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Microcomputers for experimental psychology

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The design and use of CPUs on a single inexpensive circuit are discussed. Necessary additional equipment is noted, and the potential for using the microcomputer in the laboratory is explored.

Computer circuits have been decreasing in size and cost since computers were first invented. The ultimate reduction is now reality: a "computer" on a single integrated circuit, less than 1/8 in. square, for a price well under $100 in quantities. Capability continues to grow, with more powerful designs and faster technologies promising greater performance and lower prices. Foster (1972) has extrapolated the current trends to predict a computer on a chip, having processing power equivalent to a 7090, for about $1 by 1997. Even current large-scale integration (LSI) devices tend to reach the $10-$15 range once quantity production is achieved.

Thus, it would seem that we now have an embarrassment of riches in computing power available at a very low cost. If a computer is available for under $100, then a wide variety of applications in psychology, education, and everyday life should be immediately achievable. The computer in a briefcase described at this conference last year (Norman, 1973) should be a reality soon, if not right now.

This paper explores what else is needed to make use of this abundant technology and some possible courses of action. A range of microprocessors is considered, with one explicit example; the additions that are necessary are explored; and some suggestions of the applications strategies that could be followed are given.

MICROPROCESSORS

Microprocessors have resulted from two types of development made possible by advances in large-scale integration. LSI techniques make possible the order of complexity of logic normally found in a small computer CPU on a single silicon chip. One motivation for development has been the consumer-oriented calculator, produced at a price everyman could afford, but possessing a minimum amount of function. The other was the desire by terminal manufacturers to include inexpensive "intelligence" in their products, through processors implemented in LSI. The former produced character- and arithmetic-oriented processors, while the latter produced designs which are more like "computers" as we know them. At the moment, most microprocessors can be characterized primarily in one of the two categories. We shall concentrate on an example of the computer-like devices; the offerings have been reviewed by Lapidus (1972) and by Wiener (1973).

The first commercial computer on a chip was the Intel MCS-4, introduced in 1971. This is a 4-bit machine, originally created for a calculator, but apparently useful in many forms of computer control. A second offering from Intel, the MCS-8, is an 8-bit computer on a single chip introduced a year later. Many of the other microprocessors are not strictly single-chip architectures, but combine two or three separate circuits in order to produce a more powerful microprocessor. This overcomes some of the drawbacks of the single-chip designs, which are due solely to the packaging restrictions, which require that all information transmitted to or from the package be multiplexed on a single bus.

Despite the MCS-8's size, it contains an impressive amount of computing structure. It contains six 8-bit accumulators, two addressing registers, a program counter, and a seven-deep stack for nesting of subroutine calls, as well as the command decoder and other logic to carry out its functions.

The single integrated circuit communicates with the outside by way of a single data bus. This results in a 3:1 decrement in possible speed of execution, in that three cycles are consumed in communicating with memory: two cycles for the halves of the 14-bit address and one for the 8-bit data to be transmitted. This, coupled with the inherent speed of the technology of implementation (MOS), results in a processor that executes about 30,000 instructions a second. This is an order of magnitude slower than current minicomputers, but not greatly different from typical speeds of computers 10 years ago. Techological improvements are likely to speed up the processors in the near future. Organizations of multiple microprocessors can also overcome some of the drawbacks of the slower technology.

WHAT IS MISSING?

The problem with microprocessors is that they are only central processors; by themselves, they cannot function. Missing is considerable circuitry to provide memory, timing, input-output, and multiplexing of the data bus. Although initially lacking, these are now beginning to be supplied by the manufacturers. The MCS-8 is available in a prototype board, supplying these functions for about $900, plus up to $560 for read-only memory. It is interesting to note that the CPU chip is only 1 out of 81 integrated circuits that make up the prototype configuration. Of the 81, half of the circuits constitute the 3K x 8-bit memory, and the rest perform timing and input/output functions.

Another approach to microprocessor architecture is now appearing. An example is the National Semiconductor IMP-16C, which uses two types of processor chips, which can be combined in 4-bit units to create a processor architecture of greater bandwidth. The IMP-16C creates a 16-bit computer with 786 words of memory on a card of 59 circuits for about $1,400.

Now that processors are becoming minor components of computer cost, the major item is likely to be memory, even for very simple designs. There are three main types of memory that can be used. They are briefly reviewed here.

ROM

Semiconductor read-only memory is typically programmed during fabrication of the chip, using circuit masks created photographically. This method is suitable for creation of large quantities (at least 50) of memories which contain identical information. This technique is useful in such large-volume situations as character generators for displays, processors for calculators, etc. It requires substantial investment in the initial pattern (e.g., $600/1,000 bits), but permits memories to be obtained for about $7.50/1,000 bits in quantities of 100. Introduction of machine-aided techniques for fabrication may continue to bring the one-time charge down some, but the per unit cost is likely to drop more substantially, accentuating the volume characteristics of the memories.

For small-quantity production of ROM devices, the programmable ROM (PROM) offers the opportunity to program a read-only device by application of special electrical pulses. The process is usually irreversible and is useful for prototype construction where ROMs will be used ultimately. These devices currently run between $20 and $30 per 1,000 bits.

RWM

Semiconductor read-write memory (also called RAM, for random-access memory) is currently in active development stages, and great improvements can be expected in the near future. Off-the-shelf random access memory chips seem to be about $15 to $20 per 1,000 bits in quantity, depending on the speed and support electronics required. While RWMs will probably never approach the unit cost of ROMs, we can expect RWMs to fall below $10/1,000 bits in quantity shortly. A few such devices exist now, but they require considerable external electronics and power supplies, which raises the effective cost.

