Information art : diagramming microchips

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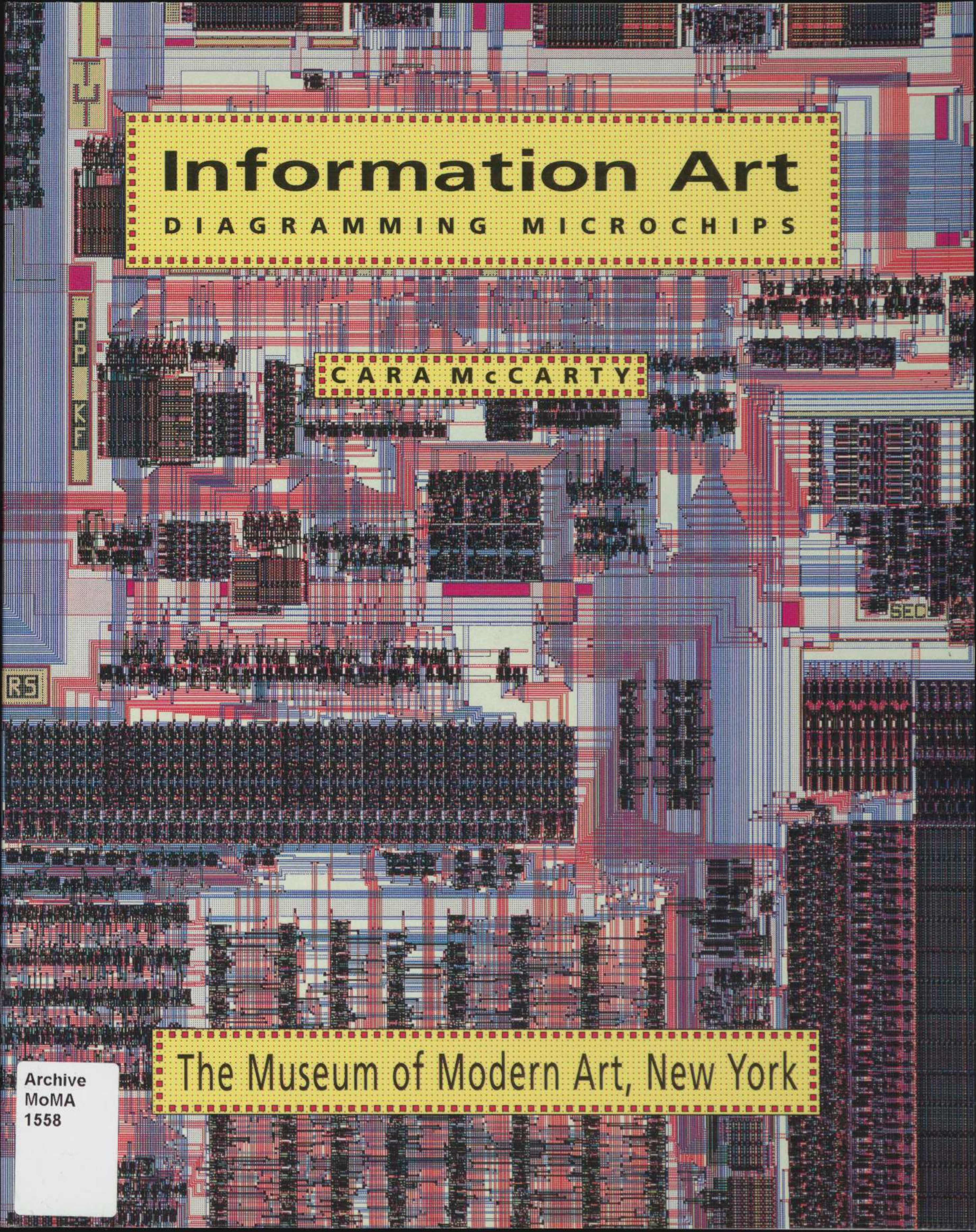
Information Art

DIAGRAMMING MICROCHIPS



CARA McCARTY

The Museum of Modern Art, New York

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DIAGRAMMING MICROCHIPS

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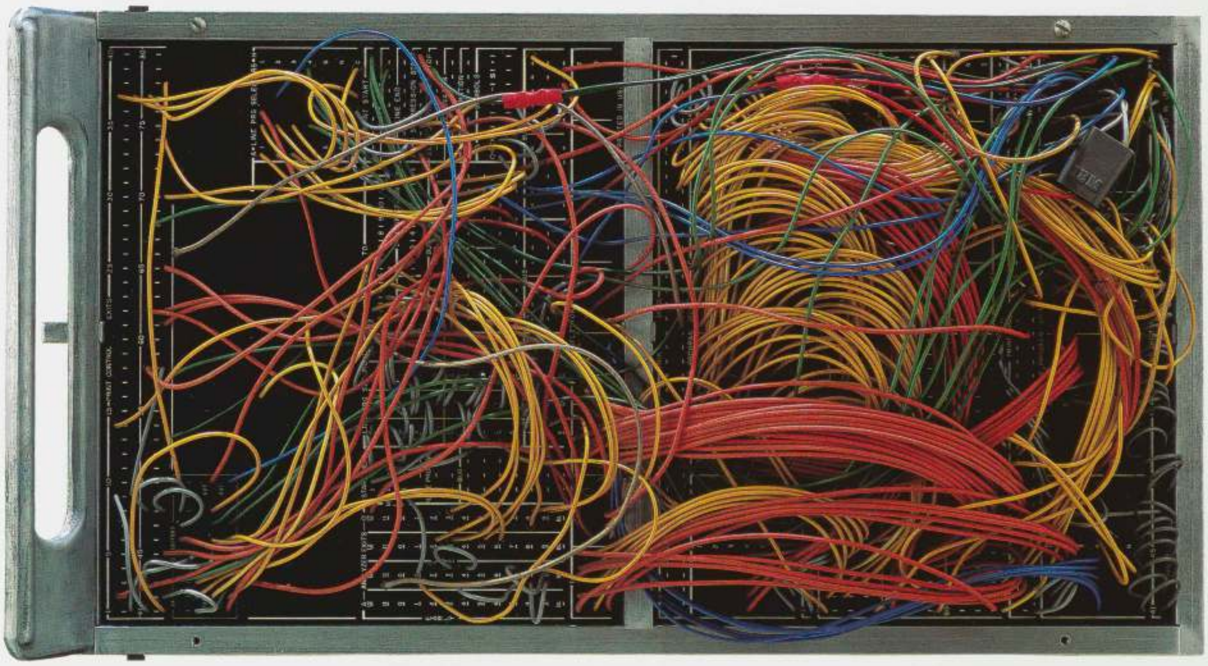
COVER: Intel 386™ microprocessor chip, detail

OPPOSITE: IBM Product Development Laboratory. Control Panel for IBM 305 (Random-Access Memory Accounting Machine, RAMAC). 1950. Aluminum, plastic-covered aluminum wires. The Museum of Modern Art, New York. Gift of IBM.

Since the end of World War II developments in technology have produced objects, seldom seen by the public, very different in appearance from the geometric shapes that have so far characterized Machine Art. The growing complexity of our machines has led to the miniaturization of parts; electronics has altered our conception of how things need to be shaped in order to work, and of how they must be related to each other.

The new machine art is visually incomprehensible unless one knows about and believes in the existence of invisible forces. Geometric machine art suggested by its finite shapes the direct action of push and pull: the new machines, or parts of machines, consist often of patterns. Printed circuits in particular, and the use of wires colored for identification in the RAMAC control panel, suggest one change that technology is likely to make on many of our common artifacts: the dematerialization of solid forms into clusters of linear relationships.

Arthur Drexler
Twentieth Century Design from the Museum Collection
The Museum of Modern Art, 1958



Information Art

DIAGRAMMING MICROCHIPS

The integrated circuit is one of the most sophisticated and influential products of our technological civilization. It is also among our most complex, most powerful, and least expensive devices, and the smallest. Its invention in 1958 brought about the microelectronics industry, which today is the second largest in the United States. The impact of the integrated circuit has been revolutionary. Not only has it established entirely new standards for mass production that require methods of fabrication and a degree of precision hitherto unknown in the industrial age, but it has led to the development of many products that did not exist twenty years ago. It is the technology that made possible microwave ovens, pocket calculators, and pacemakers, as well as moon landings and satellites. Its archetypal product is the computer.

The integrated circuit is the result of one of those rare, pivotal moments in history when discoveries in all the major sciences—chemistry, physics, mathematics, optics, and electrical engineering—converged, and combined with a culture ready to implement the technology. Scientists pushed their research to the limits, and in association with entrepreneurs created an electronic marvel that is radically changing our lives. The focal point of that knowledge is contained within a tiny sliver of silicon known as an integrated circuit, a microchip, or chip, which is layered with patterns of circuits too small for the naked eye to see.

The diagrams reproduced here are computer-generated plots of the electronic pathways that make up integrated circuits. People have diagrammed for millennia, but these diagrams reveal a world that would otherwise be invisible to us. Usually we think of diagrams as being representations smaller than the final product, but these drawings are a few hundred times larger than the actual circuits; and they are so intricate that even when enlarged five hundred times they retain their density. They are unique in that, unlike drawings of earlier logic machines, there is little distinction between what is being represented and the representing. They are not symbolic, but are multilayered patterns of the actual circuitry, and become the template of the chip. Each color corresponds to a layer that is made into a stencil, which is ultimately reduced photographically and etched into silicon. These designs were in fact not meant to be seen.

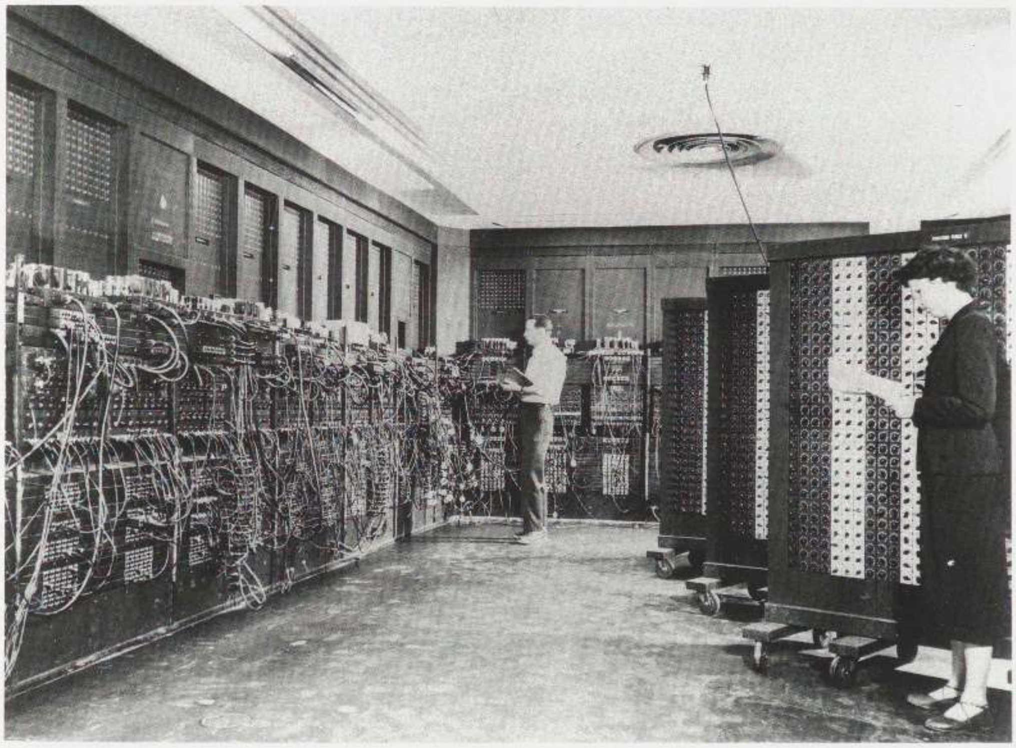
Since the Museum's founding it has recognized that beauty is not restricted to the fine arts or to useful objects, but can be found in functional machine parts and tools as well. One of the Museum's first design exhibitions, *Machine Art*, organized in 1934, was dedicated to celebrating the beauty of machines and focused primarily on mechanical objects and their inner components. Propellers, springs, and ball bearings were among the objects selected for their pure, geometric forms. They were not consciously "designed" or "styled," but rather their beauty derived from their economy of design. Beauty was a byproduct of their function. Their unembellished forms became a matter of aesthetic preference for many artists and designers of this century, and set a standard for the Museum's design collection.

In retrospect *Machine Art* represented a summation of what had been the prevailing technology, for at that time machines powered by electricity were beginning to replace mechanical machines. Today microelectronics is central to our technology, and the integrated circuit is at the heart of the microelectronics industry. It enables us to process, store, and transmit massive amounts of information, quickly and reliably; and as a result much of our information today, whether it be numbers, letters, or images, exists in electrical form and passes through these tiny devices.

The term "information" is being used in connection with these diagrams to underscore our increasing dependence on this technology. The complex network of lines channel the flow of data, and their configurations determine how it is processed. Unlike painting, which is primarily an emotional and aesthetic endeavor, these are designs of rigorous efficiency guided by rules of logic and laws of physics. Artifacts of rational thought, they do not allow for ambiguity.

The consideration of the diagrams as art derives from their patterning. They are the most complex patterns people have ever made, and because of their intricacy they can be deciphered completely only by a computer. But even if we never understand them, we can delight in their marvelously complex and variegated designs. Their dynamic patterns give us an intuitive notion of what the technology is about and make the microchips tangible to us. The sheer intricacy of the configurations suggests the thousands of hours, the effort and the precision, required by teams of engineers to produce a single design. The pattern relationships of these diagrams are providing inspiration and source material for artists. They are icons of our time just as mechanical components were of the first part of the twentieth century.

The microelectronics industry was launched in 1947 with the invention of the transistor, a switching element used to control the flow of electricity. The transistor's small size, low power consumption, and in particular its reliability were its greatest advantages over the bulky vacuum tubes it replaced. However, its widespread commercial potential was not realized until the invention of the microchip, which was a technological feat. It meant that for the first time transistors could be interconnected as flat patterns of microscopic circuits within a single material, silicon. The fabrication process eliminated the need for separate components that were laboriously hand-wired and soldered together, making it possible to manufacture many transistors simultaneously and permitting the miniaturization of electronics. For the past thirty years much of the design effort and competition among companies has been devoted to researching ways to pack an increasing number of electronic components into ever-tinier spaces. The earliest silicon chips contained two transistors; today ten million transistors can be integrated into one microchip, and it is estimated that by the end of the century a single chip could contain a billion transistors.



ENIAC Computer. 1946. A single microchip today has significantly more computing power than ENIAC, which was 18 feet high, 80 feet long, and required 18,000 vacuum tubes. The ENIAC's main purpose was to calculate trajectories of artillery shells.

Microchips are the core of the portable computer, which can outperform the unwieldy room-size computers developed after World War II. A single chip no larger than a thumbnail is faster, more reliable, less expensive, and has more power than the first large electronic computer, ENIAC (Electronic Numerical Integrator And Calculator), developed in 1946. And it requires only the power of a single lightbulb to operate. It can perform millions of calculations per second and its small size accounts for its speed, which is measured in nanoseconds—billionths of a second. In comparison, snapping one's fingers takes approximately five hundred million nanoseconds.

Miniaturization characterizes today's technology. In the machine age bigger was usually better, but in the electronic age the opposite is true. We are moving away from the visible, the tactile, and the directly manipulatable and toward the invisible. For some time we marveled at the microcosm through the microscope, but this world is becoming increasingly accessible and familiar to us. The microscopic level has already been penetrated by biologists, chemists, and physicists, and now computer scientists are actually designing for it. They are mapping technology, diagramming electronic circuits whose functions are embedded in the minuscule structures of silicon crystals. Although perceptually the chips are tiny, structurally they are vast and complex; they now consist of ten to twenty-five layers. It is impossible to design at that level and with such density without the aid of a computer.

Although it may appear that the ever-increasing miniaturization of technology is being pursued for aesthetic reasons, it is motivated by practical considerations: it improves performance. Performance can mean many things—functionality, low power consumption, speed—and with integrated circuits these are all maximized by miniaturization. A basic rule in microelectronics is the smaller the better. The compact nature of integrated circuits allows them to operate at high speeds for long periods without failure of components. They work by "on" or "off" pulses of electric current, and the transistor is their basic switching element. The less distance electricity must travel the faster it moves, therefore more efficient chips are being achieved by increasing the number of components and by shortening the wires connecting them. By making transistors smaller, more can be accommodated in a given size chip. Furthermore, smaller transistors consume less power and switch on or off faster. In an industry where time-saving is paramount, minute differences in time—often only fractions of seconds—become decisive.

Microelectronics represents the essence of mass production. Currently, even in small companies tens of thousands of identical chips can be fabricated in a day for only pennies apiece. Because the amount of material and the manufacturing procedure remain virtually the same regardless of the number of elements, the cost of the chip does not increase significantly with the number of transistors. And chips are continuing to perform more complex electronic functions at ever greater speeds and lower costs. In fact, prices have fallen so much that many electronic products once considered luxury items are now less expensive than some of life's necessities. Integrated circuits have changed from being costly devices for use almost exclusively in space and military equipment to forming the basis of all modern electronics.

Many of the benefits we enjoy and the conveniences we take for granted derive from these tiny devices that are concealed in computer systems and in the products we use every day. As a culture we are predisposed toward speed and efficiency, and microchips have greatly increased our expectations. For example, we take for granted fast and thorough service when making airline reservations or when using electronic cash dispensers, and we expect our telephone calls to go through instantly. Computers have assumed much of our routine work and have alleviated many tedious tasks and computations. When the first computers were invented after World War II, many scientists thought that only a handful would be sufficient for the entire world. Today they number in the millions and may soon become as commonplace as televisions.

Despite their ubiquity there is an element of mystery to integrated circuits. They are mysterious because they are sensorially inaccessible to us. They have no visible moving components, gears, or levers and they are silent, yet they perform operations and calculations at imperceivable speeds. The only movement involves electrons, which equally elude our senses. We press buttons to interact with electronic devices and the results come immediately, but most of us do not have the knowledge to understand how it happened.

Since even on a computer screen the diagrams are too small and too dense to be legible, the plots are produced as tools for viewing the design and verifying the circuit layouts. They are like multilevel road maps, with the transistors and circuits resembling highways, valleys, rivers, and small back roads. They are indispensable: usually generated as three- to four-foot-square drawings, they provide engineers with an overview of the layout and the relation of its subdivisions, and assist them in determining which areas of a chip can accommodate more components. Colors and textures distinguish the various circuit layers and the spatial relationships of elements. White areas indicate unused space—territory that is still available for development.

