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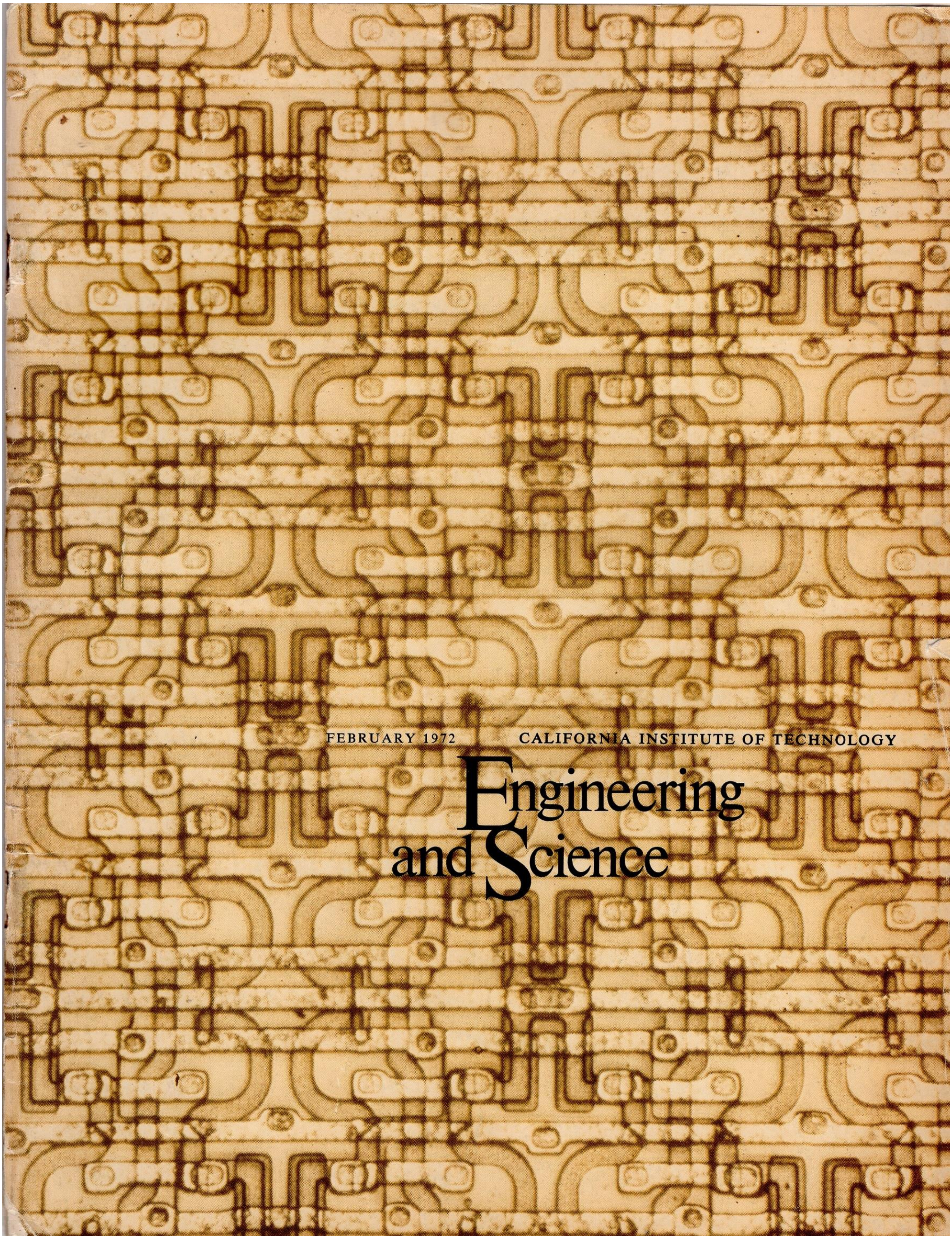
February 1972



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Engineering and Science

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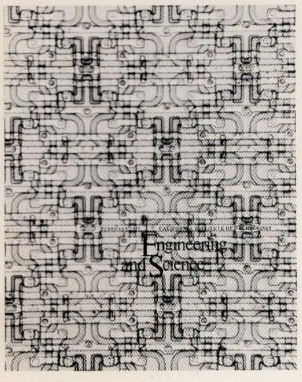

In this issue

Changing Technology

On the cover—one of the first transistorized semiconductor computer memory circuits of any commercial significance—the 1101, manufactured by Intel Corporation and photographed by Caltech's Carver Mead. This three-year-old memory circuit has 256 bits (a bit being the basic unit of information storage capacity) and already belongs to history. Today's more sophisticated versions have up to 4,000 bits—and the end is not in sight. In "Computers That Put the Power Where It Belongs" (page 4) Mead discusses the revolution in microelectronics technology that is not only reducing computer memory size but has the potential to reduce the size of a whole computer while at the same time significantly increasing its power. Mead's goal: computers for people instead of people for computers.

Enigmatic Mars

Ideas about Mars (mistaken and otherwise) have existed as long as men have observed the night skies. But in the last six years, the Mariner spacecraft have contributed the first really precise data about the planet for scientists to examine and interpret—and the result is the clearing away of a few mental roadblocks and many conflicting theories. Many, but not all. Two planetary scientists, Bruce Murray (in "Mars:—Science Fiction to Science" on page 10) and Carl Sagan (in "Is There Life on Earth?" on page 16), agree that information from Mariner 9 will settle some of the dust of disagreement about Mars, but they still disagree about the likelihood of life on the planet.

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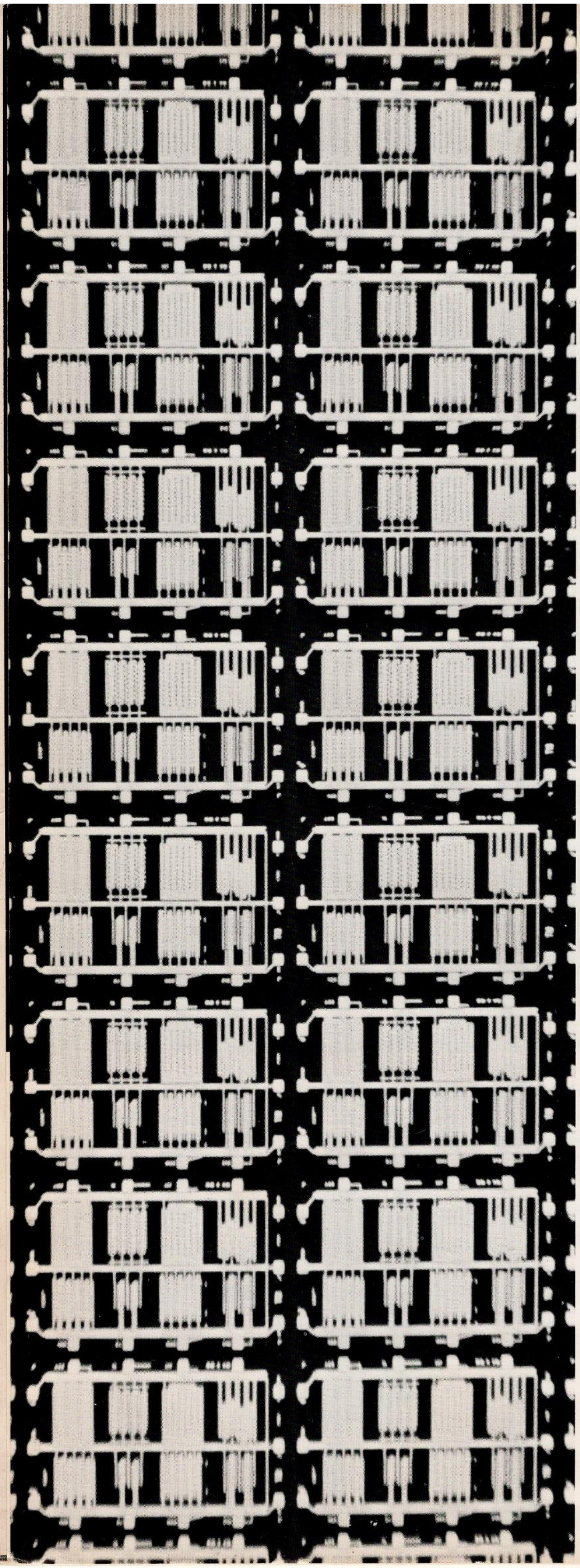


Computers That Put the Power Where It Belongs

In the next ten years almost every facet of our society will be automated to some degree. Whether this will be a change for the good or for the bad will depend on how it is done.

