optical astronomers emit photons in the visible and near-infrared band of the electromagnetic spectrum. Many of these objects appear dim; few of their emitted photons reach the earth. There are two ways to capture more photons from dim objects. One is to point a telescope at the same object, night after night, storing the photons photographically or electronically to build up a cumulative image. The other is to build larger telescopes that can capture more photons in less time. The principles are still straightforward; the engineering problems have multiplied to a point where they have become formidable.

When the human eye looks at a star, the light focused on the retina enters the eye as a beam whose diameter equals the diameter of the pupil. When the eye sees a star through a telescope, though, the pupil receives what was a light beam whose increased cross section grows in proportion to the square of the diameter of the telescope's aperture, or primary mirror -- its primary light-collecting area. Large telescopes today have apertures between 2.5 and 5 meters in diameter. Backyard telescopes, by comparison, typically have much smaller apertures: between 75 and 150 millimeters.

At night, while gazing at a star, the pupil of the human eye is approximately 6 millimeters in diameter. Viewing the same star through a telescope with a 25-millimeter aperture intensifies the light reaching the eye approximately 16 times. A 250-millimeter aperture intensifies it 1,600 times, and a 2.5-meter aperture intensifies it 160,000 times. The area of a 25-meter aperture, therefore, would have 16 million times the collecting power of the unaided human eye. Theoretically, a telescope with a 15-meter aperture can collect as many photons in one night as a telescope with a 5-meter aperture focused on the same object can collect in nine nights.

Resolving Powers

Resolution problems are more intimately connected to the nature of light and what happens to light in transit from source to sensor. In theory, larger telescopes have better resolving power than smaller ones. Interference between photons hitting different parts of the mirror determines resolving power; a perfectly built telescope will show the image of a star at its focus surrounded by faint rings produced by this interference. This effect is called diffraction.

Using diffraction theory, the diffraction limit of an optical telescope -- the minimum angular separation of objects in seconds of arc -- is calculated as 5 arc seconds divided by the telescope's diameter in inches. A 25-centimeter telescope can resolve objects at an angle of 0.5 arc second. By this rule, the half-century-old 5-meter Hale telescope on Mount Palomar in California would be capable of 0.025 arc second imaging, which is equivalent to resolving points 50 meters apart on the moon. In practice, however, ground-based telescopes with the best optics and largest apertures rarely attain angular resolutions better than one arc second. This is because the turbulent atmosphere tends to blur the incoming wavefronts from celestial objects. With a resolution of one arc second, such telescopes can bring a dime into focus from a distance of about 1,600 meters, read a tennis ball label from 15 kilometers, or resolve points that are 6 kilometers apart on the moon. By contrast, the National Aeronautics and Space Administration's 2.4-meter Hubble Space Telescope, flying above the atmosphere, is expected to attain 0.1 arc second imaging or better.

Size and Design of Current Telescopes

The largest telescope in the world today is the 6-meter instrument at Zelenchukskaya in the Soviet Union. There are several other instruments in the 2.5-meter to 3.6-meter range eleswhere that were built in the 1960s and early 1970s. Larger telescopes have not been built because single, solid, primary mirrors larger than about 5 meters are prohibitively expensive and notoriously difficult to support.

The primary mirrors of most of these giant telescopes are made of highly inert glass-ceramic materials whose dimensions do not change much in response to heat or cold. The mirrors are ground and polished to the tolerances needed to focus light waves accurately, and are then coated with highly reflective metals such as aluminum.

Such telescopes usually, but not inevitably, reside in the familiar giant hemispherical domes that protect them from weather. Vertical slits in the domes open to reveal the night sky. The telescope is mounted at angles that rotate about an axis parallel to a line drawn through the earth's poles. Once it is pointed at an object and is rotated around this axis at a speed equivalent to the earth's rotation (but opposite to the direction of rotation), the telescope can track the object all night. This design, known as the equatorial mount, has dominated astronomy for centuries.

Building equatorial mounts to support mirrors larger than about 5 meters is regarded as impractical and very expensive because of the engineering problems involved in rotating such large structures around an axis that is neither perpendicular nor parallel to the ground. Telescopes with vertical and horizontal axes of rotation are called altitude-azimuth telescopes, and they require nonconstant rotations simultaneously about both axes -- a condition that requires a computer to make the necessary drive rate calculations needed to track a star. For the last 30 years, knowing they have been stuck with a size limit of around 5 meters, optical astronomers have worked to squeeze more information from their telescopes by devising clever instruments and tricks. The typical efficiency of a good optical telescope is about 5 percent; that is, only 5 out of every 100 photons that actually strike the mirror are recorded by detectors in back of the telescope.

How does one capture more information and learn more from it? Many things have been tried to improve photographic emulsions.

Electronic Charge-Couple Devices

To help produce images of fainter objects, electronic charge-couple devices have been developed that can record more than 70 percent of the photons that fall on their surfaces. The CCD works on photoelectric principles whereby light entering silicon knocks electrons loose from the parent atoms. The number of freed electrons is proportional to the intensity of the light striking the surface of the CCD. Up to 20 percent of the photons striking a telescope mirror can now be recorded with the best of these CCD systems.

Extremely sensitive image-photon counting systems have also been devised. The CCD collects photons and then displays the collected charges on a television screen. Astronomers can now watch an image, such as a quasar, build up as its photons reach the detector on earth almost literally one at a time.

Even with the best CCD, though, existing telescopes are barely able to make out the most distant galaxies. There are not enough photons reaching even the best spectrographs to record the red-shift (a measure of relative distance) of the most distant galaxies known. Today's telescopes are also severely limited in angular resolution because of atmospheric blurring. Nor are their apertures large enough to be effective in the near infrared (the infrared region closest to visible light).

Larger Mirrors Not Practical

The Soviet Union's 6-meter telescope, which weighs 800 tons, is reported to have problems stemming from its weight. The mirror is cast from a 42-ton block of glass. Sixty holes have been drilled in its back for placement of support mechanisms. Reportedly, the mirror suffers thermal distortions that affect image quality. Indeed, most American astronomers say that only a small number of astronomical findings have been made by this Soviet telescope.

There are other barriers to scaling up existing technology and breaking the 5-meter barrier. A 10-meter mirror blank has never been cast. Such an object would be heavy, difficult to handle, and costly and would take years to polish. It would also be perilous to put so giant a mirror on a truck and drive on rough roads to a remote mountaintop. In addition, the dome would be both huge and expensive for an instrument with the f/3 or f/4 focal ratio typical of existing reflectors (focal ratio reflects the depth to which a mirror must be ground -- the longer the focal length, the shallower the curve and the longer the telescope). And the classic equatorial mounting would not be able to support the weight of so large an instrument.

Indeed, the cost of building large, conventional reflectors with conventional techniques rises as the cube of the diameter of the aperture. For example, a 10-meter, Hale-type reflector would cost eight times as much as the actual 5-meter Hale telescope on Mount Palomar would today, and it would very likely take 20 years to build.

Telescopes in Orbit

Nevertheless, larger telescopes must be built. There are jobs that simply must be done from instruments that cannot be placed in orbit. "For parts of the spectrum where we can see through the atmosphere, there is a clear case, in terms of cost and science, for staying on the ground," says John T. Jeffries, director of the National Optical Astronomy Observatories (NOAO) in Tucson, Arizona. "There are certainly some things we can't do on the ground and for them we must go into space. But they are complementary, not competitive, science."

The atmosphere absorbs radiation in ultraviolet wavelengths, for example, and ground-based telescopes are blind in this portion of the spectrum. Orbiting observatories are sensitive to these and other high-frequency emissions, and for some tasks -- all tasks, as claimed by some astronomers -- a new era in astronomy is dawning. Orbiting observatories are opening new windows on the universe. New objects and new conditions have been found in the Milky Way and beyond by satellites equipped to analyze energy in the far-infrared, ultraviolet, x-ray, and gamma-ray portions of the spectrum. These spectra, including those portions of the infrared spectrum farthest from the visible, are stopped by the earth's atmosphere. Even with the cleverest engineering tricks, they cannot be studied from the ground. The Infrared Astronomical Satellite, IRAS, recently discovered numerous galaxies that glow extraordinarily bright in the far infrared while appearing as faint, barely detectable galaxies at visible wavelengths picked up by ground-based telescopes.

