Information scientists have long recognized that "one picture is worth a thousand words," and over the last decade, extensive research and development has been devoted to pattern analysis and image understanding by computers. Practical applications of such computers include the processing of biomedical images for diagnosis; the recognition of characters, figureprints, and moving objects; remote sensing; industrial inspection; robotic vision; military intelligence; and communications data compression.

This special issue attempts to bring together a body of work by leading researchers in computer architecture, image processing, pattern recognition, and pictorial database management. The increasing importance of this work lies in both active research results and in the promise of newer, broader applications. I hope that these articles will stimulate further investigations towards the cost-effective development of intelligent image analysis computers, which in turn will bring us closer to our ultimate goal: promoting better man-machine interactions in the era of real-time knowledge information processing.

Intelligent image analysis functions. The deficiency of today's computers stems mainly from the I/O mechanisms: computers still cannot communicate with human beings in natural forms, such as spoken or written languages, pictures or images, documents, and illustrations. Existing computers are far from satisfactory in their I/O speed and speech, vision, translation, and real-time responses. To develop "human-oriented" interactive computers we must first upgrade their capability to understand "natural" information representations and then respond to them intelligently and perhaps more reliably than human beings can. Computers with intelligent I/O will benefit both professional and non-professional computer users.

Three research areas have been identified in the development of intelligent man-machine interfaces: natural language processing, such as designing computers that understand English, Chinese, and other natural languages; speech understanding, which demands both speech analysis and synthesis; and the focus of this issue, image processing and recognition, in which pictorial and imagery data are processed on-line and interactively with high accuracy.

To implement image processing and recognition, we need to develop subsystems for input, output, and analysis of imagery data retrieved from a large image database system, which may be part of a larger knowledge base system. From input such as logic circuit diagrams, chest X-ray pictures, or aerophoto images (Figure 1), the corresponding output could be the layout of a VLSI circuit design, a precise description of an abnormality in the lung area, or a combat map generated in real time. The processing that takes place between input and output involves a wide variety of image analysis functions for image enhancement and segmentation, feature extraction, pattern classification, structural analysis, image description, and interpretation. Some of these functions can be implemented directly by VLSI hardware and some by special software packages. Advances in image I/O devices, pictorial query processing, and image database management techniques are also needed to achieve an integrated system design.
The role of VLSI. VLSI, an integral part of image processing implementation, is usually defined by gate equivalent count, line width, storage density, and circuit complexity (Table 1).

Four alternative VLSI phases can also be defined. In general, a VLSI-1 chip should have at least $10^3$ gates with a line width of less than 2.5 µm, a storage density greater than 30K bits/cm², or a circuit complexity greater than 16K gates. When reaching VLSI-4, we can expect $10^6$ gates per chip with a 0.5-µm line width, a storage density of 1M bits/cm², or over one million transistors of circuit complexity. IC wafer size has increased from one inch to six inches in 20 years, and Bell Laboratories has projected that 8-inch wafers and 1M-bit memory chips will be available by 1985.

Worldwide sales of electronic products reportedly reached $200 billion in 1980, the same as for automobile sales. Fujitsu in Japan has announced a new nonsilicon device, the high-electron mobility transistor, which has a 17-ps switching time, 30 times faster than the fastest silicon counterpart. The very high speed integrated circuit project at the Pentagon involves producing 4-ps devices, and has met with some success. In the research community, wafer scale integration has been vigorously considered in implementing algorithmically specialized computer structures. All these technologies have created a new architectural horizon for designing the next generation of new computers, which the Japanese call the fifth-generation computer systems. The 5G systems are being designed to achieve the projected knowledge-base information processing for the 1990's.