The plots are laid out in a grid format, and each circuit component is located at a specific "address" on the coordinate system. The grid is a form we can understand, for it has been used for centuries by many civilizations as a compositional device to impose order, discipline, and structural clarity. It is an ordering principle consistent with our way of thinking, reading, and organizing information. The most efficient construction we can make to store and retrieve information, it is also a visual aid to thinking. When we let our imaginations roam, the grid patterns of these diagrams resemble the warp and weft structure of woven textiles, aerial views of cities, agricultural fields, paintings, calendars.

Circuit Layout

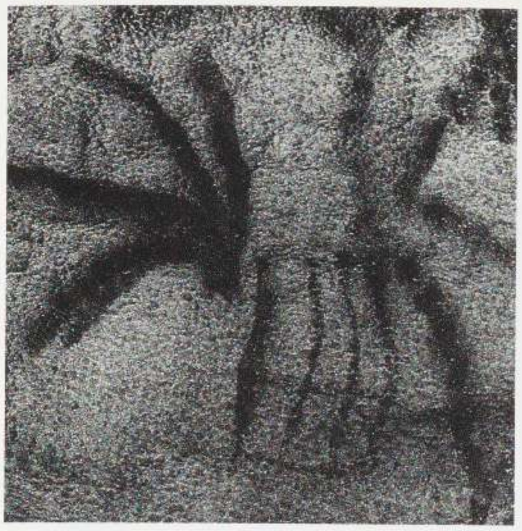
The design and pre-production planning of integrated circuits are considerably more expensive and time consuming than the manufacturing phase. Beginning with the functional requirements for a design, engineers create a network of components capable of performing the desired task. These components are then broken down into progressively smaller pieces until the design has been reduced to basic elements, for example transistors. The transistors are then assigned locations on the surface of a chip and routes are chosen for the wires needed to connect them.

Engineers often discuss the design of integrated circuits in terms of real estate. Their concerns are those of a developer: crowding, density, economy, and efficiency. Like developers, they want to optimize the use of space, fitting more and more into smaller areas. Space is organized hierarchically, and each line has a specific function. Currently computers are used for much of the placement and interconnection of components. They insure that each of the millions of geometric features on a microchip is sufficiently separated from its neighbors. The proximity of the wires is crucial: if they are too close they interfere with each other electrically and produce short circuiting. Because the thickness of the wires is one hundred times finer than a human hair, it is remarkable that engineers can still calculate for tolerances in manufacturing to prevent wires from overlapping.

Before the actual fabrication, computers also perform extensive simulation of designs in order to verify that the microchips will operate correctly and at the desired speed. Some circuits now have approximately five million intersections, and a single error can render a chip useless. As engineers gain a better understanding of the design process, ever larger portions of the procedure will be automated, allowing designers to concentrate on the more creative aspects of design such as developing alternative solutions.

Microchips serve a wide range of purposes, and the character of their patterns varies accordingly. The diagrams illustrated here have been organized by type: memory, logic, microprocessors, application-specific (ASIC), and neural nets. The complexity of the plots is determined by the number of components and by the functions they are to perform. A multiplicity of operations can be achieved by combining the basic building blocks—transistors and wires—in different ways. Their diverse patterns convey the chip's function.

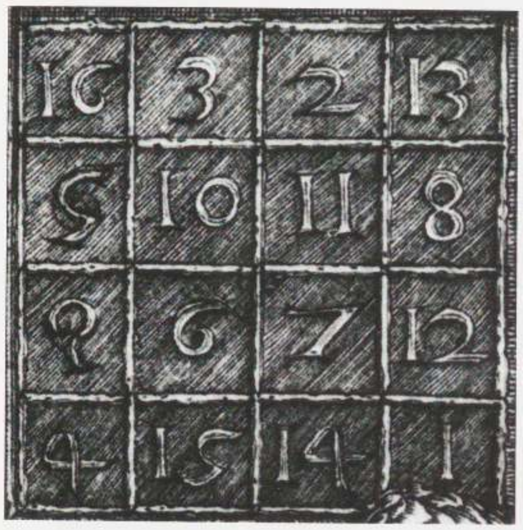
Memory chips store enormous quantities of



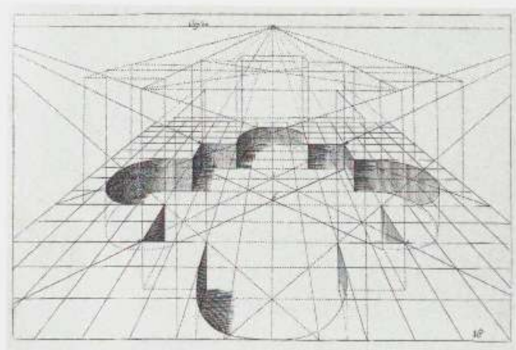
The cave of Lascaux, France, 15000 B.C. The grid symbol in the cave paintings of Lascaux is perhaps the earliest depiction of a grid.

Chinese character for "field."

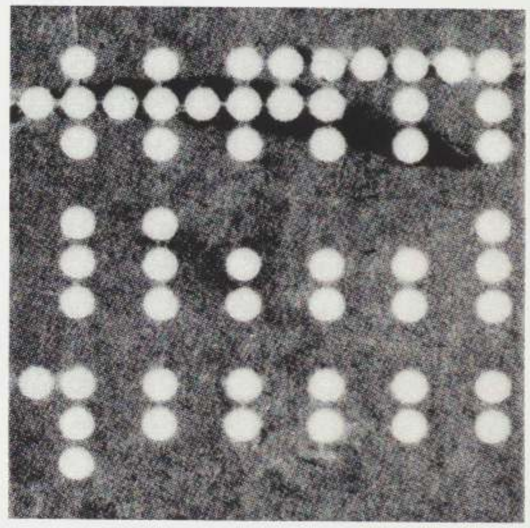
Timgad (Thaumgadi, Algeria). 100 B.C. An aerial view of a Roman city laid out on a rigid orthogonal plan.



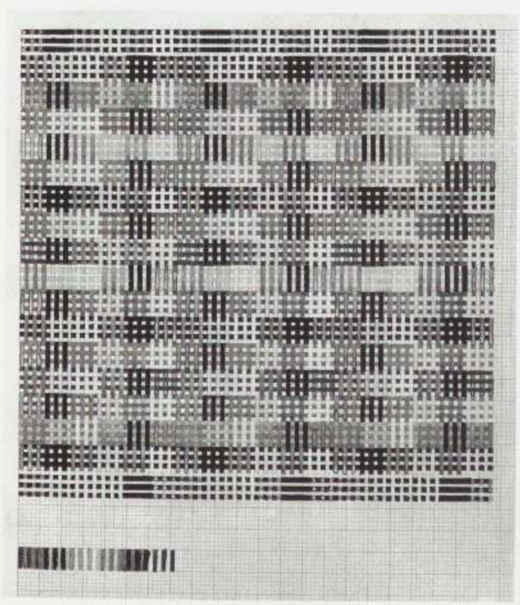
Albrecht Dürer. *Melencolia I*. 1514. Engraving (detail). National Gallery of Art, Washington, D.C., Rosenwald Collection.



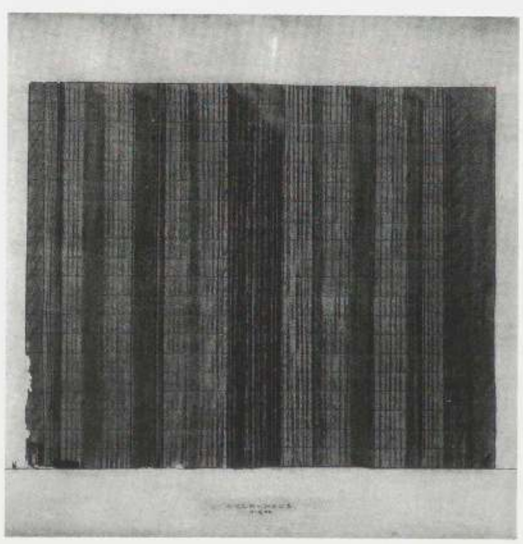
Jan Vredeman de Vries. 1604-05. Engraving. This engraving shows the use of the grid structure to define architectural perspective.



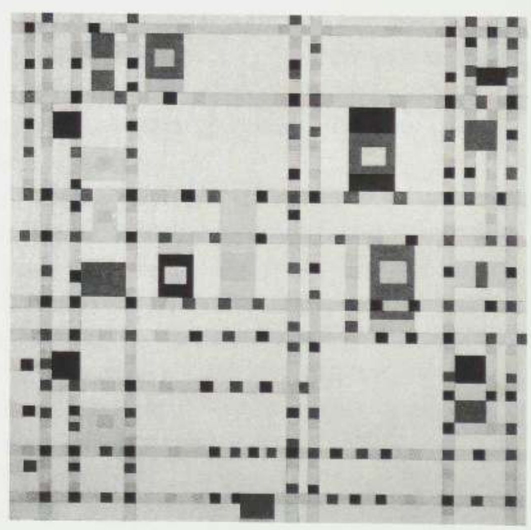
Jacquard Loom Card (detail). c. 1800. Punched paper card used to control the pattern woven by a Jacquard loom.



Anni Albers. Design for tablecloth. 1930. Gouache. The Museum of Modern Art, New York. Gift of the designer.



Ludwig Mies van der Rohe. *Friedrichstrasse Skyscraper, Project*. 1921. Elevation (east side). Charcoal, pencil on brown paper. The Museum of Modern Art, New York. Gift of Mary Callery.



Piet Mondrian. *Broadway Boogie Woogie*. 1942-43. Oil on canvas. The Museum of Modern Art, New York. Given anonymously.

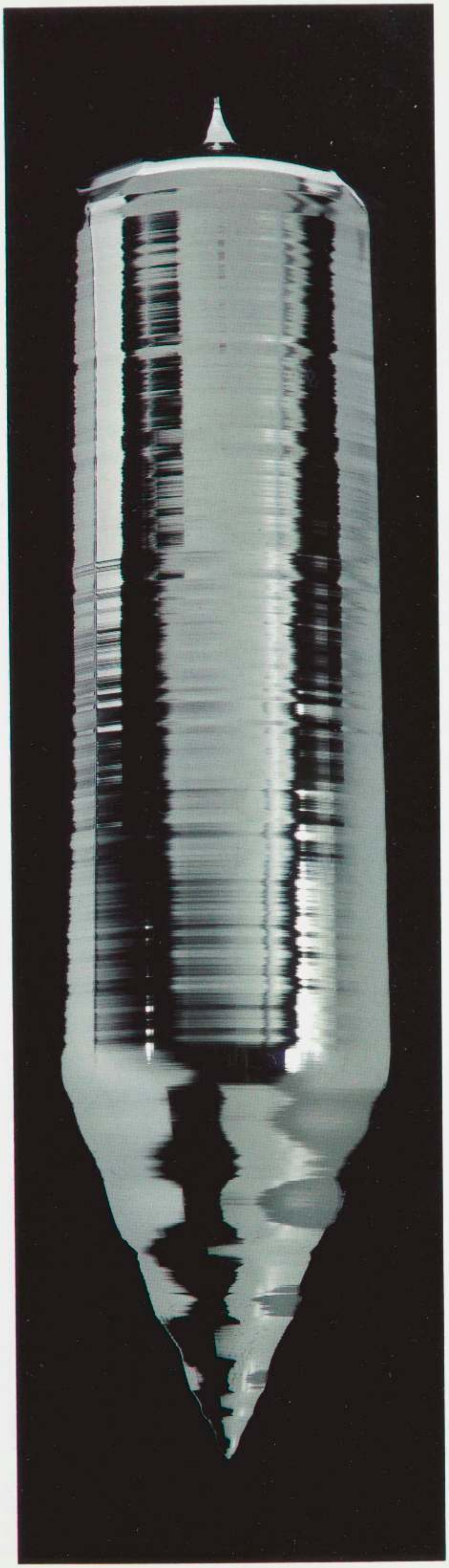
information. Laid out in tabular form, they are primarily one cell repeated thousands of times in very dense, orderly arrays, or grids. The computer is ideal for replicating thousands of identical components with very high speed and accuracy. Memory units are the densest of all integrated circuits, often resembling impenetrable blocks.

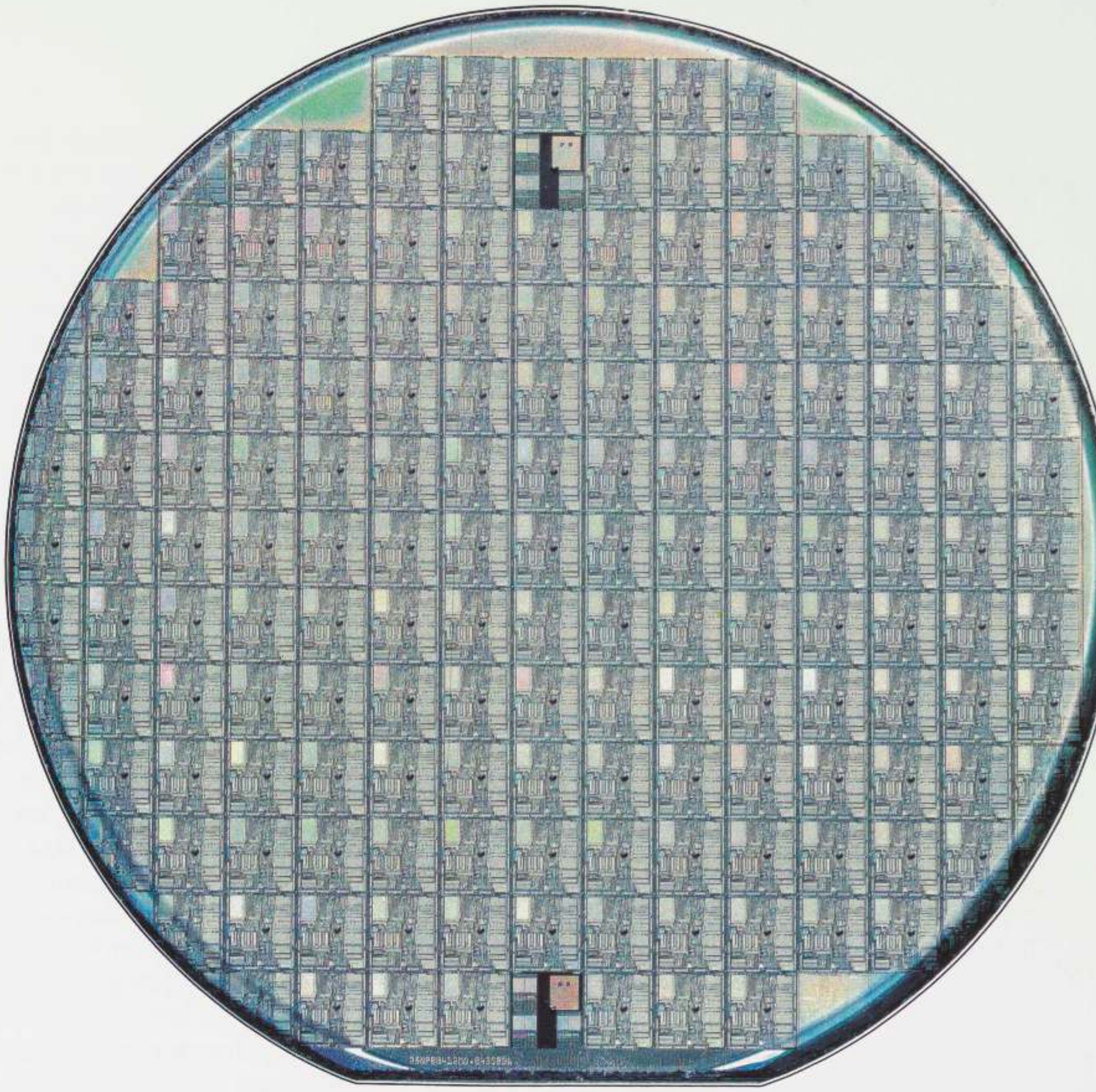
Logic chips calculate, compare, and control information or physical devices and their patterns vary considerably. Although some logic chips can be used for many applications, an increasing number of them fall into a category that has been given the name application-specific integrated circuit (ASIC). ASICs are tailored to optimally meet the requirements of a particular application and are rarely usable for anything else. For example, an ASIC might provide a critical control function for an automobile or a laser printer. In most cases they have modest performance requirements and do not need particularly large numbers of components; however, the goal is to design them quickly and cheaply. The circuit is often built using a library of pre-designed standard cells and gate arrays that are laid out in rows and wired together entirely automatically. Their veil-like patterns are less regular than the tight configuration of cells that characterizes the memory unit.

Microprocessors are used for more general applications and combine both logic and memory functions in a single chip. They are a computer's central processing unit. Infinitely versatile, they can be programmed for many different applications. The circuitry is organized into distinct regions, creating many different pattern areas. Portions of the layout are still drawn on the computer by hand to achieve more efficient placement of critical elements. They are the most difficult and time-consuming of all chips to lay out: even with automation it can take teams of twenty to thirty engineers several years to design one.

As computer technology and design become more refined, researchers are experimenting with neural nets, integrated circuits that emulate the functioning of the human nervous system. Both the hexagonal cell structures and the radial diagram reproduced here have been modeled after the human retina. Each mirrors the eye's actual neural network. They are intended to be used as eyes in robots for object and pattern recognition.

Originally circuit layouts were hand-drawn on paper, and then occasionally cut out from rubyliths, red cellophane-like sheets. Their network of lines is a looser configuration than those drawn by computer, and the connections between points are often asymmetrical and diagonal. They have a crafted look when compared with the precision associated with machine production. Computers simplify laying out the diagrams in a more uniform way, creating grids with neat rows and columns. As plots have





A silicon wafer (shown actual size) etched with 142 identical 386 microprocessor chips. The two darker squares at top and bottom serve as test chips.

OPPOSITE: A silicon crystal before it is sliced into individual wafers.

become increasingly complex, the layouts have by necessity become more rectilinear and regularized. The diagrams are so intricate today that it often takes hours to print one.

The change in character from the early plots to the more recent ones resembles the change from ranch house to high-rise, from suburban sprawl to city. Initially, silicon is like a vacant lot. Since the earliest integrated circuits had few components, their configurations spread out much like a ranch house. Today the dense compositions are built up in planes with several layers consisting of detailed patterns of tens of thousands of transistors and circuit structures. The bottom layers are even buried within the silicon itself, forming the foundation.

