Engineering Notes

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A Forecast of the Future of Computation

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I. Introduction

RECENT hardware advances can be reduced to one common denominator: the "miracle" of the chip.[1-3] As large-scale integration continues its astounding progress, commercially available densities of only two years ago are already obsolete; the 100K chip is said to be on several drawing boards. Thus, we can expect that future system architectures will be characterized by parallelism and modularity; new "hard-wired" components will include hierarchical and associative memories, array processors, and many other devices.[4] An especially noteworthy hardware feature will provide data security through cryptographic methods[5] with "chipped" plugs containing programmable ROM's (read-only-memory) in all cabled connectors. A multitude of firmware[6] applications likely will include not only compilers, but also the management of hierarchical and relational data bases, as well as many common elements of current software, including many components of computer operating systems.

II. The Miracle of the Chip

Computer technology is now 30 years old. Since its beginnings, it has been characterized by a fiercely competitive race to develop faster and more versatile processors, larger memories,[7,8] and more reliable components. The most spectacular breakthroughs in hardware technology have taken place with the introduction of integrated circuity (IC's) in the early 1960's. Since then, the cost of maximum complexity chips obtained with medium- and large-scale integration has remained essentially constant but the number of components on the IC's has increased by several orders of magnitude.

Monolithic chip characteristics are compared in Table 1 for memories and logic arrays.[3] There is no indication that we are approaching their limits to growth; the techniques of electron-beam lithography[9] are understood well enough to permit considerable increases in component densities. Another way of looking at this picture is to measure the width of strata and components currently deposited in terms of their atomic diameters. We are still very much in the macroscopic domain with line widths of hundreds of thousands of atoms. Even projections for 1990 would indicate that anticipated gains are well within the scope of macrotechnology. Thus, it is readily conceivable that in less than 20 years the "true computer on a chip" will have been born.

Electronic computer architectures require ever greater volumes of random-access (RAM) and intermediate-storage memories.[10] A number of interesting semiconductor and other technologies are being investigated to design larger and faster memories. At least four methodologies look very promising.

Beam-addressed metal oxide semiconductor (MOS) memories[9] employ an electron beam to read and write data on a single unstructured MOS chip. Basically nonvolatile, the data have to be rewritten after 6 to 10 reads, dependent upon beam currents and data recording rates.

Holographic read-only memories[7] with up to a billion bits addressable capacity have access times measured in microseconds. Unfortunately, their usefulness is limited to special applications where only archival storage is required.

Magnetic bubble domain memory systems[11] with access times below 1 msec are nonvolatile and require minimal operation power. Thus they fill the gap between the fastest electromechanical devices (8 msec on head-per-track disk memories) and core memories (less than 1 μsec).

Charge-coupled electric domain devices[12,13] (CCD's) currently are implemented by *N*-channel MOS technology. The CCD storage element is dynamic and must be refreshed periodically, similar to a dynamic MOS RAM.

Parallel developments still very much in the R&D stage are likely to come to fruition just as chip technology, coupled to electron microscopy,[14,15] will approach its capability limits. Current research in the field of structured molecules is quite promising and should come into its own by the end of this century. Biologists have already "engineered" DNA molecules; electronic engineers also undoubtedly eventually will reach their most ambitious goal – crystal lattice electronics.[16] For a starter, molecular rectifiers already have been built from atoms whose respective ends have different binding energies, thus acting as anode and cathode. Achievement of the precise spacing in such crystal structures seems still to be a problem, but research scientists are confident of ultimate success.

III. Computer System Architecture

We begin with the notion of real and virtual architectures.[17,18] Throughout the 1960's no differentiation was made between the machine architecture as seen by the software programmer and the hardware design engineer. Systems programming, in particular, still is much concerned with the real hardware whereas applications programming has found some relief in high-level languages and virtual systems.

During the 1970's, systems architectural research[19] centered on hierarchical memories, virtual machines, and other conventional concepts, showing little imagination. For the time being, we may assume safely that the indicated trends will continue, and radically new architectures are not likely to emerge soon. Therefore, we may have to live for at least a decade with the conventional architectures shown in Table 2. All architectures known to date can be characterized by their 1) physical organization, 2) control and flow of data, and 3) data representation and transformation.

Table 1 Monolithic chip characteristics

	Memories		Logic arrays	
Year	Bits/chip	Width, atoms	Bits/chip	Width, atoms
1970	300	200	100	300 K
1975	15 K	20 K	2 K	60 K
1980[a]	500 K	3 K	25 K	20 K
1985[a]	20 M	500	400 K	4 K
1990[a]	800 M	100	6 M	1 K

[a] Projected estimates.

