Medium-Sized Computers: Bringing Computers into the Lab

The massive computers that have revolutionized America's manner of conducting business have had a more modest effect on its science. Large computer systems like the IBM 360 or the PDP-10 have, of course, been a necessity for scientists making the complex calculations required in quantum mechanics, x-ray crystallography, and other fundamentally mathematical problem areas. The systems have also been crucial to such mammoth projects as the space program. But the typical scientist, unwilling or unable to devote a significant portion of his time to developing the engineering and programming skills necessary for efficient use of these sophisticated systems and perhaps unable to meet the high cost, has reaped little benefit from the race to ever larger and faster machines.

The minicomputer, in contrast, is fast becoming a staple in the individual scientist's laboratory. Inexpensive and simple to program, the smallest ones are ideal for routine calculations such as curve fitting, rate determinations, and statistical analysis. But perhaps more important, minicomputers have catalyzed the development of a new generation of high performance instruments—Fourier transform spectrometers and quadrupole mass spectrometers, for example—that collect and quantify large amounts of data in a very short time. Typically, these minicomputers are designed and programmed exclusively for one application. The scientist may thus be freed from the need to learn programming and engineering, but only at a great sacrifice in flexibility of the instrument.

Between these two extremes lies a middle ground, the medium-sized computer with a capacity of 16,000 to 64,000 words, compared to the maximum of about 8,000 words in a minicomputer, or the minimum of several hundred thousand words in a full-scale installation. Computers of this type have been widely used in industry for process and equipment control. Only in the last 3 to 5 years, however, have scientists (and administrators) begun to appreciate the versatility and cost-effectiveness of medium-sized computers for use by small groups of investigators. This trend has also been spurred by the establishment of large computer networks that allow institutions to purchase computer time rather than computer hardware (*Science*, 5 October, p. 29), thus freeing more resources for the purchase of medium-sized machines.

Innovative uses for medium-sized computers are being developed in many disciplines, but their greatest impact will probably be felt in the health sciences. Although applications are being developed at many institutions, a sampling of the potential applications can be obtained by consideration of some of the projects at the National Institutes of Health (NIH) in Bethesda, Maryland.

Application to Unusual Problems

When NIH created its Division of Computer Research and Technology some 7 years ago, one of the first acts of the new division's director, Arnold W. Pratt, was the establishment of the Computer Systems Laboratory (CSL) to work with institute scientists on the application of computer technology to problems that do not lend themselves to normal processing. Since then, says laboratory head Alan M. Demmerle, CSL has assisted in the design and installation of some 20 new systems. About 40 percent of the systems involve minicomputers dedicated to a single instrument or application; the rest are built around medium-sized computers. The applications run the gamut from data acquisition in nuclear magnetic resonance and mass spectroscopy to control of psychological experiments, from automation of routine biochemical tests to providing medical telecommunications and tentative diagnoses for practicing physicians.

In each case, the approach has been much the same. Investigators with a problem that might be solved with computers solicit assistance from CSL; if CSL actively sought out such problems, Demmerle argues, it would run the risk of seducing the scientists into purchasing equipment they don't really need and may not use effectively. Engineers from CSL then work with the investigators to identify the problem precisely and determine exactly what is expected of the computer.

Using the investigators' funds, the engineers next purchase the state-of-the-art computer that most closely fills the scientists' requirements and design and build the interfaces necessary for connecting the instruments or experiments to the computer. And finally, they program the computer so that it can be used by individuals who have no knowledge of computers. They also perform maintenance on the system once it is in operation.

A good illustration of this approach can be found in an installation developed for the National Institute of Arthritis, Metabolism, and Digestive Diseases (NIAMDD). About the time the computer division was established, several NIAMDD scientists were each planning to purchase instruments that incorporated data acquisition and digital recording devices with the prospect of analyzing the recorded data at the NIH central computer facility. Because all of the instruments were to be located in one building, however, it became apparent that the aggregate cost of such an approach was of the same magnitude as the cost for installation of a centrally located medium-sized computer. Such an installation would allow a much greater flexibility than any of the highly specialized devices that would have been purchased. It would also have sufficient capacity to allow considerable data manipulation, signal averaging, and more complicated data reduction.

Most of the instruments were to be spectrophotometers and spectropolarimeters that produce data at a relatively slow rate, about 500 to 1000 bits (or pieces of information) per second. Marvin Shapiro and Arthur Schultz of CSL thus chose a time-sharing system in which the computer acquires data simultaneously from as many as ten different instruments while running one or more analysis programs in a background mode. They were not, however, able to connect two other instruments directly to the computer.

These instruments, an x-ray diffractometer and equipment used to record the response of retinal cells to light flashes, produce signals at such a rapid rate—about 10,000 bits per second—that they are not readily amenable to time-sharing. Each of these is thus interfaced to the central computer through a minicomputer that records most of the data. The link to the larger machine allows the experimenter to expand the storage capacity of the minicomputer and to take advantage of other peripheral devices, such as printers.