Although the design of integrated circuits is guided by principles of logic, there is leeway for individual character. If five engineers were given an identical set of instructions to design a chip no two solutions would be alike. There are many different styles of implementing a chip's structure to have it perform the same function. The design is arbitrary in the sense that elements can be arranged in innumerable ways. Color is an individual preference, and every company has its own distinct look.

Fabrication

Integrated circuits begin as tiny pieces of sand. Silicon, found in common beach sand, is the second most abundant element in the earth's crust. In its pure form silicon conducts very little electricity, but by altering its state with the addition of minute amounts of other materials, it becomes a semiconductor. In other words, it can function as either an insulator or a conductor of electricity and is therefore an excellent material to use for structuring pathways to control the flow of electricity.

The development of integrated circuits depends on our ability to control and manipulate the atomic structure of materials. The raw material silicon is prepared by first purifying and heating it to its melting point. Molten silicon is then grown from seed crystal into a large, cylindrical crystal averaging four feet in length by six inches in diameter. Because misaligned atoms can obstruct electronic pathways, the material must be flawless; by growing silicon synthetically in a highly controlled manner the required position of every atom can be achieved. The crystal is sliced with a diamond saw into thousands of very thin discs, called wafers, onto which the circuit layers are etched.

Using fabrication methods that differ radically from traditional manufacturing techniques, microchips are processed rather than assembled from discrete parts. The microscopic circuits are etched onto silicon wafers by photolithography, a technique borrowed from printing technology. Integrated circuits are built from patterned layers of different materials stacked one on top of another. During fabrication a mask or template is constructed for each of the ten to twenty-five individual layers. By exposing various chemicals to light projected through the mask, a copy of the template can be created on the surface of the silicon wafer. Hundreds of identical chips can be fabricated simultaneously on a single wafer. The exact alignment of the patterns is critical. The fabrication process represents the epitome of precision: there is little room for error. In the end each integrated circuit is tested and then sectioned into individual chips.

Defective chips must be discarded—it is physically impossible to repair them. There are many ways that chips become damaged; for example, layers might be imprecisely aligned, or might be too thick or too thin. Even the tiniest dust particles, smaller than the eye can detect, can disrupt the delicate patterns being constructed on the wafer. For this reason fabrication is performed in "clean rooms," where the air is continually filtered to a purity far exceeding that in hospital operating rooms (many bacteria are larger than the features found in today's integrated circuits). Workers cannot wear makeup or jewelry and are required to put on protective clothing resembling space suits to prevent dust, lint, dandruff, and other bodily particles from falling onto the wafers. In the most advanced facilities, workers are completely enclosed within suits equipped with breathing apparatus.

Technology does not have a form—we give it one, and integrated circuits are among the most highly designed and exquisitely crafted artifacts of our civilization. When they were invented, few realized the impact of the microchip on our society. Not only is the technology responsible for the change in many of our products, but it is dealing with some of the most vital design concepts of our time. It has encouraged researchers to pursue the design of a number of products on a previously unimaginable scale, in particular micromachinery. The same techniques used to design and fabricate integrated circuits may eventually lead to the development of miniature electric motors, compact spacecraft hardware, microscopic surgical tools, and even "microbots," programmable flea-sized robots capable of performing microscopic repair work.

The microchips themselves are perhaps more interesting than the machines in which they lie buried. They are objects of wonderment, and the diagrams illustrated here bring to life their concealed beauty. Although not designed for aesthetic appeal, the diagrams are beautiful and powerful images in their own right and are influencing textile artists, graphic designers, and painters. The texture of the lines, intrinsic spatial features, delicacy, repetitive detail, and colors create sumptuous patterns that have the same power to inspire and intrigue us as some of the best paintings of our time. They are patterns for delectation; we can take pleasure in them even if we do not understand the technology. The diagrams are, however, paradigms of technology, and their complex network of lines provide intuitive clues to the precision and efficiency we have come to associate with microelectronics. They represent our most sophisticated form of industrial design.

Cara McCarty

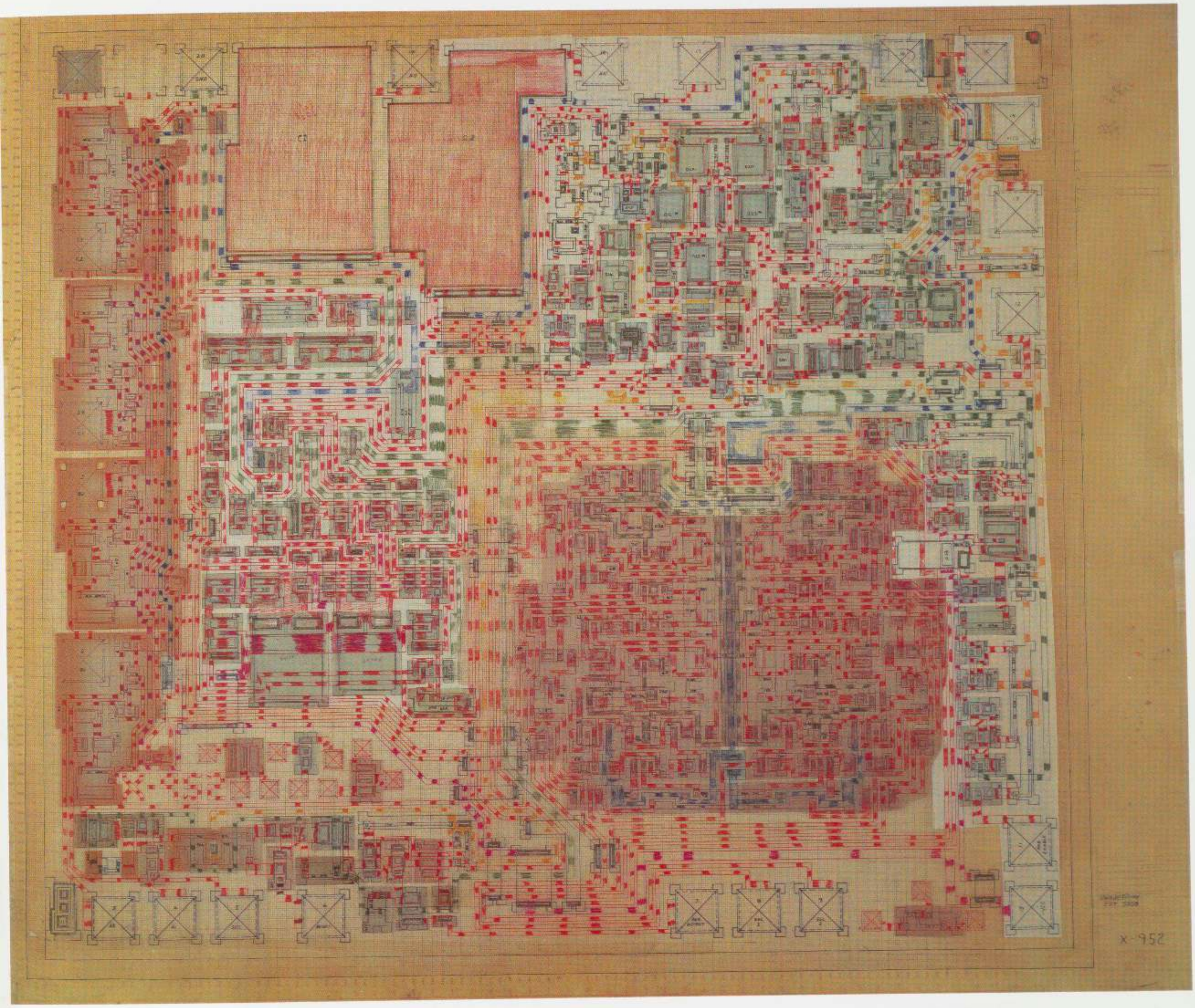
Intel 386 microprocessor chip (shown actual size). 1985. Silicon. (Diagram illustrated on page 32.)

Diagrams

Logic

Texas Instruments
c. 1976
122 transistors
Logic Chip (experimental)

At the time this plot was hand drafted, it was still possible to verify the design of individual components visually. To repeat a circuit element multiple times, an engineer would trace the initial drawing of the component, photocopy it onto mylar, then cut and glue it onto the diagram. The collage technique is referred to as "paper-doll layout." Intended for use in a military computer, this particular chip was designed to sense low-level memory signals, amplify the signals to a specific size, and then store them in a memory cell for later recall.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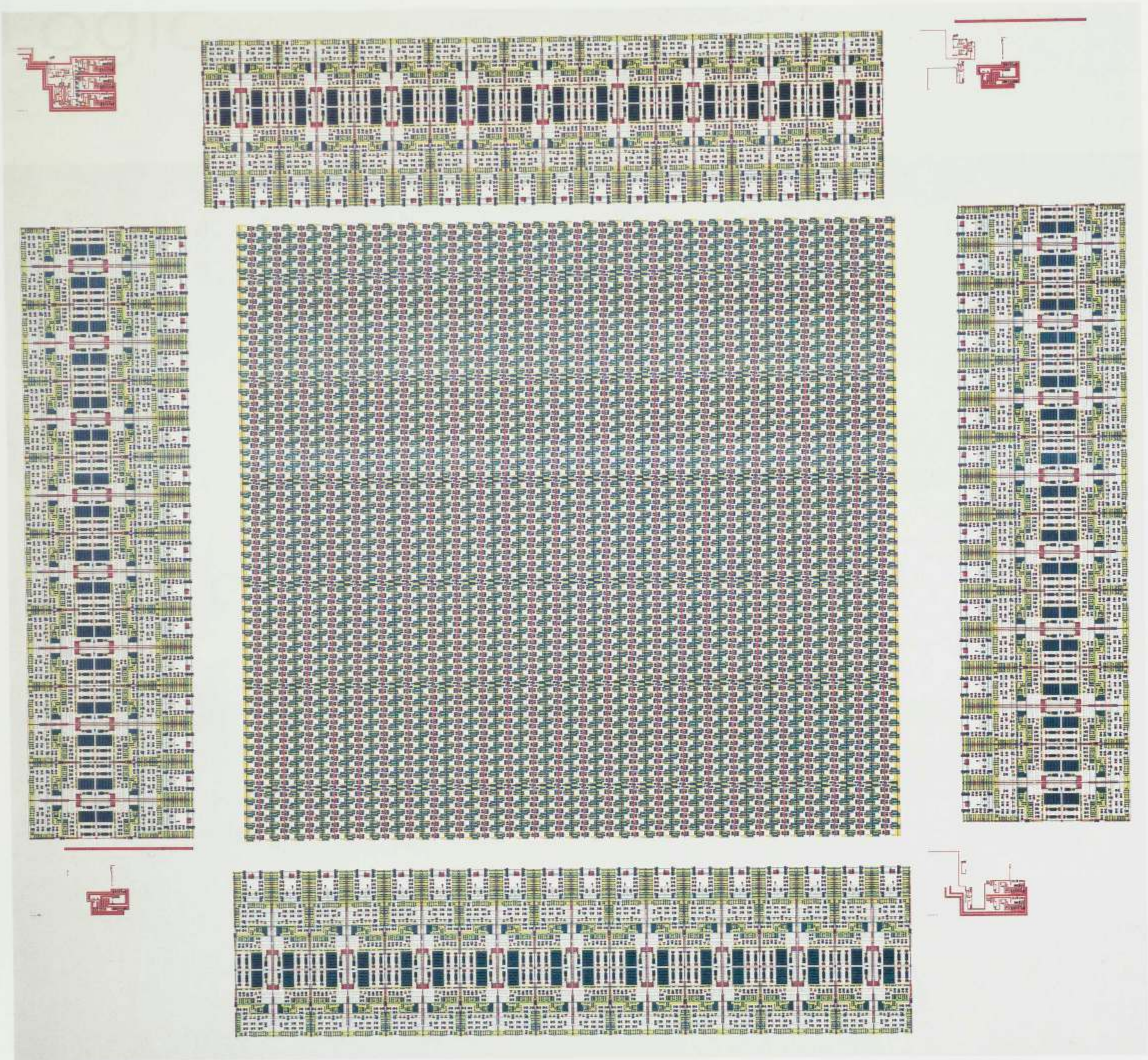
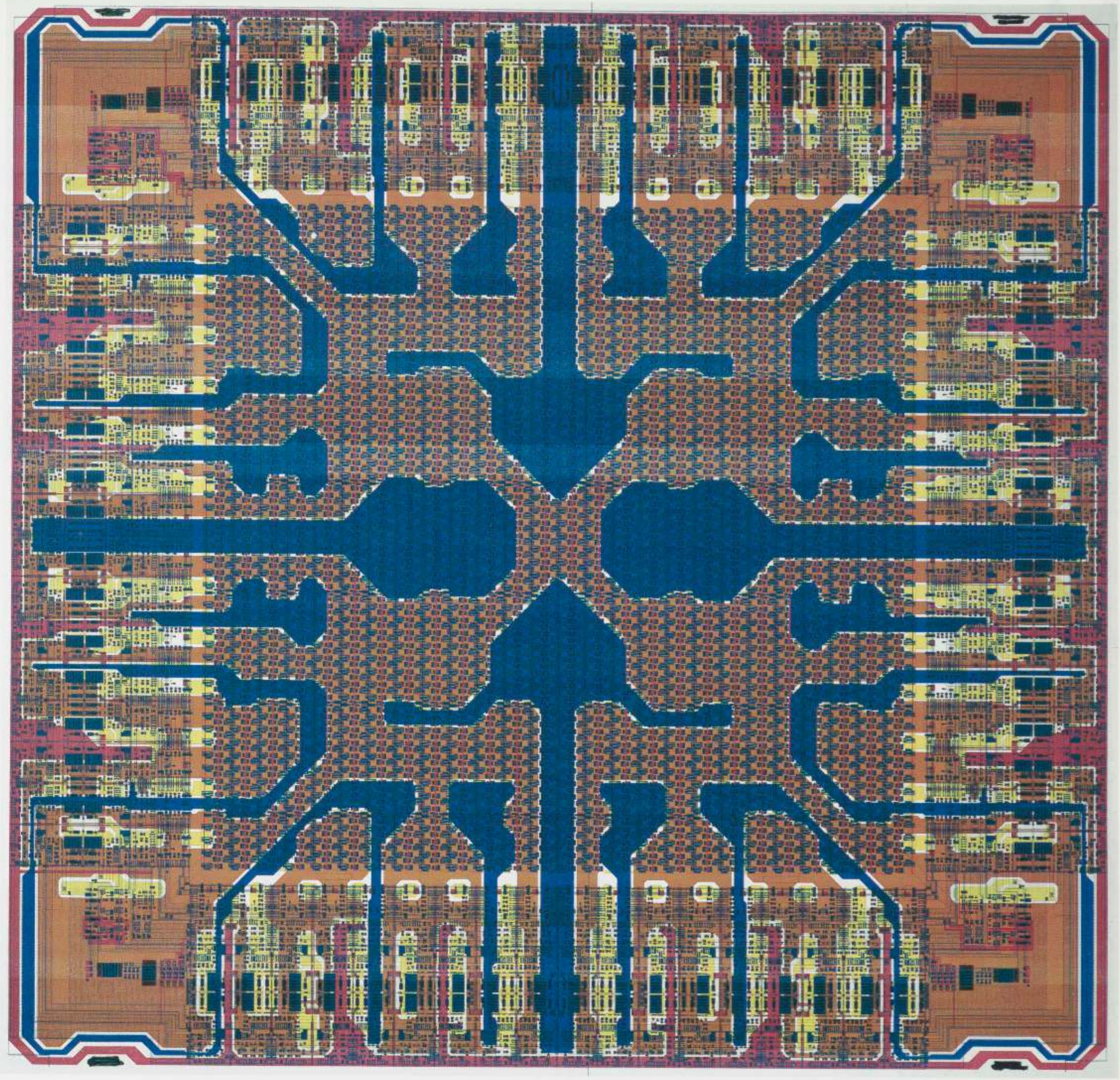


IBM, East Fishkill, New York
1986
15,000 transistors
Logic Chip

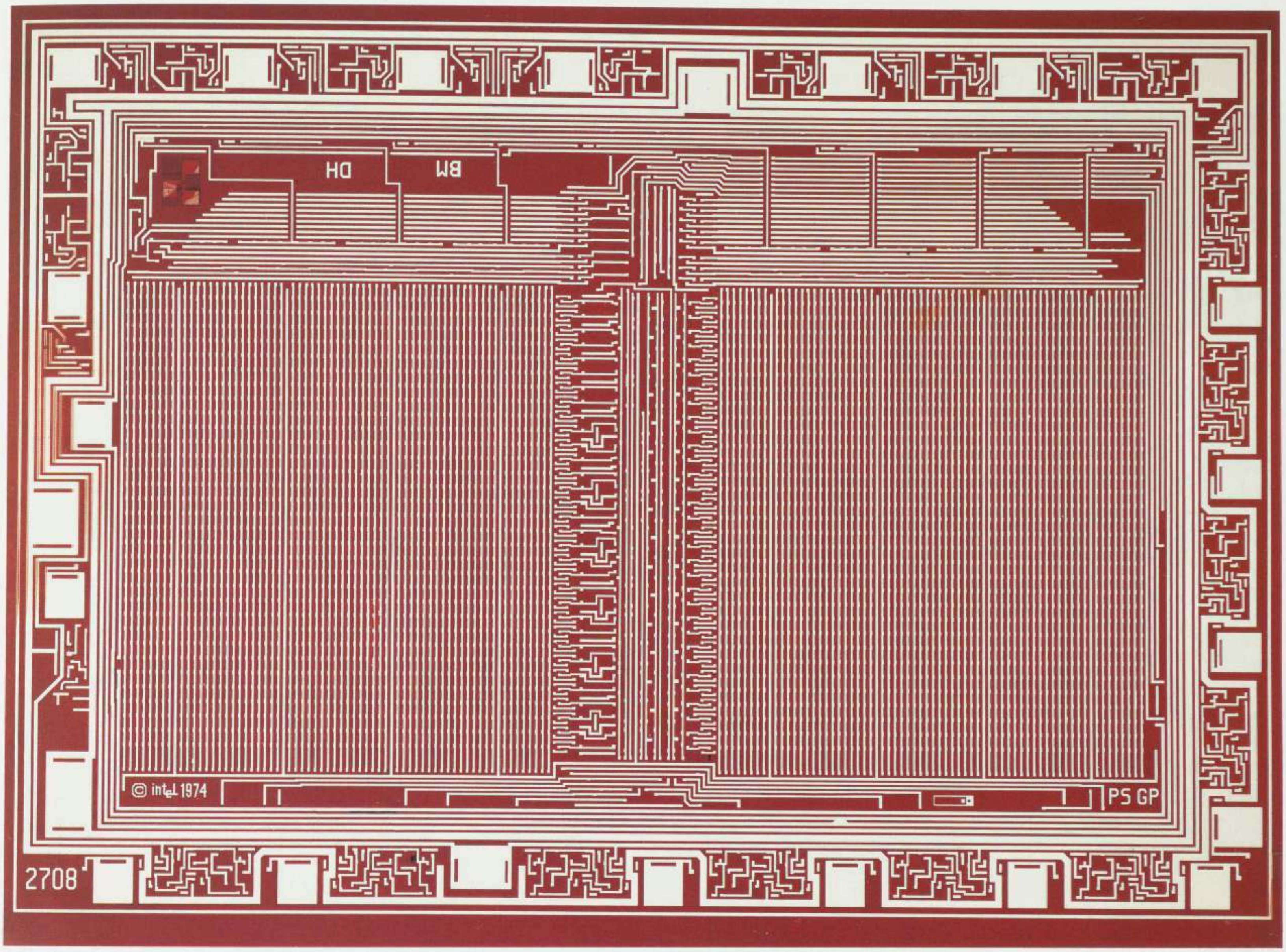
The devices on this chip are wired together to perform many different arithmetic and logic functions, and are used to assist a microprocessor in a personal computer. The uniform pattern is achieved, not with the collage technique of the previous diagram, but by using the computer to repeat one cell thousands of times. The diagram on the right shows the last metal layer that goes on top of the chip illustrated above. The orange and blue patterns represent wires that are used to distribute power to the components in the layers below.



