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THE SMALL COMPUTER IN THE LABORATORY: ITS ON-LINE APPLICATION

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by

R.H. Goodman and C.A. Josling

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INTRODUCTION

In the past two decades complex computers have been developed. These machines can perform a variety of tasks, such as solving mathematecal equations, maintaining business records for large industries or controlling the flow of traffic in a city. There has been considerable development in the field of small computers. These computers are intended primarily for on-line applications of control and data acquisition; their use for data processing is limited. The cost of such computers has been steadily decreasing. This decrease has been due to advances in various technologies; making use of the transistor, the integrated circuit and low priced ferrite core memories.

While there is no entirely satisfactory method for evaluating computer performance (R. A. Arbuckle (1)), general trends may be seen. One performance criterion has been presented by Knight (2) and is applicable to a wide variety of computing capabilities. In the evaluation of small computers suitable for the laboratory, many of the parameters of Knight's formula are not applicable. One possible method of simplification has been suggested by D. J. Doyle (3). Doyle's formula implies a basic system with standard input-output facilities and defines a performance parameter P as:

$$P = \frac{(WL - 7) \cdot MS}{ADD} \qquad (1)$$

where: WL = word length

MS = memory size

ADD = add time

The value parameter V = C/P where C is the cost. This factor V has been plotted as a function of time, using performance figures calculated for a basic 8K core memory complete with paper tape input-output and represents a sampling of various manufacturers (Figure 1). Table 1 contains a summary of this data in tabular form. The exclusion of any manufacturer simply indicates the lack of data.

This article will describe some of the problems of interfacing these computers to laboratory instruments.

TYPE OF EXPERIMENTS

In most experiments four separate aspects may be seen: the purpose, the technique, the collection of data and the interpretation. Methods of data collection vary with each experimental situation but could be classified as:

(1) Visible examination.

(2) Readings of dials, meters and indicators.

(3) The analyzing and counting of individual random or sequential events.

Some experiments are more readily adapted to on-line computer techniques than others. Experiments of Class 1 are the most difficult and those of Class 3 are simple. Before discussing the nature of the interface a brief description of the typical on-line computer will be given.

FEATURES OF AN ON-LINE COMPUTER

The general features of a computer suitable for on-line experiments are: the availability of accumulator input-output lines, an interrupt facility and a direct excess to memory channel. A diagram of such a computer is shown in Figure 2.

Formula 1 used word length, memory size and add time as the parameters for defining computer performance. These three parameters will be examined in turn.

A. Word Length

Computers suitable for on-line applications have word lengths of twelve, sixteen and eighteen binary bits. The largest numbers which can be represented by these "words" are 4,096, 65,536 and 262,144 respectively. If high accuracy is required a longer word length or double precision arithmetic would be necessary in order to handle the available information.

The word length affects the instruction set and the amount of the memory that can be conveniently addressed. A twelve-bit word machine has eight principal instructions and can address 4,096 core locations of which only 256 can be directly referenced. Of the eight principal instructions; one is used for input-output control and one for manipulating the contents of the accumulator. With the latter, each bit represents a separate operation, and these bits may be combined to provide a complex instruction. In a sixteen-bit word computer, there are thirty-two principal instructions and 1,024 locations may be addressed directly. This expanded instruction set greatly simplifies programming and the ability to address large amounts of core reduces the requirement for indirect addressing. In the eighteen bit machine there are sixteen principal memory reference instructions and the capability of directly addressing 8,192 registers. This means for both sixteen and eighteen bit machines the use of indirect addressing is not a programming necessity.

B. Memory Size

The memory size required depends on the computer application. Most computers allow for single, double and floating point arithmetic operations. Double precision requires two storage locations per number and floating point arithmetic requires up to three locations. Double precision data handling slows down arithmetic operation as shown in Table 2.

The speed of arithmetic operation is directly related to the last parameter of our equation: Add Time.

