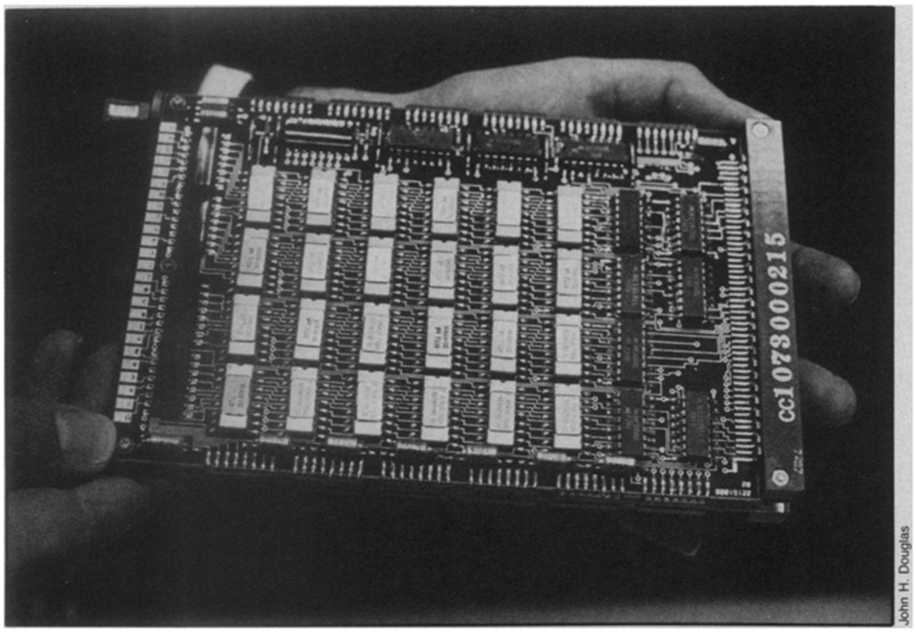
Computers 1: From Number Crunchers To Pocket Genies

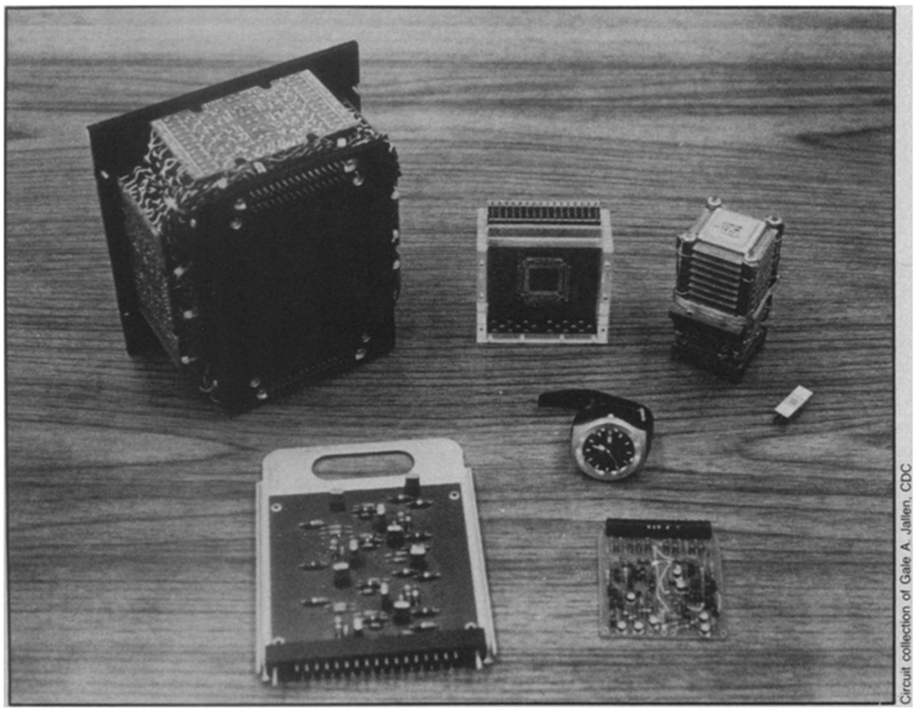
A series of technological breakthroughs has begun to bring the computer revolution to the average person

BY JOHN H. DOUGLAS



John H. Douglas

One of thousands of replaceable segments from a STAR, containing multiple IC's.