Memory

Intel Corporation
1974
Erasable Programmable Read-Only Memory Chip (EPROM)

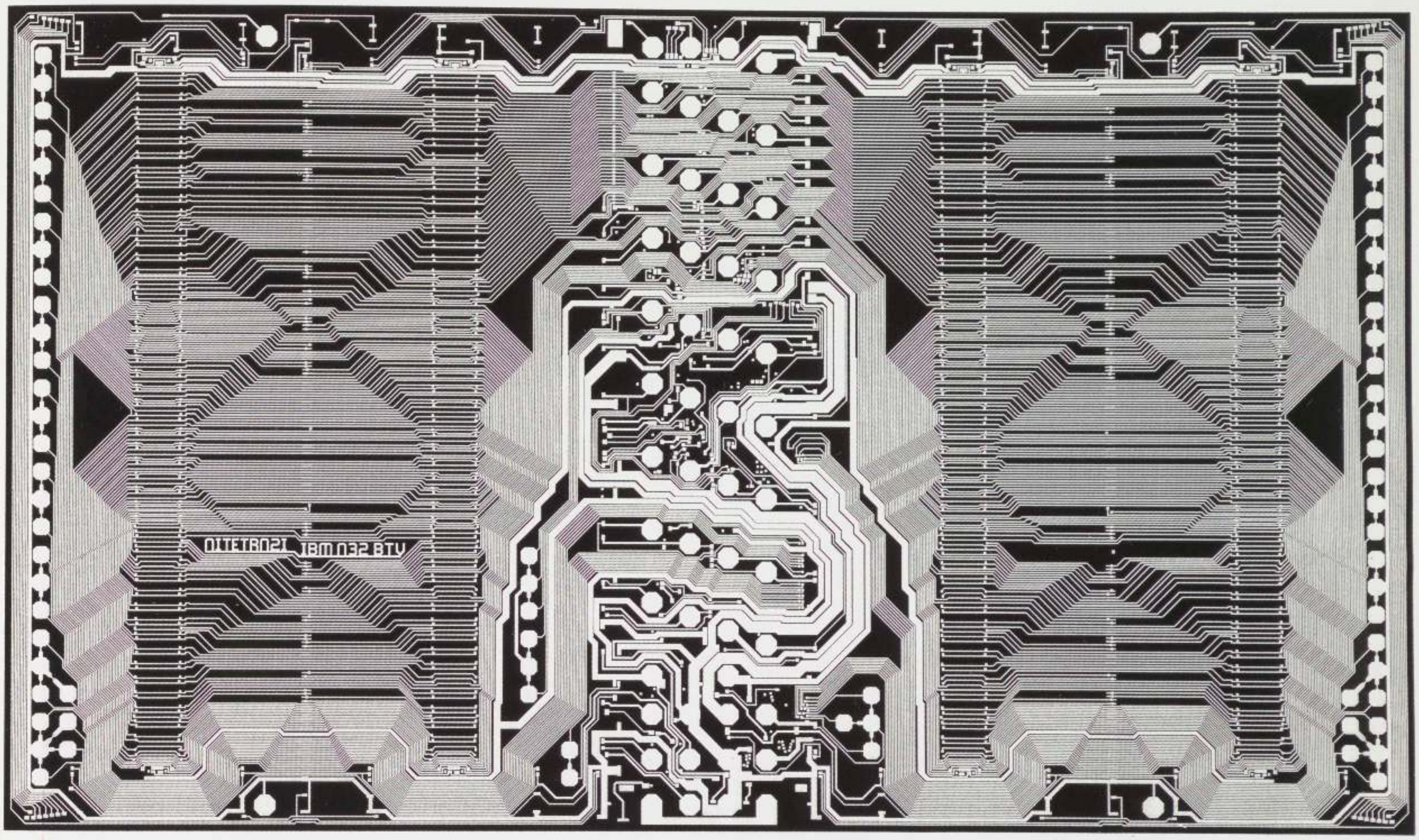
Before companies used computers to assist with the design of integrated circuits, the entire process of creating a chip was performed manually. After the design was hand drawn on paper, operators hand cut the circuit patterns into red cellophane-like sheets called rubylith. The design was then reduced photographically. The diagram illustrated here represents the metal mask, the last significant layer in the fabrication process.



© intel 1974
PS GP
2708

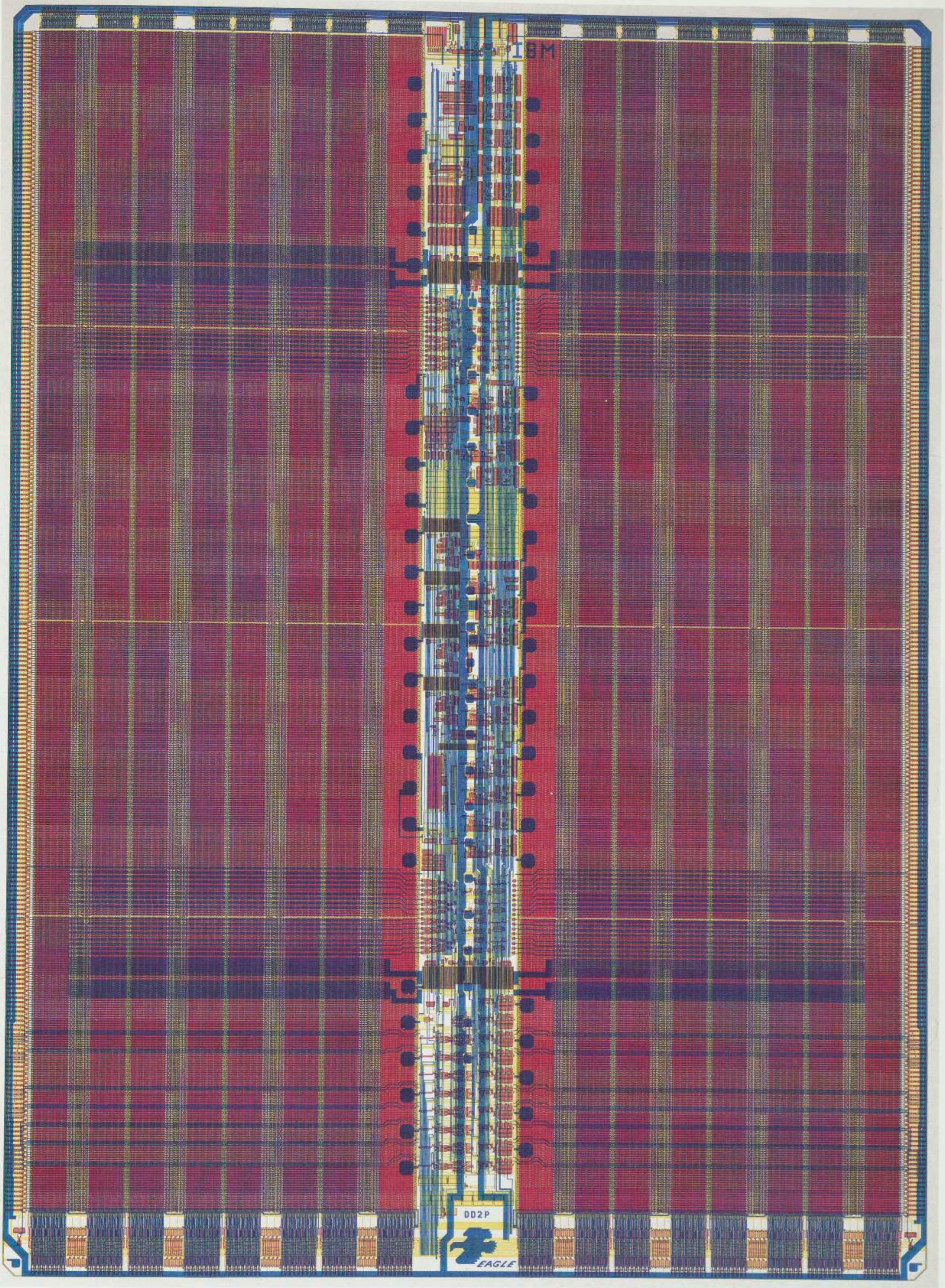
IBM, Burlington, Vermont
1982
288,000 transistors
Dynamic Random-Access Memory Chip (DRAM)

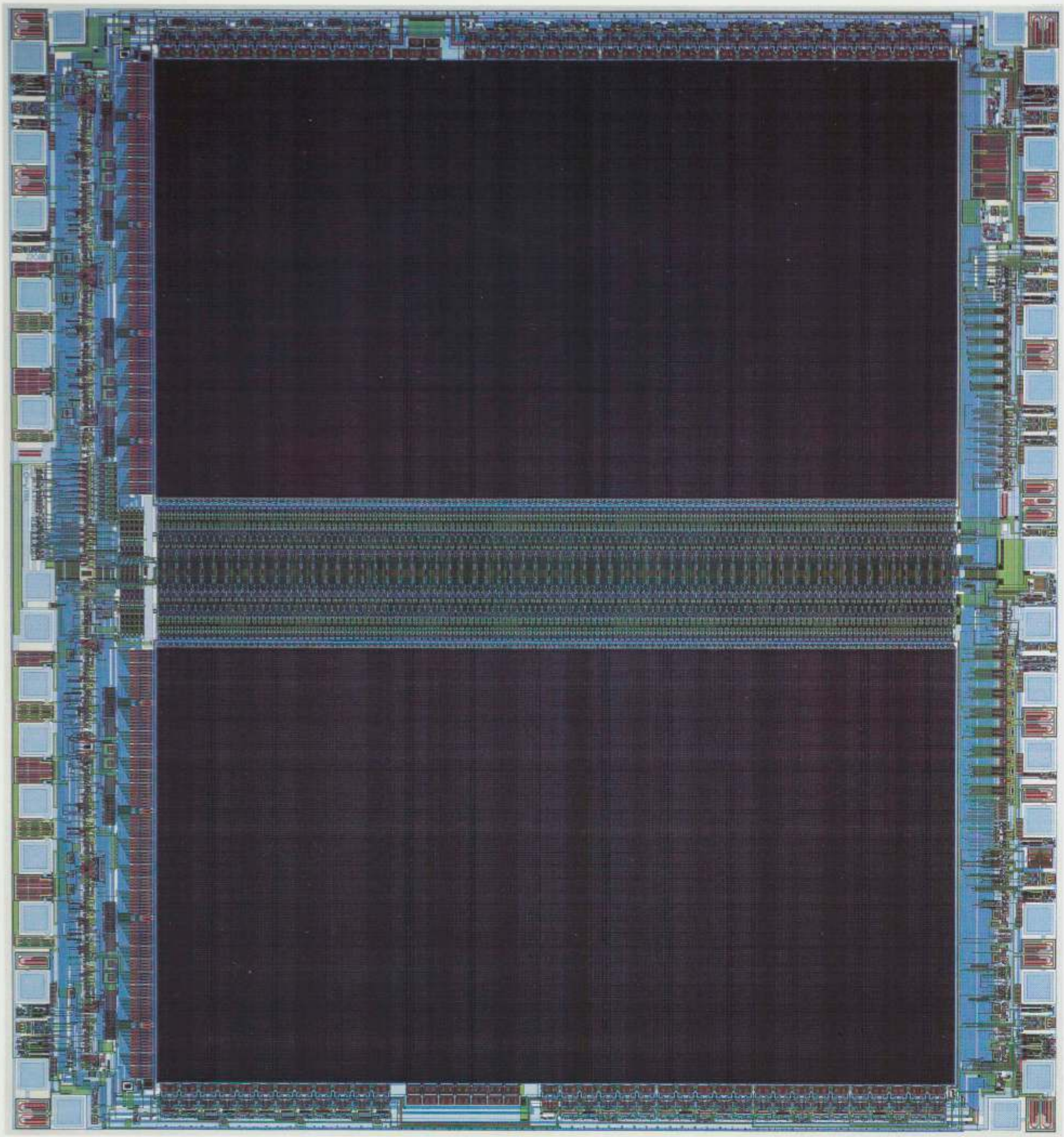
There are different types of memory chips, but the most common are known as DRAM. Often considered the main memory, they are the largest storage area within a computer. The term "random access" refers to the ability to access the desired information directly, independently of other data in the storage unit. Unlike other memory chips, DRAMs store data and programs temporarily, only for as long as the power remains on.


01TETR021
IBM 032 BTV

IBM, Burlington, Vermont
1984
1 million transistors
Dynamic Random-Access Memory Chip (DRAM)

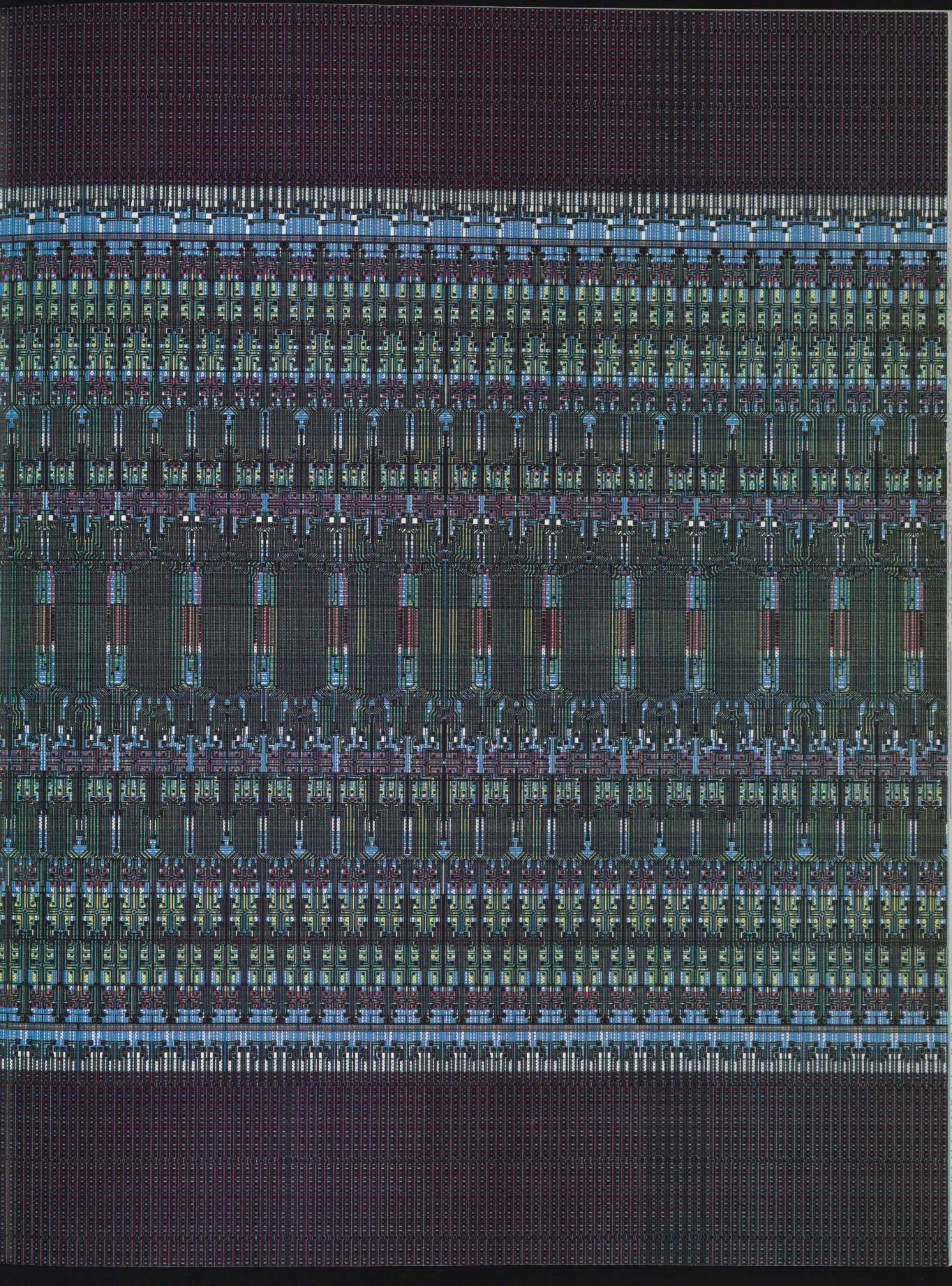
Resembling a solid block, this dense and regular pattern is characteristic of memory devices. It has the capacity to store approximately one hundred pages of double-spaced typewritten text, or one-sixth of a 250-page paperback novel. Today's chips are capable of storing the equivalent of several novels.