C. Add Time

Add time is the time required to add two single precision numbers. It may seem that for low data rates the difference between an add time of 3 and 18 microseconds is not significant, but, it requires many cycles in order to execute simple arithmetic operations. In order to illustrate the problem, consider an experiment which requires the input of four single precision numbers A, B, C and D, the calculation of the equation A x B + C x D, and the result stored away. Table 3 shows the maximum data rate for machines with add time of 3.0, 18 and 36 microseconds, which has been calculated with the assumption that programming has been used for all multiplications. It can be seen that the long cycle time machine (36 microseconds) is only useful for experiments with input rates of less than 100 cycles per second.

The application of a computer in the laboratory requires the interfacing of the computer to the experiment. Such interfaces may be very complex. Interface problems for the three different classes of experiments will be discussed.

INTERFACING

The interfacing of a computer to the experiment will depend on the nature of the computer. General features of an interface can, however, be described for a computer with input and output lines on the accumulator and an interrupt facility and a direct access to memory channel (DAM). The DAM channel requires an external memory address register and memory buffer register, and is used for high speed input and output of data. It is not under program control. An increment (add one) memory buffer capability should be included in the DAM channel. For each of the experiment types listed in the "Features of an On-Line Computer", a brief description of the interface will be given.

A. Experiments of Class 3

Experiments of Class 3 are easily interfaced since the information obtained from these experiments is in digital form. The simplest method of interfacing such an experiment is to have each incoming event trigger a flip-flop connected to the interrupt line. This signals the computer to start a data processing routine which takes 25 memory cycles for single precision storage (SP), and 30 memory cycles for double precision storage (DP). If this time is too long, then a data storage register may be added to the interface. This register accumulates counts and the contents are transferred to memory at fixed intervals. The transfer occurs to the accumulator after many events and requires 30 (SP) and 35 (DP) memory cycles. A storage register will only be useful for experiments that involve a sequential increase or decrease of the address. If a 25 memory cycle time is too long when counting random events, then the DAM channel must be used. The increment memory buffer feature of the DAM channel reduces the time to one or two memory cycles per event. A summary of these various interfaces is given in Figure 3. These types of interfaces have been used for pulse-height analysis work (4), Mössbauer spectroscopy (5), and the data channel of an X-ray diffractometer (6, 7).

B. Experiments of Class 2

In experiments of this type the information is generally an analogue signal. The main problem is the conversion of this signal to a digital number using an analogue to digital converter (ADC). When this has been accomplished, the information may be transferred as described above. The operation of ADC's depends on the comparison of the input signal (V_{in}) to a voltage derived from a digital counting register (Figure 4). The results of this voltage comparison cause a control unit to modify the contents of the counter until the input signal and reference voltage are equal. There are three classes of ADC's which differ in their control circuits. They are:

1) ramp or counter
2) successive approximation
3) continuous.

The operation of these types of converters is shown in Figure 4.

If the desired parameter is a mechanical analogue, it must be converted to an electrical analogue which is then converted to a digital number. These converters are generally slow and have an accuracy of 3-4 decimal digits. Table 4 is a list of some mechanical to electrical converters.

C. Experiments of Class 1

These experiments are difficult and expensive to interface. So far in this paper we have described the role of the computer as a data acquisition system but not as a data processor. The amount of data processing which can be accomplished in a small computer is limited, and it is more efficient to accumulate the data on-line and perform the processing in a larger computer. The recognition of systematic patterns, such as cells viewed with an optical or electron microscope is typical of such experiments. The encoding of such information in digital form is possible by the use of an image scanning device, similar to a television camera. This type of scanning produces detailed information and requires a large amount of memory storage. As an example, a picture of a 1,000 line resolution and 32 shades of grey requires 5 million bits of data storage. This amount of storage is greater than the largest computer core memory, but is possible using such bulk storage devices as disc-packs and drums. Problems of programming for pattern recognition and the handling of such complex signals are not completely understood. This stage of computer utilization is still in the development process.

Thus, the use of computers depends on the nature of the experiments. Those experiments which are performed with instruments, such as chart recorders and scalers are easily adapted to on-line computer usage. Those experiments which require human judgment and evaluation are not.