The central computer is a Honeywell DDP-516 with a storage capacity of 32,768 16-bit words. Additional equipment includes magnetic tape and disk storage units, analog-to-digital converters, and teletypewriters. Each instrument connected to the system also has a remote operator's console that includes a storage oscilloscope for displaying acquired data and communications from the computer, six push-button controls for operating the system, and six thumb-wheel switches for entering numerical data. The total cost of the system was about $280,000 for hardware and about $500,000 for the labor involved in programming and construction of the interfaces and other specialized equipment.

Essentially no knowledge of computers is necessary for data acquisition with the system. Once the computer is activated, it begins a series of questions that elicit the necessary data for any experiment. With an ultraviolet spectrophotometer, for example, the computer first asks for a file number to tell it where to store the data. It then requests the initial and final wavelengths for the spectrum to be observed, and the size of the desired wavelength interval between measurements.

The experimenter then merely starts the spectrophotometer, pushes a RUN button on the remote console, and the spectrum is recorded and stored. The computer can also be told to perform repetitive scans for averaging of the spectrum or for obtaining kinetic data. Manipulation or bulk processing of the acquired data, however, requires a knowledge of Fortran programming and computer operation, although a few easy-to-use programs for standard data manipulation are available and others are being devised.

The principal benefits of a direct link between the instruments and the computer are increased sensitivity and speed, says NIAMDD's William H. Jennings. By averaging several spectrophotometric scans, for example, the computer obtains a much higher resolution than would be possible with just a strip chart recorder. In some cases, it also obtains the results as much as 10 to 20 times faster.

Collection of the data in digital form, moreover, makes subsequent calculations—such as determination of extinction coefficients, difference spectra, and rates of reaction—much easier. And, with the use of an X-Y plotter, the computer can quickly convert raw data into publication quality graphs.

The Honeywell computer is also being connected directly to the larger machines in NIH's central computer facility. This connection will be very useful, Jennings says, when extra storage capacity is needed for programs or data and when particularly complex problems are being processed. The link is also useful in the preparation of new programs, since program development is generally much easier on the larger computers. The NIAMDD system is one of only two NIH systems that are now being linked to the central facility, although several others will also be linked within the next few years. It is also one of four such NIH systems that perform similar functions in the acquisition of instrumental data; none of the other systems is as extensive, however.

Medical Applications Also

CSL has also developed several interesting applications for medium-sized computers in medicine. One prototype system, for example, is designed to provide economical, reliable, easy-to-use computer services to practicing physicians. Laboratory test results and other information about each physician's patients are stored in a Systems Electronics Laboratory 810B computer. The physician can retrieve any of this information by querying the computer with a standard touch-tone telephone, and receives a voice response.

The computer also correlates all the patient information and provides the physician with a description of the disease most consistent with the patient's symptoms. By noting discrepancies and similarities between this description and the patient's condition, the physician can initiate new descriptions and ultimately arrive at a diagnosis. The system can also be used for minor calculations, such as determining the volume of replacement fluids in burn care, and is connected with a mass spectrometer for use in identification of poisons. The system has not, however, had any significant testing by community physicians.

Another installation will employ a Xerox Sigma-3 to monitor the recovery of postsurgical patients in the intensive care unit of the NIH Clinical Center. A variety of sensors will enable the computer to record such patient functions as arterial and venous blood pressures, temperature, heart function, blood loss, and urine loss and alert the attendants to any serious changes. Only one bed in the unit is now connected to the system, but there are plans to connect five more within a few months.

Some investigators hope to connect the system so that it can also administer replacement blood and certain drugs when necessary, as does a more advanced system at the University of Alabama Medical Center in Birmingham. Despite the success of the Birmingham system, however, many physicians still question the propriety of such intervention by machines and the overall safety and reliability of the system. The use of computers in medicine, in fact, may represent one application where the biggest problem in realizing all the potential benefits lies not in developing the technology, but rather in developing an adequate medical expertise to use all of the information provided and in overcoming the skepticism and fears of the potential users.

Perhaps the most unique applications of medium-sized computers, however, are to be found in an installation used by investigators at the National Institute of Mental Health (NIMH) to conduct experiments in psychology and psychophysiology. These applications involve experiments in which the computer not only collects and analyzes the data, but also interacts with the subject and, in some cases, controls the course of the experiment.

Most psychological testing involves the presentation of sequences of visual or auditory stimuli and the simultaneous monitoring of the subject's vocal or electrophysiological responses. In the past, such experiments have generally been implemented with flash cards or with complex assemblies of special purpose electronic devices. The exposure of flash cards by the experimenter is a technique that is particularly prone to the introduction of artifacts arising from undiscerned patterns in the presentation of the cards or from interactions between the experimenter and the subject.

Weeks or months are frequently required to assemble the electronic devices for an experiment or to change from one experiment to another; once an expensive piece of equipment has been constructed, moreover, the investigator is frequently loath to proceed to a new type of experiment. Both the flash card and the electronic approaches lend themselves readily to the use of computers.

About 4 years ago, NIMH decided to catalyze research in this area by installing an SEL 810B for several staff psychologists who were interested in adapting their experiments to its use. The time-sharing system, which was implemented by a CSL group headed by Daniel Syed, is similar to the NIAMDD system in that each investigator's apparatus is connected to the computer through a specially constructed interface, several experiments can be run simultaneously, and conventional batch processing of experimental data can be performed in a background mode. The experimental applications, though, are quite different.

