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COMPUTER-CENTERED DATA HANDLING SYSTEMS*

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MASTER

Introduction

The last few years have witnessed the birth and rather spectacular growth of a new instrumentation technique — that of using a stored program digital computer as a data gathering, analyzing, and control tool for experimental research. Computer-centered data systems have been used for pulse height, time-of-flight, and multiparameter analysis¹⁻⁷ and with hodoscope arrays for real-time particle trajectory reconstruction.⁸

Advantages of Computer Use

While the details of these systems differ markedly, their unifying thread is the use of a general purpose digital computer to provide advantages not readily available in special purpose hardware. Some of these advantages are listed here.

Versatility of Function. Since most specialized functions can be handled by detailed programming, the computer-experiment interface may be kept general. Thus, the hardware is designed only to accept and transmit arrays of binary digits. The meaning to be assigned to these digits is determined on the one hand by the computer program and on the other by the particular detector, encoder, analog-to-digital converter, etc. which was their source.

Thus, depending on the program that is stored in it and the equipment that is connected to it, the computer can serve many different experimental functions. It may be a pulse-height analyzer at one time, event recorder the next, and a magnetic tape sorter-recorder the third. In one program configuration it might provide elaborate

visual display modes complete with manual intervention facilities. A different program might eliminate the display entirely in favor of faster data response times. In certain situations it might be reasonable to have it serve as both a data gatherer and, at the same time, the device that controls the data gathering equipment, as in neutron spectrometry or X-ray goniometry.

Output modes exhibit the same versatility. Output may be typewritten, printed, punched on paper tape or cards, or written on magnetic tape. The format may be altered to meet any necessity. Visual output — via a cathode ray tube (CRT) connected to the computer — may take the form of graphs, map displays, or isometric views of data fields. The displays may have grid lines superimposed on them, labeled axes, or even represent composites of experimental data and theoretically computed curves.

Concurrent Data Reduction. In a number of situations the most important single advantage the computer can offer is that of concurrent (or real-time) data reduction. The kinds of experiments which profit most from a real-time computational facility are those in which the raw data are so complex that they are not readily interpretable by the experimenter and in which one or more of the following situations exists: a) the experimental conditions are very costly and it is imperative that the research group know as fast as

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possible of system flaws; b) the experimental run is very long and it would be very tedious to have to repeat it because of an undetected fault; c) the results must be interpreted immediately because further steps depend on the outcome of past ones.

Feedback. There are two kinds of feedback that a computer-centered system can provide. The first, feedback to the experimenter, was mentioned above. The second is feedback directly to the equipment. In the first mode of operation the experimenter can be viewed as closing the control loop. For the second, as a result of computations on the data, the computer directly controls the experimental gear.

Multi-experiment Control. The demands on a computer's available time are frequently very modest in the data systems we are discussing. Thus it is possible to take data for and control more than a single experiment with one computer. Time-shared operation of this type is most advantageous where complex, but infrequent, control functions are to be performed on many pieces of apparatus or where data rates are low.

Computer as a Computer. The final advantage of the use of a computer is the most obvious one. It is, of course, that when the computer is not being used in a data system it can be used as (what it is) a general purpose digital computer. Thus many of the simpler computations may be accomplished in the laboratory using what would otherwise be idle time for the experimental equipment.

In Fig. 1 these various aspects are listed and their particular relevance to some of the research areas of interest at this Symposium are checked. The check marks represent the current status of usage. Undoubtedly, in the future, some of the unchecked boxes will be filled and new columns will have to be added to represent the extension of the

computer's use to different research areas.

Disadvantages of Computer Use

A number of disadvantages to the application of computers to data systems exist. Prime among these is the loss in data handling speed in comparison with comparably priced special purpose devices. This is a direct consequence of the fact that the data manipulating functions must, in general, be accomplished in the computer by the normal mechanism of program steps. It is frequently possible to circumvent this limitation by direct wiring into the computer. However, to the extent that this is done, the computer becomes "special purpose" and many of the arguments about generality no longer obtain.

A second disadvantage is that the computer-centered system will probably cost more than the equivalent special purpose device in any single system configuration. (Obvious exceptions exist.) Thus the experimenter who knows exactly what measurements he wants to make over the next five years would do well to purchase, if it is available, a fixed program device. The argument for the computer configuration can only be made if the research requirements are either unknown, highly varied, or require real-time data processing.

A third, and by no means minor, disadvantage is that every operation must be programmed. This means that the scientist must be willing to learn the necessary programming skills. It is true that, as time passes, system and subsystem program tapes are increasingly traded between laboratories with similar equipment. The unskilled recipient of such a system tape is, however, in about the same position as he would be with the equivalent special purpose system. Not being able to modify to suit his special needs negates much of the advantage that the computer system inherently has.

