are just not known at present. It is obvious that this phenomenon is importantly affecting university structure and function. It is also obvious that it is receiving a tremendous amount of attention and reaction. Because of this importance and visibility it deserves the kind of comprehensive examination that can provide insights into the behavioral aspects of the phenomenon.

A Caution and a Hope

We are aware that the pursuit of these questions may be viewed with alarm by some groups. Insidious motives may be ascribed to proponents of a national study to examine student unrest. We see no way to avoid such criticism. It is our belief, however, that such a study, dedicated to a better understanding of the dynamics of the process of student protest, can be useful in resolving the substantive issues which are being raised in these protests, and is important in its own right as an area for behavioral research.

Note

1. A separate report on these sessions with the college presidents is being prepared for publication.

Choosing a Scientific Computer for Service

Computers can be cheap and available or prohibitively expensive, depending on choice of size and type.

M. V. Mathews

Digital computers give promise of serving mankind as no other machine and no animal has ever done. They, and the other technology which our science can create, inspire realistic visions of an economic and intellectual plenty which was formerly unimaginable. Computers promise to control production machinery with unprecedented flexibility; to store, summarize, and quickly provide the business information needed to run complex industries; to marshall demographic and economic data; to predict complex phenomena such as weather; to compute dosages of, and administer, radiation in radiotherapy; to watch over the care and genetic development of the plants and animals that provide our food; to play instruments, to sing, and to draw pictures; perhaps even to play games for our amusement. They promise to replace both the unwilling slave as man's servant and the willing dog as man's best friend.

In order to realize these potentials, we and others are investing much effort —to develop computers, to train users of the computers, and (hopefully) to apply these machines in solving important problems. Unhappily, our progress is slowed by the very progress that is being made in computer development; we are impeded by subtle and unexpected difficulties which we do not completely understand. For example, introduction of the current generation of computers, which are clearly more complex and slightly faster than previous machines, has almost ended computer solutions of useful problems in many places. Because of their cheapness, the new machines were irresistible; because of their complexity it is taking years to write the system programs that will make them usable.

We find ourselves close to the position of needing every person who can program a computer to write the system programs, and to rewrite them as fast as the next generation of machines is constructed. Furthermore, this programming is intriguing; we can easily enjoy serving computers rather than making computers solve our problems. (Computer science is often a synonym for serving computers.)

Schools have rightfully assumed the tasks of training computer users and applying computers in solving worthwhile problems. In doing so, they face not only the difficulties I have mentioned but also unprecedented costs, and the problem of choosing from a large array of possible machines. These vary in cost, according to size, from $10,000 to $10 million; there are more than 30 domestic producers, some making over 20 different models. There are scientific computers, business computers, and remote-access computers, all different.

Computation is young, and computer experts are few. Often schools must choose a machine and develop a program for its use with very little technical help. It is to be hoped that computer manufacturers will soon provide technical guidance to assist in wise selection of computers, at least from their own line of machines. At present this seems not to be the case. In reply to a suggestion that a Columbia University seminar on the relations between research, education, and computers hold sessions dealing with the technological reasons for selecting a particular computer, the representative of a large computer manufacturer on the program committee replied, "As to the subject of choice of computer, the points you raise are mainly technological whereas a real computer is chosen on grounds other than the technology: available funds, whether for rent or for sale; space available; future expansion capabilities; the existence of a joint user's committee with pooling of funds—these are all factors which I call political rather than technological, and I suspect that these factors outweigh what might otherwise be a purely technical decision." The current weight of political factors may indeed be significant.

In the remainder of this article I point out some technical factors which I feel are vital considerations in choosing a computer. Choice of the proper

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computer can make the difference between a tolerable and an intolerable financial burden; between having elite computing facilities available to only a few and a copious supply of computers available for all; and, in some cases, between useless and useful computing. Here I consider only the *scientific* applications of computers; my experience does not extend to business. The general conclusions are that computers are no longer a single kind of machine, and that a computer must be selected to match, in both size and type, the problems at hand. Economic factors are very important in that one must purchase today's machines rather than tomorrow's machines, and that one should plan to keep a computer for a long time because of the cost of reprogramming.

Comparison of Computers

Table 1 presents some comparisons of the performances of a selected group of computers. The machines are described in terms of the number of bits (binary digits) in a word of core memory; the time required to read a word from memory ("memory time"); the time needed to add a number in memory to a number in the accumulator ("add time"); and the monthly rental, including service. For machines which cannot be rented, the figure given in the "rental" column is $\frac{1}{40}$ the purchase price. In some machines, memory is organized into six- or eight-bit arrays called bytes. This is a useless word size for most scientific computations; the word size used in Table 1 is either two or four bytes.