The Hubble Space Telescope

The Hubble Space Telescope, initially scheduled to be launched from a space shuttle in 1986, will excel at resolving faint, distant objects. It is expected to probe seven times as deep into space, detect objects one-fiftieth as bright, and pick out familiar celestial objects with ten times the resolution of the largest ground-based telescopes. It will view the universe clearly in the ultraviolet, the last major portion of the spectrum that is relatively unexplored. Other orbiting observatories are under consideration as well.

Once launched, however, space instruments are difficult to adjust, upgrade, repair, or experiment with. Further, discovery by itself is not enough: After exotic new objects have been found in deep space, it is as important to study them with conventional telescopes to understand their nature as it is to turn space-borne instruments on objects studied from the ground to round out knowledge of them.

The Hubble Space Telescope has a relatively small aperture (2.4 meters), which makes it unsuitable for doing high-resolution spectroscopy (a large aperture and long exposures are required to scoop up enough photons). It has a small field of view. It cost more than $1 billion. It may never be made more than it is: Future space shuttles notwithstanding, it is never going to be as easy as it may be on a mountaintop on earth to slip out old instruments and add the latest, most sensitive detectors.

Further, in an expanding universe, light from the faintest, most distant, and most rapidly receding objects has been massively redshifted. To pursue such objects, sensitivity in the ultraviolet and other short wavelengths is useless. The near infrared is the optical region of choice, and this is the realm of the ground-based giants.

So there is a resurgence of ground-based astronomy, and ways are being developed to defeat such traditional limitations as the atmosphere. According to Jacques Beckers of NOAO, clever ground-based instruments are in the wings. For example, an adaptive-optics technique that literally subtracts atmospheric effects has been developed by the military. "We can borrow their ideas and knowledge," he says.

Techniques to Undistort Images

When a star's wavefront enters the atmosphere, it is distorted. The seeing is not good. The image in the telescope's focal plane is fuzzy and speckled. In adaptive optics, Beckers says, the wave is corrected, or undistorted, before it reaches the telescope's focus. This is done with the help of an optical element, a special mirror, that analyzes and then physically reshapes the distorted wavefront.

Wavefront distortions occur on a measurable scale proportional to the wavelength of electromagnetic radiation. An incoming wavefront hits the primary mirror, is measured for its disturbances, and a correction is calculated. With the help of piezoelectric translators on its back, the mirror then changes shape to correct the wavefront, thereby making it flat -- just as it was when it left the star. The light then goes to the focus of the telescope. If successfully applied, Beckers says, such a technique would make a giant ground-based telescope as good as space telescopes in resolution.

Other image-restoration techniques, such as speckle interferometry, can be used as well, he says, so "we could sit on the ground and cover huge areas with unmatched clarity." In optical speckle work, a special instrument scans ultrashort-exposure photographs of electronically intensified images. A computer then compensates for the turbulent motions of the atmosphere and combines the scans. This essentially removes the twinkle from starlight.

"Light Buckets"

Astronomers are basically gatherers and interpreters of light. The more photons they can collect from celestial objects, the better they can understand those objects. Telescopes are "light buckets" for this kind of work. Only a few photons per second arrive on earth from very distant, faint objects. The bigger the bucket, therefore, the better the photon collector. Certainly, for some kinds of observations, such as galactic spectroscopy, astronomers do not gain that much by going to space. Spectroscopy of very distant, faint objects can be done more efficiently, with more flexibility, and at lower cost on the ground. Says University of Arizona astronomer Ray Weymann, "We're just plain photon-starved. It's hard to get spectrographs to be a whole lot more efficient. That means to continue to work on some problems, we need more aperture." Besides, he says, galaxies are inherently fuzzy, and the angular resolution gained from a space telescope does not add that much. "So we may as well have a larger light-gathering power on earth." Ten meters, for instance.

A 10-meter telescope would open up new regions of the sky, astronomers say, and help them ask many questions about the origin and structure of the universe. How did the cosmos take on its present lumpy structure after being a smooth gas right after the big bang? Were there as yet undiscovered particles present at the big bang that led matter to form galactic clusters and superclusters?

Exploring the Evolution of Galaxies

Astronomers like to use the universe as a kind of time machine. The most distant galaxies they can now see are 7 billion light-years out. Larger telescopes might enable them to peer 11 billion light-years into the past, to when the universe was about 10 percent of its present age. Photons from such distant objects could be studied to learn what kinds of galaxies existed 11 billion years ago. If they were lucky, astronomers could see spectra of galaxies at an early age, showing the very evolution and clustering of galaxies and might see examples of galaxies forming.

A giant ground-based telescope would also work well in the near infrared because telescope sensitivity in infrared frequencies goes up for some conditions as the fourth power of the mirror diameter. A very large mirror would allow direct study of the center of the galaxy and a look at warm regions of star formation.

Inside the Milky Way there appear to be remnants of supernovas and clouds of ionized gas. Is there a black hole at the center? A compact star cluster?

The riddles of star birth could be explored. What events lead to ignition of stars? With today's telescopes, star-forming regions of a galaxy are difficult to study. It is a confusing picture of stars in different steps of evolution with different spectra. A giant telescope could distinguish between an actual new star and nearby clumps of dust that scatter light and mimic stars.

A giant telescope might also, for the first time, locate protostars only 100 astronomical units across -- less than 100,000 years old. It could study the halo around the Milky Way and the globular star clusters that inhabit its outer fringes. Today, astronomers can study only the brightest giant stars in the diffuse-appearing globulars. A larger telescope would get spectra from these objects and allow a better picture of the galactic halo to be made.

The Multiple Mirror Telescope (MMT)

Bold new telescope designs have therefore been proposed. They have in common the goal of breaking down the primary mirror into more manageable pieces. They could not be designed, built, or operated without computers.

One design approach has been proved on the prototype scale. This is the MMT, the Multiple Mirror Telescope on Mount Hopkins in Arizona. A joint project of the Smithsonian Institution and the University of Arizona, the MMT offers a glimpse into the future of ground-based optical astronomy. Dedicated in 1979, it is the world's most compact, most complex, and most unusual-looking telescope.

The MMT relies on an astronomical concept that can be traced to Charles Darwin's grandfather. In 1779 Erasmus Darwin wrote, "Suppose 20 glasses, either lenses or concave specula, are so placed as to throw all their images of a certain object onto one focus -- there will be one image with 20 times the brightness that one lens or speculum could produce." Skeptics said a multiple-mirror telescope could not hold images together,

(please turn to page 26)

Expert Systems: Pre[illegible]re

J.J. Harvey
ITT Europe Engineering Support Centre
Harlow, England

"Over the next decade, fu[illegible]ogies, new hardware architectures, and more powerful software will result in expert systems being introduced into almost all areas where expertise is routinely applied."

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Two Contrasting Views of Artificial Intelligence

Expert systems technology is in its infancy, emerging from the new and expanding field of AI (artificial intelligence). There are two contrasting views of AI. One, the theoretical viewpoint, is concerned with understanding how computers can be developed to perceive and understand to the level of human ability (Figure 1). The other, the engineering viewpoint, is concerned with developing computers that can demonstrate human ability without requiring a theoretical foundation. Just as it was possible to construct bridges before the science of mechanics was well developed, so too is it possible to develop intelligent systems that can contribute to problem solving and decision making before a comprehensive theoretical foundation has been developed.

As illustrated in Figure 1, the major AI areas mirror human abilities: locomotion and manipulatory skills in robotics; communication skills in natural language and speech; the ability to distinguish and recognize images in vision; and problem solving skills in expert systems.

Techniques to Develop Computer Models

Orthogonal to these viewpoints are the AI techniques used to develop computer models. These can be classified into several areas. First is knowledge representation which covers the formalisms used to describe both declarative and procedural knowledge. Declarative knowledge is what we know (facts, theories, hypotheses), while procedural knowledge describes how we use that knowledge (strategies and tactics). Second is knowledge processing, that is, the mechanisms that search through the knowledge and make reasoned deductions to reach a conclusion. Third are learning techniques that produce new knowledge by observing how effective the existing knowledge is in interacting with the world. Fourth are the planning strategies for organizing problem solving. And fifth is the user interface which determines how the system interacts with the users.

Expert systems cover the area of human ability concerned with problem solving and applying expertise. They are computer systems that use knowledge and inference or reasoning procedures to solve problems that are normally handled by experts. Thus an expert system is designed to capture the knowledge of experts in a particular application area (known as a domain), and make that knowledge available to less experienced personnel.

Components of an Expert System

There are three main components in an expert system: user interface, inference engine, and knowledge base (Figure 2).

User Interface

The user interface allows the user to interact with the system to present the problem and see the conclusions. A key feature is that the expert system can justify its conclusions, in the same way as a human expert, and can say why particular options were taken up or ignored.