Circuit collection of Gale A. Jallen, CDC

Evolution of computer technology from a 2-"bit" transistor logic circuit of the late 50's, lower left, to the tiny 1,000-"bit" MOS memory of today, far right.

First of three articles dealing, respectively, with the state of the art in computer technology, projections of things to come, and an assessment of the computer's impact on society.

Few people realize just how sophisticated is the new technology thrust into their daily lives in pocket calculators and digital watches, or what the impact is likely to be as these technological advances propel computers into almost every operation of society. Once an expensive colossus, the exclusive domain of a technically trained elite, the computer is finally on its way toward becoming a household appliance—an attendant infinitely adjustable to our needs, but one to which we will also have to adapt.

The key to cost reduction and ease of use for the computer has been miniaturization, a process that now produces complete electronic circuits visible only under a microscope and in the future promises to create elements resolvable only by electron microscopy. Some 20,000 transistors can be crammed onto a chip less than a quarter inch on a side, and within a few years such "integrated circuits" (IC's) may contain a million transistors—or their electronic successors.

The first important result of miniaturization has been a dramatic reduction in the power required to operate various instruments, making them more portable. A digital watch that can run for a year off one tiny battery, for example, is made possible by a low-power chip of computer-like circuitry. This IC first processes the roughly 33,000 pulses a second coming from a quartz crystal and then translates these into signals that drive a display which, itself, represents new breakthroughs in solid state physics and materials research.

Another result of miniaturization has been the greatly increased speed of circuit operation. Delay time in the fastest IC transistors is less than that required for an electrical signal just to travel along the wires connecting components of older computers. To achieve the mathematical capability of today's pocket calculators using conventional transistors once required a desk-sized computer costing several hundred times as much as the calculator and still not able to match its speed. A vacuum tube computer with all the functions of these "pocket genies" would be an electronic behemoth, spread over several fan-cooled standing cabinets, strung together with heavy cables, and requiring the power of a major radio station.

For the most part, miniaturization has been a gradual, though steady process. In central computer memories, for example, strings of magnetic rings, called cores, have been used for nearly two decades to store data. In binary notation, if the core is magnetized in one direction, its contents are read as "zero;" if magnetized in the opposite direction, as "one." A large computer may need 10 million of these cores, yet they are still hand-strung, under a microscope. Only by sheer hard work have manufacturers managed to keep cores competitive with other memory devices, by shrinking them to only 18 thousandths of an inch in diameter and reducing access time to a submicrosecond.

Some advances, however, have been sudden and spectacular. In the mid-1950's engineers at Texas Instruments, Inc. and Fairchild Semiconductor discovered how to create transistors and other components on a single chip of silicon, using a technique called "photolithography." In this process a mask was used to shield various portions of a photosensitive coating that is selectively etched away along the lines of the mask. Carefully selected impurities are then diffused into the silicon substrate and after several repetitions, a multilayered surface has been developed which includes all the components and metallic connections needed for a complex circuit. The basic design of these microscopic transistors, however, was still similar to that of their larger cousins, depending on exchange of both electrons and "holes" through the junctions of dissimilar semi-

A primer on computer technology

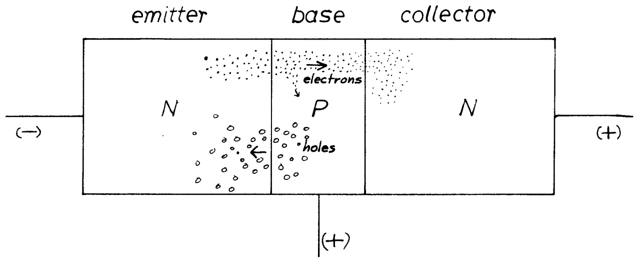
The main obstacle to understanding how computers work is realizing just how simple they really are. Electronic idiot-geniuses, capable of beating any thousand mathematicians at speedy calculation, they lack any shred of "intelligent" imagination and perform simple arithmetic with a clumsiness that would appall a third grader.