The machines, or "installations," are grouped into three size classes. The large installations contain a central processor, 32,000 words of core memory, a 1000-line-per-minute printer, a card reader and punch, eight tape units, and disk files with about 6 million words of storage. The medium-size installations consist of a central processor, 8000 words of core memory, a 1000-line-per-minute printer, a card reader and punch, four tape units, and a disk file with about 500,000 words of storage. The small installations consist of a central processor, 4000 words of core memory, a printer, a card or tape reader-punch, and a small disk file. The characterizations large, medium, and small apply to typical installations in schools. Some industrial and some big university installations are much more extensive than sizes called "large" in Table 1.

A given central processor may be classified in either of two size groups, depending on how much is attached to it. It is often more attractive in one group than another.

From among the infinite number of performance measures which could be proposed, four costs are listed in Table 1. These are as follows:

1) (Monthly rental, in dollars) × (memory access time, in microseconds).

2) (Monthly rental, in dollars) × (add time, in microseconds).

3) [(Monthly rental, in dollars) × (memory access time, in microseconds)]/(memory word size, in bits).

4) [(Monthly rental, in dollars) × (add time, in microseconds)]/(memory word size, in bits).

All these measures are costs in the sense that one would prefer a machine having a low value for each of them, all else being equal. Which of two machines is judged superior may depend on which measure is used to compare them. There is no simple measure which is universally accepted. However, I will draw conclusions only from trends which are large enough to be clear in all the measures proposed here.

In Table 1 the central processors of the computers are characterized by an initial "brand" letter indicating whether they are made by large companies (brand A, B, or C) or small companies (brand X, Y, or Z); by a word, or words, indicating their intended use—for scientific computation or for general-purpose computation (business as well as scientific); and by a final identifying letter (A, B, C, D), so that a given processor can be identified in several different installation sizes.

In Table 1 the computers are un-

Table 1. Some comparative data for a sample of computers. For characteristics of large, medium-size and small installations and for an explanation of the performance cost measures, see text.

Machine	Rental (dollars per month)	Word size (bits)	Memory time (μsec)	Add time (μsec)	Performance cost measures* (Monthly rental) × (memory time)	(Monthly rental) × (add time)	[(Monthly rental) × (memory time)]/(memory word size)	[(Monthly rental) × (add time)]/(memory word size)
			Large installation					
B–Scientific machine B	34,000	48	1.4	2.0	48,000	68,000	1,000	1,400
C–Scientific machine A	28,000	36	0.5	1.8	14,000	50,000	390	1,400
A–General-purpose machine D	29,000	64	.75	1.3	22,000	38,000	340	600
X–Scientific machine B	21,000	36	1.	2.1	21,000	44,000	580	1,200
Z–Scientific machine A	21,000	32	0.8	1.7	17,000	36,000	520	1,100
A–Scientific machine B	16,000	32	1.7	1.7	27,000	27,000	850	850
			Medium-size installation					
Y–Scientific machine B	8,000	24	1.9	3.8	15,000	30,000	630	1,300
Z–Scientific machine A	10,000	32	0.8	1.7	8,000	17,000	250	530
X–Scientific machine B	8,000	36	1.	2.1	8,000	17,000	220	470
A–Scientific machine B	8,000	32	1.7	1.7	14,000	14,000	430	430
A–General-purpose machine C	12,000	32	2.	4.	24,000	48,000	750	1,500
A–General-purpose machine B	9,000	32	5.	12.	45,000	108,000	1,400	3,400
B–Scientific machine A	12,000	24	1.25	2.5	15,000	30,000	630	1,300
			Small installation					
Y–Scientific machine A	2,500	16	1.	2.	2,500	5,000	160	310
A–Scientific machine A	1,500	16	3.6	8.	5,400	12,000	340	750
A–General-purpose machine A	4,000	32	6.	39.	24,000	160,000	750	4,900
X–Scientific machine A	2,000	18	1.	2.	2,000	4,000	110	220

* Monthly rentals are given in dollars; times, in microseconds; memory word size, in bits.

named, for a variety of reasons. These data are inappropriate for, and not intended for, use as the basis of a choice between two specific possibilities for a given installation. Specific configurations—the number of card readers, printers, tape recorders, disks, channels, special attachments, and core memory locations—vary enough so that few installations will be exactly represented by the data of Table 1. Pricing policy and discounts given schools also vary in idiosyncratic ways. In addition, the calculation of specific, detailed costs and performance estimates is an educational exercise which all computer purchasers should do for themselves. Finally, we have estimated the costs for purposes of illustration only, and have no wish to argue about the validity of the methods or to guarantee that there are no errors.