A major consideration for the designer of user interface concerns how the initiative

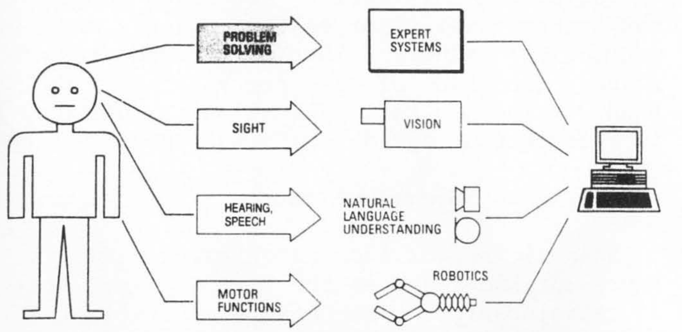

Figure 1: Artificial intelligence models human behavior.

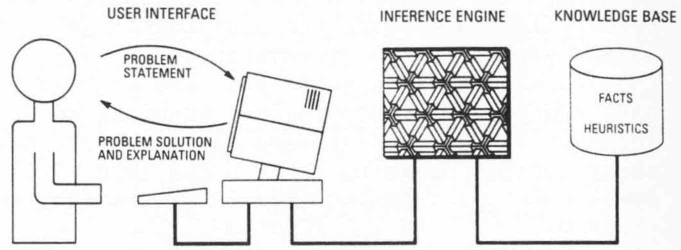

Figure 2: Main expert system components: user interface, inference engine, and knowledge base.

is to be shared between system and user. When the system takes the initiative, it directs the dialog and asks questions of the user; unless requested, the user cannot present information to the system. Consider, for example, a diagnostic expert system that takes the initiative; the system selects a hypothesis and asks questions of the user until that hypothesis is confirmed or fails. This works well for inexperienced users who may not have alternative views, but can be frustrating for experienced users who might have an alternative hypothesis or additional information, and who might feel that their views are not being considered.

When the initiative is shared, the user is able to volunteer information without a specific system request, and to share in decision making. Returning to the diagnostic example, if the initiative is shared, the system invites the user to select a hypothesis from those that are available. Further, at each decision point the user is invited to comment on the current hypothesis to suggest an alternative course of action.

As might be expected, the design of an expert system in which the initiative is shared is more complex than one in which the system takes the initiative. Even more complex would be a system in which the user takes the initiative completely. In this case, the difficulty is in constraining the interaction to cope with a wide range of possible user inputs, which might be in natural language with all its inherent ambiguity and thus beyond the present capability of the technology.

Inference Engine

The inference engine, or reasoning mechanism, is similar to the control structure in a conventional program; it operates deductively and selects the relevant knowledge to reach a conclusion. Thus the system can answer users' queries even when the answer is not explicitly stored in the knowledge base. The aim is to imitate human reasoning so that the user can understand the steps taken by the system. One of the designer's main tasks is to choose an appropriate inference technique.

Various inference techniques exist, each of which models a different reasoning procedure. For example, the backward chaining or goal directed technique models the thinking used by a diagnostics expert in starting with a hypothetical fault and reasoning backwards to identify possible causes of that fault. In contrast, the forward chaining or data driven technique models the reasoning used by a configuration expert in starting from a list of requirements to determine the detailed bill of materials necessary to satisfy those requirements. Both forms typically use an inference net to model the reasoning process.

Characterizing inference techniques in this way provides a broad generalization of their use. In practice, however, both techniques may be required; one part of the problem might be suited to a forward chaining strategy, while another is best suited to a backward chaining approach. The challenge is to provide these techniques in a way in which the knowledge engineer can experiment with different options to arrive at an optimal strategy.

Another important aspect of inferencing is the ability to deal with problems where the data is uncertain. This might be necessary, for example, during diagnosis if the data or evidence for the cause of a fault is unreliable. The user will typically express this as a degree of certainty or probability for the occurrence of the evidence. Techniques for reasoning with uncertainty will be a component part of the inference engine.

Knowledge Base

The knowledge base is perhaps the most important component as it contains the experts' knowledge and expertise. For this reason expert systems are often known as knowledge based systems. A major advantage is that the knowledge base is separate from the control part and the inference engine, enabling knowledge to be added or changed without worrying about control or going through the lengthy development process required for conventional programs.

The designer of the knowledge base must choose a suitable representation technique to describe the experts' knowledge. Important factors are the expressive power of the representation (the ease with which the experts' knowledge can be described and read) and the computational efficiency (the run-time performance overhead in processing the representation used). At one extreme, a highly expressive representation might use free-form natural language to describe the knowledge, while at the other extreme a representation based on a programming language might be used to ensure rapid execution. In general the chosen technique is a compromise that is understandable to the experts, so that they are encouraged to maintain the knowledge base and validate its performance, yet provides an acceptable speed of execution.

Underpinning this choice are the principal knowledge representation techniques used in expert systems applications: rules, semantic networks, frames, and objects.

"Rules of Thumb"

Rules are the most common form of representation. Each rule consists of one or more conditions which, if satisfied, give rise to one or more actions (Figure 3). Knowledge bases using rules have the advantage of being easy to change since, in principle, each rule is a declarative statement of knowledge which is isolated from the other rules. Furthermore, rules seem to match the way in which experts formulate their knowledge in a kind of "cause and effect" way. Typically experts develop a store of heuristics, or "rules of thumb", which can readily be described using a rule-based representation. However, when there are more than a few hundred rules the ease with which they can be changed causes a problem because it becomes difficult to determine how a change will affect the overall problem solving behavior. One way of minimizing this problem is to separate the knowledge base into groups of rules where each group addresses a different aspect of the problem.

A variation on the rule-based representation is one using the predicate calculus form of logic. In this variant the rules adopt the mathematical rigor vested in logic and use logical deduction in the inference technique. The value of this representation depends on whether the application is suited to inference using logical deduction.

Semantic Networks

Semantic networks or associative networks represent knowledge in the form of a network of relationships. The network consists of a series of nodes interconnected by arcs, that is, by lines connecting the nodes (Figure 4). Nodes represent the elements of the knowledge while arcs determine the relationship between nodes. This might be an inheritance relationship in which one node inherits the properties of the other node, or a descriptive relationship in which one node describes the properties of the other. The problem with such networks is the difficulty of updating them to reflect new knowledge or changed relationships.

Frames

Frames are an increasingly common form of representation, combining the ideas of semantic networks and rules. A frame is a template consisting of a number of slots and, optionally, the values that the slots can take. These values can be in the form of rules where a deductive process is necessary to derive the value of the slot. Frames have the advantage of explicitly representing data relationships in hierarchical form so descendant frames in the hierarchy can inherit values from superior frames.

EXAMPLE RULES - TOY CASE	
IF THE ANIMAL HAS HAIR OR IF THE ANIMAL GIVES MILK THEN THE ANIMAL IS A MAMMAL	IF THE ANIMAL HAS FEATHERS OR IF THE ANIMAL FLIES AND THE ANIMAL LAYS EGGS THEN THE ANIMAL IS A BIRD

EXAMPLE RULES - REAL WORLD
IF THE TRAFFIC PER LINE IS NORMAL AND THE TYPE OF LINE CIRCUIT IS ELC THEN THERE IS ONE SPARE LINE PER 479 LINES AND THE NUMBER OF LINES PER ASM EQUALS 128 AND THE NUMBER OF LINES PER PBA EQUALS 6

Figure 3: Knowledge representation using rules. This is the most common form of representation in today's expert systems.

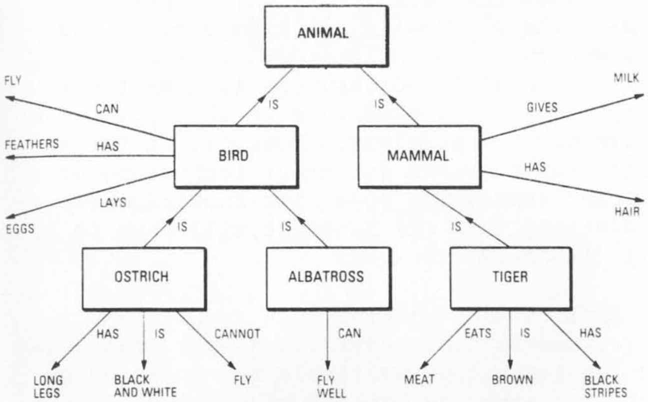

Figure 4: Knowledge representation using semantic networks. Knowledge is represented by the nodes, while interconnecting arcs (i.e. the lines) determine the relationship between nodes.