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Table 2 Computer architectures characteristics

Processor description	1975 MIPS[a]	1980 BIPS[b]	1985 BIPS	1990 TIPS[c]
Functionally parallel units	10	0.3	10	0.3
Pipeline organization	100	3	100	3
Parallel array	100	3	100	3
Associative array	50	1.5	50	1.5

[a]MIPS = million (10^6) instructions per second.
[b]BIPS = billion (10^9) instructions per second.
[c]TIPS = trillion (10^{12}) instructions per second.

The first, and perhaps most obvious, is the purely scientific machine class. Its current capability of 10 million operations per second is expected to grow to 300 billion operations by 1990 as demands of the scientific community for raw computing power will remain strong. Where data and instruction streams become more manageable, the pipeline processor will remain about an order of magnitude faster than the fastest modular unit processors. It is perhaps worth noting that the projected processing speed for pipeline machines in 1990 is still nowhere near the limits imposed by component spacing on chips with densities indicated in Table 1.

Of greater interest to the commercial world of data processing should be current trends with parallel computer systems.[20,21] Most applications today are done serially, whereas the problem structure is parallel. The current trend of multiminis, now often in networks, definitely will lead us to parallel processing where the number of submachines is expected to rise meteorically.

The last entry in Table 2 is reserved for associative or content-addressable processors. Few such devices are now in existence, but they are very likely to emerge with great vigor once current hardware problems are overcome. They will contribute significantly to new forms of data base management systems which are flexible and truly relational in nature, rather than hierarchically and rigidly structured.

IV. System Developments

The symbiosis of computer communications has been in the making for at least 20 years. It began with remote job entry, time sharing, and real-time applications, attaining considerable maturity by the middle 1970's. Although the cost of computing declined steadily, the same could not be said for the cost of communicating. Thus, the recent emphasis is on better utilization of our limited communications bandwidth through packet switching and the creation of national and international value-added carriers and networks.

Recent legislation by the Federal government concerned with the privacy issue and the integrity protection of personal data will extend shortly also to the private sector. In addition to increasing the physical security to protect computer and terminal installations, data security is receiving growing attention. Most recently, proposals have been made to incorporate cryptographic transformations, through hardware, into all end-to-end data streams. The pertinent solicitation of the National Bureau of Standards produced a veritable avalanche of studies in the public domain – and probably even more which are proprietary in nature.

Software engineering has emerged in response to criticisms that programming has been, at best, an art or a craft – but not a science. The emphasis is on the need for project management with all of its forcing functions to increase both the productivity of programmers and the quality of their product. Modular and structured design techniques are being advocated; the design team concept stresses the need for egoless performance of individuals.

Hardware technology is advancing so fast that current concerns over hardware costs and central processing unit (CPU) efficiency shortly may become meaningless. But we see no comparable reduction in the cost of software. Very-high-level languages (VHLL) undoubtedly will emerge to take the place of today's procedure-oriented languages. In the VHLL, a single word will suggest a whole set of high-level statements. The language will be used to provide a quasiformal description of the programming problem itself. Even the software systems for future generations of machines will perhaps be written in the form of VHLL statements.

A partial solution to current software problems undoubtedly will come from interactive computer graphics.[22] Current applications range from basics with hundreds of vectors, to applications of greater scope requiring color and movement, to complex applications with thousands of details and extensive support in terms of hardware and software. However, the major limitation today is that intelligent graphics terminals simply are not portable.

We can expect intelligent graphics (and other) terminals to attain the status of the telephone as soon as CRT technology is replaced by digital (flat) screens with high resolution – and low cost. This technology is currently in the laboratory stage; it is expected to mature concurrently with the conversion of the telephone into a purely digital network. This development is predicted cautiously for the middle 1980's and it certainly will contribute to a proliferation of these devices with consequences which we can assess only dimly. Whole sectors of education, health services, law enforcement, banking, general office work, even entertainment and retail merchandising, will be transformed totally from established norms. "Communicate – don't commute" will perhaps become a reality toward the end of this century, much to the relief of those concerned with air pollution and traffic congestion.

V. Conclusions

With the advent of the superchip we surely will be able to tackle the last frontier in man-machine communications by including voice as an essential element of the man-machine interface. Selective voice command recognition already is being accomplished by specialized systems. It operates on small vocabularies and requires care in the voice calibration process. But linguistic complexities are still far beyond the capabilities of even our largest machines. Yet, with the projected increases in chip densities and internal machine parallelism, selective speech systems for recognition and response should be the first to appear on the technological scene.