New computer architectures. Conventional computer architectures generally fall into three configurations: pipeline computers, array processors, and multiprocessors. Pipeline machines generally have a single instruction, single data stream, used mainly for exploiting the "temporal" parallelism in continuous vector processing. An array processor uses multiple processing elements under a common synchronous control in locksteps. Single instruction, multiple data streams are expected in an array processor, which exploits spatial parallelism to achieve parallel processing. A multiprocessor system contains multiple processors with shared memory/peripheral resources. Usually, interactive multiple instruction, multiple data streams are expected in a multiprocessor. Most of the existing image analysis computers have either the SIMD array processing or the SISD pipeline architecture. Some of them combine pipelining and array processing into a hybrid structure to explore both temporal parallelism and spatial parallelism. Only a few image processing computers can use the multiprocessor approach because of the difficult problems in algorithm partitioning and resource allocation for multiprocessor systems.4-11

The advent of VLSI technology has triggered the thought of implementing many signal/image processing algorithms directly in specialized hardware chips.12,13 To promote image understanding, a machine inference mechanism is highly desirable in future computers. The new concept of data-driven computations is also being considered for artificial intelligence applications.3 Data flow computers are designed for asynchronous data-driven computations using functional programming languages with no side effects. All these new concepts on VLSI computing architectures and distributed asynchronous data flow multiprocessors should be seriously investigated and evaluated for potential use in image processing and pattern recognition. Extending control flow computers from two-dimensional arrays to three-dimensional pyramid structures is also a viable approach.14 Multiple-pipeline computers also have potential for parallel image processing if task scheduling problems can be solved efficiently.

The six articles in this special issue cover array, pipeline, and multiprocessor approaches to image pro-

![Figure 1. Pictorial functions of an intelligent image processing computer embedded in a knowledge base system.](image)

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<th>Table 1. VLSI domain and definition phases.</th>
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<td><strong>DOMAIN PHASE</strong></td>
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<tr>
<td>VLSI-1</td>
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*G/C = gates/chip, µM = micron (10⁻⁶ meter), KB = 1024 bits, and KD = 1024 devices (transistors or diodes).
cessing/recognition. Two concrete computer systems are presented: the cytocomputer for biomedical image processing and the massively parallel processor for satellite image processing. A survey of image processing computers in Japan is also included. A progress assessment of pattern analysis computers is also given with emphasis on architectural evaluation and application potentials. (For a general survey of computer architectures for image processing, see Danielsson and Levialdi's survey.)

Azriel Rosenfeld's "Parallel Image Processing Using Cellular Arrays," reviews basic methods of image processing using one-dimensional or two-dimensional cellular arrays at the pixel level and discusses the possible uses of cellular hypercubes, cellular triangles, cellular pyramids, and reconfigurable cellular graphs for image processing at the region or higher levels. "Biomedical Image Processing" by Stanley Sternberg describes the cytocomputer architecture and its potential uses. This system is being developed at the Environmental Research Institute of Michigan. Cytocomputer image processing operations are based on the concepts of cellular automata. The system has a multistage pipeline cellular architecture under a common master control, and application areas include anatomy, developmental biology, nuclear medicine, cardiology, and transplant rejection.

Kendall Preston, Jr., presents "Cellular Logic Computers for Pattern Recognition," an updated assessment of various cellular logic computers, including Illiac III, CLIP series, Cellscan, GLOPR, BIP, cytocomputer, PHP, and MPP. The article by Kai Hwang and King-sun Fu, "Integrated Computer Architectures for Image Processing and Database Management," demonstrates the need for a unified system approach combining both image analysis functions and image database management capabilities in an integrated system. This approach was initiated by the Pumps project at Purdue University, which has a multiprocessor architecture with a shared pool of VLSI resources.

"Image Processing on the Massively Parallel Processor" by J. L. Potter describes the 16K-processor array in the MPP, its instruction set, and the image processing applications, including statistical pixel classification, feature extraction, syntactic pattern recognition, and real-time scene analysis. Masatsugu Kidode's "Image Processing Machines in Japan" introduces a dozen image processing and recognition machines developed by Japanese industries and universities. These machines have been applied in optical character reading, speech recognition, image I/O, medical diagnosis, remote sensing, and industrial automation.

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References


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