Objects

Objects use a similar representation to frames and incorporate the notions of slots, values, and inheritance. The key difference is that communication with objects is in the form of messages which results in objects being used as agents to perform tasks requested by other objects via these messages. Thus an object can represent a group of rules with messages being used to schedule execution of the rules.

Development of an expert system is really the development of appropriate representations for the experts' knowledge. Tools for building expert systems generally offer a choice of knowledge representation techniques so that the knowledge engineer can select one that is appropriate to the application.

Benefits of Expert Systems

The most obvious benefit is that expert systems capture human intelligence and judgment for use in areas where resources are scarce and therefore at a premium. This is particularly important in high technology companies with a large demand for expertise.

As with conventional technology, a strong case can be made for using expert systems technology if it can be supported by some measure of the benefits. However, this is not an easy task since there are no established methods for estimating the impact of a developed system on an organization. Some work has been done within ITT on formalizing and applying such measures. Benefits may include a cost reduction through reducing the number of skilled personnel needed, a reduction in the time taken to solve a problem, or the wider availability of specialist expertise in a particular area.

Other potential benefits are the ability of the technology to manage more complex systems and the provision of computer support in areas where conventional computer technology has not been of assistance. An example of complexity management is to be found in VLSI (Very Large Scale Integration) design where there is a need to develop digital circuits with more than 100,000 gates. Automated computer support is used to configure System 12 digital telephone exchanges (manufactured by ITT Corp.) where differing administration requirements and frequent changes make it difficult to develop a satisfactory conventional computer solution. A key feature of the expert system developed by ITT to support the configuration of exchanges is that the rules governing the process can easily be changed.

New Products and Services

Expert systems technology offers the opportunity for developing new products and services, including tools for building expert systems (estimated to be worth $220M by 1990), and systems for such tasks as providing consumer advice.

Experience within ITT has shown that expert systems have a major impact on productivity and achieve cost savings in areas where traditional programming has been unable to make inroads. Applications include fault diagnosis at printed board and system level, the configuration of telephone exchanges and the population of the related data tables, and real-time decision making. ITT's strategy for expert systems has focused on their immediate use within the corporation while ensuring adequate research and development to provide the techniques that will be needed for future applications. New techniques will emerge from investigations into architectures for diagnostic systems and VLSI systems, and into how multiple inference mechanisms can be integrated into a set of knowledge engineering tools. The corporation has not only benefited from implementation of a number of expert systems, but has also gained considerable experience in the technology and established a strong technology base. Present experience indicates that the range of applications will increase in the future, bringing further benefits.

Development of an Expert System

Development of an expert system takes place in a number of stages. This process, which is known as knowledge engineering, covers two aspects. One is knowledge acquisition, that is, capturing the experts' knowledge and storing it in the knowledge base in a usable form. The other is knowledge processing, which is the application of that knowledge to solving a problem.

Knowledge Acquisition

Knowledge acquisition is a major limitation on the widespread use of expert systems since it is a skilled and time consuming task. Two principal techniques are used to acquire an expert's knowledge: handcrafting and induction.

Handcrafting, which defines the rules directly, is based on interviews between the knowledge engineer and the experts to identify the domain knowledge. The output is a set of rules (or an alternative representation) that encompasses the experts' knowledge.

Induction uses computer-based tools that induce rules from examples supplied by domain experts. The output is a set of rules that can be reviewed and amended. Alternatively the examples could be amended and the induction repeated.

The choice of technique is determined by how knowledge is represented in the application area. Handcrafting is more appropriate when knowledge is represented as a set of rulebooks, or as a set of engineering and manufacturing standards. However, induction is more appropriate when knowledge is represented as a set of examples of the skills practised by engineers in the domain.

If knowledge exists in one of these forms, knowledge acquisition has a good foundation. However, if knowledge does not exist in either form, it will take considerably longer to develop an application.

Knowledge Processing

A number of technologies are available for building expert systems, including general and special purpose languages, applications shells, and toolkits. Languages such as LISP and its dialects fall into the first category. Their drawback is that the knowledge engineer has to develop the required expert systems mechanisms as none are provided by the language. This is a skilled and lengthy activity.

Special purpose languages include OPS5, OPS83, and Prolog, all of which incorporate techniques that are specific to expert systems. The OPS family has been used in industry generally to build expert systems for particular applications. As long as these techniques are appropriate to the application there are few problems. However, if the application requires different techniques or greater expressive power for knowledge representation, then the language will have to be significantly enhanced.

Applications shells, such as EX-TRAN, Sage, and Emycin, provide a higher level view of the techniques available for building an expert system and hence further simplify the knowledge engineer's task.

Expert systems toolkits include Knowledgecraft, ART, and ESSAI. These toolsets incorporate components that are used in most expert systems, such as knowledge acquisition tools, and various knowledge representation and inference mechanisms. They provide a common set of components in the form of building blocks which can be used to acquire and process knowledge in a wide range of applications.

The trend is towards greater generality and flexibility by offering the knowledge engineer a variety of techniques that enable applications to be developed within a common framework. This approach reduces the specialist knowledge needed to build expert systems, enabling knowledge engineers to concentrate on applying the techniques rather than on developing them.

Resources Needed for Development

The resources required depend on the complexity of the domain and the goals set for the expert system, as well as on the chosen technology. A project team will consist of domain experts (although they need not be full time), knowledge engineers, and technology support. The knowledge engineers form the link between the experts and the expert system; they are akin to systems engineers, their task being to acquire knowledge relevant to the domain and populate the knowledge base. Technology support is needed to provide advice and guidance on using the technology, and to enhance it should this prove necessary.

Evaluation of Performance

Once an expert system has been developed it must be evaluated to validate its performance against known and previously solved problems. Evaluation should involve domain experts who can critique the performance of the system, pointing out omissions in the knowledge base and suggesting improvements to the user interface. This stage provides a review point for further development.

Expert systems develop incrementally, that is, the knowledge base grows as more knowledge becomes available. Throughout this process of enhancement, the expert system is both usable and useful.

Future Expert Systems

If it is to be possible to build expert systems that can solve the whole range of problems in a domain, then such systems need to integrate and be able to reason with a wide variety of knowledge about the problem area. Fault diagnosis is an example. Most present diagnostic expert systems use empirical knowledge bases, that is, knowledge based on experience. This has the advantage of computational efficiency and is often the only solution in situations where causal knowledge (knowledge of the effect based on an underlying model of the problem) is unavailable, such as in medical diagnosis. Empirically based expert systems are satisfactory where experience covers the full range of problems encountered, but are inadequate for novel problems. In this case the typical reaction of the system is to give up and call for the expert. Empirical knowledge bases are also limited if a detailed explanation is required of the problem solving method, since it can only be given in terms of empirical associations rather than in terms of the underlying cause.

Experts use empirical knowledge for problem solving because it is both cognitively easier and faster than using causal knowledge (knowledge of cause and effect) which reasons from first principles. However, when experts are faced with novel problems they do not give up, but use their knowledge of structure, behavior, and cause to arrive at a solution. Hence future expert systems will combine both forms of behavior.

The issues raised for research and development in expert systems are fundamental and include the following.

Techniques to Represent Knowledge

An expert system needs to deal with multiple models of the problem area: knowledge of the structure or topology of the area such as the physical connectivity of components in a VLSI circuit, or the units in a computer system; knowledge of function and behavior, such as the electrical characteristics of the components in a circuit and their behavior under simulation; knowledge of the design and the constraints observed by the designer, such as the reasons behind using a particular connectivity; knowledge of the physical laws operating and governing behavior, such as Ohm's Law; knowledge of the interpretation of behavior which may involve knowledge of problem solving skills such as troubleshooting and fault finding; and knowledge of previous cases, that is, empirical knowledge.

These models are further complicated by the need to represent time and the ways in which behavior might vary over time.

There is a need to develop techniques to represent these models; there may also be a need to extend the representations that are available. In addition it will be necessary to consider the problems associated with large knowledge bases and distributed knowledge bases.

Techniques to Process Knowledge

As future expert systems will use both empirical and causal reasoning, there is a need for techniques that can switch between these modes using the different models of knowledge available and in response to the user's input. There may be multiple sources of data or evidence which may interact with the different models to provide partial solutions which together can contribute to an overall solution.

The inference mechanisms, search techniques, and methods for dealing with uncertain evidence depend on the problem and cannot be expected to be homogenous for the knowledge base as a whole. Techniques need to be developed that reflect this mix of inference mechanisms, which might include mechanisms that can be invoked by the knowledge engineer or by the system as part of the problem solving process.