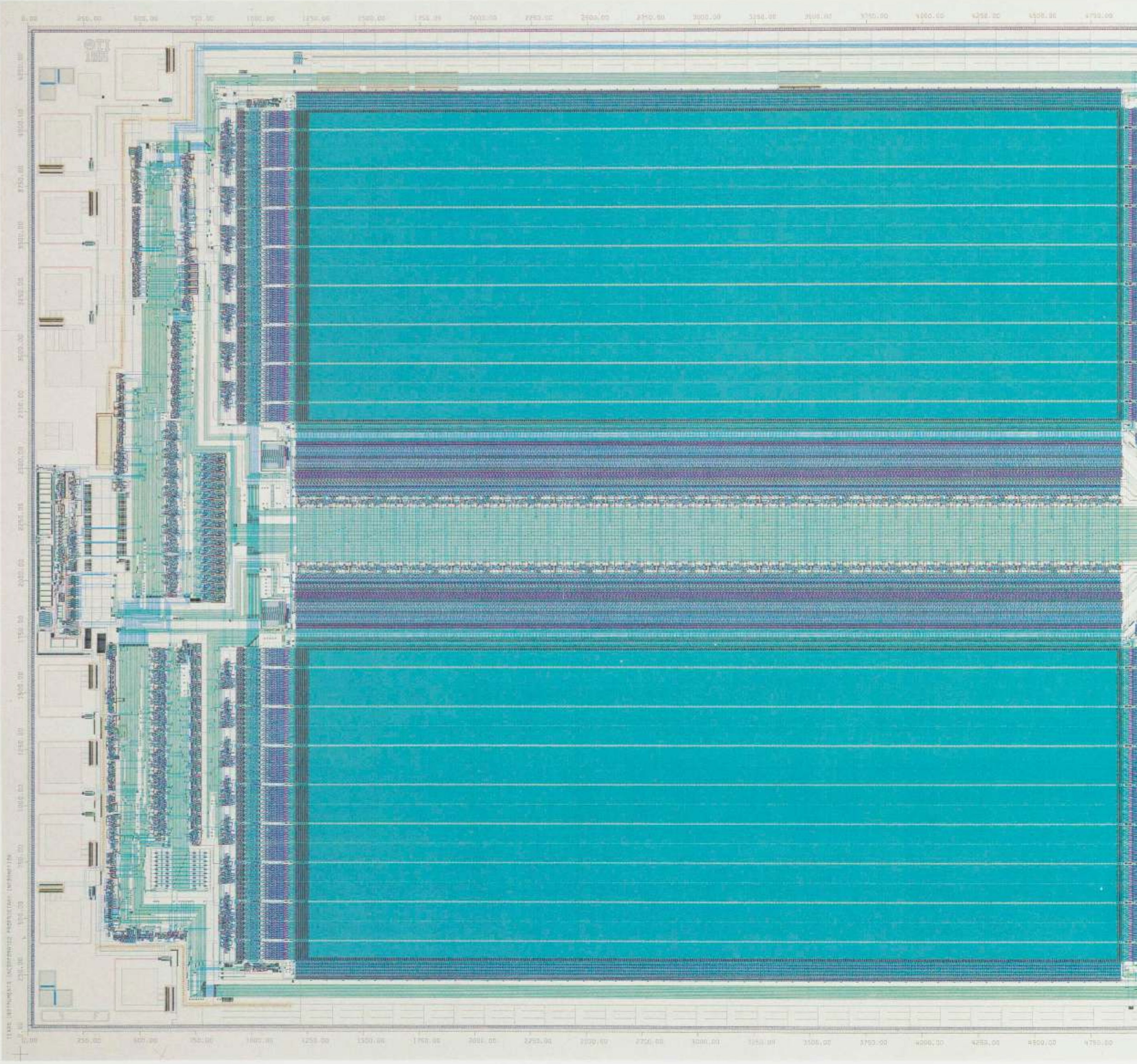

IBM
DD2P
EAGLE



Intel Corporation
1986
over 1 million transistors
Erasable Programmable Read-Only Memory Chip (EPROM)

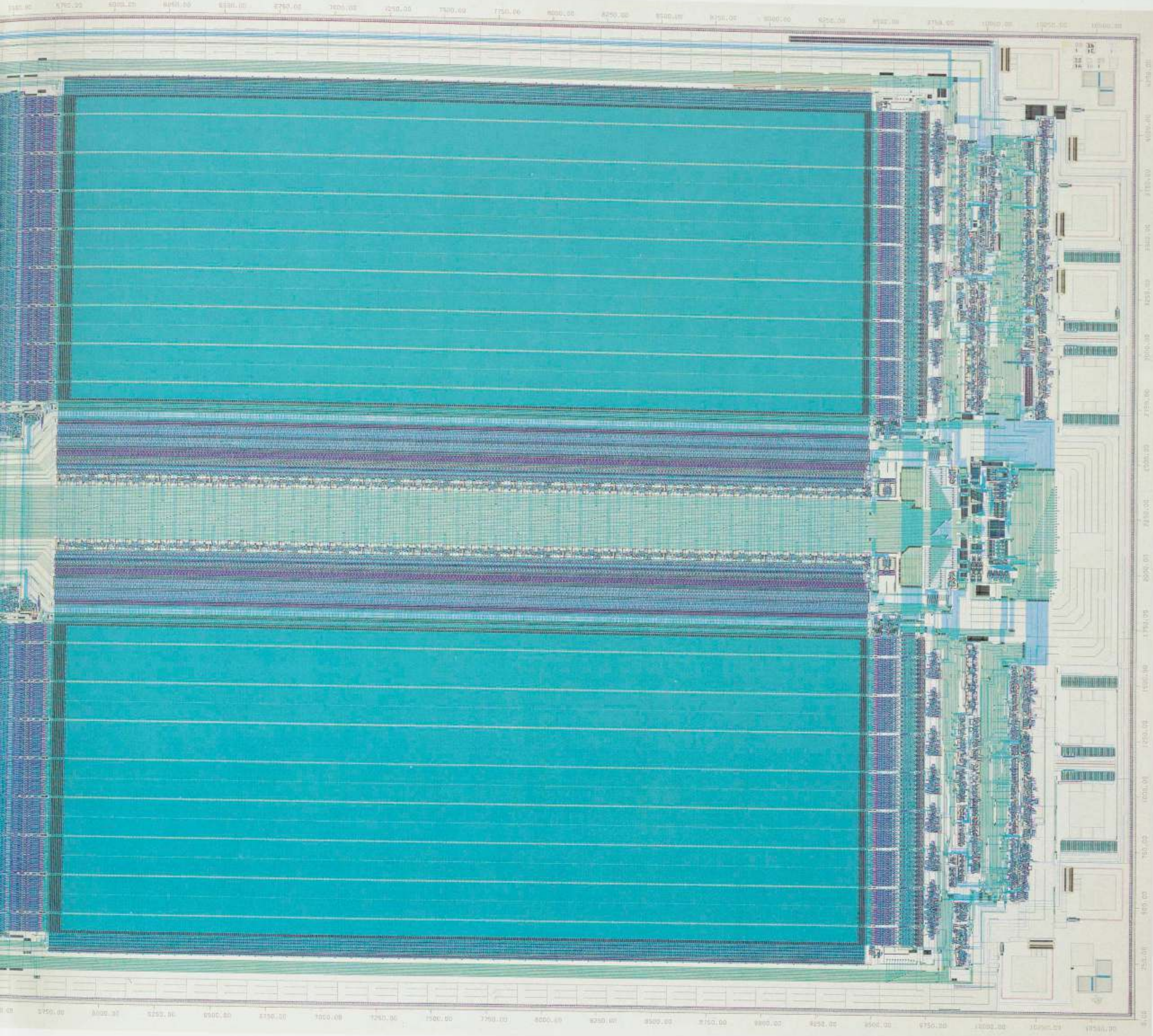
An EPROM stores information essential to a computer's operation. Unlike DRAM memory chips, EPROMs retain data even when power to the computer is interrupted. They can hold information indefinitely, but the data can easily be erased and rewritten whenever new programming is required. Opposite: detail of center circuitry.



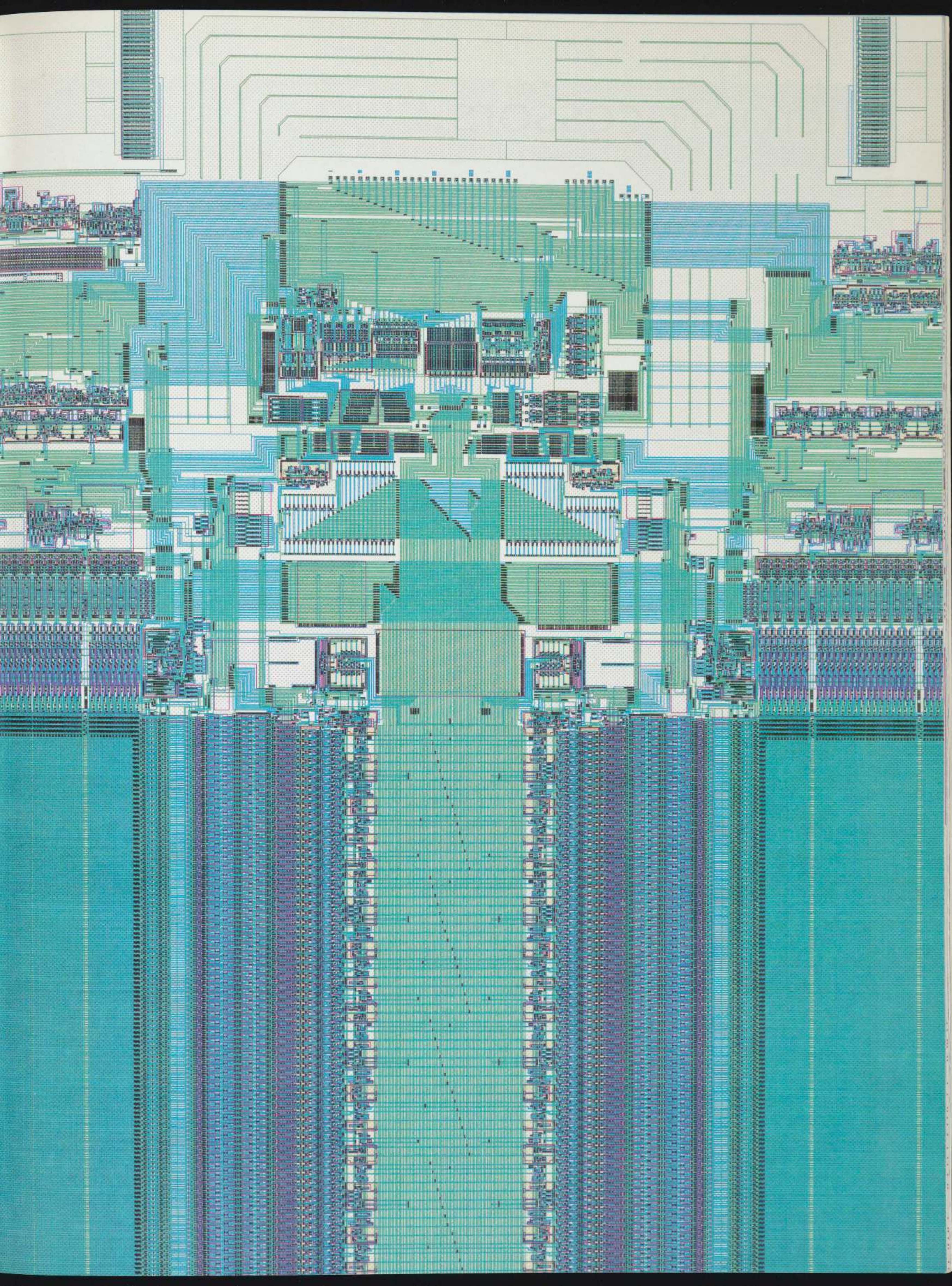


Texas Instruments
1985
over 1.2 million transistors
Dynamic Random-Access Memory Chip (DRAM)

The data storage areas are located in the four uniform quadrants, and the intricate circuitry required to access the information is located at both ends of the device. On the following page is a detail of the circuitry at one end of the chip.



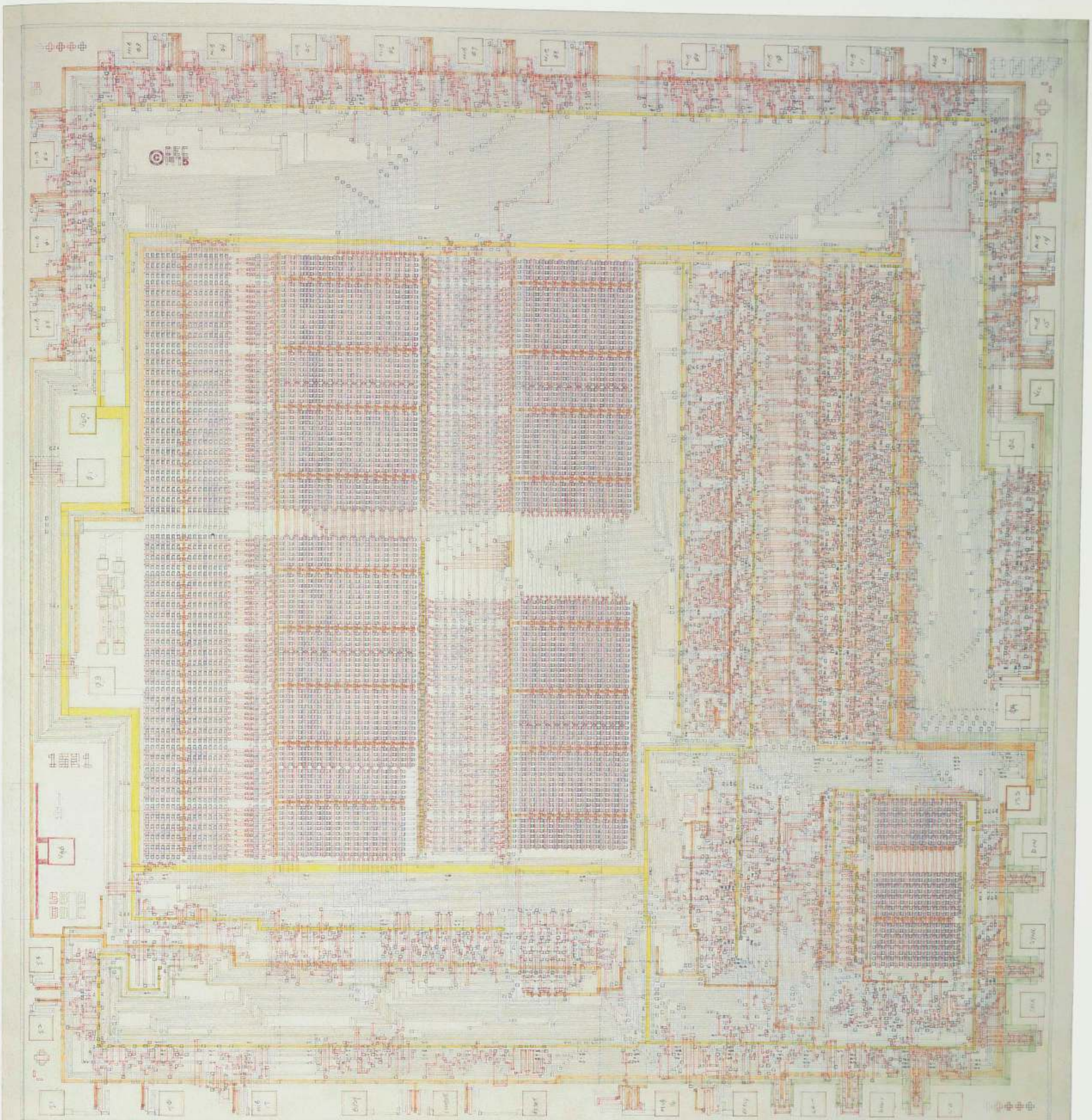
Detail of diagram illustrated on previous page.



Microprocessors

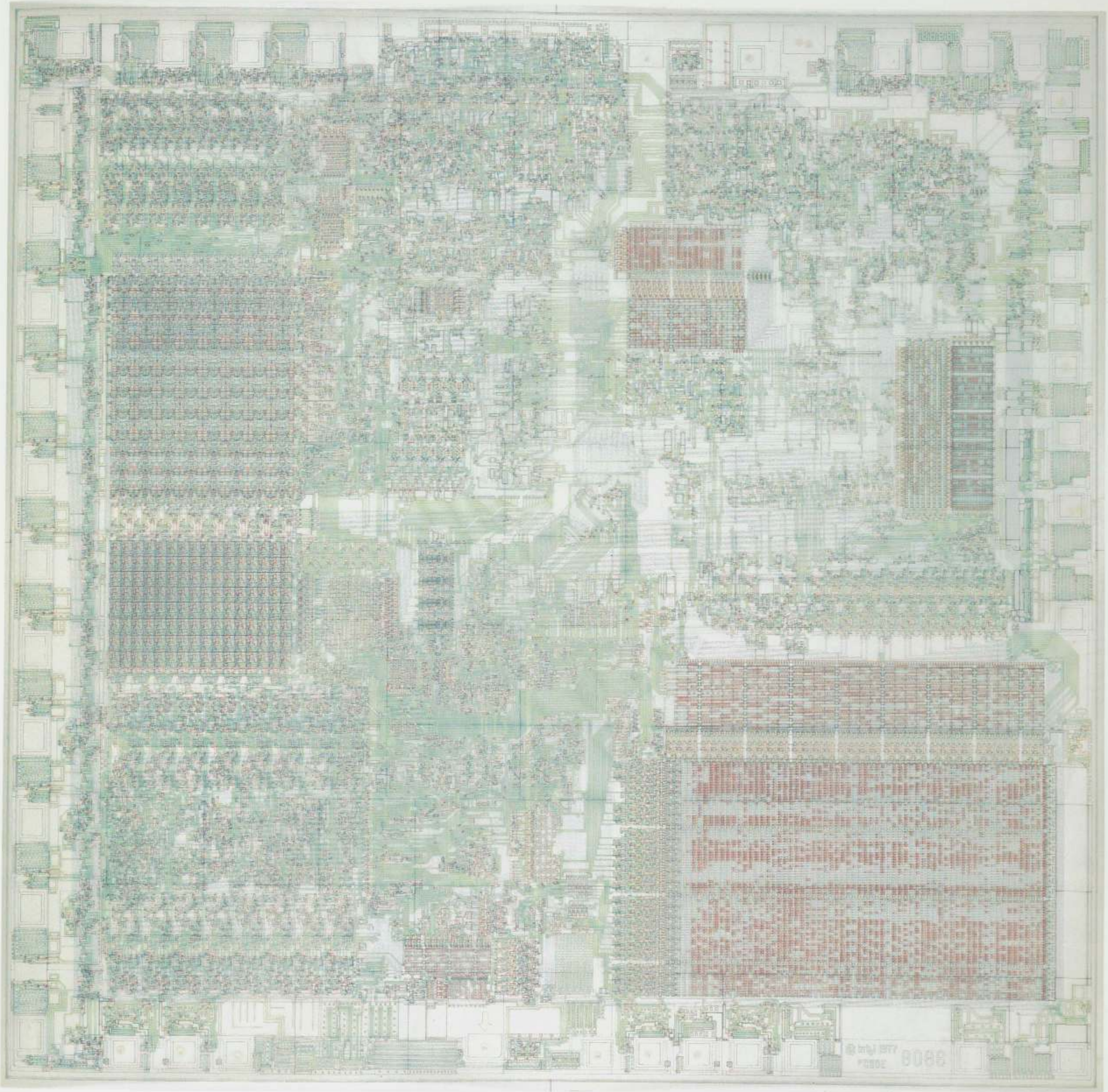
Digital Equipment Corporation
1975
8,000 transistors
Central Processing Unit Chip (microprocessor)