It will be good if it can be done in a humanizing way. If we can get machines to do things that people don't like to do, and if people can feed information into the machines in their own very human ways, this automation will be a constructive and humanizing process. The machines will do the grub work and liberate people to do more creative things.

It will be destructive if people have to learn the language of the machines and deal with them on *their* terms to exist at all—if the human beings have to learn to think like machines or else be discarded by society. The pressures in this direction are already apparent in those levels of society where the computer is heavily used —in business, in science, in engineering, and in manufacturing. Huge general-purpose computers are bent to specific tasks by elaborate programming and software systems (software being the term that describes all the written programs for computer use). But the human being must do most of the bending. He must learn the language of the computer. He must alter his logic to fit the logic of the computer. Even now he can't do certain things because they don't fit the "system." And it is going to get harder to do simpler and simpler jobs as these computers are applied to ordinary, everyday tasks.

This development is well on its way. But it needn't take over society wholly. There is another force in juxtaposition to it that may act to humanize this whole process: the development of powerful, special-purpose electronic machines that will make people more efficient in their everyday jobs, that will put more power at their fingertips.

This is an intermediate step in the miniaturizing of an integrated circuit. The designs in each of the squares represent specific electronic functions that are first plotted on large sheets of film and then reduced photographically to about a tenth of an inch. Designs are etched on silicon wafers by ultraviolet light through this plastic mask. The wafers are then superimposed one on another to produce a complete transistor "chip."

by Carver Mead

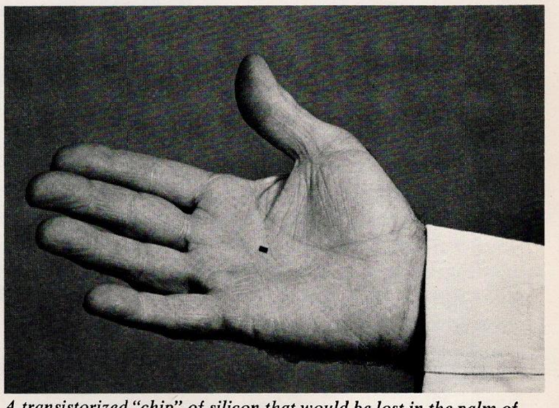
A person doesn't feel dehumanized by such a machine—one that frees him from routine tasks and is under his control. Quite the opposite. This is why people like to drive automobiles, and why they don't feel dehumanized by them. An automobile is a machine that can give you a lot of power, yet it leaves you as much in control as if you were walking. There is no reason why automation of information cannot proceed in the same way.

The next ten years will see a clash between these two forces—two philosophies, really—and society's fate will hang in the balance. The catalyst is the microelectronics technology and its ability to put more and more components into less and less space.

In the past 200 years we have improved our ability to manufacture goods and move people by a factor of 100. But in the last 20 years there has been an increase of 1,000,000 to 10,000,000 in the rate at which we process and retrieve information.

This change was brought about by development of integrated circuit technology, a development that has made individual transistors obsolete—just as transistors made electronic tubes obsolete. The number of transistors that can be placed on a silicon chip has doubled every year since 1960 until it is now possible—using advanced techniques in photolithography—to put 10,000 transistors on a chip that would have held only 1 ten years ago.

There are basically two types of microcircuits: One uses metal oxide semiconductor (MOS) transistors, and the other bipolar (NPN) transistors. (The NPN transistors were developed by William Shockley, '38, and won him the Nobel Prize in 1956.) Both of these transistors are produced in patterns on a silicon chip by a photographic process that reduces the size of each transistor to one ten-thousandth of an inch.



A transistorized "chip" of silicon that would be lost in the palm of your hand can hold as many as 10,000 of a computer's memory circuits. Soon a million circuits may fit on this size chip.

In the near future, using an electron beam for generating the very small patterns required, it will probably be possible to put a million transistors on the same chip that now holds 10,000. This would mean that an entire computer, consisting of a single chip, could be built for about $25. And with this decrease in size comes an increased ability to build more talent into smaller machines.

Up to the present time, what electronic processing machines have been best at is arithmetic. But in the future they will be doing things that aren't arithmetical. They'll be handling all kinds of information, and they will be especially useful in searching out and sorting data. The great strength of the integrated circuit isn't that we can make larger memories, which is what the computer industry has pretty well confined itself to so far. The real advantage is that we can have a tiny computer deep down inside our telephone, or our washing machine, or our car.

This technological revolution has been held up so far by the limited view of what can be done with microelectronics by the computer industry. The fundamental architecture of computers has not changed since 1946, when John von Neumann reinvented the stored-program

We are so attached to the idea of the big number-crunching machine for storing information that we don't yet see the real power of the new microelectronics technology.

Carver Mead works out integrated circuit design with students in his microelectronics class. His students emerge from the class with the ability to design small, powerful user-oriented computers and automated machinery.

computer as conceived by Charles Babbage and others 100 years before, and put the necessary new technology of electronics into it. If you read Von Neumann's instruction set for his machine, you will find that it is basically the same set we have in many machines we use today.

The use being made of microcircuits today can be compared to that of the early days of the electric motor, which was invented at a time when most industries had a big steam engine out in back driving a big shaft the length of the factory. Belts running down from the shaft powered individual machines. The industry had already invested in the pulleys, shafts, belts, and machines; so, from an economic point of view, they could not change the way things were done. Even though it was perfectly clear that the way this innovation should have been used was to put electric motors on each machine, it couldn't be done rapidly. The most that could be done economically was to replace the big steam engine with a big electric motor.

This is the dilemma the computer industry is in now. It has an enormous investment in big machines and big software programs, and the only thing the industry can do right now is to use the new microelectronics as it fits into the existing system.

We are so attached to the idea of the big number-crunching machine for storing information that we don't yet see the real power of the new technology—ability improved by a factor of 10,000 to do the logic where we need the logic done. We have computer power coming out of our ears. What we need is the kind of systems we would like to have in our automobiles, in our telephones, in our typewriters—where people now spend vast amounts of time on the repetitive and mundane operations involved in keeping track of a lot of little things.

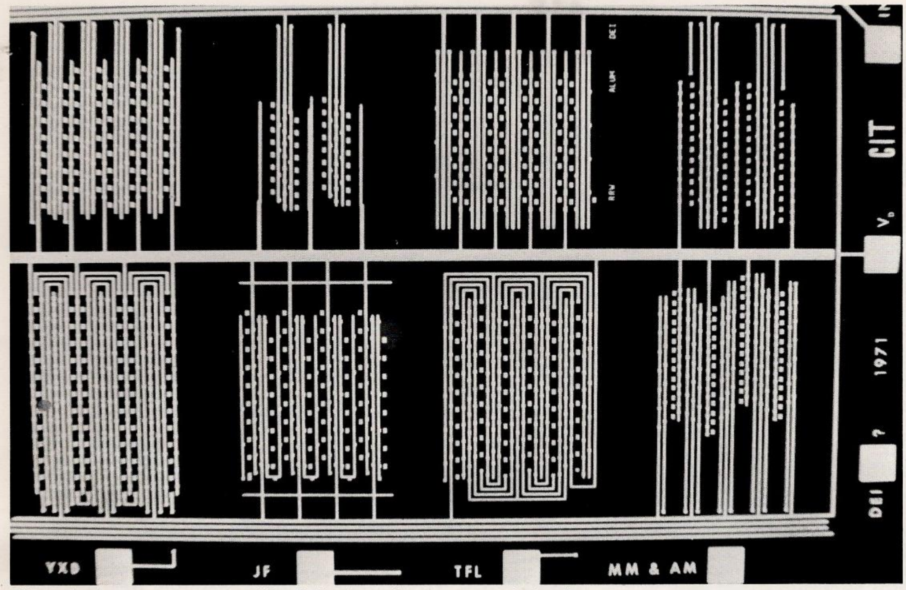
The average man keeping track of his bank account (or even the typical engineer or scientist working on typical problems) very seldom faces huge computational problems; he usually deals with many small calculations. A large general-purpose computer, with the appropriate software, and serving a multitude of users on a time-shared basis, is the present approach to solving his need. Helpful as this may be, a small, extremely powerful calculator is much handier. I am convinced that time-sharing, as such, will gradually disappear as small electronic machines of more and more power become available at lower and lower prices.