User Shares Initiative

An expert system needs to provide ways in which the initiative for problem solving can be shared with the user rather than being dictated by the system as in most present expert systems. This includes enabling the user to present input unsolicited and to share in the decision making process. Input could take place at critical points in the process, enabling the user to suggest the optimal path to be followed when the system is faced with a choice of paths.

The expert system must provide explanations to the user in terms of the underlying physical cause. Any explanations should take account of the user's level of knowledge of the domain, which can be learned by the system through the user interface.

Validation and Maintenance of Knowledge

Present knowledge bases are still modest, ranging from 200 to around 4,000 rules, but with an expected growth of up to many thousands of rules. Development of knowledge bases is a skilled task, while knowledge engineering is in its infancy. Consequently, rules may be generated that give rise to inconsistency or incompleteness in the knowledge base, resulting in errors, or at least a less than optimal solution, in any conclusion reached by the operational system. Inconsistencies are difficult to detect by a manual review with limited tools support, and in general it is not possible to establish completeness.

Any validation process should therefore consider both the consistency and completeness of the knowledge base. Consistency covers rules that conflict (i.e. rules with mutually exclusive decision parts that can be satisfied at the same time) and rules that are redundant (i.e. with decision parts that have the same effect). A further complication is that inconsistency may be related to the control strategy; thus rules which are consistent under a breadth-first search scheme might be inconsistent when a depth-first scheme is used. Completeness ensures that rules exist to provide a solution for all possible situations.

It may prove possible to develop techniques that support the automatic reorganization and refinement of the knowledge base over time and that can learn from experience in operation.

Learning and Knowledge Acquisition

Techniques need to be developed that reduce the time taken for knowledge acquisition. Empirical models could possibly be derived automatically, perhaps by some inductive process, from the causal models of the problem area. This still leaves the problem of knowledge acquisition for causal models. Research into the process of learning may lead to suitable techniques being developed.

The Search for New Architectures

So far the article has only considered the challenges facing the software designers. In parallel there is an equal, if not greater, challenge facing hardware designers in the search for new architectures that can exploit the growing availability of knowledge systems. Present generation computers use Von Neumann style processing based on the sequential execution of program instructions. This style, of course, is reflected in the nature of conventional programming. What is needed is processing based on the parallel execution of knowledge, each piece of which is independent yet may affect the solution of the problem.

Systems are becoming increasingly complex as technology makes it possible to provide more and better features for business and industry. This complexity can be viewed in terms of the growth in the sizes of programs that have been developed and of the density of transistors on a chip. The next generation systems, already under development, will offer even greater capabilities and, for the first time, a means of managing this complexity using intelligent systems based on artificial intelligence. Intelligent systems will emerge from this combination of hardware and software and the various enabling technologies.

Truly Intelligent Systems

Expert systems technology has already advanced to the point at which it offers innovative and cost-effective solutions to a wide range of industrial problems. Over the next decade, further improvements in methodologies, new hardware architectures, and more powerful software will result in expert systems being introduced into almost all areas where expertise is routinely applied.

Truly intelligent systems, that is, systems that enable us to interact with them at the same level as human interaction, will provide a gateway to knowledge much as formal education has done up to the present day. The key difference is that intelligent systems will be constantly available sources of knowledge with the ability to adapt and filter the flow of knowledge so as to meet the needs of individuals throughout their lives.

Ω

Experiments in Artificial Intelligence, and Problem Solving Programs

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"The harder it is for a human to solve a problem, such as proving a complex theorem of mathematics, the harder it is to write a program to do something similar."

This article is based on the contents pages and Chapter 3, *Problem-Solving Programs*, of the book *Experiments in Artificial Intelligence for Microcomputers* by John Krutch, Second Edition, 1986. The book is published by Howard W. Sams & Co., 4300 West 62nd St., Indianapolis, IN 46268, 164 pp, $14.95; this excerpt is reprinted with permission, which is gratefully acknowledged. This is an excellent and interesting book, with good experiments, giving programs written in BASIC; the programs are not quoted here since we do not print equations nor detailed programming, but rather try to present material which is understandable to the non-technical reader.

Contents

Problem-Solving Programs

Computers have been used to solve problems in business, science, and industry almost since the first one rolled off the assembly line. But the problem-solving ability of computers to date, while impressive, is not as wide ranging as it could be. Programs can be written to solve complicated problems in such fields as mathematical analysis, statistics, navigation, and celestial mechanics, but the area in which any one program can operate must be narrowly defined by the programmer. Furthermore, as might be expected, the harder it is for a human to solve a problem, such as proving a complex theorem of mathematics, the harder it is to write a program to do something similar.

Many researchers, therefore, are interested in making computers solve a wider range of more challenging problems. We will examine two programs they have developed: Thomas G. Evans's geometric analogy program and Newell, Shaw, and Simon's General Problem Solver (GPS). Then we will look at a problem-solving program written in BASIC. The program is called TF, and the problem it attempts to solve is an interesting one: the prediction of human behavior.

The Geometric Analogy Program

Most IQ tests are divided into three parts. One part tests mathematical abilities; one part tests verbal abilities; the remaining part tests the ability to visualize and find analogies among geometric figures.

A geometric analogy program written by Thomas G. Evans in 1963 solves the sort of geometric analogy problems commonly found in IQ tests, and does a good job of it, too. The program operates in a simple, straightforward way; it reduces the task of solving geometric analogy problems to a mechanical process. A problem of this type is shown in figure 3-1. Let's see how the Evans program would attempt to solve it.

There are seven figures in figure 3-1; they are labeled 1, 2, 3, a, b, c, and d. The problem can be stated thus: 1 is to 2 as 3 is to a, b, c, or d?

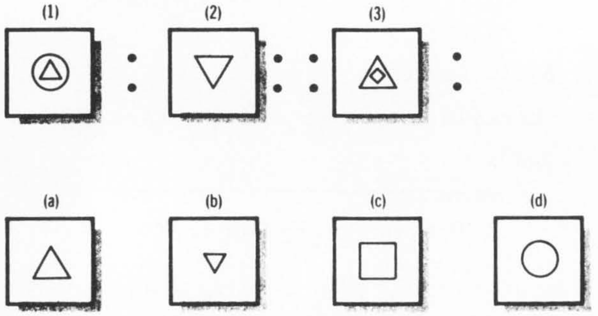

Fig. 3-1 Geometric analogy problem

Comparison of Transformations

If we stop to consider, we will see that the solution to this problem revolves around the comparison of transformations. To understand what is meant by this, note that five pairs of figures are involved. These pairs are:

1:2
3:a
3:b
3:c
3:d

Each pair of figures represents a transformation. For example, the pair 1:2 represents a figure, 1, that has been transformed into figure 2. The program must determine what the transformation between 1 and 2 is, and decide which of the pairs 3:a, 3:b, 3:c, or 3:d represents the same transformation (or most nearly the same).

The first thing the program must do is build a representation of the important positional features of each of the geometric figures. If we let p stand for a circle, q for an equilateral triangle, and r for a square, the representation that is built for each of the figures in figure 3-1 would look similar to:

```
1 = q inside p
2 = q
3 = r inside q
a = q
b = q
c = r
d = p
```

Notice that the only positional relationship in this list is inside. Other relationships that could develop (depending on the figure) are, for example, above and to the left of.

After the program generates the representations, it checks each pair of figures to see how the figure on the right side of the transformation has been altered from the figure on the left side. The result is:

```
1:2 p deleted
    q scale change x 2
    q rotated 60 degrees
3:a r deleted
3:b q scale change x ½
    q rotated 60 degrees
    r deleted
3:c q deleted
    r scale change x 2
    r rotated 45 degrees
3:d q deleted
    r deleted
```

The final step is to compare the transformations for pairs 3:a, 3:b, 3:c, and 3:d with the transformations for pair 1:2. The transformation that most nearly matches the 1:2 transformation is the answer. In this example, the program would choose c.

Imitating Human Thought Processes

If you were attempting to solve this problem, you might use many of the same methods that were employed by the program. You would probably look at the 1:2 pair, determine how 1 had been transformed to produce 2, and then try to find a pair from the 3:a, 3:b, 3:c, and 3:d pairs that involves the same transformation. This is exactly what Evans's program does.