The value of the comparison lies in the fact that certain general trends are clearly evident; the most important of the trends is this: the cost per computation is becoming higher for big machines than for small ones. The highest cost ratio shown is more than 20 to 1 (for example, compare the machines listed first and last in Table 1 with respect to the first performance measure). This is a huge variation. One would expect such a trend to be self-evident; it is not, nor did this relation exist in the past. A few years ago, new machines were invariably larger, faster, and cheaper (in terms of cost per computation) than the smaller machines they replaced. The change is attributable to the fact that the central processors and memories for small machines are now as cheap and fast, per computation and per bit, as those for large machines. A large machine differs from a small one mainly in having more memory, tapes, disks, printers, and so on, attached to the central processor. As a result, it can handle larger problems. However, if the problems are small, the small machines can do them more cheaply. Many student exercises are in the small-problem category, and small machines are therefore the most economical for these exercises.

An earlier argument against use of small machines was that they lacked software support, particularly compilers. This objection is no longer valid. Almost every machine is now supplied with an effective Fortran programming language. Furthermore, the manufacture of Fortran compilers is so well understood that they can be routinely and quickly produced and will operate reliably.

The second trend evident in Table 1 is a difference in costs between scientific computers and business or general-purpose machines, the costs for the general-purpose machine being higher. This difference is most marked for the small and medium-size machines; for these, the largest cost ratios are about 10 to 1. (For example, compare the two machines listed last in Table 1 with respect to the first performance cost measure, or compare Z–Scientific machine A with A–General-purpose machine B with respect to the second performance cost measure.) While these differences in cost are not so large as those associated with differences in computer size, they are significant in terms of yearly rentals and in the context of school budgets.

The cause of the trend appears to be compromises in design, made to make some machines more attractive for business computation. Particularly undesirable, from the standpoint of the scientist, are memories organized in byte arrays; to achieve a word size useful for scientific purposes, several bytes must be assembled, and this is a relatively slow process.

A useful comparison of operating times can be drawn, in the category of medium-size installations, between A–Scientific machine B and A–General-purpose machine B. These computers are quite similar, but the scientific machine can retrieve a word from its memory in one-third the time the general-purpose machine requires, and can add in one-seventh the time required by the general-purpose machine.

Differences in costs between scientific and general-purpose machines decrease with increase in the size of the machine. In the small-installation category (Table 1), A–General-purpose machine A stands out as the most expensive. Costs associated with this machine exceed by a factor of 4 those associated with A–Scientific machine A—the next most expensive. In the large-installation category, costs are more uniform; A–General-purpose machine D is about on a par with other machines in this group with respect to two performance cost measures and the cheapest with respect to the other two.

From the size trends we concluded that it is important to fit machine size to problem size—that is, to use small machines for small problems. Now we can add that scientific problems can be done much more economically on scientific-type computers than on general-purpose computers. Whether business problems can be done more economically on general-purpose computers is an interesting question that is beyond the scope of this discussion.

Some savings can be realized through the use of "off-brand" machines. For example, X–Scientific machine B and Z–Scientific machine A are the cheapest in the medium-size-installation category, by a factor of about 2. In addition, they have many wires "hanging out" and have a general look of being unfinished or changeable. Thus, they are especially attractive for use in an engineering school, where electrical connections are to be made, and interactions established, between the computer and many other items of equipment. It is perfectly possible to design and construct special units to be appended to these computers. These new units can be made from the standard plug-in packages from which the rest of the computer is assembled. (I need hardly add that all this requires competent engineering.) "Off-brand" machines can also be used for routine computations, but for these purposes they are more nearly comparable with computers like A–Scientific machine B.

There is a slight interrelationship between central-processor size and installation size. X–Scientific machine B, Z–Scientific machine A, and A–Scientific machine B all seem more useful in a medium-size installation than in a large one. As more memory devices and peripheral devices are associated with a central processor, it becomes worth while to modify the processor by adding more registers and other special features. These are available in the large central processors. However, they are complicated. An alternative, which should be considered, is the use of several medium-size computers, which can interact if necessary.

Consoles and Time Sharing

The use of consoles which provide immediate access to a computer via a teletypewriter is a possibility that has wide popular appeal. The availability or nonavailability of time sharing on various computers has been the primary consideration in a number of places. In addition to giving fast service, consoles are simpler to operate, in some respects, than computers, and their languages are easier to learn than most computer languages. Hence they have broad appeal. However, in considering console computing, it is essential to understand what one is buying and how much it costs.