Serial Devices

Shift registers and other serial devices can be used for storage of data in those computer systems where access is not frequent. Shift registers are now below $10/1,000 bits in quantities, and can also be expected to decrease in price. Some support logic is required to determine the location of desired information, and this logic raises the effective price for applications in which only a small number of registers is used.

In summary, much of the economy of microprocessors hinges on the replication of specific tasks in many systems, thereby spreading the high initial costs of programming and fabrication of ROMs over many units. This is feasible where a terminal manufacturer produces hundreds of terminals, each with the same basic program. It could be feasible in some experimental control apparatus for psychology and in various tools for education.

The cost of input/output, as in any other computing system, can be sufficient to offset any economies gained in the use of an inexpensive central processor. Input/output at the level of the interface logic is quite simple and inexpensive; it is the equipment beyond that interface which may wildly increase the cost. Here there is, of course, no inherent advantage of the microprocessor unless the processor itself is part of the terminal.

The discussion thus far should probably convince most users of computers in psychology to ignore the fact that microprocessors exist. The development and support of these devices is now at about the stage that minicomputers were 10 years ago. Many psychologists spent considerable time developing minicomputer systems, which would be much easier to assemble today, given the support now available from many sources. At present, the microprocessor receives less support than the mini did then, so direct use of these devices is inadvisable for most psychologists.

A more fruitful discussion might point up the possible uses in psychology. This would help to identify areas of application where systems suppliers could concentrate their efforts, or where likely products using microprocessors might be adapted to use in psychology.

Some suggestions, along with comments on likely implementation, follow.

SOME USES IN EXPERIMENTAL PSYCHOLOGY

In experimental control, the most directly obvious application would seem to be a small, self-contained control device for implementation of a univeral language for psychological experiments. Considerable programming–the translator or interpreter for the language and its run-time subroutines–could be produced once and replicated in ROM with each device. There are several notations that are quite compact and would require little RWM storage to represent the actual program for the experiment (cf. Snapper, 1973; Castellan, 1973).

Thus, the microprocessor could be a compact version of its bigger brother, the mini, and could carry out the entire experimental program. It may be more useful, however, to consider using the microprocessor as a "front-end" in conjunction with a larger conventional computer for many experimental applications. Such an arrangement would combine the advantages of computing power at the experimental site with those of having a large computer system available for program preparation and storage and data analysis. This mode of operation is analogous to the role of the "intelligent" terminal in business information computer systems. The functions that can be handled at the terminal are provided by the terminal (such as error checking, formatting, editing, and communications protocol in the business case), thus reducing the response constraints and load on the central facility.

A front-end would occupy the position of a terminal in a typical timesharing system, and the communications protocol could be identical with that used by the terminal. Each trial of an experiment would be specified by the main computer in terms of actions to be carried out and data to be recorded. These commands would be transmitted to the terminal in an intermediate language having a concise format. The microprocessor would carry out the experimental trial, and return data regarding responses and latencies to the main computer for analysis and determination of the parameters for the next trial. Thus, the main overall control of the experiment would be in the main computer, which would make possible the use of very sophisticated strategies and high-level languages, while the actual control over stimuli and response collection would be handled by the front end.

Such an arrangement would be feasible for experiments involving little or no contingent control within a single trial and where the length of the intertrial interval can be long enough to permit the transmission of data and activation of the main control program. Preliminary study of a similar design without a microprocessor showed that a wide range of reaction time experiments can be performed with this system.

Such a front end could be produced relatively inexpensively and would provide many of the advantages of real-time control to persons who have access only to a conventional timesharing system. Again, initial costs are high, and the possibility of such a design's being economically viable hinges on the ability to replicate a system over many devices.

THE INTELLIGENT TERMINAL

If a device for psychological control is to pretend that it is a terminal, perhaps it should be a terminal. There are a number of terminals that now incorporate microprocessors, usually for formatting and editing of input information. These are aimed primarily at the business market, but some recent devices indicate that other areas may also benefit.

The terminal that is really a computer is here, although sometimes the terminal feature gets left out. There are two examples now on the market that look like terminals, but are really self-contained single-language processors, one for BASIC and the other for APL. These two processors do not function as terminals, but that should be possible. Control interfaces should be adaptable to these processors, giving a control computer and display for $3,500 to $6,000.

The intelligent terminal also may be marketed in a form that will allow the user to expand or modify the terminal's control routines. One terminal currently available shows expansion possibilities for the terminal that resemble those of a minicomputer, and some of the options seem to imply the possibility of user-generated control programs. All of the possibilities have not yet been explored, even by the manufacturer.

OUTSIDE EXPERIMENTAL CONTROL

This discussion has centered on experimental control because that is the area of psychology that is most interested in the internal matters of hardware. Microprocessors will be used extensively in the terminals and other peripheral devices of all sorts on almost any computer system. The point is, of course, that they will be invisible; their only effect on the user will be the increase in reliability due to the more compact technology, and some enhancement of the capabilities of devices that previously used discrete logic to accomplish certain functions.

In conclusion, it seems that the psychologist should not become involved with microprocessors, per se, at present. He should recognize that they exist, however, and be prepared to explore the possible adaptation of other devices employing these circuits. Due to the number of replications of a design needed to make it economic, it is currently unlikely that this technology offers much to the end user who needs a one-of-a-kind device. There is considerable potential for the equipment manufacturers, and for the adaptation of equipment found in other fields.

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