Choice of Computer

Once it is determined that a laboratory group can profit from the use of a general, rather than a special purpose, control facility, the next problem that must be faced is that of the selection of the computer. This is a very complex decision. Contributing to the choice, beyond the computer's obvious physical characteristics, are such things as the programming (or software) support, the laboratory's long term plans in the area of data processing equipment, the availability of instrumentation support for the "front end" and interface operations, and the range of problems to which the computer will be applied.

It is not the purpose of this paper to discuss these problems. This information is available elsewhere.⁹ These issues are raised here only to point out their importance to the success of the operation. The general and detailed characteristics of the selected computer will control the manner in which it must be connected to the experimental apparatus. Differences in data-taking speed of up to five to one are possible even though the computers employed have the same nominal arithmetic speed. These differences are a direct consequence of the computer's input-output capabilities which, thus bear heavily on the choice.

Existing Systems

As short a time as one year ago there were only a few computer-centered systems in operation. At that time, when discussing this mode of operation, it was necessary to expose these few examples to the light, comment on their simple virtues, and extrapolate their future growth. In the intervening year a number of new systems have been completed or are soon to be completed.¹⁰⁻¹⁸ In addition some of the older systems have matured, and, in the process, have realized some of the potential originally claimed for them.^{16,19} Thus, in reviewing the work

done in this field, it is no longer possible to describe every installation. Rather, three rather diffuse classes of use will be outlined along with some systems exemplifying them.

Computer as a Multiparameter Analyzer

This was one of the initial uses of a stored program computer in on-line physics research. It still represents the largest single class of use.^{2,4,6,7,10,16-19} One of the early systems of this type is currently in operation at the 60 inch cyclotron at Brookhaven.⁴ Figure 2 shows the, by now, familiar block diagram. This configuration acts as a two dimensional event recorder (two events of 12 bits each), and, simultaneously, as a 64 x 64 analyzer on the high order bits of each event's digitization. It is also equipped for a two way exchange of information via a real-time operated CRT and a light pen.

Little has changed in this system with respect to its data taking, storing, and displaying operations since its installation. The most striking area of growth has been in programming. A flexible set of analysis routines has been prepared for use on the computer on a quick-in/quick-out basis. These routines are used extensively for kinematic analysis, hypothesis testing, etc. The scientists using the system have trained themselves to accept a different mode of operation than that to which they were accustomed. If the character of the data accumulated poses an immediate question, they stop the data run, store the intermediate results, run the appropriate analysis routine, reload their intermediate data and then resume the experiment. This procedure takes, typically, five to twenty minutes depending on the complexity of the analysis.

This short term "batch processing" technique, while not quite on-line operation, is a very close approximation

to it. The interaction with the experiment is very immediate. In fact, a number of the routines are written to communicate their results in a form directly compatible with the experimental data. Figure 3 shows an example of this type of programming. It presents, on the left, an isometric view of the two dimensional data field as accumulated during the experiment. The right side of the figure presents the kinematically calculated expected response as plotted on the same coordinate field by the same plotting program. The two loci represent the expected width of the experimental response as based on the detector size.

It is easy to see what a useful technique this is when such results are available on short notice during the course of the experiment. Mollenauer will have more to say about it later in this session.¹⁹

Concurrent Data Reduction

The advantages to be gained in this mode of operation were outlined above. To date, the most striking example of this technique was the experiment by Foley et al.⁸ at the Brookhaven Alternating Gradient Synchrotron (AGS). This work was part of a program to study basic strong interactions in the energy range available at the AGS. The experimental equipment was made up of particle selection scintillation and gas Cerenkov counters and a group of scintillation counter hodoscopes for flight path analysis. The digitized event information was fed into a 5 μ sec buffer memory²⁰ which had a capacity of 32 data words, each 96 bits long. During the time between accelerator beam bursts the data from the last burst were read out over telephone lines (about one mile) to the Brookhaven Merlin computer and were also recorded directly on magnetic tape. Figure 4 illustrates the experimental set-up.

At the computer the kinematics of each event were calculated. The results were then immediately used to update 24 different histograms. Since the analysis and updating procedures took less time than that available between bursts, the remaining time was used to display selected histograms on a CRT at the experimental site. (The CRT signals were sent back over additional telephone lines.)

At the end of each data taking session (or during it if difficulties were encountered) the computer was used to compile the necessary cross section and statistical data.

The operation was extremely successful — resulting in much faster and more accurate experimental work. Within a few weeks the next experiment in this series will be operating using a much larger buffer memory (8,192 words of 48 bits each) and faster (coaxial cable) data transmission facilities.^{14,15}

Another group at Brookhaven is currently setting up an experimental program at the AGS which will exploit the newly developed, direct reading spark chambers.²¹ These chambers, which have a readout and recovery time of the order of 200 μ sec, will be part of a data system made up of a 4096 word buffer memory, two data magnetic tape units, and an on-line digital computer.