OTHER FEATURES OF AN ON-LINE COMPUTER

There are certain experimental situations where the use of the on-line computer arithmetic facilities is necessary. The computation of cross-correlation or auto-correlation coefficients to improve signal to noise ratios is an example of this on-line computer. The output of the computer will be an improved signal which may be examined before processing.

Another feature of the on-line computer is that it may be used as a controller. For example, in an experiment involving three parameters (X, Y) and the temperature (T), the computer can monitor and set the desired temperature while collecting the (XY) data. Thus, three parameter experiments are easily implemented with an on-line computer.

The computer in the laboratory is a valuable tool for data acquisition. A small on-line system will handle many experiments simultaneously.

ACKNOWLEDGEMENTS

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TABLE 1

Computer Cost Versus Performance Data

No.	Computer	Date	WL	M_k	Add Time μsec.	$C_{k\$}$	C/P
1	SDS 920	¼ 1963	24	8	8	120	8.4
2	SDS 92	2/4 1965	12	8	3.5	42	3.6
3	SIGMA 2	4/4 1966	16	8	2.25	36	1.14
4	CDC160A	3/4 1960	12	8	16	80	32
5	PDP 1	3/4 1960	18	4	10	120	27.3
6	PDP 4	2/4 1962	18	4	16	54	23.6
7	PDP 5	3/4 1963	12	4	18	32	28.5
8	PDP 7	¼ 1965	18	4	3.5	45	3.6
9	PDP 8	3/4 1965	12	4	3	22	3.3
10	PDP 8S	3/4 1966	12	4	36	14	24
11	PDP 9	¼ 1967	18	8	2.0	35	0.8
12	IBM 1130	¼ 1964	16	8	4	46	2.5
13	3C 416	2/4 1966	16	8	2	32	0.9
14	HP 2116	¼ 1967	16	4	2	26	0.72
15	DDP-116	2/4 1964	16	8	3.4	51	2.4
16	ASI 6130	3/4 1965	16	8	1.8	47	1.1

TABLF 2

Typical Arithmetic Routine Fxecution Time
FAE (hardware multi/div.)

			Floating point 7 dec. digit	Floating point 9 dec. digit
ADD	3 μsec.	19.5 μsec.	100 μsec.	886 μsec.
MULT.	360 μsec.	1.4 msec.	1.63 msec.	3.3 msec.
	21 μsec.(EAE)	270 μsec.(EAE)	530 μsec.(EAE)	

TABLE 3

Typical Execution Times for Input of AB CD on the forming of A + B) + (C X D)

	Flag Search + Input (30 cycles)	MULT. (A x B)	MULT. (C x D)	Double Add	Total ms
3.0	45 μsec.	330 μsec.	330 μsec.	15 μsec.	1.420 = 1000 cps
18.0	180 μsec.	1.5 msec.	1.5 msec.	90 μsec.	3.27 = 300 cps
36.0	240 μsec.	5.3 msec.	5.3 msec.	90 μsec.	10.96 = 100 cps

TABLE 4

Some Mechanical to Electrical Transducers

Parameter	Transducer	Comments
Angle (Θ)	Optical or brush encoder	Directly to a pseudo binary (e.g. Grey-code)
Distance (L)	Linear resistor ($L \alpha R$)	($L \alpha R \alpha V$) use a constant current and ADC
	Fringe (Moire)	Requires a counter
Velocity (v)	Permanent magnet in a coil	Gives a $V \alpha (V)$
Acceleration (a)	Pendulum or weight and spring	Period α a $L \alpha a$
Pressure (p)	Manometer	$P \alpha L$
	Bellows	$P \alpha L$
	Semiconductor strain gauge	$P \alpha R$
Solid-Liquid (SLI)	Linear resistor and float	$L \alpha$ (SLI)
	Photo cells series	$R \alpha$ (SLI)
Interface Composition (K) (2 element)	X-ray or optical spectra	Counting rate αK Intensity αK
Temperature	Thermocouple	$V \alpha T$
Rate of flow	Manometer	see pressure
	Magnetic transducer	see velocity