Another area of potential development is the special-purpose machine—the self-contained, stand-alone machine having nothing to do with computing—a nurse-medicine machine, a chromosome-microscope machine, an oven-cooking machine. There are hundreds of examples.

Let's look at a few in detail.

In recent years a number of hospital activities have been computerized. One particular set of functions that resist computerization are the duties of the medicine nurse, whose activities during a shift are an object lesson in how to get old fast. She doesn't have time enough on her shift to do a proper job, yet all she has to do is make one mistake and a patient is dead. All her effort is aimed at one simple problem—to translate the doctor's written orders for particular dosages for particular patients into the correct medication in the correct dispenser. And she must do this for 50 to 100 people three to four times a day.

But basically this is a simple problem with a simple answer: Design a system where all she has to do is go to



These designs were conceived by Caltech students as part of the class in microelectronics. After being reduced to a tenth of an inch, each circuit is etched on a silicon wafer. The end product must be an integrated circuit in which transistors, diodes, resistors, capacitors, and interconnectors operate as a single unit.

the medicine room, punch a patient's name into a machine, and wait briefly for the right medicine to pop out.

If this is done with a large general-purpose computer, it requires a broad data-base and extensive software programming. But the performance of such a system can be variable. The probabilities of error are rather high. If something isn't typed in just the right way, if the program isn't just so, the computer will give the nurse three pills instead of one, and the patient may die. Such variable performance is too costly in this situation; the system has to be as close to zero error as possible. A small, powerful, special-purpose computer designed to meet the specific needs of the nurse and her job eliminates most of these error-causing variables. Each hospital floor could have separate local "medicine machines" with the reliability such an operation needs. The more hardware you have —and the less software—the closer you are going to come to that zero error.

If you give the nurse such a system, she doesn't have to be solely a medicine nurse any more. She can do what she was trained to do—care for people. She can pay attention to how they are feeling. The system relieves her of inhuman kinds of activity, of doing the things that machines can do better.

Another example of work now done by big machines that could be done more efficiently by small machines is the chromosomal analysis project at Caltech's Jet Propulsion Laboratory (*E&S*, February 1971). Chromosomes are microscopic threadlike bodies present in every plant and animal cell. They carry genes that determine hereditary characteristics. They occur in pairs running from one to over 100 pairs per cell nucleus, depending on the species. Man, for example, has 24.

At JPL a large general-purpose computer with proper programming and software has been able to scan photomicrographs of chromosomes as they occur in a cell. These are then digitally reconstructed by a computer that determines the pairs by detecting the similar shapes. Using this information, a composite photograph of the chromosomes in pairs can then be prepared for study by geneticists. The present disadvantage of such a system is that only the largest hospitals and institutions can afford it.

A small special-purpose processor built right into the microscope would make such analysis available to any hospital or clinical laboratory. Anyone who does chromosome analysis could have his own. All he would have to do is to stick his sample under the microscope, position it, and push a button. In a minute or so, out would come a photograph. Such an apparatus is not only possible with the use of microelectronics, it wouldn't even be hard to make.

We could go a step further and design a multipurpose microscope adaptable to a number of special-function modules. To do chromosomal analysis would only require plugging in the module marked "chromosomes." Someone else who is doing blood cell counts would have his own module to plug into the same microscope.

With the use of microcircuitry we are putting power where it belongs, in the hands of each individual user. It has nothing to do with computing. All the researcher or technician knows is that he has a microscope that will present a photograph of what he wants, the way he wants it, by his simply pushing a button. He doesn't even have to know data processing is involved. He doesn't need to know there is any electronics in it. All he knows is that he has the world's greatest microscope. We have a user-oriented machine, not a machine-oriented user.

The computer business as structured today is a fantastic anomaly—as a business. We don't normally find businesses that are based on the nature of their technology. Businesses are characterized by the nature of their product. The automobile industry is not called the gear and wheel and pulley industry. It is called the automobile industry. The telephone industry is providing a service that can take information from here and put it there. It doesn't have anything to do with whether there are relays or transistors in the central switching system.

The computer industry, in contrast, is the only one I know that is still characterized by the nature of its technology—digital machinery. It is becoming a very mature industry, and it is inconceivable to me that at this late date it should still be characterized by its technology rather than its market.

The reason for this peculiarity lies in how computers came about. They started with vacuum tubes and were extremely unreliable. They required a covey of technicians fluttering around them to mother them through every problem. They were hard to use because they were implemented with what we now call "machine language." We then had to have people who lived, slept, and breathed this language, turning it into something that was useful.

This concentration of functions requires a big installation. And once the technicians are gathered, it is prohibitively expensive for them not to be at work solving problems. Thus, the big computing center evolved.

Now—after we have developed a relatively reliable machine and a rudimentary language—there are two alternatives. We can build another machine with a language that is more suitable for problems other than computations, or we can write some software that makes the machine with its computational language easier to use for other problems.

It is here that we run into the "frozen-in" phenomenon. It would make more sense to take the first alternative, but the industry is frozen into the second because of the vast

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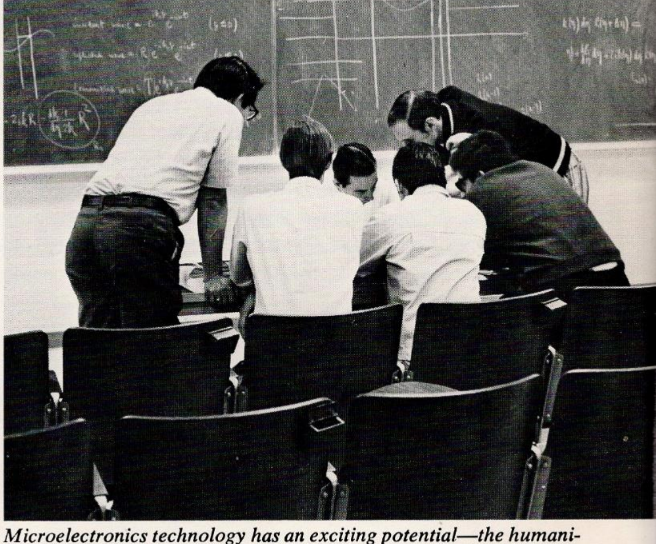
Carver Mead teaches the "little guys" who will build tomorrow's user-oriented machines.

In the view of 37-year-old Carver Mead, professor of electrical engineering, the humanization of computers will come about only through the intercession of the "little guys"—the scientists and engineers who have an intimate and working knowledge of both computers and microelectronics, but who are not a part of either technology.

It will be these men, he believes, who will build the special-function, user-oriented machines that will provide a counterbalance to a computer technology that now demands machine-oriented users.

Mead has already put this philosophy to work in a unique class—EE 281, *Semiconductor Devices*—where about 20 students from a variety of scientific and engineering disciplines receive an intensive introduction to microelectronics and its present and potential applications. Some design rules are developed in the class, and each of the students—few of whom have seen an integrated circuit before—is asked to build one on his own.

A grant from General Electric bought the computer software for Mead's class, and several local firms donate



Microelectronics technology has an exciting potential—the humanization of our automated society. And Carver Mead's class (EE 281) is the place to learn about it.