General voice recognition is at least one order of magnitude more difficult and is unlikely to occur before 1995. In alternate terms we may refer to it as voice-to-print transformations. Its perfection will cause some major upheavals in general office work; a good deal of the work we now do gregariously at our office locations thus can be transferred to our homes or to specially equipped communal offices.

Language translation or print-to-print transformations are of the same complexity as general voice recognition. Computer linguists have wrestled with this problem for decades and successes have been limited to small vocabularies and the technical literature. However, with the immense storage capacities of future machines and their incredible internal speeds, we should achieve this capability also during the middle 1990's.

Coupling these two technolgies with the generation of digitized voice (already in existence) will achieve real-time systems for voice translation. The world of commerce, law, as well as the international mass media and news services will benefit greatly from this final step in computerized communications.

Where will it all lead to? In a nutshell, the answer is that we are approaching the "final" transition to the real-time world of an international information society. It forebodes a way to make better decisions by individuals and societal units, giving mankind a chance better to manage its limited resources. As Norbert Wiener put it so forcefully, it may signal an era where we can begin to make human use of human beings.

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Streamtube Analysis of a Hydrogen-Burning Scramjet Exhaust and Simulation Technique

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CURRENT design philosophy for scramjet-powered hypersonic aircraft results in configurations with the entire lower fuselage surface used as part of the propulsion system.[1] The lower aft-end of the vehicle acts as a high-expansion-ratio external nozzle.[2] At hypersonic velocities, the ram drag and gross thrust are large compared with the net thrust; therefore, extreme care must be taken in designing the external nozzle in order to optimize the thrust and lift while minimizing moments that could result in large airplane trim drag penalties and possible instabilities.

The scramjet hydrogen/air combustion products exhaust plume is characterized by embedded and intersection shocks, expansion fans, wakes, reacting gases, and high temperatures.[3] An understanding of these phenomena must be acquired, and design methods must be developed before this type of engine/airframe integration concept becomes a viable hypersonic system. The strong coupling between the propulsion system and aerodynamics of the aircraft makes a simulation of the hydrogen-burning scramjet exhaust imperative for both nozzle design and aerodynamic force data acquisition. NASA Langley has pursued an extensive scramjet/airframe integration R&D program for several years, and has recently developed a promising technique for simulation of thermally perfect scramjet exhaust flows (molecular weight changes less than 2% throughout the flow) using freon/argon gas blends in equilibrium expansions from total temperatures near 500 K (Ref. 3). Freon/argon blends were selected because contractual studies have shown that they can match the ratios of thermodynamic properties (mainly specific heat ratio γ) of the combustion products permitting a simulation at a much lower temperature level.[4] This Note presents the results of a study to determine if this simulation technique can be extended to more complicated flows approaching the complexity of the actual exhaust flow. An analysis is made to determine the state of the flow and the accuracy of the substitute gas simulation in the presence of a shock discontinuity.

Analysis Methods

A one-dimensional finite-rate analysis was used to determine the actual state (equilibrium, finite-rate, or frozen) of a 2-D scramjet nozzle flow. Conditions representative of Mach 6 and 8 cruise flight ($\phi = 1$ and a dynamic pressure range $2.4 \times 10^4 - 7.2 \times 10^4$ N/m^2) were examined. The explicit finite-difference nozzle code of Ref. 5, employing an average γ, ideal-gas expansion was used to compute streamtubes for these two flight conditions. Earlier calculations for these conditions have shown that the assumption of an average γ, ideal gas does not alter the flow significantly.[3] Area distributions were obtained for equilibrium and frozen expansions and found to be almost identical. It has been assumed that the finite-rate area distribution will be bounded by the equilibrium and frozen distributions; therefore, the frozen area distribution was used in the computations. The finite-rate streamtube code of Ref. 6 was used with the selected area distribution to compute equilibrium, frozen, and finite-rate expansions.

In the finite-rate streamtube code, the chemistry modes were expanded in a finite-rate process, while the vibration modes remained in equilibrium. Subsequent calculations with a finite-rate vibrational streamtube code[7] indicate that the nonequilibrium vibrational energy in the nozzle expansions at any point is less than 10% of the total internal energy of the flow. Therefore, the treatment of the vibrational energy, as in equilibrium, is an acceptable assumption for the purpose herein, since the associated distortion of the flow structure is extremely small.

Results and Discussion

The results that follow are presented for a nominal streamtube that essentially provides the correct area distribution for a Mach 6 flight case. Initially, two streamtubes for this flight condition were analyzed, one representing the narrow flowfield region near the nozzle wall, and the other representative of the flowfield region from the wall to the center of the flowfield. The static pressure and temperature distributions for both streamtubes are presented in Fig. 1, where all quantities are nondimensionalized by the conditions at the nozzle entrance (subscript 3). Since the

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