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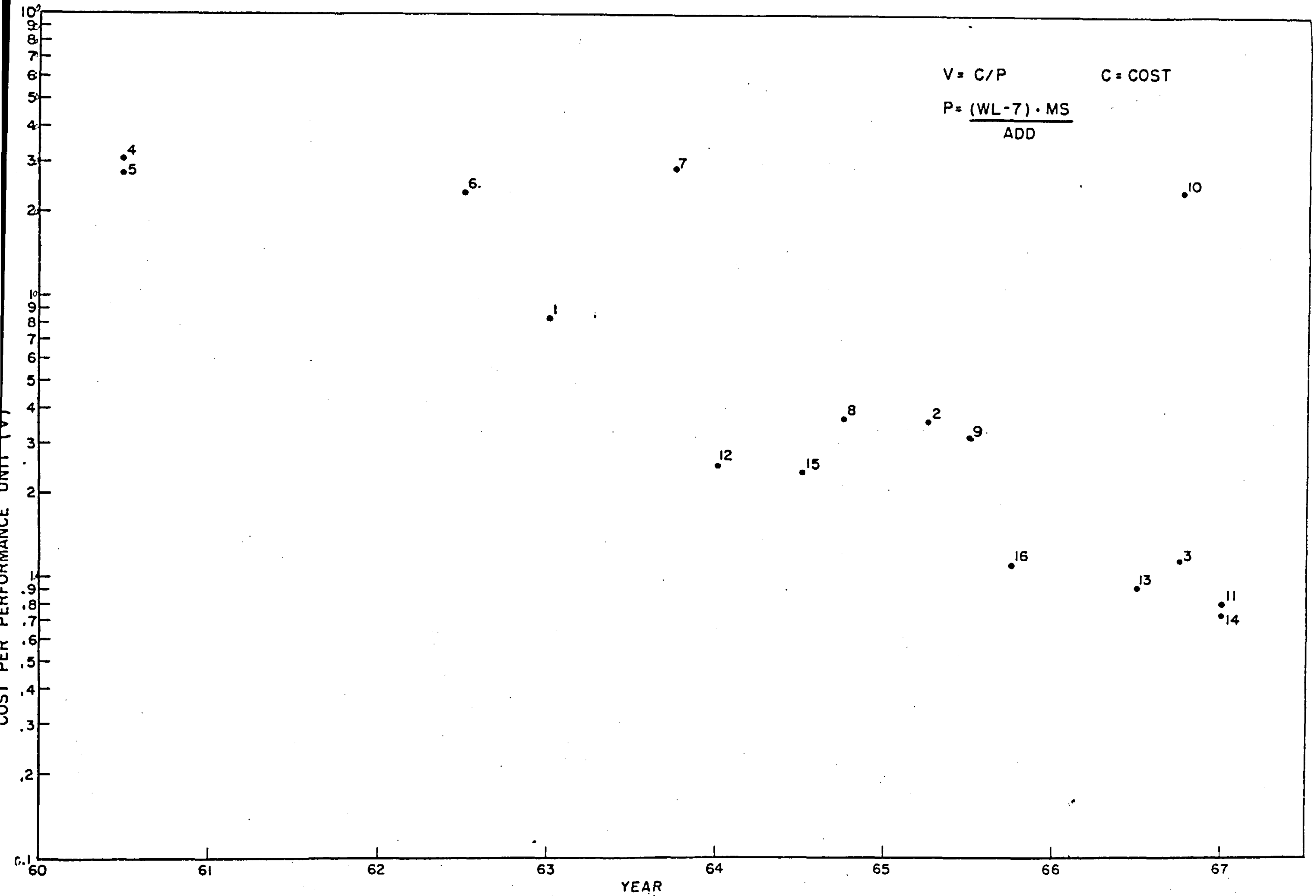

Figure 1. Computer cost versus performance rate in Table 1.