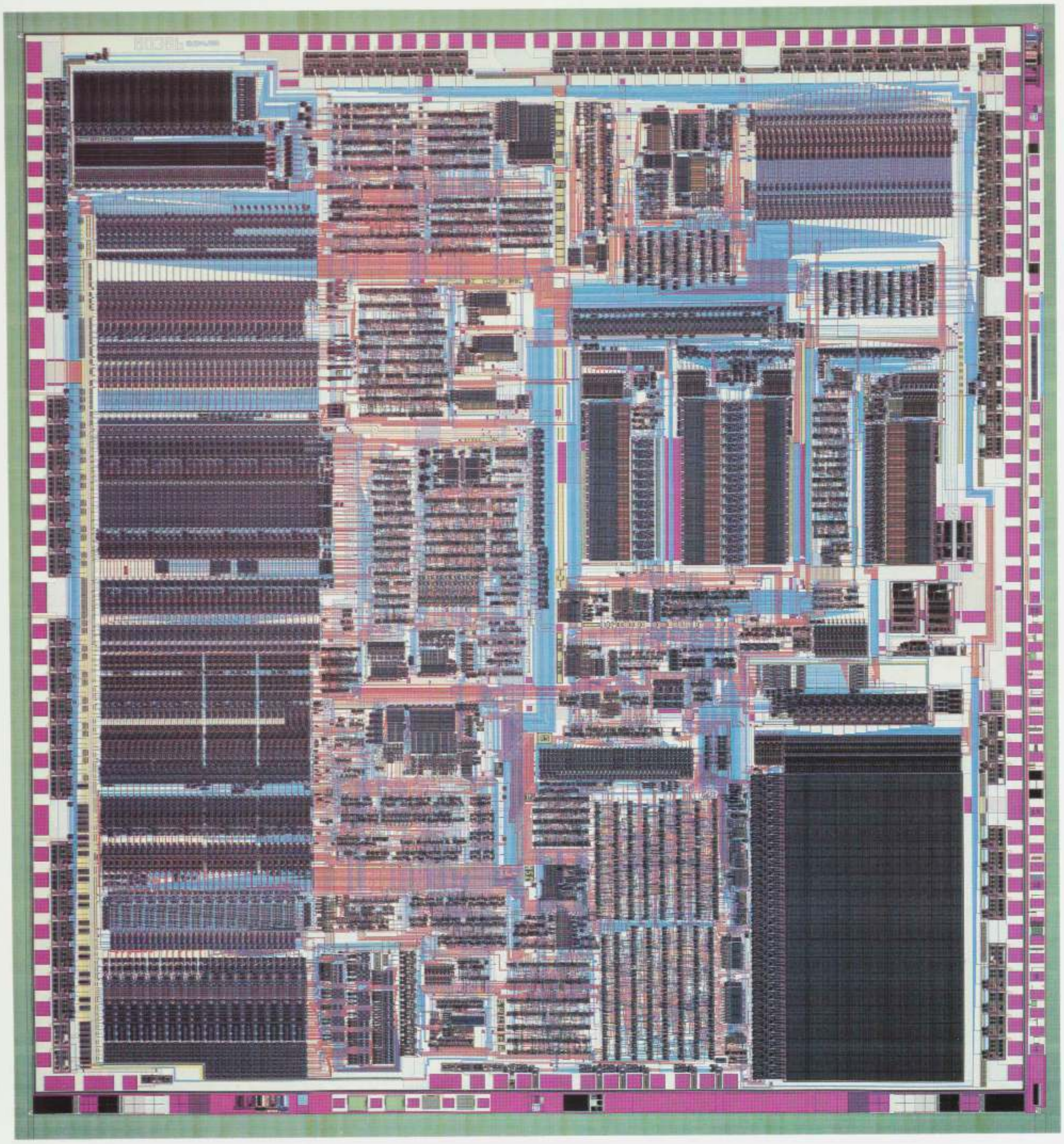
The "brain" of a computer is its central processing unit. Used primarily for medical purposes, this was the analytical element in an ultrasonic image-processor, which for example determines the status of a pregnancy without exposing the patient to potentially damaging X-rays. Other applications include those of controller for animated sign displays and remote processor for scientific experiments in hazardous areas.



Intel Corporation
1978
29,000 transistors
Microprocessor (8086)

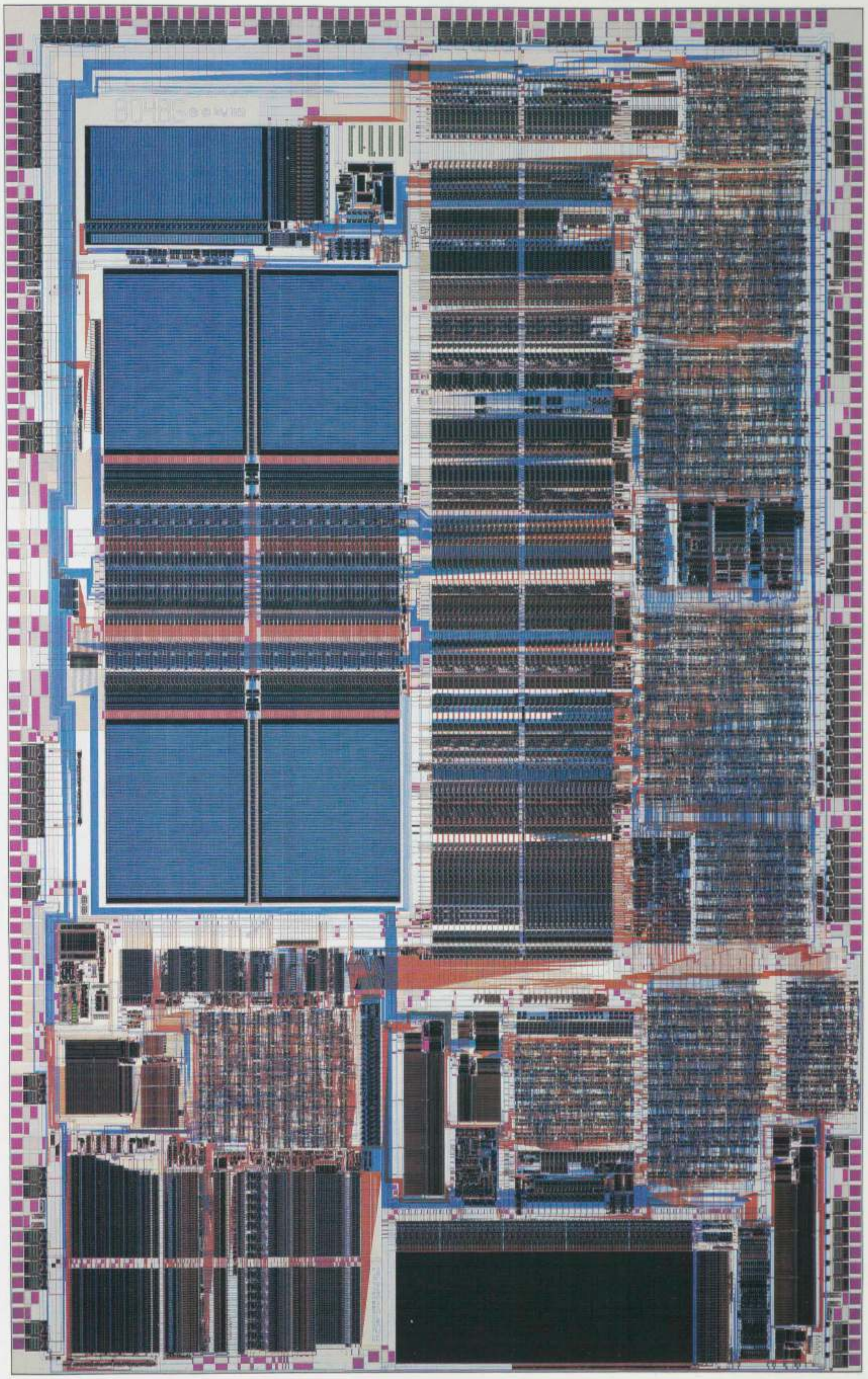
The 8086 was developed for copiers, early robots, and numerous industrial applications, but its primary use is in personal computers. Much of this diagram was designed by hand.



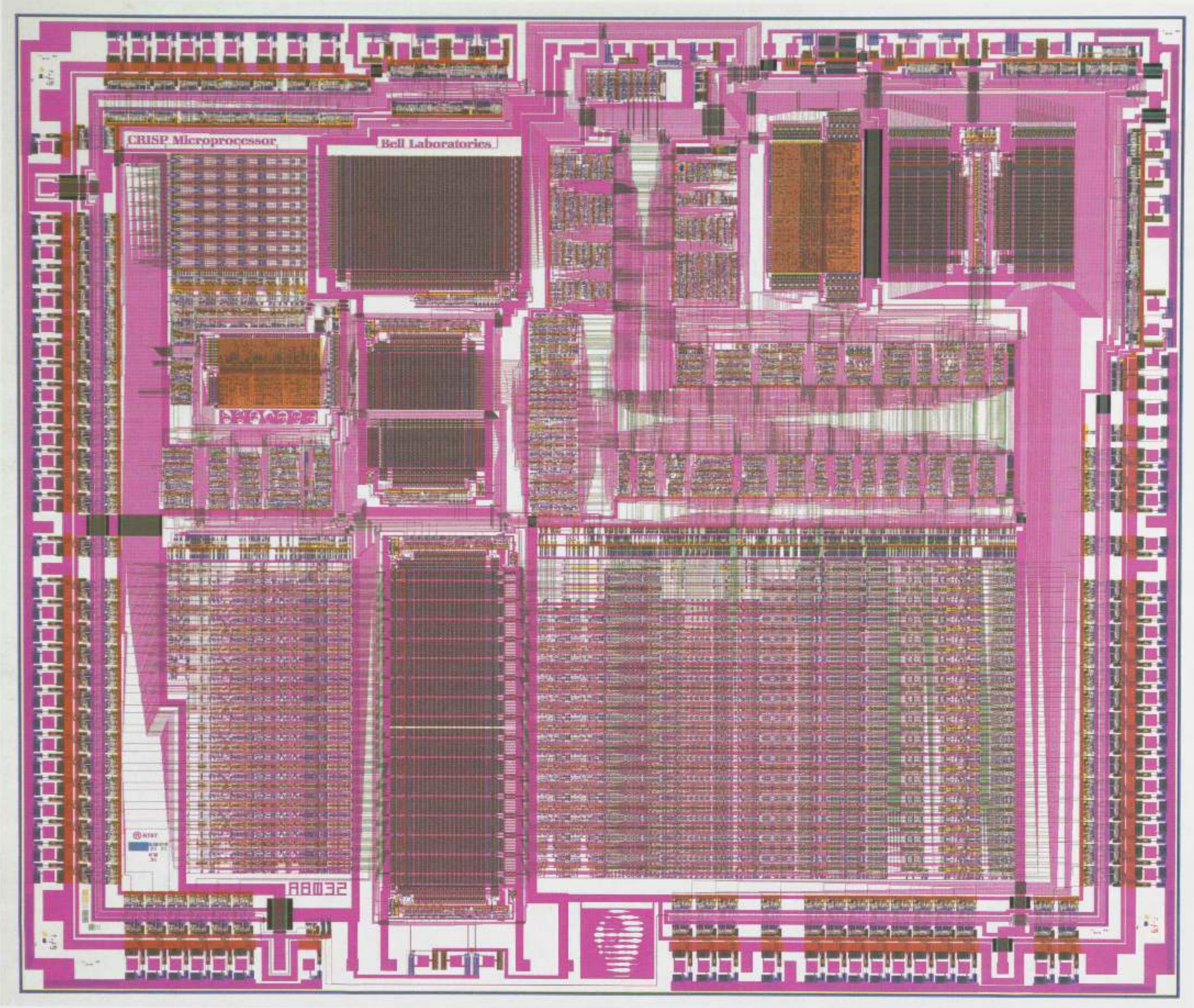


Intel Corporation
1985
229,000 transistors
Microprocessor (386™)
The Museum of Modern Art, New York. Gift of Intel Corporation

Microprocessors have the most varied pattern areas of all integrated circuits. Their web of circuitry is organized into distinct regions that perform a number of specialized functions. The diagrams on these two pages belong to the same family of microprocessors. The chip on the right is a more sophisticated and considerably faster version of the one above, accommodating what previously would have required five to six chips. The 386 chip serves many functions, and is found in trains, planes, laser printers, and telephone switches, but the most common use is in personal computers. The 486 microprocessor was designed to provide the computing power of a mainframe in a desktop computer. It is capable of executing over 20 million instructions per second.

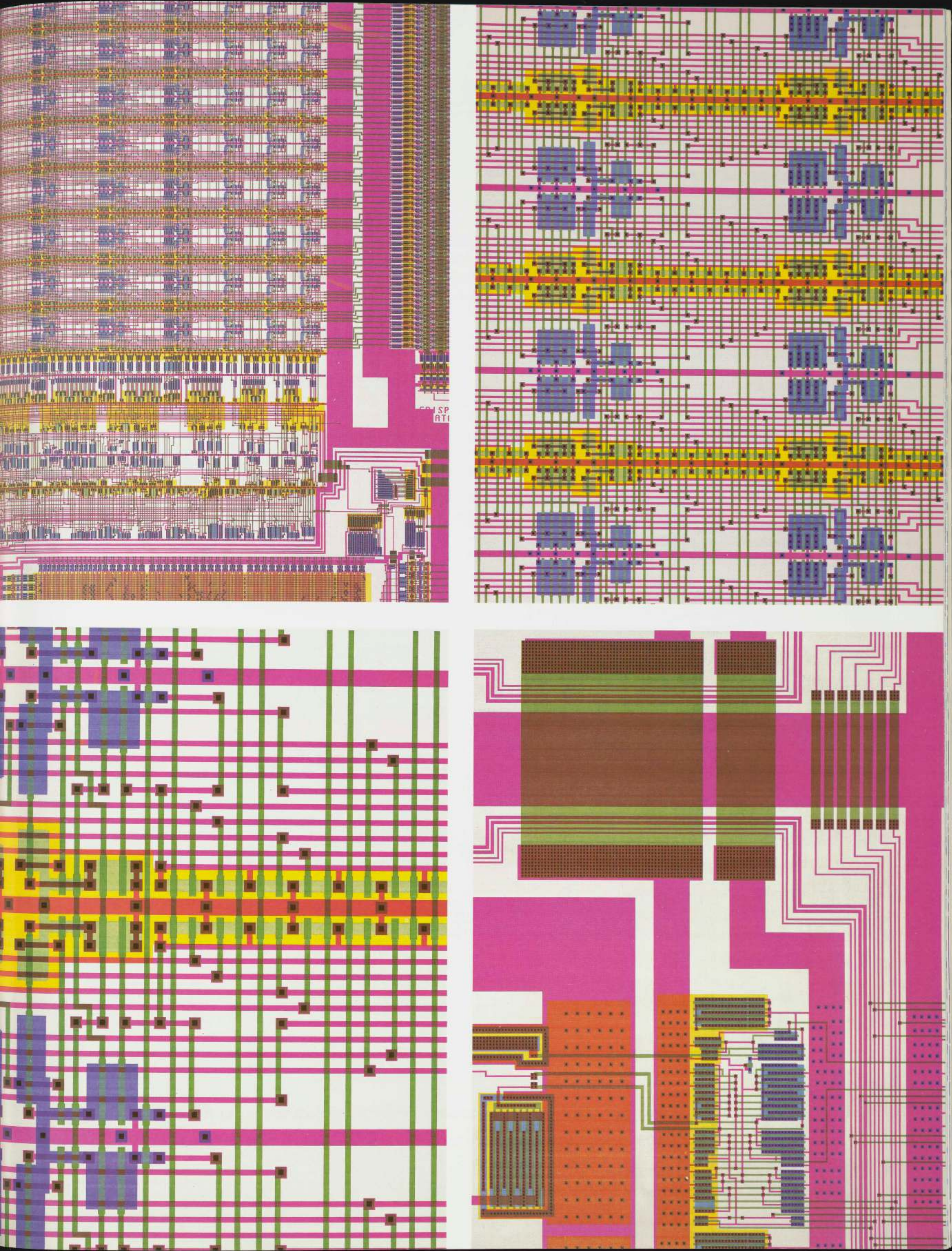


Intel Corporation
1989
1.2 million transistors
Microprocessor (486™)