Do the Mariner 9 results increase the possibility that life exists on Mars? No, says Bruce Murray— but Carl Sagan disagrees (p. 16).

Mars: Science Fiction to Science

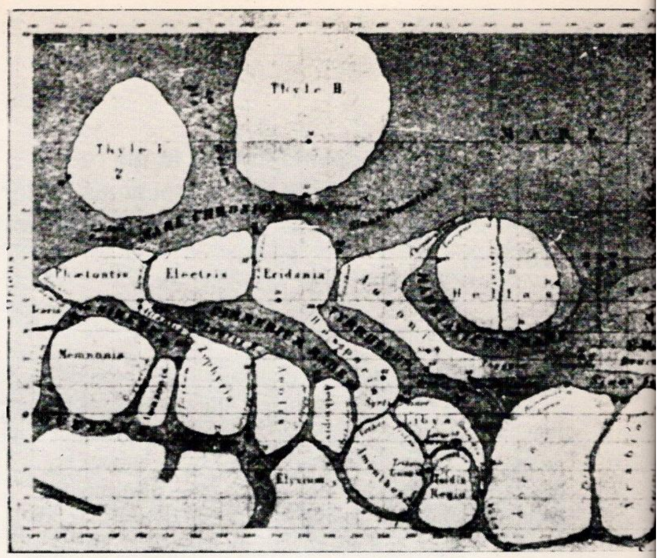
by Bruce Murray

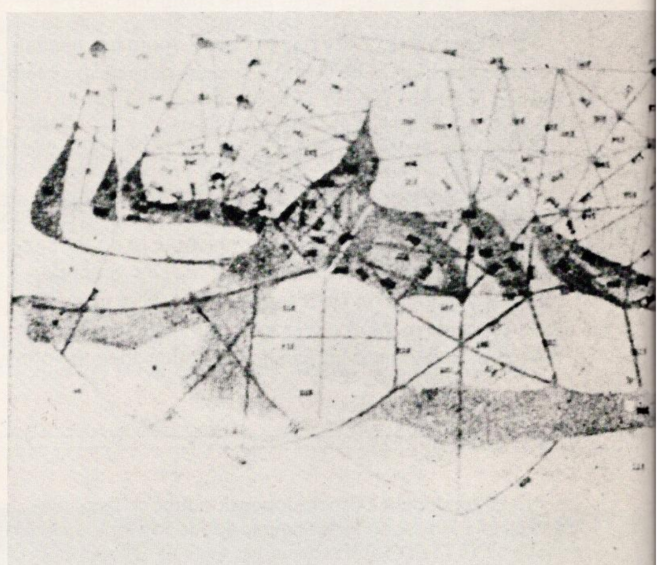
In the last six years Mars has been plucked from the mists of science fiction and scrutinized with the dispassionate eyes of four Mariner spacecraft. As a result, the supposed likeness of Mars to Earth has now nearly vanished. Instead, Mars is now recognized as an independent planetary object, exhibiting on its surface the results of a unique planetary evolution that is still taking place.

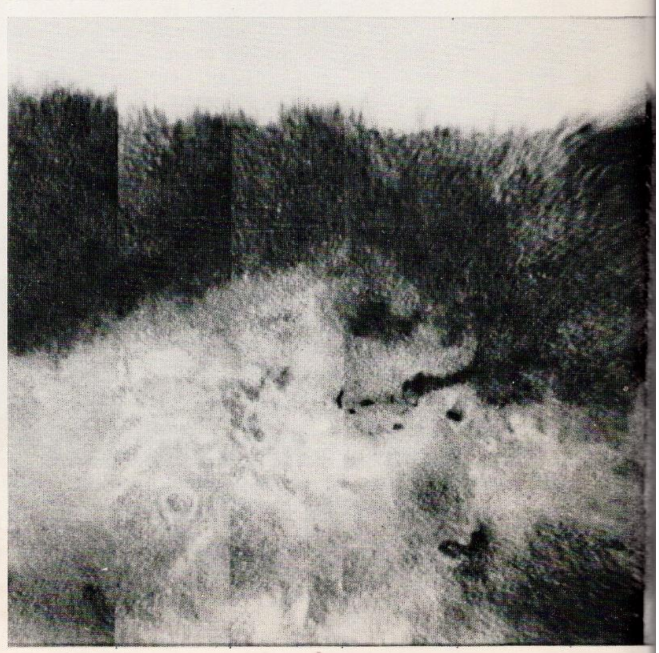
But at the same time Mars is also an interesting sociological study. A look at the history of the observations made of the planet and the conclusions drawn illustrates that scientists, despite all their protestations, are human beings. (It is my feeling that they are perhaps a little *more* human than most people.) They are far from objective about the subjects they study—despite their great attempts to be so—and the study of Mars has been particularly good as an illustration of the difficulty the scientist has in knowing when he has really removed all prejudice from his mind and is dealing only with the observed facts in front of him.

I suggest that we have probably not yet reached that point in regard to Mars.

Throughout recent history, especially from the time of astronomer Percival Lowell in the late 19th century, our observations of Mars have been biased by the belief that the planet was similar to Earth. When we look at a really good, Earth-based telescope photograph of the planet, it is easy to understand why such biases exist. The planet, after all, is not strongly marked. So, if we are really looking for features, we can read almost anything into the the drawings and photographs. Mars varies from a rather dusty orange color to a somewhat darker color that could be taken for green. But there is no true green on the planet at all. There are white polar caps as on Earth. The cap changes in each hemisphere in conjunction with the Martian seasons, just as the Earth's would if viewed from space. Those light and dark markings do change their appearance throughout the Martian year in a sometimes regular, sometimes irregular, pattern. When viewed







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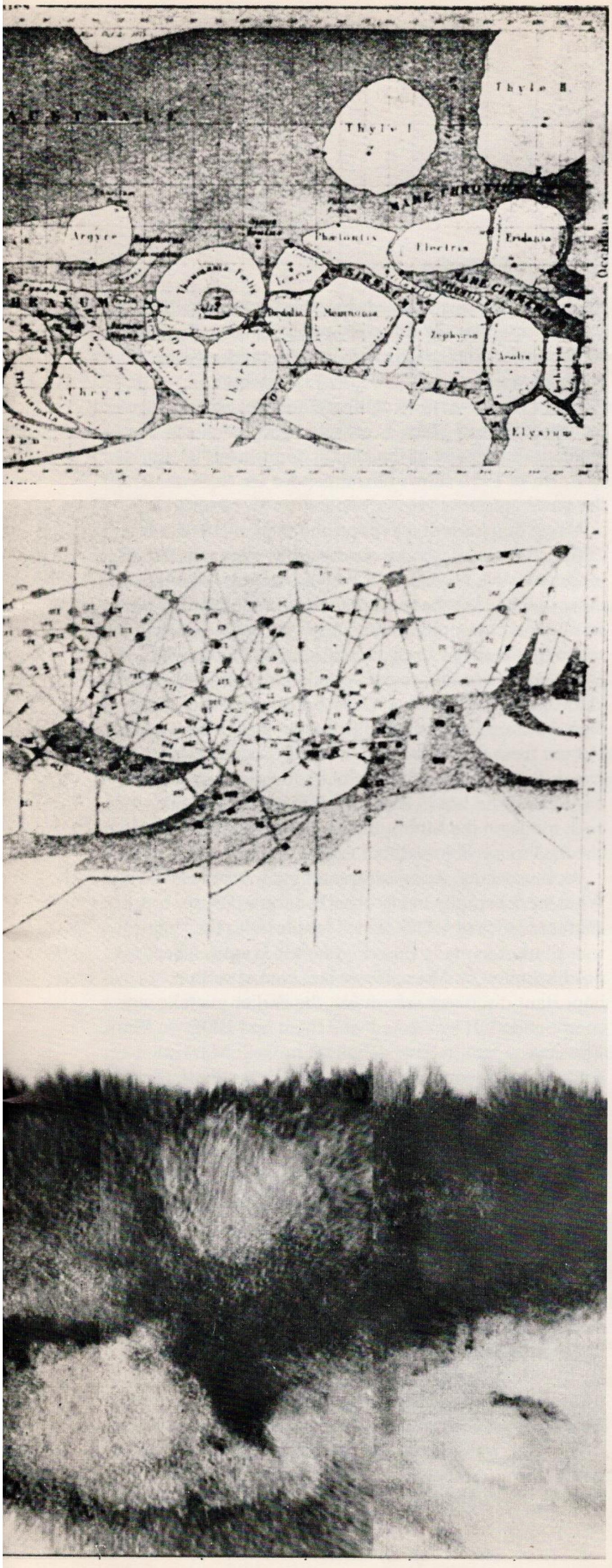


through telescopes at the turn of the century, Mars could easily be assumed to be like Earth—and was.