Opinions about consoles vary greatly. Consoles provide easy computation for simple problems. It is easy to learn the console languages; it is easy to write short programs; it is easy to gain access to the computer; it is easy to debug and revise programs, because answers come back quickly. Unhappily, consoles are much less satisfactory for large problems. It is not pleasant to type a long program, or to feel slightly rushed by the presence of the computer at the other end of the line when one is coding a complicated algorithm. Although routines for editing programs from a console have been given careful attention, it is hard to equal the facilities provided by punching the program onto computer cards. In many systems the amount of core memory is too little for solving some problems. The amount of backup memory for storing programs and data is small, and such storage is expensive relative to storage on cards and tapes in one's own office. Most console systems do not allow the user to write a magnetic tape or to punch cards; hence, communication to other computers is limited. Thus, although the idea of debugging a program on a console and running it on a batch-processing machine is attractive, in most cases the process is often impossible to carry out.

To summarize, the console can provide simple computation for the masses—provided they can afford it. Consoles have little to offer in advanced programs—programs which are complex, large, and long.

What about costs? There are three possible modes of obtaining or arranging for console computing service. One can rent consoles from an existing commercial service; one can buy a moderate-size computer, teletypewriters, and a simple time-sharing program; one can buy a large computer, plus consoles, and set out to develop an advanced time-sharing service.

The last possibility is not a method of obtaining computer service but, rather, a method of serving computers. Anyone interested in this possibility should consider waiting until someone else has written the necessary programs, then decide if he really wants them. Those who insist on entering this branch of computer science should have dedicated programmers measurable in tens, available dollars measurable in millions, and time measurable in years.

Some sample costs of renting commercial console service are \$2000 to \$3000 per console per month. These figures include both the cost of the fixed attachment and the charges for use. They do not include the line charges, which can be high if distances are great (a hundred miles or more).

Some savings can be achieved through running one's own machine. For example, A–General-purpose machine C supports ten consoles for an overall monthly rental of \$20,000. With the time-sharing system, a fixed piece of core memory is assigned to each active console, hence the system is memory-limited. Through the addition of more memory, the number of active consoles could be increased to about 30, and the cost brought to about \$1000 per month per console. More than 30 consoles could be installed in the system, provided no more than 30 were turned on at a given time.

In this example, most of the consoles would be used for student problems. If, say, 20 minutes of console time is needed per student per problem, then 30 consoles would handle 90 problems per hour. However, in a batch-processing mode of computing, these problems might require 10 seconds each, on the average. (Most student problems consist of an attempted compilation which fails.) Thus the same machine could handle over 300 problems per hour. I conclude that present console systems are expensive as compared to other modes of computing.

Some alternatives to consoles exist. A number of small computers consisting of a teletypewriter, a 4000- to 8000-word memory, and paper-tape input and output may be purchased for from \$10,000 to \$50,000 each. Both Fortran and assembly programs come with these machines. In an engineering environment, such machines might well serve as consoles. Their cost is less per terminal than that of consoles. They provide far more computing power, but they require more complicated languages, which are probably harder to learn.

Another alternative is a remote terminal consisting of a small computer. Most of the machines listed in Table 1 under "small installation" can be electrically connected to larger computers. Small problems can be handled within the terminal computer. Problems which exceed its capacity can be transmitted to the larger machine. There they are added to the batch-processing queue. The results are returned to the terminal for printing or display. With proper scheduling, turnaround time need be only a few minutes. Because the central computer is used as a batch processor, the limitations, costs, and complications of time sharing are avoided. A very simple remote terminal consists of only a card reader and printer.

Permanent Computers

Several years ago, when computers were developing rapidly, renting a machine was almost always better than buying one. Now, strong factors favor purchase. The break-even time for holding a machine, as estimated by many schools, is between 40 and 50 months. The expected life of most machines, as limited by failure of components, exceeds these times, hence purchase is attractive. A realistic estimate of break-even time must take into consideration interest on the purchase price of the machine, and service charges; neither of these amounts is insignificant.

Other factors favoring purchase are the difficulty and great expense of reprogramming—of converting programs from one machine to another. The programs may cost more than the machine. The supply of programmers is critically small; reprogramming is uninspiring work.

As an alternative to reprogramming, I suggest the concept of permanent computers. A computer should be purchased to do a particular set of jobs and should be used for these jobs until it or the jobs wear out. The availability of a new and cheaper machine is insufficient reason for converting from the old machine. Reprogramming is too costly. New machines are purchased to handle new jobs or to meet additional demands. Old machines are abandoned when they are no longer used.