The first problem in addressing oneself to a computer is that they can "think" only in binary notation—digits of either zero or one. These *bits* (binary digits) of information are the easiest to store and manipulate, since the electronic device involved is either off (zero) or on (one). Since people usually don't think in binary (except for a few patient specialists who sometimes find people more and more difficult to talk to), various *languages* have been devised to allow non-specialists to communicate more easily with computers. A built-in *compiler* then translates these formulas or instructions into binary notation before execution of a *program* begins.

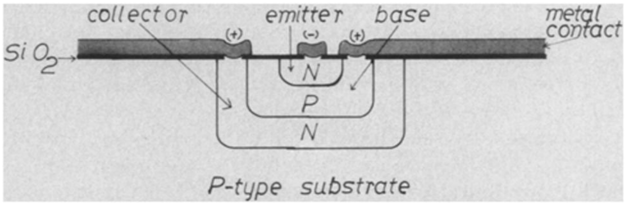
Once translated into binary, numbers are processed in *logic* circuits, which reduce arithmetic operations to a series of logical functions such as AND, OR, NOT, etc. Each logical function requires a separate circuit, involving perhaps a half dozen separate electronic elements. Just to add two *bits* of data may require nine of these circuits.

Since a complex program using the largest computers may require billions of operations involving billions of pieces of data, the need for extreme speed and small size becomes apparent. Although the earliest computers used electrical relays and vacuum tubes to form logic circuits, not until the invention of the transistor could the process of miniaturization begin that has led to the computer's growing impact on daily life.

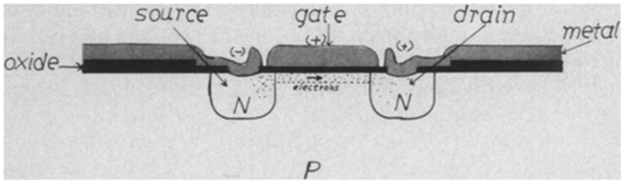
In the early *junction transistors*, separate layers of a semiconductor (usually germanium) were *doped* with impurity atoms that bound themselves to the germanium in such a way that either an electron was left over (creating an *n-type layer*) or that an electron was missing (creating a *p-type layer*). Sandwiched together, an n-type layer could conduct electrons toward a junction, while a p-type layer brought *holes*—*if* voltage was applied in the right *(forward bias)* direction. If voltage was applied the other way *(reverse bias)*, very little current flowed.



When a doped layer had a junction on either side, current across the whole device could be controlled by adjusting the voltage on the middle layer (called the *base*). If a base were made of p-type material and raised to a positive voltage relative to one n-layer (called the *emitter*), electrons flowed from emitter to base. If the other n-layer (called the *collector*) was then raised to an even higher positive voltage than the base, the electrons would flow straight through the base and into the collector. By lowering the base voltage, the electron flow between emitter and collector could be stopped. Such a device thus acted as a switch or amplifier and was called a *transistor*.



To combine many of these into one *integrated circuit*, a *chip* of silicon is doped to form (say) a p-type layer, on which an n-type layer is grown. The surface is oxidized to form an insulating layer, and then covered with a light-sensitive *photoresist*. Where ultraviolet light falls through a carefully positioned *mask*, the photoresist hardens. An acid bath etches away the nonhardened portion of the photoresist and oxide layer, allowing the material underneath to be further doped. After several repetitions, a multilayered structure has been developed on the chip that includes transistors and many other circuit elements, all connected by thin metallic strips deposited in a final step.



Because of the multiple steps, such integrated junction transistors are relatively expensive to make, so an alternative design was invented to reduce the number of steps, increase density and lessen the amount of power needed to operate the devices. This *field effect transistor* uses the electric field on one of it metallic contacts (the *gate*) to induce current flow between two similarly doped regions (now called the *source* and *drain*). Key to the process is the very thin layer of oxide under the gate through which the applied field induces a conducting *channel* in the underlying silicon—hence the term *metal-oxide-semiconductor* (MOS) technology.