In addition, by a remarkable coincidence, the planet Mars has the same length day as the Earth, to within 35 minutes; and its axis is offset from the plane of the ecliptic by exactly the same amount, 23 degrees.

Given these similarities, it is not hard to imagine why it has been assumed that Mars is like Earth or how this view colored early scientific opinion. To some extent it is still a legacy from the past. I call it "Lowell's Legacy." For it was he who staked the most—and lost the most—on his belief in the Earth-Mars similarity. In fact, he lost his professional reputation as a scientist.

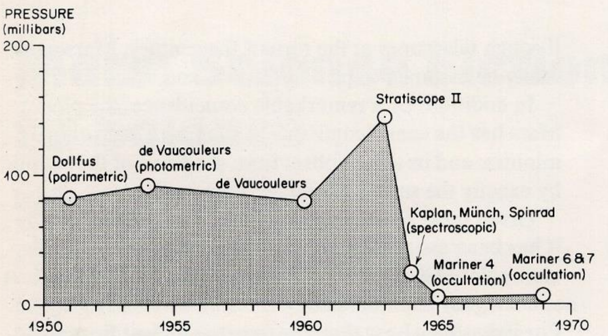
Lowell's classic grandiose book on life on other planets contains a collection of maps done in the period between 1860 and about 1912. Following them in chronological order shows the maps gradually changing in appearance.

One map of Mars drawn by the Italian astronomer Giovanni Schiaparelli in 1877 depicted circular features that show quite accurate observation, but Schiaparelli later attempted to "improve" this map by indicating nice sharp linear features. In the period from 1881 to 1884 the features started getting narrower and more organized. They began to connect, and then finally in 1894, when Lowell came on the scene, they became nice straight lines intersecting at what appear to be nodes of some kind. By 1905 dual canals had appeared in some places on his maps.

This is how the idea of artificial "canals" rather than natural channels or breaks originated. Lowell concluded from his "observations" that the canals intersected at oases. They were, he wrote, canals for transporting water. He believed they were evidence of a dying civilization whose planet, eons ago, was like the Earth. But, being smaller, it lost its atmosphere and most of its water—an idea that was dismissed by most serious scientists at the time. What wasn't dismissed was the idea that plant life might exist there. Rather crude ways of studying the Martian atmosphere existed then, and the results indicated a strong resemblance to the Earth's atmosphere in constituency and pressure.

Lowell's Legacy remained with us even as late as 1969

The features of Mars have not changed drastically in the last 100 years, but astronomers' views have. And not always for the better. Schiaparelli's crude 1877 map (top) is not only more accurate than Lowell's 1894 rendition (center), but even resembles the actual 1969 photomosaic of the same region.



Throughout the 1950's various estimates of the atmospheric pressure on Mars were uniformly an order of magnitude too large— and so did their share to contribute to other erroneous ideas of the planet's similarity to Earth.

(see graph above). In the 1950's it was still believed that plant life of some sort existed on the planet even though a number of techniques had been developed to bring more precision to the study of Mars. Measurements in 1950, 1955, and 1960 cut the estimates of Martian atmospheric pressure down to something like 10 percent of the Earth's at ground level (101.3 millibars). This is roughly equivalent to the air pressure at the top of the Peruvian Andes.

At this pressure—low as it is—many of the conditions present on the Earth might prevail. For example, liquid water could exist on the surface of Mars.

In the early 1960's, however, Guido Münch, professor of astronomy, and two others at the Mt. Wilson Observatory used spectrographic techniques and came up with a figure of about 25 millibars, which is less than 2.5 percent that of Earth's. Finally, in 1965, Mariner 4 yielded a figure of 5 to 8 millibars (about ½ to 1 percent of Earth's pressure). This range was verified by Mariners 6 and 7 in 1969 and by the present Mariner 9. It is obvious now that water cannot exist in the free state on the surface of Mars; there is too great a vacuum. The water evaporates. And therefore the chances of any sort of plant life sufficient to cause surface markings are minimal.

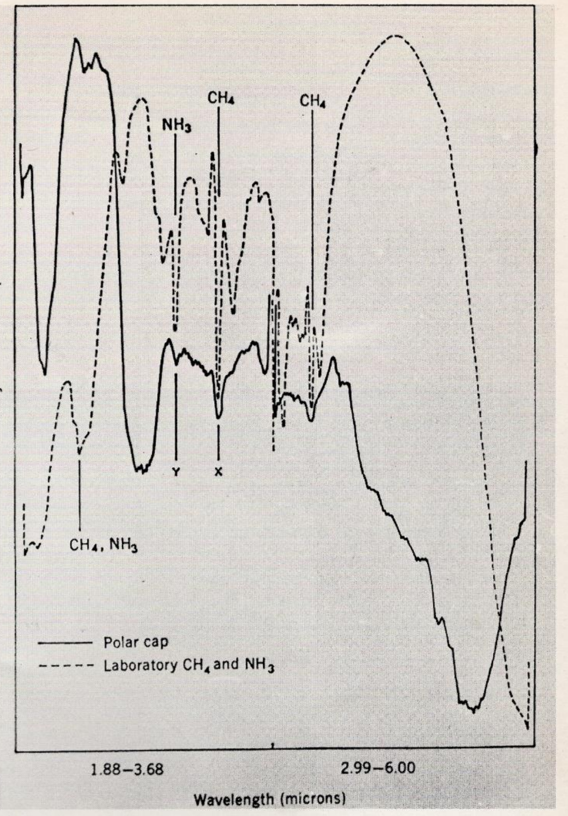
Yet, even as we were getting more precision into our measurements of Mars, Lowell's Legacy persisted. An incident during one of the closest appositions of Mars to Earth in 1956 shows how much we are captives of the past.

Using first a small telescope and then, in 1960, the 200-inch Hale telescope, observations were made of Mars in the invisible wavelengths beyond the red—the infrared —in which plants have characteristic reflections. The compound chlorophyl has an absorption feature in this range that is easy to spot, and absorption features in Mars' spectra in the wavelength region characteristic of chlorophyl were detected. It was concluded that these features were in the spectra from the dark areas on Mars, but not from the light areas. Now, if that were true, it would suggest that there is plant life on Mars in the dark areas and not in the light. If these observations had been made on the Moon, the results would have been checked to see if something wasn't wrong.

As it was later reported, something was indeed wrong. What were actually being observed were the spectral characteristics of HDO, which is similar to the "heavy water" used to make the early atomic bombs. There was no chlorophyl on Mars. However, even after this important discovery was made, the earlier mistake was compounded. It was asked why there was HDO on Mars. The answer would have delighted Lowell: Mars once actually had an ocean and then lost all its water! The heavy-water-like HDO was the enriched fragment that was left over.

Thus, two mistakes in a row were made before the final explanation became clear. The absorption features had nothing to do with Mars. What was being measured was absorption in the Earth's own atmosphere. The original measurements had been made at times when there were slightly different amounts of water vapor—and HDO —in the atmosphere.

