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USE OF THE PDP-5's IN NUCLEAR EXPERIMENTS AT LRL

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Many PDP-5's are now used in a variety of functions in the Lawrence Radiation Laboratory in Berkeley, California. In the following I would like to elaborate on several systems of which the PDP-5's form a part. All systems that we are concerned with have a data acquisition function in the first place. A secondary function is the analysis of data. In cases where the dataflow is very large, only some processing is performed in order to achieve a comprehensive display of reduced data on the oscilloscope. But, in other cases, we see rather sophisticated data reduction, which is controlled by an experimenter in the true on-line configuration.

An example of this is the PDP-5 system in the 88" Cyclotron, which is built and programmed by Lloyd Robinson. On the first slide, (Figure 1), the layout of this system is shown. During a run of about an hour, data is gathered in the 4096 channel pulse height analyzer. During that hour, data of a previous run can be processed. The switch box is used to achieve convenient access to the different software systems. The switch box performs in fact, two functions:

1. It selects a program which is then read from the Library tape into the lower 4K part of memory.

2. Once a certain program is loaded in core, it selects certain functions from that program.

In the first case, a Bootstrap Program of 28 wired-in instructions are stored in the core using the data break mode. This bootstrap teaches the PDP-5 how to load in a larger loader from the micro system tape, which in turn loads the program selected with
the switch box. This all happens automatically after setting the switch in the desired position and depressing the load button. After the program is in core, the switch can be set to select one particular function. When the function push-button is depressed, an interrupt is caused in a small executive program, which calls and starts the selected function.

The data is stored in the upper 4K of memory and is also recorded on the second micro-tape. The data consists of 4096 words in which numbers are stored that are seldom larger than 12-bits (maximum size of words is 20-bits). The overflow of the few numbers that exceed $2^{12}$ is stored in some overflow tables located in the lower 4K memory.

With Light pen and keyboard, the experimenter can guide the data processing of information displayed on the scope to wherever he desires. Of all images - mainly energy spectra - the Y coordinates are supplied by the PDP-5 but, the X coordinates are supplied by an external sweep generator to achieve less flicker and easy Y-scale manipulation (magnification and origin relocation).

Quite another PDP-5 system that is now in construction is shown on Figure 2. It is a system for the Center of Research for Management Science of the Department of Business Administration of the University of California campus in Berkeley. In fact, their experiments have little to do with the experimental work going on at the Lawrence Radiation Laboratory, except that they will use very much the same hardware in the construction of which we were able to give them support.

This system will be used for communication experiments between subjects that are placed in a specific business game situation. The main aspect of each game situation, from the system's point of view, is that the communication is limited to channels of well-known characteristics, in this case, teletypes.

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The main functions of this system are:

1. Data collection of all internal communications.
2. Data transfer control between any station to any other station or group of stations.
3. Off-line communication with computer center or limited data processing in the PDP-5 itself.

The challenge here is to design the systems so that the subjects like to use it, and that it is tolerant to human failure. In the first period it will function mainly as a message switching center where free English can be used by the subjects. Another more limited mode of communication between subjects is formed by the use of Tree language, where subjects are forced to use prearranged parts of sentences according to a prearranged set of sequences.

A more ambitious plan is an attempt to measure peoples decision abilities and judgment. It calls for a game where a subject is confronted in a competitive situation with an artificial counterpart. The counterpart is a software robot of which the decision behavior pattern is well known.

A 630 system will be used to implement the message switching center. The construction of the whole system including all of the software, is still in the beginning phase so that we have to wait for another opportunity to report on some of the results.

Figure 3 shows the general layout of a system as used in the Counting Physics Experiments. To the left are the data sources, namely, Scintillation Counters, Spark Chambers that feed into a Vidicon system, and Spark Chambers of the wire variety that feed into a wire chamber core scanner. In the top left is a box called "Fast Electronics Decision Logic" where decisions are made, whether the event is one of interest or not. All
the information is fed via interfaces into the PDP-5; it can be displayed on the oscilloscope and the data can be stored on magnetic tape.

Figure 4 gives an impression of the cycle of the dataflow which, in terms of time, may take as much as several weeks or even a year, and that is because the data processing is off-line. The evaluation by the experimenters may then originate a new experiment. Figure 5 shows the same cycle, but now there is an additional inner cycle added to it which allows the experimenter to be in more direct contact with this experiment. The data sources here again are the Vidicon, the Wire Chamber Core Scanner, and the Scintillation Counter-Memory Buffers.