Most integrated circuits are used as modules in larger devices, and thus come contained in a sealed unit with projecting pins for ease of replacement as *plug-in devices*. A pocket calculator will contain one such unit, a giant computer requires many thousand. —*J.H.D.*

conductors. (Hence the name "junction" or "bipolar" transistor.)

Then came design of a transistor tailor-made for miniaturization. In 1960, scientists at Bell Laboratories proposed using the electric field from a small metal "gate" to induce current between two slightly separated semiconductor regions, and two years later RCA demonstrated the first "field-effect" transistor. (It's also sometimes called a "unipolar" transistor, since either holes or electrons—not both—are conducted.) Not only could these be packed closer together in integrated circuits than bipolar transistors, but because of their greater simplicity, the fabrication process was speeded up and made less costly. The new process involved laying conductive metallic strips over a thin layer of oxide to separate them from the silicon substrate and was thus called metal-oxide-semiconductor (MOS) technology.

Transistor circuits can be used either as memory cells or as the "logic" units that perform arithmetical functions in a computer. Traditionally, bipolar circuits have been considered fast, relatively bulky and power consuming, and expensive. MOS circuits have been prized for their compactness, cheapness, and low power requirements, but they have generally operated many times slower than comparable bipolar circuits. As a result, MOS circuits provided the key to small, battery-powered calculators—where power, cost and size were at a premium but great speed was not (few people care whether the answer to an arithmetical problem is displayed on their calculator in a millisecond or half a second). MOS circuits also have begun replacing magnetic cores in the central memories of large computers, and if their cost keep descending faster than that of stringing millions of tiny rings (very likely), core memories may become obsolete. Bipolar circuits, meanwhile, have maintained their position as undisputed leader in fabrication of the super-high-speed central processing units (CPU's) of very large computers.

These traditional roles for the two main branches of integrated circuitry may not last long, however. To make bipolar devices more compact, inexpensive and less power consuming, manufacturers have developed a new process called integrated injection logic (I^2L). By combining various elements of a circuit and carefully arranging them on the silicon substrate so as to require the minimum number of fabrication steps, the I^2L technique achieves the density of an MOS circuit while maintaining the speed of bipolar circuits. And power is low enough that some companies now believe they can produce a wristwatch with bipolar transistors, using I^2L circuitry.

MOS technology, meanwhile, is also developing in new directions. To capitalize on the low power capabilities, manufacturers found that the configuration requiring the least power involved using both an electron-conducting ("n-channel") and a hole-conducting ("p-channel") transistor. Only one transistor at a time conducts in this "complementary MOS" (CMOS) configuration, so power consumption is extremely low—the CMOS circuit in a wristwatch, for example, dissipates only a couple of microwatts power. The configuration is also highly stable, making CMOS circuits ideal in applications involving physical abuse and extraneous currents, as in computers for automobile engines.

Purcell operating the CDC STAR 100.

John H. Douglas

The latest innovation in MOS technology promises to make these devices much faster, so that they may begin to compete with bipolar units in CPU's. A principal cause of delays in MOS devices is charge build-up in the silicon substrate; if a thin layer of silicon could be used instead, and individual elements better isolated, the "capacitance" would be reduced and less charge would accumulate. To accomplish this, sapphire (an insulator) can be used as the substrate, with circuit elements formed by diffusing appropriate atoms into a thin layer of silicon grown on the sapphire's surface. Such silicon-on-sapphire (SOS) devices have the low power dissipation of other CMOS circuits, but more closely approach bipolar speeds. So far they are more expensive, but the gap is narrowing.

Traditional roles of computers are themselves changing, with many new "families" of computers—with units of all sizes, designed for mutual compatibility—competing for a share of the market. Even the definition of a computer is becoming uncertain: Very little distinguishes a pocket "calculator" with 86 built-in mathematical functions and capable of executing a complete program of 49 steps from a desk-top "computer" that may solve the same sorts of problems, but which has a larger memory and some plug-in peripheral equipment.