Lowell's Legacy persisted even as late as 1969, as an incident related to the Mariner 6 and 7 flights indicates. By that time, because of what we had learned from Mariner 4, we were fairly sure that the north and south Martian frost caps were frozen carbon dioxide—dry ice— rather than water. This was one of the issues Mariners 6 and 7 were to settle. They carried two instruments that could tell us something about that. One was an infrared



radiometer to measure temperature. The other was an improved infrared spectrometer similar to the one that led to the spurious identification of vegetation on Mars in the 1950's. The radiometer flying over the caps sent back information suggesting that the surface temperature was very cold—about 150 degrees absolute (or 190 degrees below zero Fahrenheit). This finding supported the idea that the frost was carbon dioxide.

The infrared spectrometer saw some strange features, marked X and Y on the chart to the upper right. These features are about where we would observe methane and ammonia gas in the spectrum if we looked at a mixture in the laboratory. These substances, of course, are by-products produced when living organisms decay, and initially they were interpreted in that sense. It was announced that the white stuff of the polar caps was frozen water and that Mars was a veritable paradise for living things.

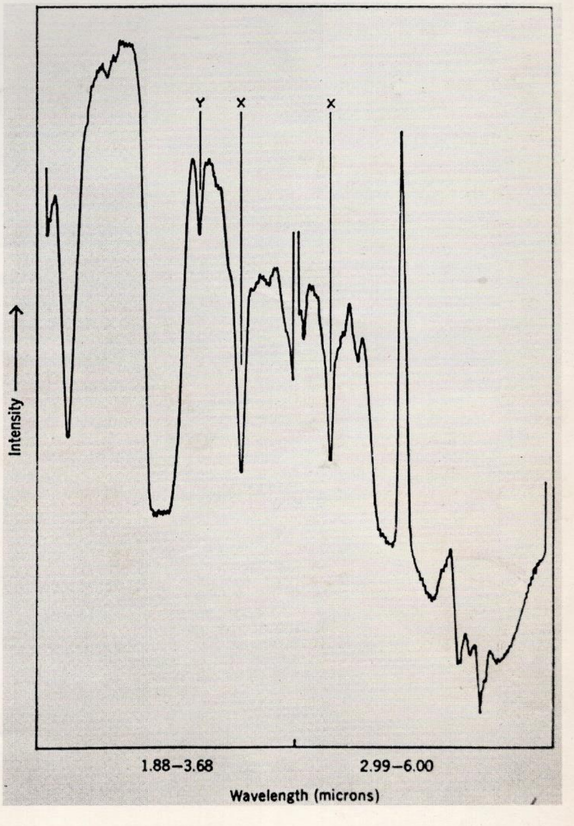
Eventually, with more careful work, it became clear that something else had features X and Y—very, very dry solid carbon dioxide. The spectrometer had not discovered evidence suggestive of life, but of a more hostile environment than had ever been supposed!

Why were all these mistakes made in favor of the existence of life? Why were pressure measurements estimated high instead of low? Why would a scientist assume he was detecting Martian chlorophyl rather than terrestrial heavy water? Why would someone assume the existence of ammonia and methane in a carbon dioxide atmosphere rather than solid dry ice itself?

The only explanation I can imagine is that those who made such interpretations suffered from the preconceived idea that such evidence of a terrestrial-type environment suitable for plant life might be found.

The results from the current Mariner 9 probe—and to a lesser extent from Mariners 4, 6, and 7—will do much to drive this bias from the minds of most scientists. It is clear that there is little similarity between the Earth and Mars. Some of the planetary processes we have observed bear more resemblance to the Moon. Many, it appears, are uniquely Martian.

The Mariner 4 pictures were stunning in their apparent similarity to the Moon. They showed no mountains like we have on Earth—no folded mountains, no evidence of



The strong similarity of the spectral characteristics of the Martian polar caps (sent back from the Mariner 6 and 7 flights in 1969) and the spectral features of ammonia and methane in a laboratory setting (top) initially led to the conclusion that these two chemicals —which are strongly indicative of life—were present on Mars. Later, more careful analysis, and comparison with the spectra of carbon dioxide (bottom), proved the polar caps were really very dry ice.

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These Martian canyonlands are part of a 72,000-square-mile complex photographed by Mariner 9 from a distance of about 5,050 miles. Each of these "Grand Canyons" is about ½ to 1¼ miles deep and 5 miles across with a gentle slope to the bottom. The curving segments of the canyon walls seem to be parts of incomplete craters. Probably the canyons are the result of geological fracturing, followed by sculpturing and erosion of some sort.

oceanic depressions, no signs of island arcs—none of the characteristics of earthly processes. The Martian surface, as far as we could tell from the handful of photographs we obtained, was cratered like that of the Moon. Other instruments indicated that—also like the Moon—Mars has no magnetic field. This means the planet is not shielded from the very intense solar radiation that would be hitting its surface. It suggests that maybe the planet has not boiled and differentiated, which would have given it a core like the Earth's.

Mariners 6 and 7 verified the dry-ice polar caps, the carbon dioxide atmosphere, and the moonlike topography. But they also yielded a couple of surprises. One was a view of jumbled chaotic terrain near the Margaritifer Sinus area. That area, clearly, was not like the Moon. This kind of structure on such a scale was not like anything on the Earth either. It was the first evidence of truly Martian phenomena.

The other surprising area was the circular desert, Hellas, near the equator. This bright region, 1,200 miles wide, is devoid of craters even in the closeup pictures. We are satisfied that the area was not obscured by a dust storm at the time it was photographed, that it is indeed featureless. This indicates that something is either scraping craters away or obscuring them from view. Both areas suggest a current kind of activity. They suggest that Mars is not a completely fossil planet, but an active one—at least in some areas.

The Mariner 9 photographs have been a real shock. We seem to be looking at a different planet from the one we were led to expect by the earlier Mariner results. And, so far, we have only a portion of the 5,000 useful photographs we expect to receive—even though the dust storm during the early weeks of the mission delayed our schedule for receiving them.

One area of cratered terrain photographed by Mariner 9 is totally different from any observed by earlier Mariners (*E&S*, January 1972). These do not appear to be impact craters in any simple way. They are not impact craters that have been modified. They appear to be craters caused by subsidence and collapse as material is withdrawn. This could be due to volcanic activity. The melting of vast quantities of ice beneath the surface of Mars could lead to such features. However, the volcanic origin is the one favored by the photographic team.

An area we call the "Grand Canyon" is spectacular. It consists of a whole series of valleys, each about 5 miles across and 1½ miles deep. The whole area is about 80 miles across. It is a huge feature, comparable in scale to the canyons that break up the Colorado River plateau, including the Grand Canyon. There is widespread evidence of deformation, of things breaking up, of linear features developing. They appear to be relatively uniform plateaus broken up by these huge valleys in an irregular pattern. I don't think they were formed by water. What probably occurred was fracturing to form the breaks, and this was followed by sculpturing and erosion on a grand scale by as yet unknown means. There is nothing on the Moon, there is nothing on the Earth, there is nothing on the earlier Mariner photographs that looks like this.

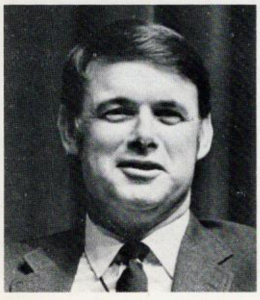
It was a shock. It still is a shock that a planet could be so different.

Another feature, affectionately termed the "elephant hide," looks the way water draining across a tidal flat would look if it were photographed on Earth. Again, this is a large feature: The whole area is about 45 miles across. It is on a plateau about 3½ miles above the mean elevation of Mars. Each fault valley is about 1½ miles across. This too is unlike anything we have seen before.