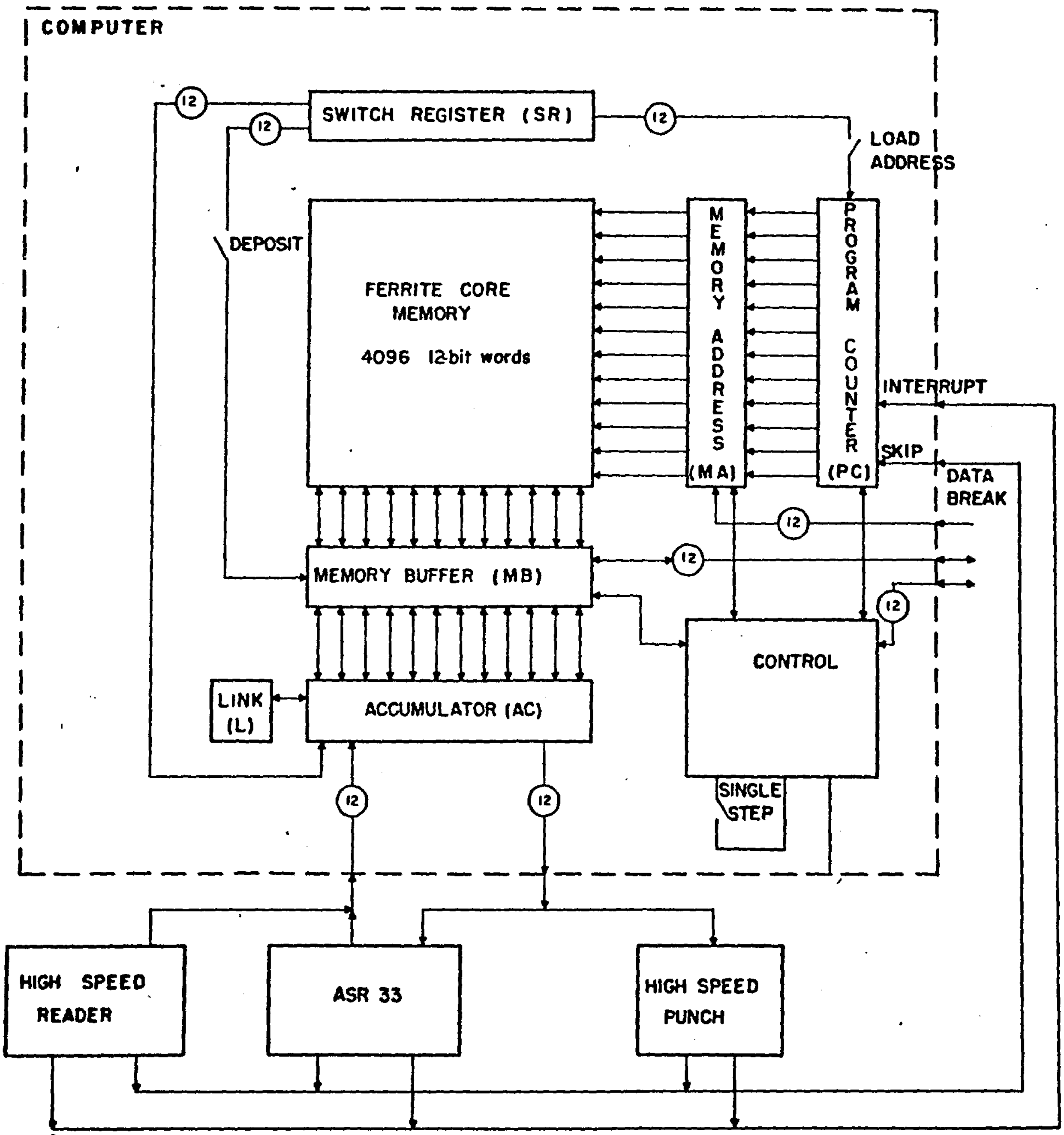

Figure 2. Basic diagram of a typical computer.