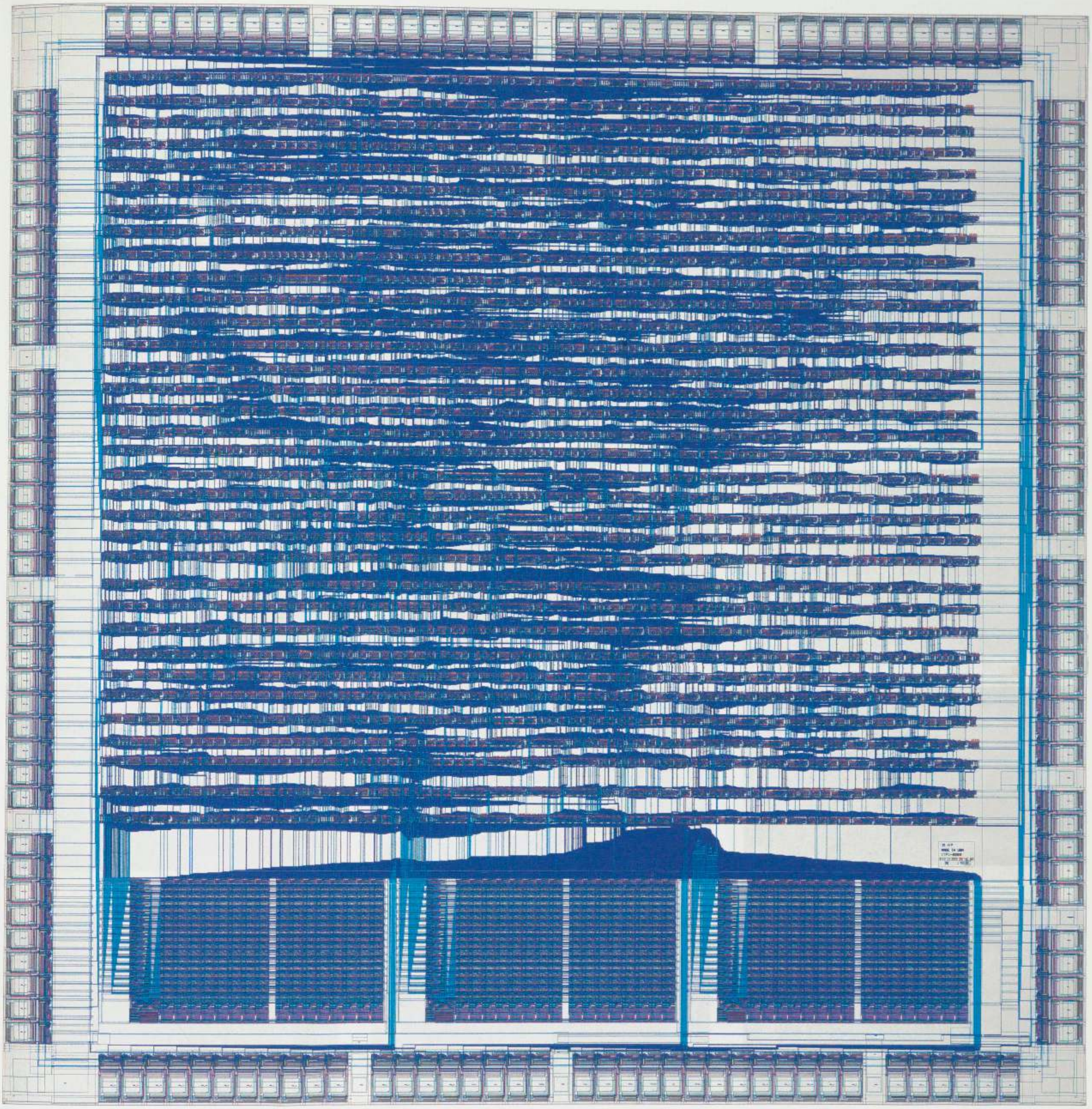
AT&T Bell Laboratories
1986
172,000 transistors
Microprocessor (CRISP)

During the 1980s the field of computer architecture was revolutionized by the invention of Reduced Instruction Set Computers (RISC processors). Prior to this machines were capable of performing hundreds of different basic operations, most of which were rarely used and introduced complications that limited computer speeds. By reducing the number of different instructions, designers were able to make each one quickly. Although more instructions were now needed to perform any given task, the net time to execute them declined. Because instructions were very simple, it became easier to pipeline them, that is, to execute several instructions simultaneously, assembly-line fashion. Moreover, the entire processor could be integrated into a single chip. The overall result was a dramatic increase in speed and reduction of cost. Opposite: four details showing circuit components at various levels of enlargement.



Hewlett-Packard Company
1987
80,000 transistors
Central Processing Unit Chip (microprocessor)

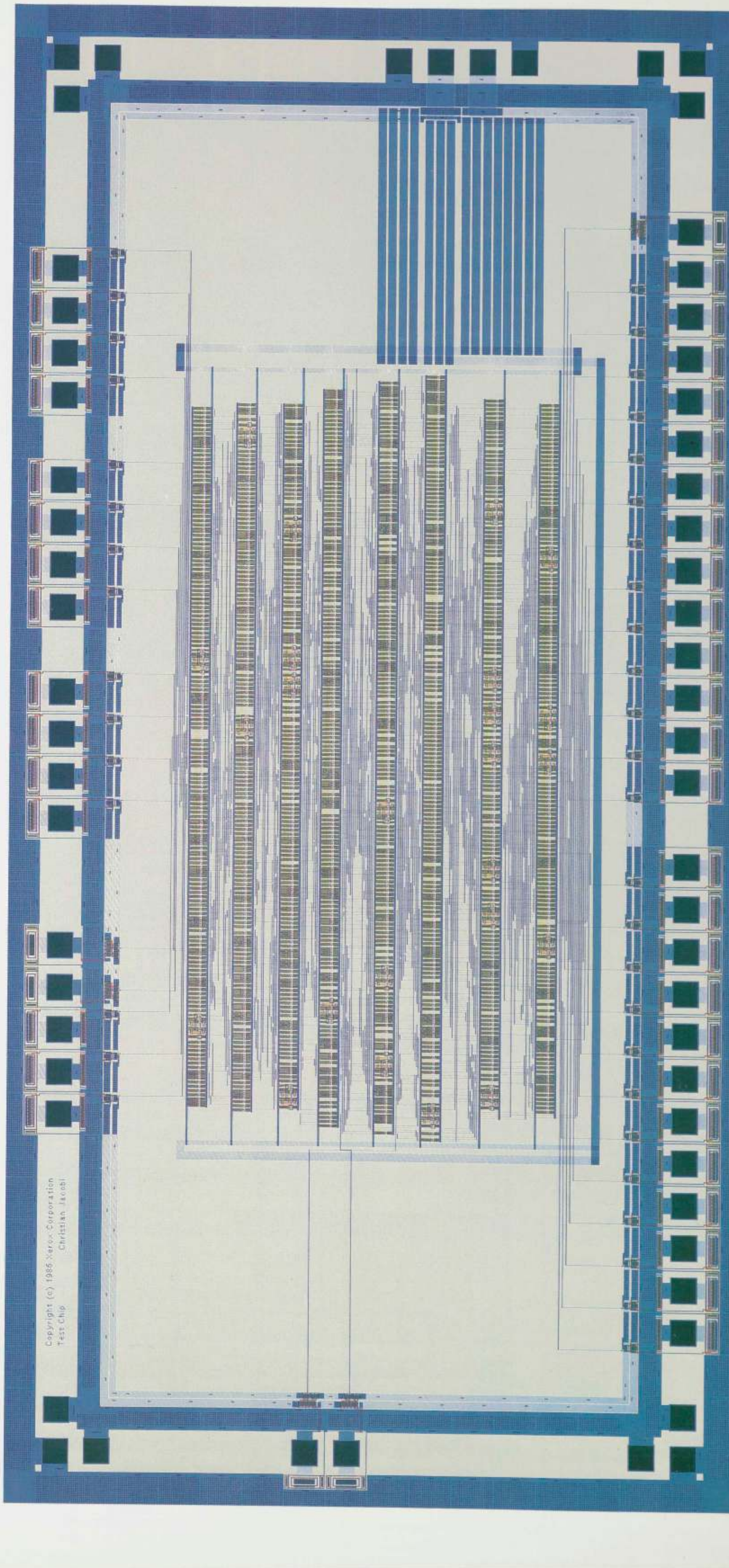
This is the heart of the central processing unit for a low-cost computer. It contains the computer's intelligence and control functions. The upper portion contains the logic sections, and the lower blocks are the memory files.

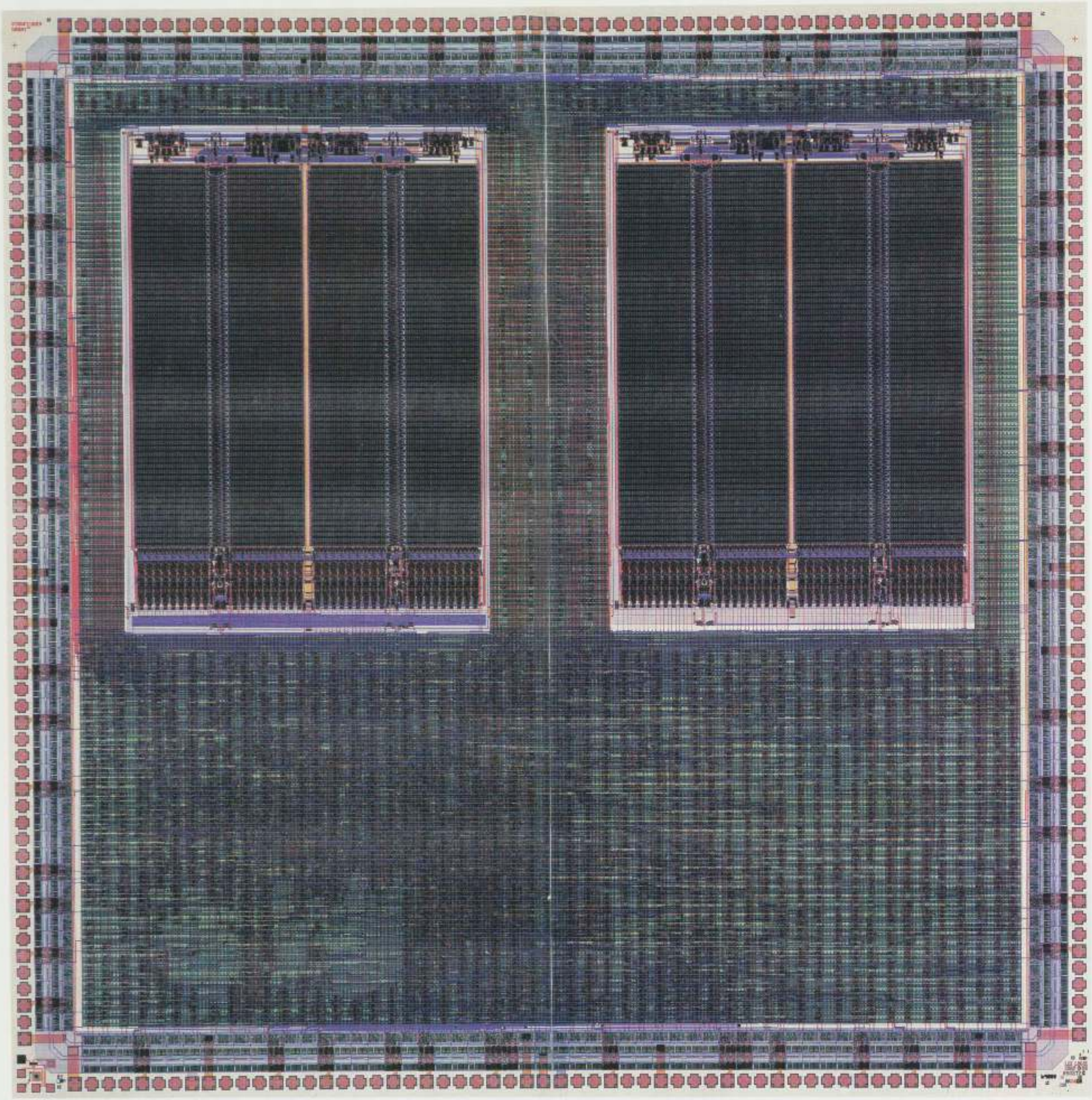


Application-Specific

Xerox Palo Alto Research Center
1986
approximately 3,000 transistors
Application-Specific Integrated Circuit (ASIC), test chip

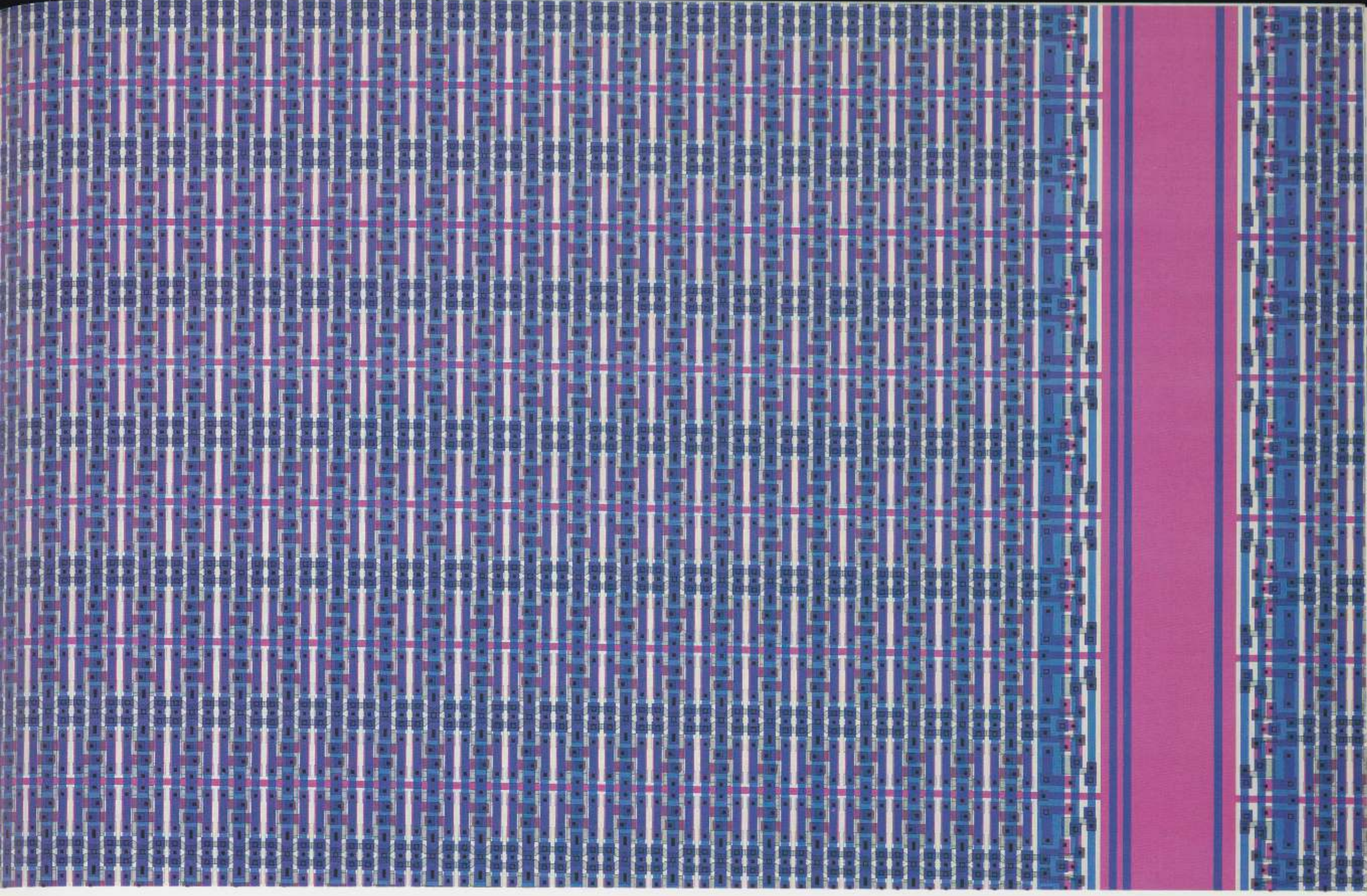
This diagram is of a chip used for testing components of a computer-aided design library

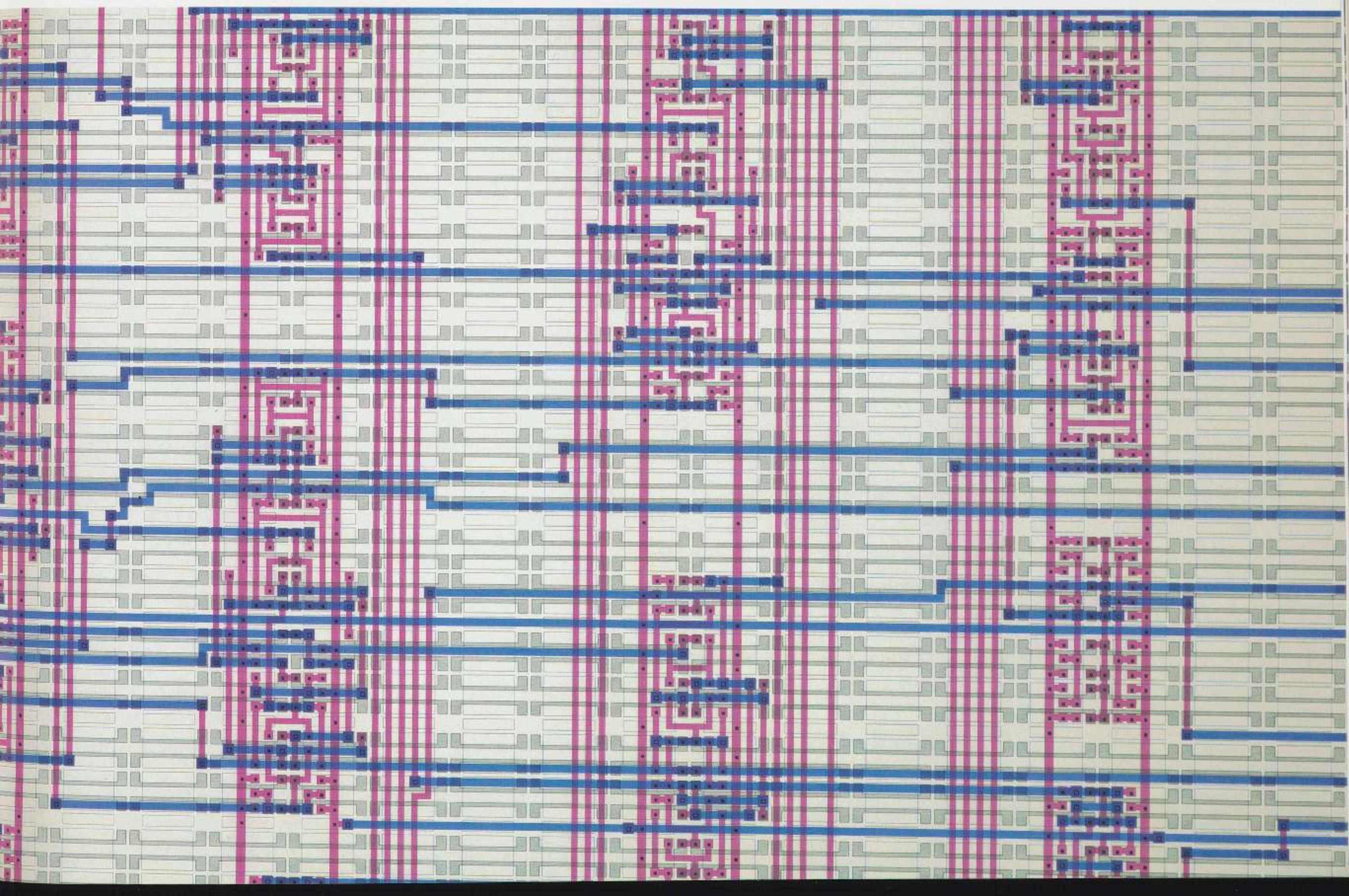

Copyright (c) 1986 Xerox Corporation
Test Chip Christian Jacobi



LSI Logic Corporation
1988
250,000 transistors
Application-Specific Integrated Circuit (ASIC)