Two of the hottest new areas are the mini- and micro-computers. A microcomputer uses the same integrated circuit "microprocessor" found in calculators, but adds a memory and access to peripheral equipment. Probably the largest market for the micros will be special-purpose applications such as monitoring and controlling automobile engines or keeping track of inventory in electronic cash registers. Again, miniaturization is the key: Complete microcomputer circuitry can now be built on a single chip (0.2 inches square)—including a read-only memory for stored programs, a random access memory to keep track of data, and circuits to interface with external equipment. Minicomputers generally have larger memories, operate much faster to handle fairly complex programs quickly, and are tied into a "system," including such conventional peripherals as an input typewriter and cathode ray display. Prices keep varying, but most calculators now sell for less than $100, micros for around $1,000, and the lowest priced mini system for about $12,000.

At the other end of the scale are the giant "number crunchers"—computers that can perform hundreds of millions of operations a second, store millions of data "words" in a fast random access memory, and which cost tens of millions of dollars. Here one must not only worry about how to incorporate the very latest technology into a giant machine that may be designed 5 to 10 years before it is delivered, but also how to adapt its quick but simple-minded workings to whole new classes of problems.

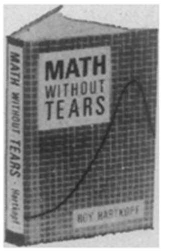
The drive for computing efficiency has led to a heightened emphasis on computer "architecture"—the overall strategy of data handling and component placement. Traditionally, in scientific computation, large quantities of data were read from a magnetic tape or punched cards onto a high-speed disk, from which sizable chunks were taken when needed, and stored in the very high speed, random access central memory. The central processing unit (CPU) then took what numbers it needed to perform operations designated by a program. Usually these operations were done one at a time and the results fed back along the memory chain to a printout unit. Unfortunately, this step by step operation made the overall computing process much slower than the capability inherent in the hardware.

To meet the challenge, designers found various ways of having several operations going on at once. In ILLIAC IV (SN: 10/13/73, p. 236), some 64 separate processors run in parallel to provide a total of 100 to 200 million operations per second. More recently, the STAR 100 (Control Data Corp.) and the ASC (Texas Instruments, Inc.) each provide up to 100 million results a second using arithmetical "pipelines"—units in the central processor that can accept new pieces of data while old ones are still going through the later stages of computation. (These speeds can be compared to tens of thousands of operations a second in the early 1950's and a few million in the mid-1960's).

Another time-saving approach is to extend the hierarchy of memories and peripheral units. Between the millisecond speeds of disks and the sub-microsecond speeds of the random access central memory lies a gap that may soon be filled by a variety of new equipment. So that the central processor does not have to waste time ordering shifts of data, auxilliary computers are attached to take care of such details. In the STAR system being installed at the Lawrence Livermore Laboratory, for example, 14 auxilliary computers are needed to keep the main processor running at top speed. CDC engineer Charles J. Purcell calls these the "14 little baby chicks around the mother hen" that allow the main computer to work at near 90 percent efficiency, rather than the 50 percent it would be able to reach if the CPU had to direct everything.

Yet, even newer technology has already made many of these machines theoretically obsolete, and the average person is just beginning to feel the "computer revolution." These most recent technologies and an assessment of the computer's impact will be the subject of subsequent articles. ☐

MATH WITHOUT TEARS



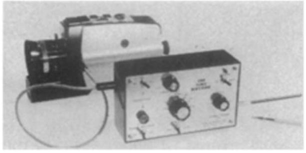
In lively non-technical language Mr. Hartkopf gives you a basic understanding of many of the everyday applications of mathematics.

Emphasizing the practical aspects of math, the author avoids mathematical terms and jargon and takes the reader from simple counting to trigonometry and calculus.

MATH WITHOUT TEARS is written with a light touch and is filled with interesting anecdotes, spiced with humor. *Learn math in the comfort of your own home at minimum cost.* ORDER NOW: MATH WITHOUT TEARS by Roy Hartkopf $6.95, plus 50¢ handling 10-Day Money-Back Guar

EMERSON BOOKS, INC., Dept. 543-B
Buchanan, N.Y. 10511

THE TIME MACHINE



TIME-LAPSE accessory for your motion picture camera. Wide scientific applications: plant growth, tidal changes, meteorological surveys, crystal growth, etc.