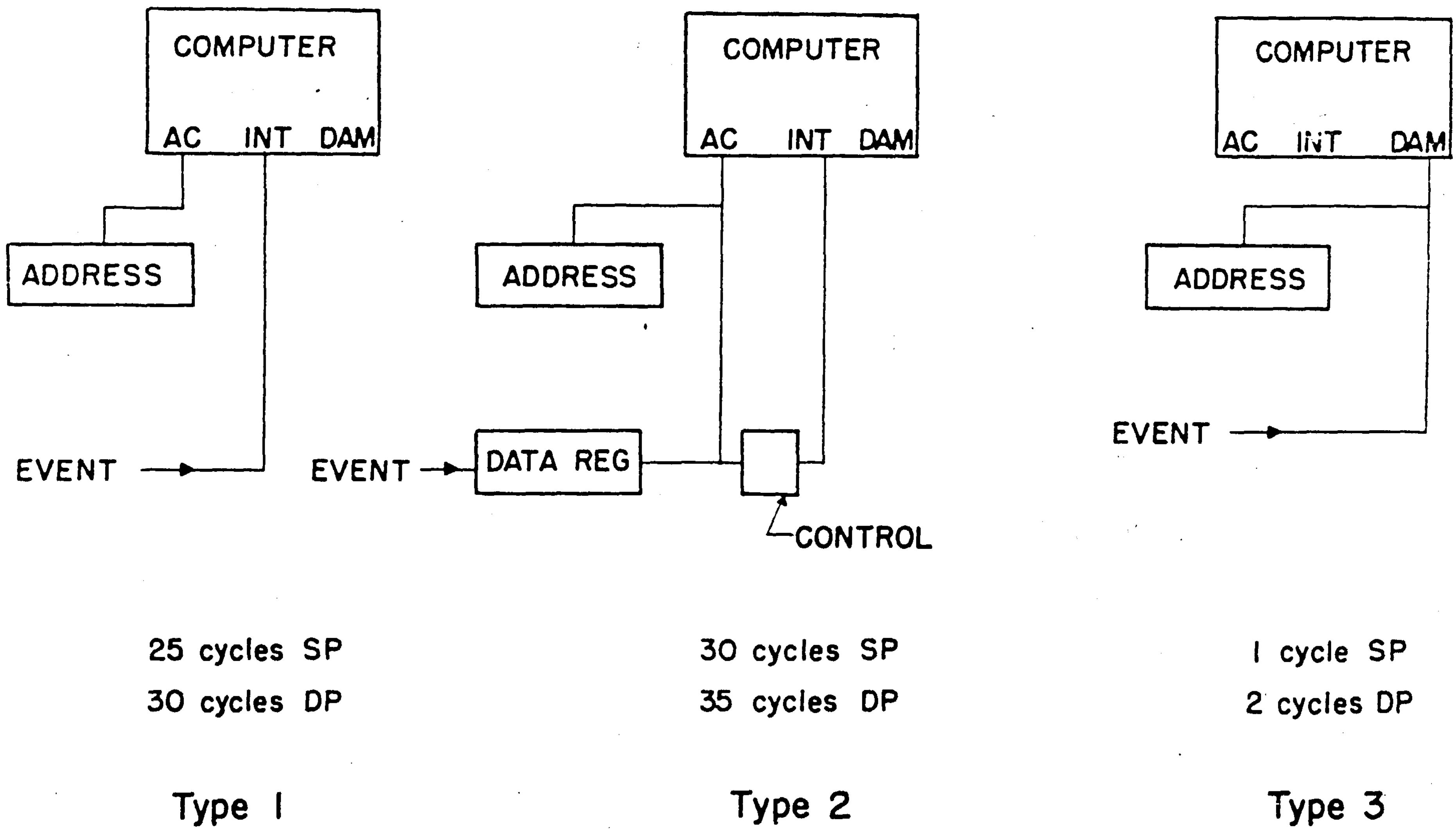

Fig 3 VARIOUS INTERFACES