Virgil R. Carlson, for instance, is examining time perception in humans as a function of the time of day and the state of drowsiness of the subject. Time perception is frequently measured by a combination of three standard techniques that involve a light which can be actuated by either the experimenter or the subject. The subject is required either to estimate the length of time that the light has been actuated by the experimenter, to reproduce the time interval by lighting the lamp for the same length of time, or to light it for a specified interval.

In a conventional experiment, the light would be operated by the experimenter in some predetermined sequence of time intervals and techniques while he records the subject's responses. In Carlson's approach, the computer randomly selects the time intervals and techniques, subject only to the provisos that equal emphasis be given to each technique and that the distribution of time intervals chosen be equal. The computer not only flashes the light for the precise time chosen and records the subject's response, but it also records the time that lapses before the subject responds and maintains a complete record of each subject's responses. In this manner, Carlson says, he gets more information and gets it faster than he would manually, and the results are freed of artifacts resulting from bias or error of the experimenter.

Edward A. Jerome of NIMH is studying how individuals are able to form concepts such as those involved in the definitions of the logical connectives *if*, *and*, *or*, and so forth. Generally, this type of study is done with flash cards: The investigator shows the subject one or more cards with selected words or symbols on them and asks the subject how they are classified with respect to rules that have been used to define the connectives. By analyzing the subject's right and wrong answers, the investigator is able to determine the number and types of questions necessary for understanding the concepts. This knowledge can then be used to assist the teaching of school children to improve their understanding of logic.

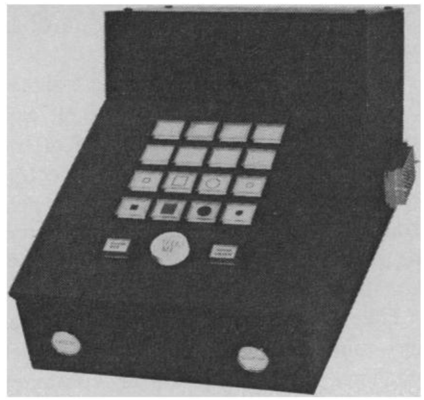

Fig. 1. The keyboard used by Edward A. Jerome of NIMH in his computer-controlled experiments on concept formation. Typical communications from the computer to the subject might read:

Now, please press all of the black buttons, one at a time. Then press the button marked SOLUTION.

Fine! That was what we will call a word. It was the word "black."

A word consists of eight buttons all of which have some dimension-value in common.

Now please send me the word "square."

The interface developed for Jerome's experiments (Fig. 1) uses a keyboard with 16 keys representing circles and squares of various sizes, colors, and color densities. By means of a storage oscilloscope, the computer asks questions that can be answered by pressing appropriate combinations of keys. If the subject gives the wrong answer, the computer shows him the right one and allows him another chance to learn the concepts involved in the question. If he gives the right answer, the computer proceeds to the next question until all of the concepts have been mastered.

The principal advantage of the computer, Jerome says, is that it removes the experimenter from the problem. Individuals react much better to an impersonal machine, he says, perhaps because it is less embarrassing when they make mistakes and perhaps because it is clearer to the subjects that they are dealing with a precise, defined system. The subject is also able to work at his own pace, since he is not impeded by the experimenter's need to explain rules, flip cards, and record answers. A not inconsequential benefit, Jerome adds, is that working with the machine is fun for most people, and this provides an additional impetus toward completing the experiment.

In experiments that are not strictly adaptations of manual techniques, Monte Buchsbaum of NIMH is using the computer to study evoked responses—electrical signals in the brain that have been initiated by external stimuli, such as intermittent sounds and flashing lights. These responses are dependent on a variety of conditions within the brain—such as the concentrations of neurotransmitters and certain enzymes—and can thus be used, among many other applications, to monitor the effects of drugs that alter brain activity.

Since the evoked response is not much larger than normal brain activity, meaningful measurements require an averaging of the responses to repetitive stimuli. Averaging these responses (as recorded with an electroencephalograph) and determining their magnitude for a variety of stimuli is a very laborious, if not impossible, task manually, but is a relatively simple job for the computer. Since the computer also can easily generate nearly any auditory or visual stimulus desired, its use eliminates the need for a great deal of other experimental equipment and gives the experimenter a great deal of flexibility to modify the experiment or change it completely. These experiments can be implemented with a dedicated minicomputer, Buchsbaum says, but only at a great cost in experimental flexibility. The larger computer also provides a much greater capacity for storing information about each subject's responses, and makes it much easier to analyze the data once they have been obtained.

These are just a few of the applications to which the NIMH installation has been put; indeed, the systems that have been described are just a small sampling of the applications of medium-sized computers on the NIH campus, and medium-sized computers represent just a fraction of all NIH computer activities. Nonetheless, these systems are typical of the modest impact that this class of computers is beginning to exert on the health sciences and of the much greater impact that can be expected in the future.—THOMAS H. MAUGH II