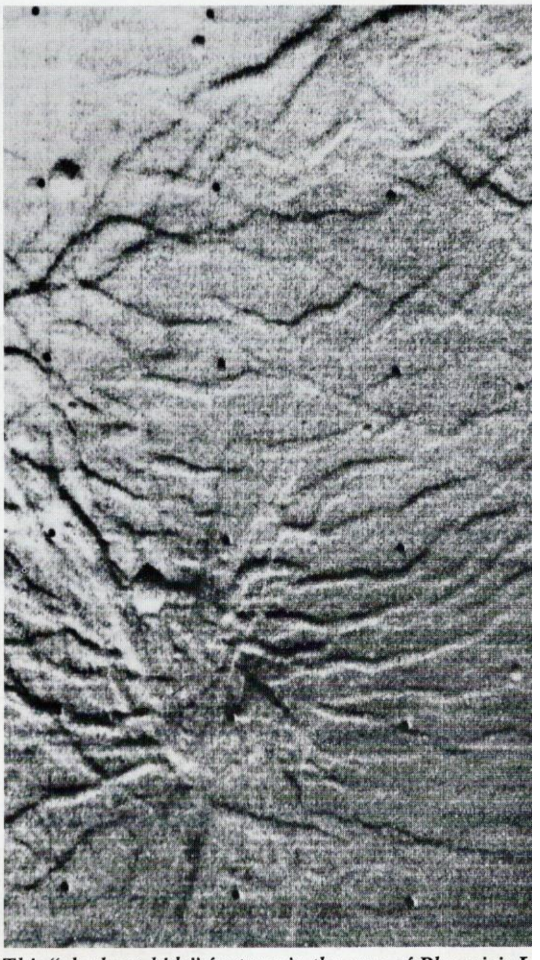
Mariner 9 found that much of the south temperate zone has irregular light and dark markings not present in Mariner 7 images of the same area taken in 1969. Some of the splotches are contained within craters; others appear to wash over craters. The largest are between 100 and 200 miles across. Mars is alive and well. If it's got a disease, it's measles—or something that makes it look funny. But the planet is very active.

All these photographs indicate that obviously Mars has many different kinds of terrains that reflect a variety of processes, or at least a varying magnitude of processes; and they clearly involve internal activity. And that is something we could never say before.

These Mariner 9 photographs are showing us whole new domains, whole new continents, and we don't really understand yet exactly what they mean. We are still in a state of shock, and it's going to take quite some time for us to digest and react to their real significance.



"Mars—Science Fiction to Science" is adapted from a talk given by Bruce Murray for the Caltech Lecture Series at Beckman Auditorium on January 10. Murray, who is professor of planetary science at Caltech, is also one of the co-investigators on the Mariner 9 television team. The View from Space *by Murray and Merton E. Davies (Columbia University Press, 1971) gives further details of the photographic exploration of the planets.*



This "elephant-hide" feature, in the area of Phoenicis L south of the Martian equator, is a plateau about 3½ mi mean elevation of Mars. It was photographed by Marin altitude of 4,000 miles just as the great dust storm was Scientists believe the area is relatively young geologicall covered by volcanic deposits at one time and later broke that cut the rocks into mosaic-like fragments.

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Do the Mariner 9 results increase the possibility that life exists on Mars? Yes, says Carl Sagan— but Bruce Murray disagrees *(p. 10).*

Is There Life on Earth?

by Carl Sagan

If the inhabitants of Mars set out to do preliminary exploration of Earth, what would they have to do to detect life here?

There are three spacecraft in orbit around Mars. We know that at least one of these—Mariner 9—is taking superb data. For the first time, the planet is being exposed to a detailed and rigorous scientific scrutiny.

Despite widely advertised opinions that Mars is lifeless, Mariner 9 has discovered surface conditions that significantly improve the chances of life there. The planet is revealed to be geologically young and active, shielded at least in places from ultraviolet radiation by atmospheric dust, and possessing enigmatic, sinuous, dendritic features which look for all the world like terrestrial river beds.

In view of the current closeup reconnaissance of Mars and the many questions about the possibility of life on other planets, it is of some interest to reconsider the appearance of our own planet as seen from space. If the inhabitants of Mars set out to do preliminary exploration of the planet Earth, what would they have to do to detect life here?

They could, for example, characterize the terrestrial environment. Ground-based telescopic observations would reveal temperatures, atmospheric pressures and composition, the presence of liquid water, frost caps, and the bright and dark markings which outline the continents and oceans. On the heels of these observations would be speculation about whether the terrestrial environment was suitable for life. There would be arguments that the great excess of oxygen in the Earth's atmosphere surely excludes the possibility of life because all organic compounds would be completely oxidized to carbon dioxide and water. There would probably be arguments that the temperatures on Earth were much too warm by Martian standards.

But other Martian scientists would object, and argue that such a view was much too chauvinistic and that perhaps life can be constructed on slightly different principles—inhabiting somewhat different regimes of temperature, pressure, and composition. The most bizarre hypothesis would be that terrestrial organisms breathe the well-known poison gas, molecular oxygen.

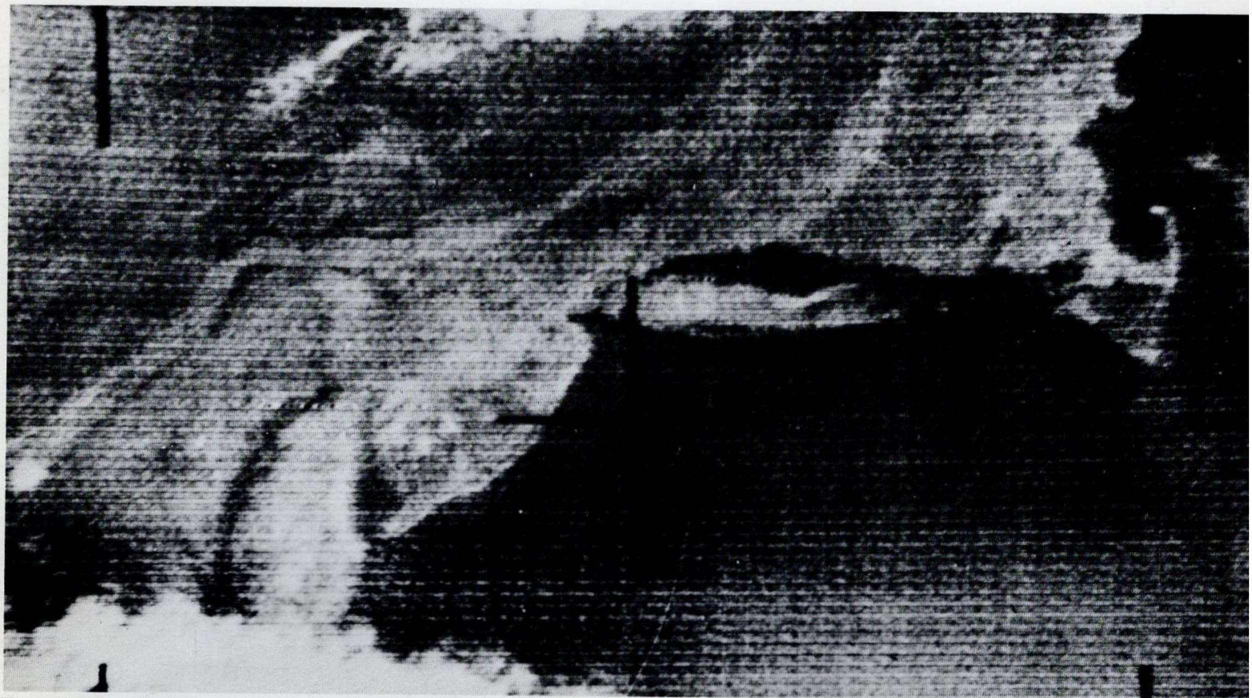
I believe that such debates would, there as here, be inconclusive. What is needed is more data.

One very simple search method for intelligent life (which, indeed, would take all the fun out of the game) is to point a small radio telescope at the Earth at the appropriate frequency. When the North American continent turns toward Mars, there would be a blast of radio emission that would knock the observer off his feet. Prolonged scrutiny would probably reveal a minimally intelligent content to the television signals, and a low form of life on Earth would thereby be discovered.

But this method works only if the Martians observe during the precise epoch in terrestrial history after radio was discovered, but before the widespread introduction of cable TV and other methods of economical usage of communications power. They would have to be observing during one or two hundred years out of the several billion in which life has existed on Earth.