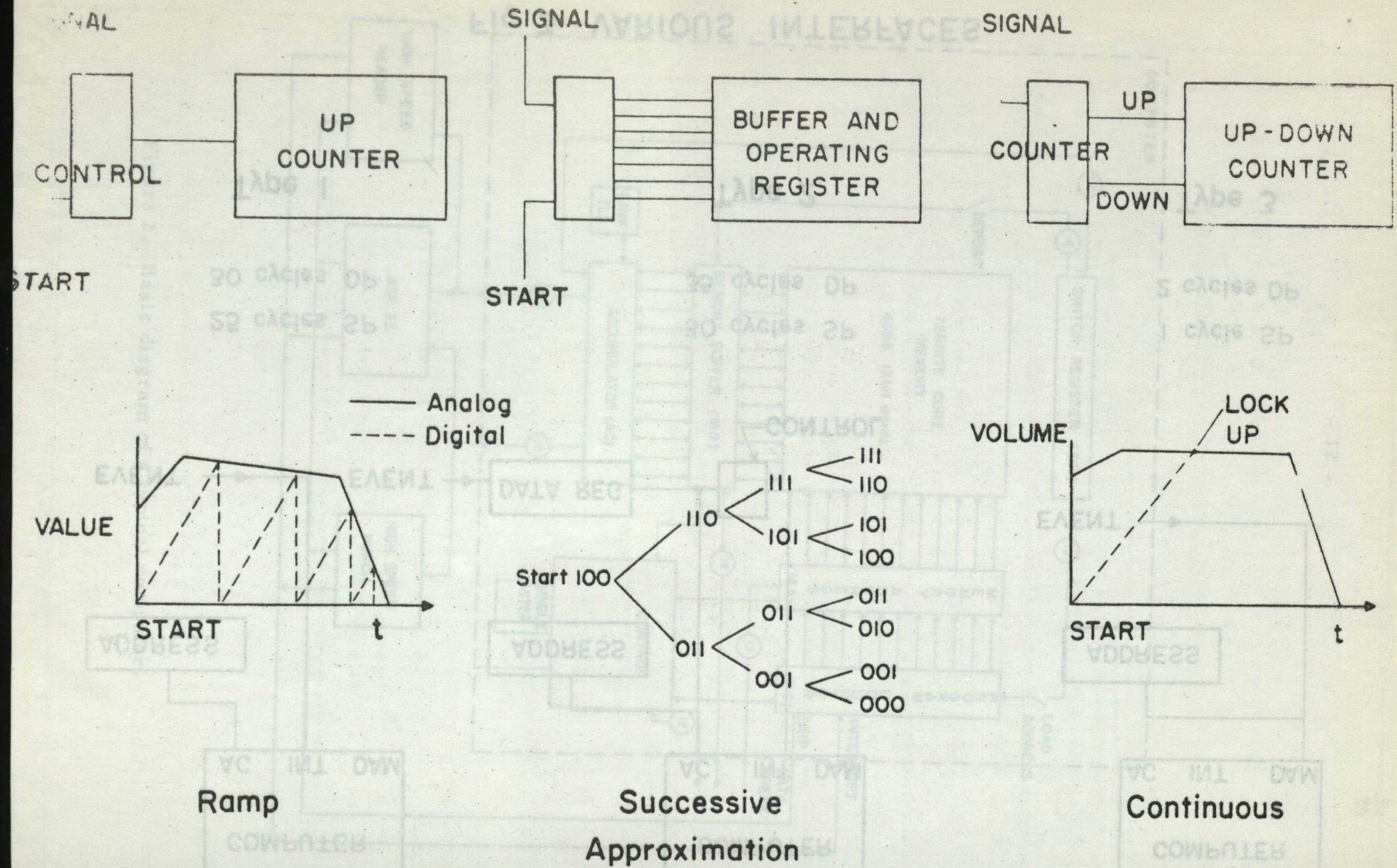

Fig 4 A-D CONVERTORS