- Mechanical or electronic release.
- Single-frame activation or scenes at intervals from 1 to 300 sec.
- High capacity NiCad batteries (charger unit included).
- Built-in photocell with sensitivity adjustment for light activation.
- Only $149.00 postpaid. Satisfaction guaranteed. 10 day return privilege.

Send check, money order—or request free brochure from

Science Dimensions
Photographic Products Division
2157 Miner Street Costa Mesa, California 92627

STRANGE PLANET

A SOURCEBOOK OF UNUSUAL GEOLOGICAL FACTS

Original articles on mammoth graveyards, foundered continents, deluge myths, musical sands, boulder trains, patterned ground, Mima mounds, giant craters, and other geological perplexities, as originally published in *Science, Nature, Journal of Geology,* and similar publications.

280 pages, hard covers, $7.95 postpaid

Published by: THE SOURCEBOOK PROJECT
BOX 107B, GLEN ARM, MARYLAND 21057

NEW! "SOLAR HOUSE PLANS"
by Edmund, Homan, Thomason and Wells

ecology • economy • utility • nature • harmony

ACTUAL WORKING BLUEPRINTS FOR YOUR SOLAR HOME

Learn all about the most fascinating possible home of the future! It can be your "now" answer to today's energy crisis in housing. And for the years ahead. Your builder can modify or actually use the complete blueprints included in the book to create a solar heated and air conditioned home that you'll be proud of . . . and comfortable in. It's even more ecological by having a beautiful earth covering.

Designed by renowned ecological architect Malcolm B. Wells, this modern masterpiece includes the patented and home-tested Thomason "Solaris System", the only proven actual working system—**proven for 10 years!** . . . the system that can cut conventional heating costs by as much as two-thirds.

HOW MUCH WILL IT COST!

For about $40,000 you can build the solar home with 3 bedrooms, 2½ baths, kitchen, dining room, living room, recreation room, photo darkroom, utility room, office/studio, lots of closets, storage.

This is the definitive book on solar homes. Experts have filled its 48 easy-to-read 8½ x 11" pages with intriguing facts and illustrations (plus an additional section of your complete blueprints). Among subjects discussed are "why solar heat?", "why earth covering?", why the owners decided to build the home shown. There is a section on architectural problems and considerations, plus one on solar heating system design, theory and construction. Other solar homes are discussed also. Everything you'll want to know about building a solar home is here — the advantages, problems, savings and suggestions.

Send today. Available only from Edmund Scientific Co. **As with everything Edmund sells, it carries a 30-day money-back guarantee. Read it. Examine it. Enjoy it. Return it for a full refund if you aren't delighted!**

Stock No. 9469Q Just $24.95 Ppd.

GIANT FREE CATALOG!
NEW. 164 Pages
Over 4,500 Unusual Bargains for Hobbyists, Schools, Industry

JUST CHECK COUPON!

EDMUND SCIENTIFIC CO.
300 EDSCORP BUILDING
Barrington, N. J. 08007
America's Greatest
Science • Optics • Hobby Mart

COMPLETE AND MAIL COUPON NOW

EDMUND SCIENTIFIC CO. 300 Edscorp Bldg., Barrington, N. J. 08007

☐ SEND FREE 164 PAGE CATALOG
☐ Charge my BankAmericard •
☐ Charge my Master Charge •
Interbank No. ______
Card No. ______
Expiration Date ______

Send me ___ "SOLAR HOUSE PLANS" BOOK(S) @ $24.95 ea. (No. 9469Q) $______
Handling ______ .50
Enclosed is ☐ check, ☐ m.o. in amount of $______
Signature ______
Address ______
City, State, Zip ______

HELPING TO DEVELOP AMERICA'S TECHNOLOGY FOR OVER 30 YEARS.

CLASSROOM TEACHING AIDS

ALL AIB PUBLICATIONS

—Relate foods, nutrition to health and total fitness

—Apply valid findings to educational needs

- Designed with scope and sequence in mind
- Classroom tested, evaluated by teachers
- Prepared under guidance of Advisory Committee
- AVAILABLE AT COST

Send for Descriptive Order Blank/Brochure

Consumer Service Department
AMERICAN INSTITUTE OF BAKING
400 East Ontario Street
Chicago, Illinois 60611