This implies that Evans used his own thought processes as a model when writing the program. Although this technique succeeds admirably here, imitating human thought processes isn't always the best way to perform some "intelligent" procedure and, in fact, may be a grossly inefficient way of doing things, like counting on your fingers instead of using a calculator. Perhaps it would even be possible to improve the Evans program if an algorithm that wasn't based on human thought processes was used. But it would be more difficult to find and incorporate into a program a completely new way of performing some task rather than making use of an algorithm which is seemingly built into our brains.

The General Problem Solver

If the geometric analogy program makes implicit use of human thought processes as part of its problem-solving strategy, the General Problem Solver (GPS) does so quite explicity. In fact, it embodies psychological theories of human problem-solving. The geometric analogy program can operate on only one class of problems. The General Problem Solver, as its name implies, can solve a much wider range of problems, though this range is not limitless.

GPS uses two vital categories of data called states and operators. To understand what is meant by states and operators, let's look at an example. Suppose you get in your car and turn the starter. The car doesn't start. You make several attempts to crank it up, but it refuses to start. You have a problem.

Defining the Initial State and the Goal State

The problem can be defined in terms of states. State as we are using the term may be considered an abbreviation for state of affairs. The problem has an initial state and a goal state. The initial state is the beginning situation of the problem: the car won't start. The goal state is the situation you want to reach: the car's engine turning properly. This is depicted graphically in figure 3-2.

Inspecting figure 3-2, we can see that the goal state contains something that is not in the initial state; this thing is called the difference between the two states. The difference between the initial state of car inoperative and the goal state of car operative could be expressed as, simply, engine turning. To get from the initial state to the goal state, the difference between the two states must be reduced to zero.

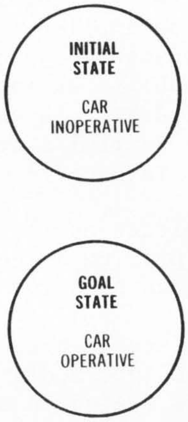

Fig. 3-2 **A problem expressed in terms of states**

Now, back to the car. You get out, open the hood, and peer at the engine. You detect a strong odor of gasoline, and realize that the engine is flooded. To get the car started you need to press the accelerator to the floor and hold it there as you turn the starter. (This sweeps excess gasoline out of the carburetor by causing the choke and throttle valves to open wide.)

Developing an Operator and an Intermediate State

You have just developed an operator. An operator is a rule that, when applied to state X, will transform state X into state Y. An operator is represented graphically by an arrow, as shown in figure 3-3.

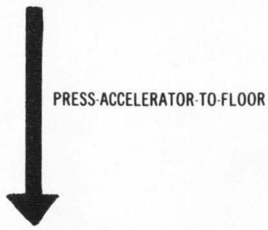

Fig. 3-3 **An operator**

Your object is to reduce the difference between the initial state and the goal state to zero. The initial state is car inoperative, the goal state is car operative, and the difference between the initial state and the goal state is engine turning. So all you have to do, apparently, to reduce the difference between the two states to zero (thereby transforming the initial state into the goal state) is apply the press-accelerator-to-floor operator to the initial state.

However, the press-accelerator-to-floor operator cannot be applied to the initial state. Why? Because you are outside your car. So you establish an intermediate state, which we'll call driver in car, that can be reached from the initial state by means of the operator get-into-car.

Now all the pieces of the puzzle are assembled and the problem of getting your car started is ready to be solved:

1. Find the difference between the initial state and the intermediate state. The difference is seated in car.

2. Reduce the difference between the initial state and the intermediate state to zero by applying the proper operator, which is get-into-car, to the initial state. At this point you have arrived at the intermediate state.

3. Find the difference between the intermediate state and the goal state. This difference is engine turning.

4. Reduce the difference between the intermediate state and the goal state to zero by applying the proper operator, which is press-accelerator-to-floor.

You have reached the goal state; the problem is solved. The entire process is summarized in figure 3-4.

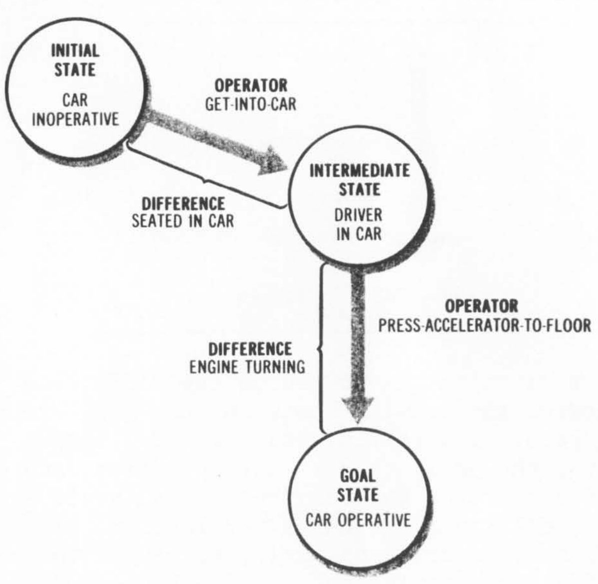

Fig. 3-4 Solution to the problem of starting the car

The preceding account is not meant to imply, of course, that a person is aware of going through all of these steps while trying to solve the problem of getting a flooded engine started or any other problem. But, according to at least one theory of human problem-solving, this is a fair representation of the internal processes that could take place when you are engaged in solving a problem, even though you are not aware of these processes without a great deal of reflection.

Finding Solutions Much the Same As We Do

The General Problem Solver finds solutions to problems in much the same way as we found a solution to the problem of starting the car. When presented with a task to solve, it first finds the difference between the initial state and the goal state. Then it tries to apply an operator that will reduce the difference between the two states to zero. If it cannot find an operator in its repertoire that will do this, GPS establishes as many intermediate states as needed, finds the difference between one intermediate state and the next, and uses the appropriate operator -- if available -- to reduce the difference between states until the goal state is reached.

It is important to note that GPS cannot devise operators by itself out of nothing. Operators (as well as a host of other material, including a concise statement of the problem itself) must be carefully coded into GPS by a programmer. But it is only fair to point out that humans have the same limitation; in one way or another we must be given most or all of the operators that we use in the process of solving problems. If you were trying to start a flooded engine, you wouldn't know that press-accelerator-to-floor was a valid operator unless you had obtained this information from a mechanic or another source. The operator might perhaps be deduced from a general knowledge of automobile engines, but that deduction would in turn be based on data that must have come from outside.

GPS can solve a wide variety of tasks. It is one unified program -- not a collection of smaller programs to perform specialized tasks. Yet it can do simple calculus problems, prove theorems of logic, and parse (analyze the syntactic structure of) English sentences. Given any sequence of letters that exhibit a pattern, it can find the next letters in that sequence. GPS can also solve

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Bar Code: A New Data Language

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"Data entry error, typically one character in every 300 characters when keyboarded, can be reduced to one in every three million characters when bar code is used."

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Bird Calls and Bar Code

Five a.m. is too early, my wife complains, to be awakened by the Western tanager and other species that convene outside our bedroom window at this time of year. Less pesticide use in our neighborhood and thicker backyard foliage brings a greater cacophony of bird song each spring.

At the risk of hearing differently from the Audubon Society, I propose that the rhythms of bird song convey short but important blocks of information in a format with interesting parallels to the human medium of bar code.

Like bird calls, bar codes are constructed with just a few data building blocks -- in this case visual patterns of wide and narrow lines and wide and narrow spaces between the lines. Also like bird song, most bar code identifies the beginning and ending of each message unit.

Profitable Computer Input

But unlike bird calls, bar code communication is less than 100 million years old. These parallel black stripes first became public on items such as soft drink cans and potato chip packages in the early 1970s. They are now dramatically changing computer input in areas ranging from labels for microfiched medical record charts and engineering drawings to capturing time and finish for road running events. For many data applications, bar code makes the difference between a profitable system and one that "doesn't fly."

And bar code is a stunningly accurate way of capturing data. Data entry error, typically one character in every 300 characters when keyboarded, can be reduced to one in every three million characters when bar code is used.

Inefficient Keyboard Input

To understand the information niche bar code has rapidly attained, consider the inefficiency of keyboard input and the inadequacy of alphanumeric symbols for digital data capture. The typewriter keyboard was invented in 1876. Common sense told businessmen that the typewriter idea was a toy that would "never" replace the clerk's longhand in formal record keeping or correspondence.

The standard typewriter key layout, sometimes called the "qwerty" keyboard (after the first six characters in the second row), was designed to slow down typists' input so that typebars would not collide. A more recent system, the Dvorak keyboard, provided faster data input but never caught on with typists who had been reared on the qwerty system.