Summary

Computers are no longer a monolithic class of machines. No one machine can economically or effectively do all types of work. A specific computer must be selected to fit the problems for which it will be used. A hard look at these problems is often enlightening.

Today, much money can be saved through choice of the smallest machine that will do the jobs it must do. Scientific computers are more economical than general-purpose computers for scientific problems. An engineering school can obtain some "off-brand" machines which are very attractive in an engineering environment. Time sharing and the use of consoles should be approached with great care. These methods provide quick solutions to simple problems at considerable cost; they impede the solution of large, complex, long problems. Reprogramming is a very costly and difficult process. Most machines should be purchased with the idea that they will be used for a long time.

The number of available machines, and their variety, is staggering. A broad and intelligent survey is essential. Table 1 gives a small sample of the range of machines that would be wrong for a given job. Certain summary data (*1*) may be valuable in making an initial appraisal. Manufacturers' representatives are very helpful in supplying specific data on price and configuration, but they are naturally biased when giving advice on what type of machine a particular institution should have to handle its problems most economically. Actual experience in programming and executing problems on a number of machines is highly educational. This exercise is worth the substantial difficulty, time delay, and expense involved, particularly if it is done by the head of the computation center. Advice from disinterested experts who are themselves using a variety of machines is also helpful.

Tomorrow, all may be different. Computers are changing rapidly—too rapidly for easy integration with present methods. A machine which is best for all purposes may appear tomorrow; a programming system which makes consoles cheap and powerful may be completed. Specific recommendations can change quickly. However, an understanding of the costs involved and the capabilities required in solving specific, important problems will continue to provide the basis for intelligent selection.

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NEWS AND COMMENT

Steam Automobiles: Advocates Seek Government Support for Research

Unlike the aircraft industry, which has always been closely tied to government research and regulation, the automobile industry grew up in a tradition of paying its own way and more or less doing as it pleased. But now, with the automobile pinpointed as a major source of social ills—ranging from air pollution to gore on the highways—the government has begun to get involved. It has set up safety standards, and recently established emission standards for 1970-model cars.

In successfully waging the struggle for less stringent safety standards, the automotive industry demonstrated its strength. Now, its autonomy and independence are again challenged, this time by an alternate form of propulsion—steam—that many regard as a solution to the problem of automotive air pollution. What role the government decides to take regarding the support of research on these new steam-powered vehicles may have a significant effect on the development of automotive transportation in the United States.

In late May, the Senate Committee on Commerce and the Public Works Committee's Subcommittee on Air and Water Pollution held joint hearings on the steam car. The hearings generally concentrated on one point: should the government subsidize research and development in an industry that traditionally has financed its own activities. Representatives from the automobile companies said such action would be undesirable and unnecessary. Proponents of steam cars said that in the interests of cleaner air, government support was essential.

So far the government has shown an unwillingness to subsidize research and development of steam cars, electric cars, or any other low-pollutant vehicles. Its position, as expressed by a Department of Transportation spokesman, has been to "leave it all to private enterprise." And private enterprise's position, as expressed by Henry Ford II and others, has been all but to ignore steam-powered vehicles because, as auto company spokesmen have candidly stated, they have a huge investment in the internal combustion engine. Ford and General Motors are conducting research on steam cars, but, as attested to at the Senate hearings, they feel that their most advantageous approach to pollution problems is the development of better emission controls for internal combustion engines.

The steam proponents testified, however, that internal combustion engines could never reach the low emission levels of steam engines without impractical and cumbersome controls. Charles and Calvin Williams, two steam engine manufacturers who have spent over 20 years developing steam vehicles, took Senator Edmund S. Muskie (D–Me.) and Senator Howard H. Baker (R–Tenn.) for a ride in their steam car. They said that their car had been tested for emissions of pollutants after 25,000 miles. It had produced a hydrocarbon level of 20 parts per million, a carbon monoxide level of 0.3 percent, and a nitrogen oxides level of 35 ppm. By comparison, the standards recently set for 1970 vehicles by the Department of Health, Education, and Welfare are 275 ppm for hydrocarbons, 1.5 percent for carbon monoxide, and 1500 ppm for nitrogen oxides. Even the Ford representative said that he found it difficult to envision a way to reduce the internal combustion engine emissions to the level already reached by steam cars. "Low emission is not an option with steam power," Charles Williams told the senators, "it is built in, requiring no 'clean air packages,' expensive catalytic mufflers, or other devices whose complexity requires tuning and maintenance."

This testimony led Muskie, chairman of the Subcommittee for Air