Multi-experiment Operation

Within this broad class of use there exist three rather loosely bounded sub-categories. The first of these is the use of the computer as a "backup" for the actual experimental equipment. The computer in this application serves as a data organizer and read-out device, whereas the experimental equipment may be commercial pulse height analyzers, scalars, buffer memories, or event recording analyzers. A good example

of this approach exists at Chalk River.³ These systems have tended to evolve along lines leading to the second category of operation as exemplified by the proposed Argonne installation.¹¹

The second operational class is that in which the computer is itself the prime data taking instrument — much as in the case of the multiparameter analyzers discussed above. The technique is extended, however, by the time-shared operation of more than one independent experiment. An example of this use can be found in the time-shared time-of-flight analyzers system in operation at Brookhaven.⁵ A block diagram of this configuration is presented in Fig. 5. The system provides a 1024-channel analyzer, a 256-channel analyzer, a CRT display, five clocks, seven auxiliary scalars, and two rpm meters using a computer with a 2048 24-bit word memory. The control of the analyzers is accomplished through the typewriter keyboard by using mnemonic commands to initiate and terminate data taking and to produce output in the form of punched paper tape and typewritten sheets. Independent control of the two experiments is maintained throughout.

The last subcategory is essentially a synthesis of the first two — along with the additional feature of direct feedback of control commands to the experimental apparatus. These systems, being the most complex and sophisticated, are naturally the farthest from complete realization. You will hear later in this session of the data handling system being constructed for use at the Bureau of Standards Linear Accelerator.¹² This system presents an interesting mixture of hardware and software (programming) control of a multi-experiment complex.

Work along this line is also going on at Argonne, Iowa State, and Brookhaven. The latter two are intended for the control of a multiplicity of neutron spectrometer stations.

Effect on Research

The use of stored program computers in data systems has already had a noticeable effect on research techniques and is bound to have more. One of the most marked effects is on the time scale of experiments. In the experiment of Foley *et al.* referred to above the set-up time was reduced by about a factor of five and the run time by about one and a half. Generally speaking, computer systems make for more efficient accelerator or reactor use. This means that either more users can be accommodated or that the existing users can do more subtle and demanding experiments. There is currently some interest in the idea of multiple, computer-controlled experimental sites on the accelerator floor — to profit from the increased efficiency available to each user.

As an unfortunate concomitant of the increased experimental output, the demands for off-line computing time are increasing alarmingly. This is especially true in high energy physics where the detection and initial real-time processing of an event generally represents only a fraction of the total analysis time needed. Similarly, with the advent of programmed neutron diffractometers (both wired and stored program), the data rates have jumped almost a factor of ten necessitating much increased central computer time. The same holds true in other areas.

This represents a severe problem. One point of view is to expand the central processor facility (possibly with remote data links). A second approach is that of decentralization — allowing multiple large computer facilities. Strong arguments can be made on both sides. There is, as yet, no clearly predominant view.

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Figure Captions

- Fig. 1 Advantages of on-line computer use in various research areas.
- Fig. 2 Block diagram of the Bell stored program multiparameter analyzer (from ref. 4).
- Fig. 3 Two CRT displays from the Bell analyzer. On the left a two dimensional data field, on the right the kinematically calculated response.
- Fig. 4 Diagram of the $\pi^- + p$ and $p + p$ elastic scattering experiment (from ref. 8).
- Fig. 5 Block diagram of the Brookhaven time-shared time-of-flight analyzers system (from ref. 5).

	HIGH ENERGY PHYSICS		LOW ENERGY PHYSICS		NEUTRON PHYSICS	
	COUNTERS, HODOSCOPES, DIRECT READING SPARK CHAMBER	IMAGE READING SPARK CHAMBER BUBBLE CHAMBER NUCLEAR EMULSION	NUCLEAR REACTIONS AND STRUCTURE	RADIOACTIVITY	NEUTRON DIFFRACTION	TIME OF FLIGHT TECHNIQUES
VERSATILITY	✓	✓	✓		✓	✓
CONCURRENT DATA REDUCTION	✓	✓	✓		✓	✓
FEEDBACK TO EXPERIMENTER	✓	✓	✓	✓	✓	✓
FEEDBACK TO EQUIPMENT		✓			✓	✓
MULTIEXPERIMENT CONTROL		✓	✓		✓	✓
OFF-LINE USE OF MODEST COMPUTER			✓	✓	✓	✓

FIGURE 1

FIGURE 2

EXPERIMENT

KINEMATICS

THE REACTION IS $1+2 \rightarrow 3+4+5$

$D+P \rightarrow P+P+N$

$T_1 = 21.1 \text{ MeV}$

$\theta_3 = 34.0^\circ$

$\theta_4 = -34.0^\circ$

ANGULAR WIDTHS OF DETECTORS $= 2.5^\circ$

KINEMATICS CALCULATED FOR ANGULAR EXTREMES OF DETECTORS

10.0 MeV IN CHANNEL $x=y=48$

DETECTOR ANGLES SLIGHTLY REMOVED FROM RESONANCE
CONDITIONS

FIGURE 3

FIGURE 4

FIGURE 5