In the era of computers, manual keyboard input quickly became a bottleneck of high costs and high error rates. Records managers often rejected digital storage in favor of microfilm and microfiche largely because of the cost of keyboard input.

While computer processors advanced from the vacuum tube to the integrated circuit, while output print advanced from leaded type bars to laser printers, input stagnated with the qwerty keyboard, circa 1876. For data applications involving repetitive typing or the typing of numeric information, manual keyboard input meant high error rates as well as high cost.

Optics Systems Can't Read Human Text

A second major factor setting the stage for bar code is the difficulty our alphanumeric characters pose for digital optics systems. Recent information theory research has debunked the myth that information can be regarded as an entity carried by a signal. Instead, information is defined as a relationship between an input and a receiving device. Hence a book contains no information for someone who can't read. (Those interested in the interconnected fields of information theory and physics, brain science, and other disciplines are directed to the works of David Bohm and Karl Pribram.)

Human symbols culminating in our fonts of alphanumeric characters evolved parallel with the human visual processing system, just as bird song co-evolved with the bird auditory system. Our brain recognizes these characters and numbers, yet overlooks the exact details of their shapes.

Early attempts at devising machine optics to "read" human text failed, partly because character font sets, or templates, used by these "readers" did not exactly match the text input. Small variations in character shape, variations in ribbon inking and thickness, and variations in print impact confused these optical character recognition machines (OCR) and resulted in high substitution error.

OCR has now achieved market acceptance in specialized areas, as with the MICR encoding that appears on the bottom of checks. But for the most part the human text system, based on analog images, parallel processing, and hologram-like memory, works poorly as input for ordinary computers, which feature digital image processing and linear memory.

Humans Can't Easily Read Bar Code

Bar code symbols, on the other hand, were designed to be effectively read by electronic optical systems. It follows that bar codes are not easily read by humans.

As a test, try learning a bar code symbology (bar code schemes are called symbologies) and then reading a few pages of text that have been printed out in that bar code symbology. While the task is not impossible for human vision and processing, it is a vastly more difficult task than learning a new natural language expressed in analog symbols. Society would look askance at someone who read bar code instead of normal text -- it might even put them behind bars!

The Universal Product Code

There are currently four major bar code systems, the most familiar of which is the Universal Product Code, or UPC. UPC has been endorsed by the principal retail associations, led by the grocery industry, and the symbol can now be found on products ranging from grocery items to record album jackets and magazine covers.

Like most bar code varieties, the UPC code is constructed out of narrow and wide bars and narrow and wide spaces. In the UPC system, a product is assigned a unique 10 digit number which indicates the manufacturer, the product, and the volume of the package. When this number is read via the bar code label at the checkout stand, the price and the name of the product are automatically transmitted to the correct cash register.

Code 39

An alternative bar code format that has achieved wide acceptance is Code 39. Compared to standard UPC code, Code 39 can handle alphabetic information as well as numeric information. Bar codes in this format are allowed to be much larger than the 10 digit UPC code -- the maximum number of characters in Code 39 is limited only by the device that reads the bar code.

Unlike some other bar code varieties, Code 39 can be printed in high, medium, or low density pattern size, with the density chosen according to space constrictions and readability requirements. Code 39 has become a favored format for document applications. Transaction documents, time and attendance records, medical records, and court records, to name a few, are being routinely tracked with bar coded labels (placed on either the document itself or on the document file) using Code 39.

How accurate is Code 39? A U.S. Department of Defense test scanned 563,243 labels (which had been printed by various means including dot-matrix printers). The study reported four substitution errors. Since labels averaged 24 characters in length, over 3,000,000 characters were correctly read for each substitution error.

Other Symbologies

Out of dozens of actual and proposed bar code symbologies, two other important types are interleaved 2-of-5, widely used in the automobile and paper products industries, and Codabar, which is popular for library circulation systems and parcel tracking systems. Both Interleaved 2-of-5 and Codabar are limited to numeric information (although Codabar does include the $-:/.+ symbols).

Rapidly becoming known as "the big four" bar code types, Code 39, UPC, Interleaved 2-of-5, and Codabar have advantages stemming from their wide availability. With these codes users can choose from several equipment vendors. Users can also print their own labels, using inexpensive programs that work on many dot-matrix and laser printers.

Be aware that pre-printed bar code labels have better data integrity than either dot-matrix or laser generated labels. The expense of custom pre-printed labels can be avoided in some applications, such as document file applications, by using off-the-shelf sequential numbered labels on sheet or roll stock.

"Reading" Bar Codes

All bar codes are read by passing a small spot of light across the bar code symbol. The scanning action must begin in the white area before the bar code and end in the white area beyond the bar code. In designing a bar code label it is a common mistake to leave too little blank space, called a quiet zone, before and after the stripe pattern.

Bar code scanners (also called readers) are divided into contact types, which use a pen shaped light wand to move across the label surface, and non-contact types which use a laser or other optical beam to read the bar code without actually touching it. Contact wands are generally lighter and less expensive than non-contact scanners. Although technique is more important with contact wands, anyone can become adept with a few minutes practice.

Non-contact scanners will effectively read soft cellophane packaging and other irregular surfaces that pose difficulty for contact wands. They have the added advantage of being non-destructive to bar code labels that must be read repeatedly yet have not been protected by a clear laminate. Specialized applications, such as reading a video tape label through its translucent storage box, call for non-contact scanners.

Translating Bar Codes

The quality of a bar code reader is affected by the quality of its input optics and the accuracy of its decoding algorithm. The decoding algorithm, the program "heart" of the decoder, translates the bar code information into an ASCII data stream that the host computer can recognize. Although many bar code readers look alike and claim to do the same thing, a superior bar code decoder program varies from an inferior decoder as much as a bottle of fine wine varies from a jar of vinegar.

Decoders should translate most bar codes on the first pass of the scanner (called the first read rate or FRR) and almost all bar codes on the second attempt (called the second read rate or SRR). In addition, the best bar code decoders don't sacrifice accuracy gained through error checking routines in order to achieve high FRR and SRR.

Many bar code readers connect via a computer's RS-232C serial data port. Others communicate through a "keyboard wedge" design that allows the bar code reader to be plugged in between the keyboard and the computer. A computer (or terminal) regards keyboard wedge bar code input as though it were typed information -- this insures that no software changes are required for applications software when using bar code.

Using Bar Codes in Document Systems

Document systems now using bar code include court records, medical and insurance records, and shipping records and accounting records. In such applications bar code provides a logical bridge between information being generated or stored (the source document or the microform) and information being tabulated or analyzed (the computer program).

As an example of a document system, consider the airbill tracking system used by the Federal Express corporation. In delivering parcels to over 300 cities in the U.S. and Canada, Federal Express determined that a bar code label on the airbill (bill of lading) provided a fast and accurate means to track shipments. Today, Federal Express uses both battery operated portable bar code readers and fixed station bar code readers to log airbills throughout the system.

In choosing a bar code symbol, Federal Express faced the following problem: Airbills needed to be printed on five-part carbon forms with the sequential 11 digit bar code stamped on the first ply. Since the bar code image would be inherently less precise on the lower plys, a symbology was needed that would tolerate this loss of resolution. Code 39 was ruled out -- the narrow elements were too closely spaced. Codabar was chosen instead, because it offered relatively wide intercharacter spacing.

Hughes Integrated Classification System

Another innovative use of bar code is found in the HICLASS (Hughes Integrated Classification System) documentation system developed by the Hughes Aircraft Company Electro-Optical and Data Systems Group in El Segundo, California.

In this application, a Percon bar code reader and a foot switch are interfaced to Tektronix graphic terminals for assisting workers in circuit board assembly. The system replaces bulky and quickly outdated instruction workbooks.

First, a worker uses the bar code wand to scan a personal identification card and route sheets that contain information on the part to be assembled. The computer terminal displays written instructions and color graphics to describe and illustrate the steps to be taken. The worker uses the foot switch to move from one "page" of instructions to the next, leaving hands free to do the work. The system software monitors progress of the circuit board, giving production supervisors an overview of work in progress.

David Liu, Hughes Technical Head of the Software Engineering and Integration for this project, says that the HICLASS software uses the latest in CAD/CAM (computer-aided design/computer-aided manufacturing) artificial intelligence concepts to develop assembly instructions and to learn from actual production experience. As in other manufacturing environments, such as in selection menus for CAD/CAM drawings and revisions, the use of bar code in the Hughes system provides high data integrity and fast input.