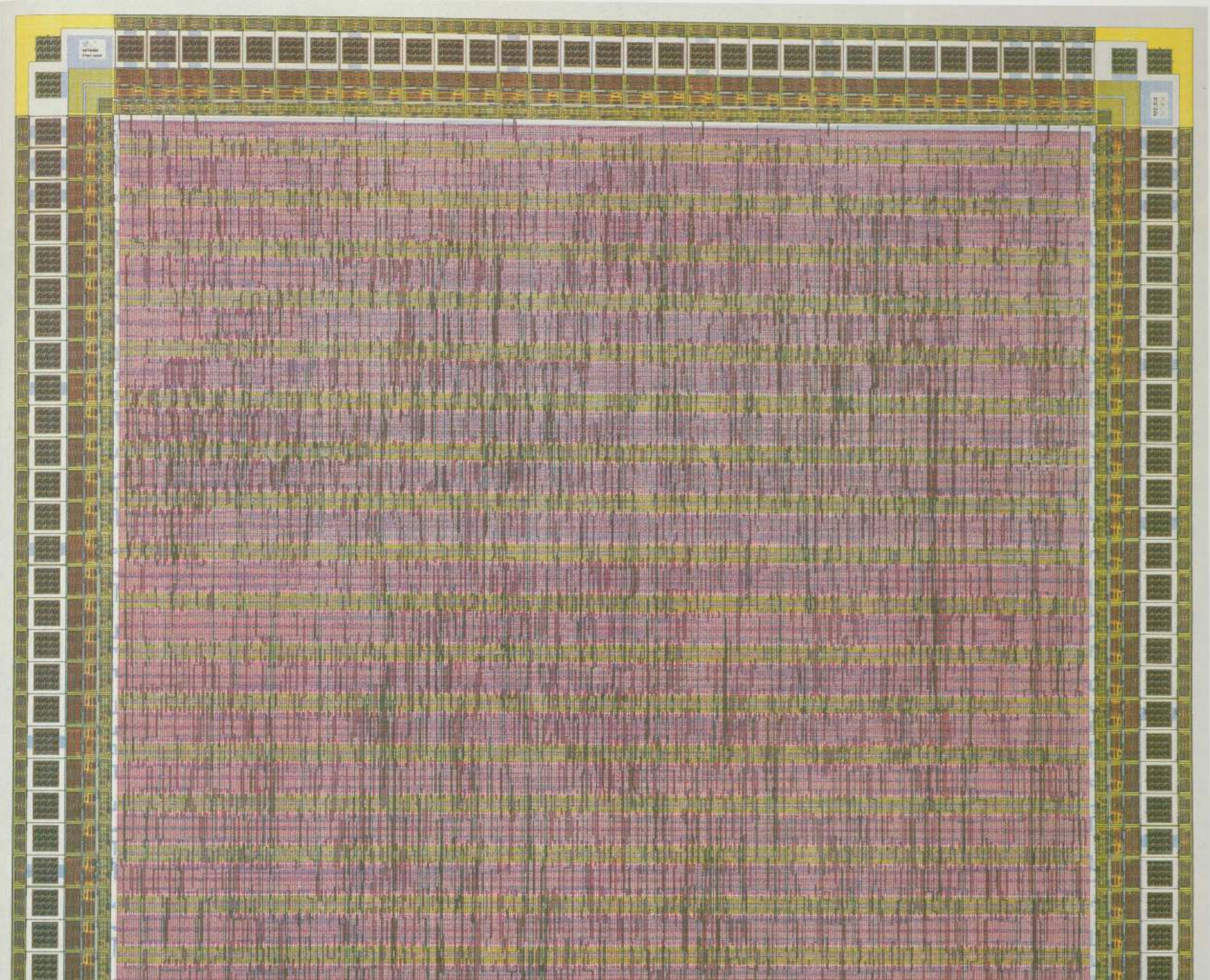
This was designed to improve image contrast in a variety of applications, including medical diagnosis, aerial reconnaissance, and automated inspection systems used in manufacturing. Developed as an application-specific product, it combines memory-cell and gate-array technology in one chip. The details on the right are enlargements of the two main pattern areas. The top diagram shows the individual cells comprising the memory blocks, the bottom illustrates the gate arrays.



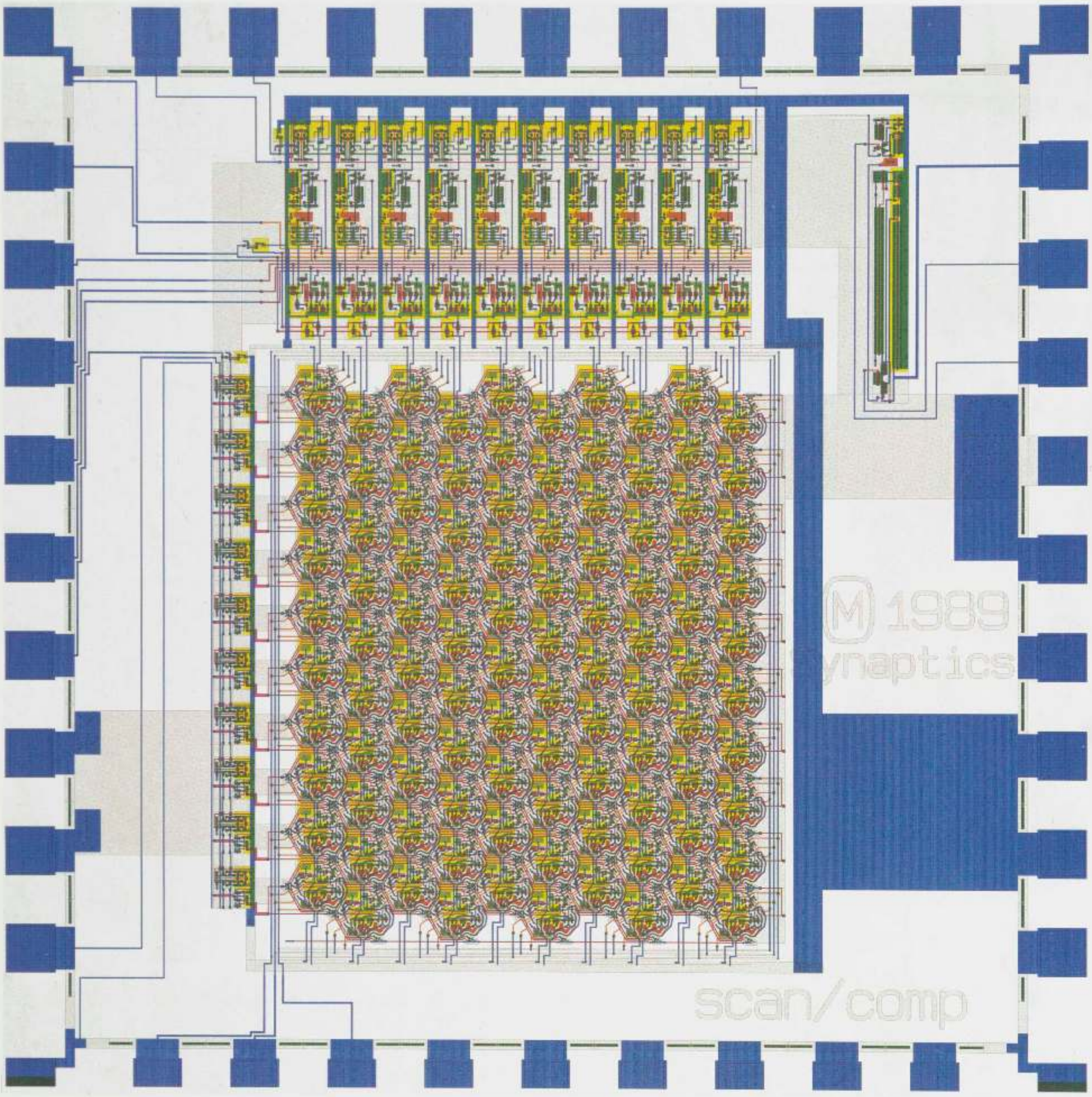


VLSI Technology, Inc.
1986
33,500 transistors
Application-Specific Integrated Circuit (ASIC)

This is an example of a gate array. It is a test chip used to verify the fabrication process and performance of chips. It has since been superseded by more sophisticated designs.



Neural Nets

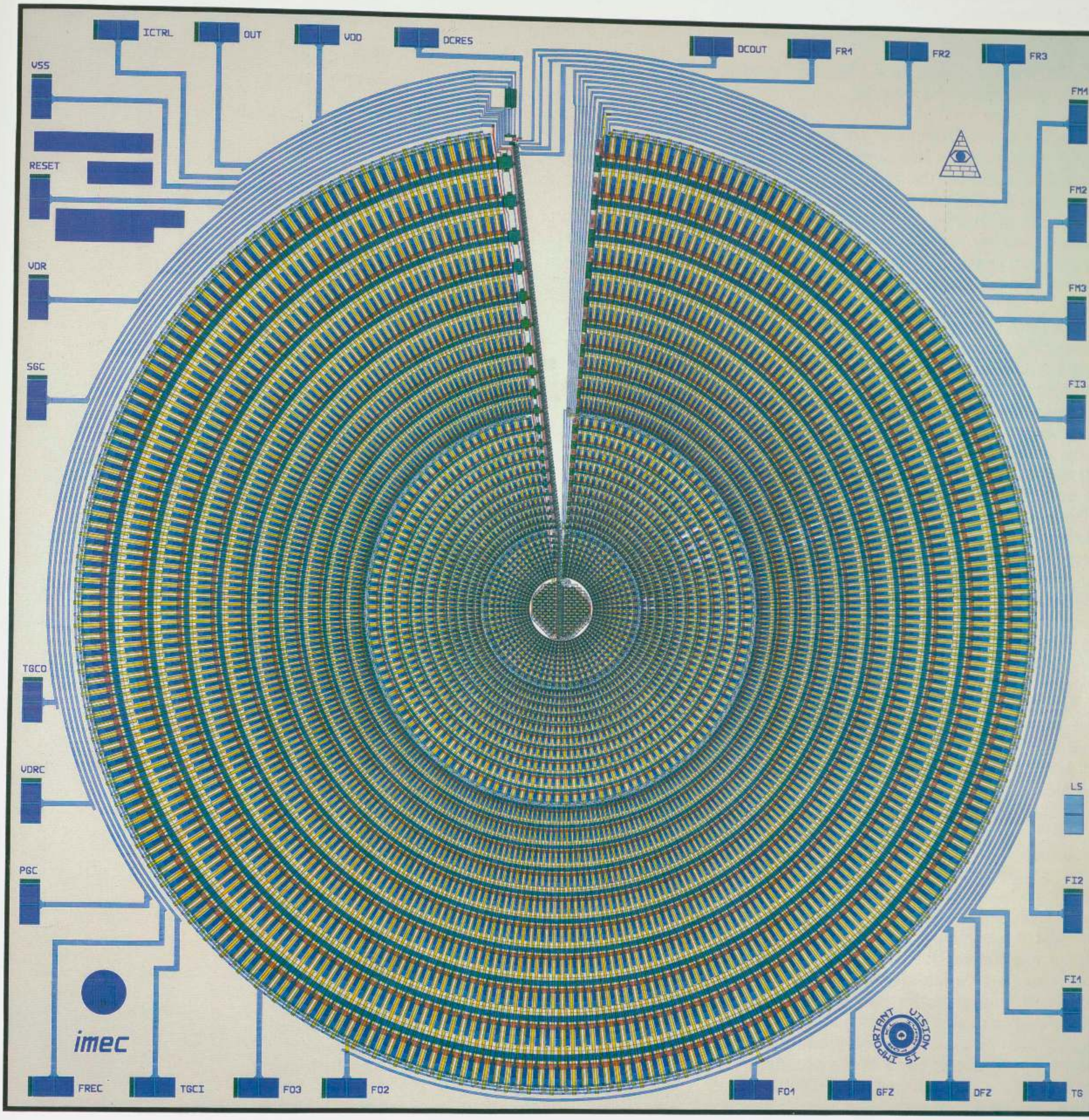


Synaptics, Inc.
1989
3,100 transistors
Neural Net (experimental)

This chip is a photo sensor and was designed to mimic some of the functions of the human retina. Containing a core of 100 electronic processing cells that detect images when light strikes them, the chip performs two operations: it highlights details in an image, and it orients and locates objects or other features by their edges. The information received by all the cells is averaged and then passed on to a computer for further interpretation. The design is based on hexagonal-grid properties, as opposed to the rectangular- or square-grid format found in the other diagrams in this publication. With the hexagonal shape each cell is equidistant from its neighbors, which allows for smoother and more accurate gathering of data.

IMEC and University of Pennsylvania
1989
Neural Net: foveated, retina-like sensor

The radial layout of this image sensor is loosely modeled on the human visual system, and consists of two parts: a peripheral and a central area (fovea). The outer part consists of 30 concentric circles and 64 sensors per circle whose size increases linearly with eccentricity. It is used for active vision, particularly in robots.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OUT
VDD
DCRES
DCOUT
FR1
FR2
FR3
VSS
RESET
VDR
SGC
TGCO
VDRC
PGC
FM1
FM2
FM3
FI3
LS
FI2
FI1
imec
IMPORTANT
VISION
IS
FREC
TGCI
FO3
FO2
FO1
GFZ
DFZ
TG

Acknowledgments

This catalog is dedicated to the late Dr. Robert N. Noyce, coinventor of the microchip.

On behalf of The Museum of Modern Art, I wish first of all to thank the Intel Corporation Foundation for having supported this entire project. I am also particularly grateful to the following individuals at Intel who were exceptionally good-natured and patient with my numerous requests: Mary Burt Baldwin, Jim Jarrett, Margie Kintz, Ann Lewnes, Pam Pollace, Clif Purkiser, Connie Stewart, and Debra Ward.

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Two leading figures in the development of the integrated circuit who graciously took time from their busy schedules and offered advice are the late Dr. Robert N. Noyce, president and chief executive of Sematech, Inc., and Dr. Carver Mead of California Institute of Technology.

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Finally, I wish to acknowledge two colleagues, Pierre Adler and Robert Coates, who were of great importance to the project. Discussions with both helped shape and refine many of the ideas in this essay. Robert Coates has been a collaborator in all aspects of the exhibition, and his enthusiasm and personal encouragement as well as constructive criticism have made all the difference.

Cara McCarty

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p. 7, *from left to right, top to bottom*:

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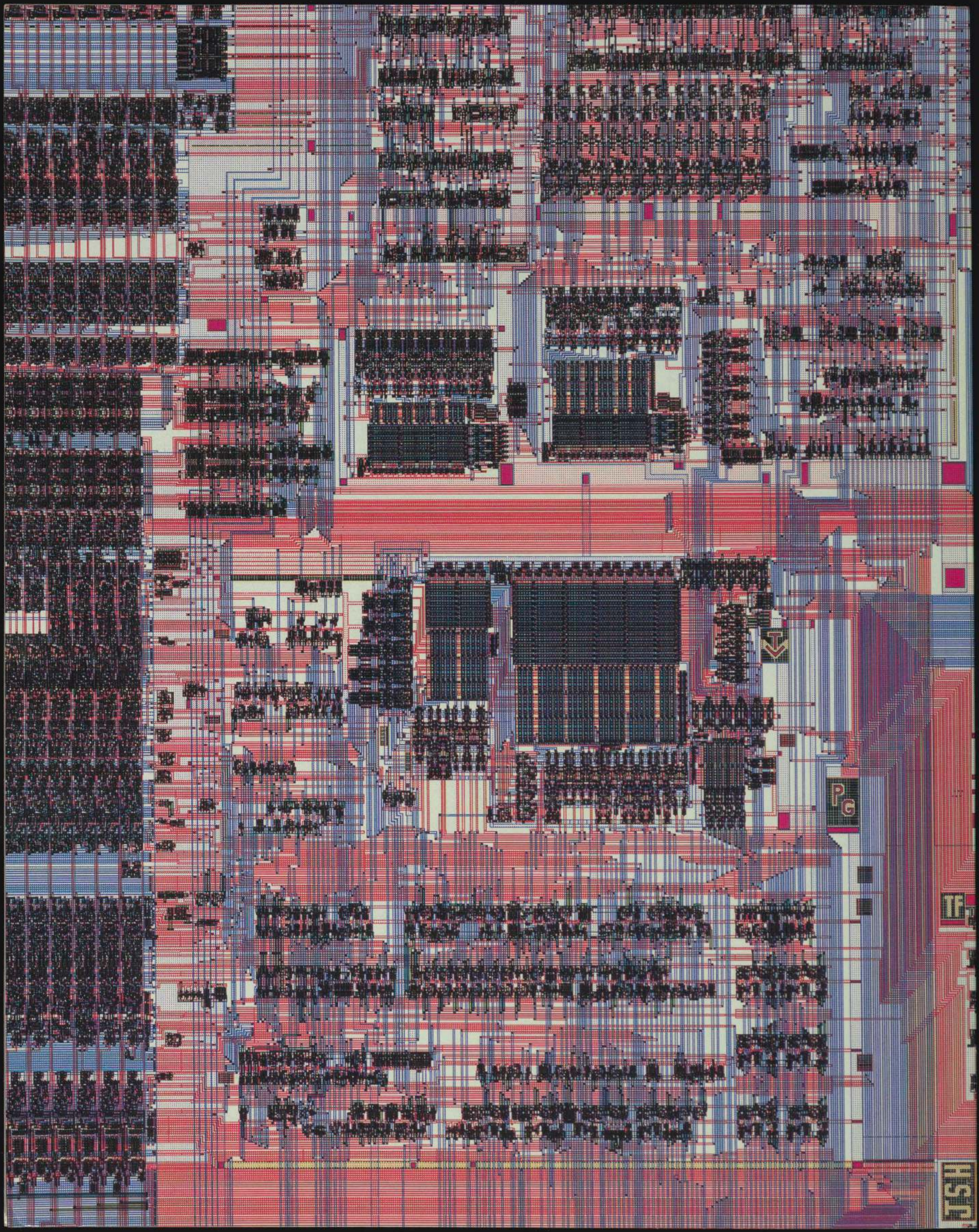
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