Another approach would be to put radio astronomical searches aside and assume a Martian photographic search in daylight for life on Earth. With a small telescope, scientists on Mars would certainly see the Earth go through phases just as we see the Moon and Venus do. But not much about the Earth would be discernible. With larger telescopes more detail would appear. The wispy white changing features would be revealed as an atmospheric phenomenon, clouds—but of unspecified composition. Once the temperature structure of the atmosphere was determined, it would be clear that these were water clouds and not carbon dioxide clouds or dust clouds.

Beneath the clouds are brownish continents which would probably be called bright areas. The more bluish or blackish areas would at first be called dark areas. But then



Tiros photograph of the eastern seaboard of the United States reveals no visible sign of life—intelligent or otherwise—in Boston (upper right), New York City, or Washington. The effective resolution is a few kilometers.

it would be noticed that these dark areas would occasionally exhibit a bright glint of specular reflection, and the existence of oceans would eventually be revealed. The rotation and obliquity—the deviation from the plane of the ecliptic—of the Earth would be determined. But at this sort of resolution it would not be possible to detect life.

At occasional times of exceptional clarity—when the thin Martian atmosphere was free from dust—scientists using a large telescope on Mars could achieve a resolution of about one kilometer on the Earth. With such a resolution, it would be possible to detect features of fair contrast if they were larger than one kilometer in extent. But features smaller than one kilometer, even if of high contrast to their surroundings, would not be visible.

Would this be enough to detect life?

The Tiros and Nimbus weather satellites photographed the Earth at one-kilometer resolution, and we examined several thousand of these pictures. We found the photographs to be biologically uninteresting. No sign of major engineering works or of the largest metropolises could be found. It has been argued that, for reasons of economy and geometry, technical civilizations tend to construct rectilinear features that have a markedly artificial appearance. But the number of such features visible at one-kilometer resolution is very few. Only about one in a thousand of the Tiros and Nimbus photographs showed evidence of rectilinear geometry on the Earth. And most of these features were natural, rather than man-made—as peninsulas, seif sand dunes, sand bars, and possible jet stream clouds.

At one-kilometer resolution there is no sign of life—intelligent or otherwise—in Washington, Boston, New York City, Moscow, Peking, Melbourne, Berlin, Paris, London, or any other major population center.

Although we believe we have severely reworked the surface of the Earth and have made a profound influence on our planet, we are in a fundamental way still undetectable at a resolution of one kilometer.

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Better resolution could be obtained by a space-vehicle reconnaissance of the Earth. Just as we are able with Mariner 9 to examine Mars at 100-meter resolution, our hypothetical Martian scientists might perform spacecraft observations of the Earth at the same resolution.

Would they detect life?

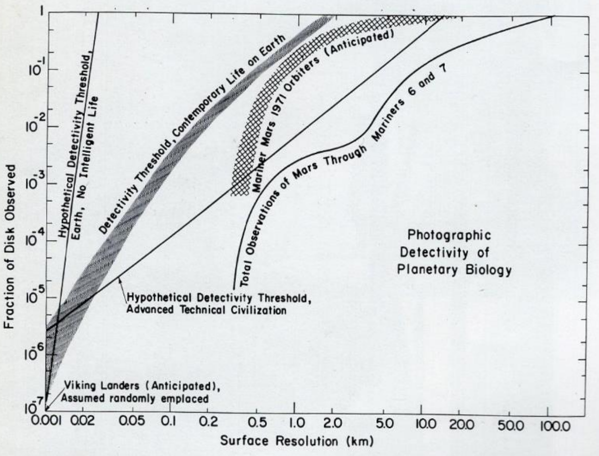
We have closely examined 1,800 selected high-resolution color photographs of the Earth obtained by astronauts aboard the Apollo and Gemini flights. Most of these photographs are at approximately 100-meter resolution. Our sample applied to cloud-free areas. Since the Earth is on the average about 50 percent cloud-covered, this corresponds to an effective non-selective inspection of 3,600 photographs of the same resolution. Dozens of rectilinear or highly geometrized features were uncovered. Of these, 60 have been classified as geological and 20 as meteorological in origin.

Some phenomena, such as dunes, are undeniably rectilinear, but are not of biological origin. Other phenomena, such as coral atolls, are undeniably of biological origin, but would almost certainly not be so identified on the basis of their geometry, without further knowledge of terrestrial biology. Some river basins have a remarkably striking geometry as seen from space, as do some cloud features. Likewise sandbars and craters have striking similarities but are not indicative of life on Earth.

A sizable number of the photographs—57—are so regularly geometrized as to defy non-biological explanations. With the knowledge about the Earth's features that we have (but an extraterrestrial explorer surely would not have) these pictures break down as follows: roads, 29; canals, 5; agricultural geometrizing of the environment, 15; jet contrails, 4; industrial pollution, particularly smokestack plumes, 4. Some cities, laced with extensive highways, such as Dallas-Fort Worth, are easily detectable. Other cities of large size (Cairo, for example) are much less detectable. Perhaps the most striking signs of intelligent life on Earth are the checkerboard patterns of agricultural and urban territoriality.

The conclusion is that with a fair number of photographs at a resolution of 100 meters or better it is very easy to detect intelligent life on Earth. At resolutions worse than

A portion of an Apollo 6 photograph of a typical populated region of the planet Earth—at a resolution of about one-tenth of a kilometer—reveals a fine checkerboard pattern which is the result of the human passion for order, geometry, and territoriality.



In this diagram, three thresholds for the detection of life on Earth—one actual and two hypothetical—are compared with past, present, and future observations of Mars. A previous analysis of photographs of the Earth with similar resolution to photographs of Mars indicates that Mariner 9 will almost surely rule out the possibility of civilization—but not of life—on Mars.

one kilometer, it becomes difficult to impossible.

Human beings have been around for only a few million years, and human beings capable of reworking the Earth to this extent have been around for only a few thousand years. A Martian exploration vehicle coming to Earth in any previous epoch would not have uncovered any of the artifacts we have just described because they have only recently arisen. Yet, for something like four billion years there has been life on the planet Earth.

What about detecting life that does not rework its environment as human beings do?

At one- to ten-meter resolutions it becomes possible to detect large plants (especially trees) and animals. Because of their top-heavy geometry, the biological origins of cows, for example, would be rapidly deduced. A cow is remarkaby unstable dynamically, which is a good sign that it is a cow and not a rock. Life forms, in general, are characterized by such disequilibrium phenomena—chemical, physical, dynamic, and otherwise. Although I do not think it is possible to predict in any detail what the manifestations of life on any other planet would be, it is clear they would be characterized by strong departures from equilibrium—departures we would search for in the biological exploration of another planet.

Because there are so many more plants and animals than technological reworkings of the Earth's surface, the photographic detection problem becomes much easier as our resolution becomes much better than 10 meters. This is shown clearly in the diagram at the left, which indicates what fraction of the Earth's surface must be observed at a given resolution to detect life.

At what point in our exploration of Mars could *we* detect a biology even as rich and diverse as our own? As the diagram at the left shows, all the observations of Mars made by mankind through Mariners 6 and 7 would not have detected even a civilization much more advanced than ours.

Mariner 9 offers the first good chance of testing (and probably putting to rest) the persistent speculation about the existence of intelligent beings on Mars. But it is unlikely to have any direct bearing on the most fundamental issues—whether Mars can be a habitat for simpler forms of life. In my view this question remains entirely open—at least until landing missions of the Viking-class journey to Mars in 1976.

Carl Sagan, professor of astronomy and director of the Laboratory for Planetary Studies at Cornell University, is currently a visiting associate in planetary science at Caltech, and a co-investigator on the Mariner 9 television team. "Is There Life on Earth?" is based on a talk given to the Caltech Women's Club on January 13, and on the paper "A Search for Life on Earth at 100 Meter Resolution," published in the December 1971 issue of Icarus. *A further discussion of the detection of life on Earth can be found in Sagan's book* Planetary Exploration: The Condon Lectures. *University of Oregon Press, 1970.*