Paperless Systems Not Yet a Reality

More generally, the success of this bar code technology reinforces a general conclusion of the industrial and office automation industries in the 1980s -- don't bury your head in the sand like the ostrich waiting for totally paperless systems. Both paper hard copy and microform facsimile are likely to survive into the foreseeable future.

Given the above, bar code works easily with the current generation of computers and the proven document systems. At this point, in other words: "Why invest in a new computer when the one sitting on your desk can be upgraded to a larger capacity and performance by plugging-in an inexpensive board or installing new software? ... Planning based on anything other than the here and now is shortsighted, regardless of what the future has in store."

Archaeopteryx, a creature that lived 140 million years ago, used the everyday forelimbs and scales of earlier dinosaurs to provide, when modified slightly, an important competitive edge -- flight. Hybrid information systems can also achieve dramatic results by applying "here and now" technologies such as bar code in creative ways.

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Blakeslee – *Continued from page 11*

that several telescopes could not be aimed accurately at one point in the sky, and that the whole idea was tried as early as the 1930s, but it was astronomer Aden Meinel, now at the Jet Propulsion Laboratory and formerly at Arizona, who translated it into the modern MMT.

The MMT is composed of six 1.8-meter f/2 mirrors mounted in a common steel structure that swivels and points all the mirrors at the same object in the sky. The six images are then combined at a common focal point, resulting in the equivalent photon-collecting power of a 4.5-meter reflecting telescope. An optical alignment system keeps each telescope mirror precisely on target.

The MMT's mirrors are each composed of pieces of glass fused together like a honeycomb. A solid 1.8-meter mirror would weigh about 1,350 kilograms; each honeycombed MMT mirror weighs only 550 kilograms. To make it more compact, the telescope uses an altitude-azimuth mount like that of a naval gun. The mounting turns vertically in altitude and horizontally in azimuth. A computer adjusts the telescope's position hundreds of times per minute so that the instrument can follow objects moving in any direction across the night sky. Further, the telescope is open to the night air as is no other large instrument; an entire wall of

(please turn to page 27)

Krutch – *Continued from page 22*

the Tower of Hanoi problem, shown in figure 3-5. In this problem, the "tower" on peg 1 must be transferred to peg 3. Only one ring can be transferred at a time, and no larger ring may be placed on top of a smaller ring.

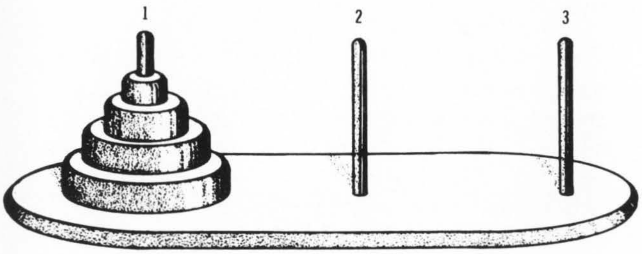

Fig. 3-5 Tower of Hanoi problem

GPS can also find the answer to the well-known Missionaries and Cannibals problem. There are three missionaries and three cannibals on the bank of a river. The missionaries have a boat that can carry one or two people. If at any time the missionaries on either side of the two banks are outnumbered by cannibals, those missionaries are eaten. How can the missionaries get everyone to the opposite bank of the river intact? GPS took sixteen minutes to solve this problem; you might want to solve it and compare your time with that of GPS.

TF: The Predictive Problem-Solving Program

Now we are going to consider a problem-solving program, TF, which is written in BASIC. TF is a predictive game. It tries to predict your next action, based on its observations of your past behavior. You type at random the letter T or the letter F; the program's job is to figure out which letter you are going to type next.

Ordinarily, of course, there is no way of telling what an element of a random sequence will be by examining the previous elements; that's why it's a random sequence. But the assumption was made when writing TF that a person's behavior can never be truly random; no matter how much you try to randomize your responses, there may be patterns in your actions of which you are unaware. So the program stores every response, whether T or F, and searches for patterns in your behavior. If it finds a pattern, and if the pattern occurs again, the program can make a prediction. Figure 3-6 is a screen print of a computer running the TF program.

YOU TYPED:	T
COMPUTER WAS PREDICTING:	T
TOTAL NUMBER OF ENTRIES:	115
NUMBER OF CORRECT PRE- DICTIONS BY THE COMPUTER:	62
PERCENT OF CORRECT PRE- DICTIONS BY THE COMPUTER:	53.9%

GO

Fig. 3-6 TF screen print

Main Program
Following is the TF main program:

(For technical details, please see the book.)

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Blakeslee – *Continued from page 26*

its housing slides away. A cube-shaped building rotates with the telescope as it tracks stars.

The MMT has performed better than anyone expected, according to its director, Fred Chaffee. The mirrors were polished to achieve 0.5-arc-second resolution, but on many nights of each year, when the seeing -- as determined by local atmospheric conditions -- is excellent, he says, the MMT can do even better than that. The MMT's mirrors are now being repolished to 0.2-arc-second tolerances, which will make them the best 1.8-meter mirrors in the world.

There are several reasons beyond polish. First, the mirrors are made of lightweight fused silica -- rather than solid, traditional low-thermal expansion, borosilicate glass -- and so they acclimate very quickly to the cool night air. Second, the observatory is on a rocky pinnacle where the air flows more smoothly over it. Third, and most intriguing to future telescope designers, is that nearly all the heat generated by people and machines around the instrument is flushed away quickly because the telescope is open to the air.

In fact, the impression is growing among astronomers that much of the degradation of seeing conditions at conventional telescopes is self-generated. Astronomers and computers generate heat; big domes trap heat. This small amount of heat creates local distortions in the air and prevents sensitive telescopes from operating at capacity. By putting telescopes in domes, astronomers have confounded themselves.

(Continued in next issue)

Opportunities for Information Systems

– Instalment 7

VISION INFORMATION SYSTEMS

Edmund C. Berkeley, Editor

As I look back on the first remembering years of my life (about age 7), I recollect being fascinated with stones, pebbles, rocks, seen under my feet as I trudged, in the early summer morning down a sharp hill wet with dew, to the spot at a certain crossroads where the bottles of milk were left for my family. It was my regular job each morning to take down the empty bottles and bring back the full ones. The horses would not or could not climb that last steep hill for just one family.

Of course, I picked up the enthralling, wet stones: pink, red, green, black, white. I filled my pockets, and became a nuisance: slow, muddy, excited. Nobody could tell me what kind of stones they were, but eventually my scientific father took me to the Curator of Mineralogy, at the American Museum of Natural History in New York, and he called the stones jasper, ferruginous quartz, bloodstones, and more. I was vindicated!

I did not realize until my first pair of glasses (about age 16) that I was nearsighted, and that this had centered my attention on objects about 4 feet away. Now with glasses, trees suddenly took on clarity, with leaves and twigs, instead of being merely blobs.

Now, I have gathered over 60 years of experience with over 15 pairs of glasses, nowadays costing about $120 a pair. I have seen professions, laws, and regulations multiply into ophthalmologist, optometrist, oculist, optical pharmacist, and so on. I now need good vision at more than five distances: ½ foot, one foot, 2 and ½ feet, 12 feet, and 100 feet or infinity. But I cannot obtain that quality of vision in the market with the ease and simplicity I would like.

It seems that the time is ripe for a computerized, hi-technology, redesign of the instruments for giving excellent visual information to a human being of any age and in any circumstances. Interchangeable frames and lenses is one step. Seeing in the dark using sniperscope principles is another step. Seeing with microscope eyes like a mouse, or with telescope eyes like a hawk, is a third requirement. Why leave these improvements to space technology and animal achievements?

The market for powerful modern visual information systems for human beings is in its infancy.

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Games and Puzzles for Nimble Minds and Computers

Neil Macdonald
Assistant Editor

NUMBLE

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

NUMBLE 8701

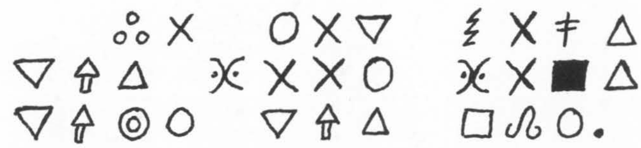
```
          A I M
      *   T H E
        -------
        N N H N
      I T A I
    I A A N
    -----------
  = I T N N D N
```

BXY18 153Z6 76833 25

MAXIMDIDGE

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

MAXIMDIDGE 8701



SOLUTIONS

MAXIMDIDGE 8611: Once is not often; twice is not always.

NUMBLE 8611: There are good cod in the sea.

Ω