The data acquisition is now largely done by the PDP-5 and its interfaces, and the storage is taken care of by magnetic tape units so that information can be fed to the computer center for off-line processing, etc. But there is an additional feature now in the on-line data reduction which results in a comprehensive display and an on-line, however low level, evaluation by the experimenter on the spot. To achieve the data deduction necessary to produce a number of comprehensive data displays on the oscilloscope, software is built which has many, by now well understood, advantages over a pure hardware system with the same function. This is especially true when an experiment stays for most of its lifetime in the development phase.

The value of an on-line evaluation of the data is especially high in Counting Physics where the experiments are often designed with very specific goals in mind — namely, the detection of a limited number phenomena. Since such experiments are built to allow events related to these phenomena only, it is very important to know if the data is of any interest at all. If this were not the case, the experimenter at least has a chance to readjust his data sources immediately and try again. The feedback loop is now shortened from weeks or years to the time it takes the physicist to form his judgment.

The choice of the size of the computer to be used on-line with the experiment, depends
on many factors. Some of them are:

- The amount of data to be processed as one event, and the number of events per time unit: the level of sophistication one desires in the on-line data reduction in relation to the level of the off-line data processing; experience with on-line systems of the technical support groups; costs, etc.

Another choice to be made is whether to serve different experiments with one on-line computer or to assign one computer to each experiment. The first approach seems feasible only when, in the first place, the experiments have settled down to a stable situation requiring little debugging time after an initial checkout stage, and in the second place, when the experiments run more or less in phase. If the experiments run "out of phase" with respect to each other, great difficulties arise in debugging one experimental program in relation to its hardware, while another one needs to be run to produce data. The consequence may easily be a complicated time-sharing organization, of which the executive program would be very difficult to realize satisfactorily.

Also, it is important to realize that in many cases, the people responsible for instrumentation have to acquire their experience on-line too. When one starts out with a complicated system, it is very possible that the system workers tend to be snowed under by numerous detail problems and so miss the opportunity to teach themselves how to handle this new tool, which is the computer, properly. In other words, "think big, but start small".

Now I would like to give you an introduction to what I have referred to as the "Datasources". The Vidicon system is a camera with associated logic which scans the image of a plate spark chamber. Very similar spark chambers were used in experiments where the film camera was the only device to record the data.
When an nuclear event occurs, the high voltage is applied across the plates and discharges (sparks) will develop wherever a charged particle left an ionized track behind, in the especially controlled gaseous atmosphere. At the same time fiducial lights are flashed. Only for ten or twenty milliseconds a usable image of fiducials and sparks will remain as a pattern of charges on the semiconductor face of the Vidicon tube. As soon as possible, after the event, the image is being scanned as parallel to the spark chamber plates as possible. The fiducials on the left side (the Start fiducials) are indicators of the middle of each gap. Only after such a Start fiducial is detected, the Video signals originating from the sparks will be processed. The first spark found will start the first of a set of four or eight 12-bit scalers, each fed by a crystal controlled oscillator. The second spark will enable the next scaler etc. When the fiducial, to the far right side, (the Stop fiducial) is detected, all scalers are halted. This means that in effect, the distance is measured of each spark to the stop fiducial, which distance is expressed in a word of 12-bits. Several horizontal sweeps will go by before the next start fiducial is detected, at which moment the process repeats itself. But in the meantime, the information from all scalers is sent to the PDP-5. The PDP-5 will reset the scalers after absorption of all the data. In most systems that we have built, one out of five horizontal sweeps results (on the average) in a digitizing sweep. Of course it is important to discriminate the fiducial signals from the spark signals, which is made possible by a system of time gates. The working of the time gates is based on the fact that we know whether to expect fiducial signals or spark signals during specific periods of time.

A Monitor Scope supplies the operator with the image seen by the Vidicon camera. Superimposed on that, the image of the digitizing sweeps and the time gates can be made visible, so that it is possible to adjust the time gates for the selection of the various Video signals. In an experiment now running in the Bevatron, one of the two Vidicon
systems digitizes a composite picture of six views from a set of three spark chambers.
The complete image shows eighty-four spark gaps in each of which four sparks can be
digitized. Since a spark location is expressed in 12-bit words, this Vidicon produces
$4 \times 84 = 336$ words of 12-bits per event. Where less than four sparks per gap were detected,
zeros will appear in some of the 12-bit words of the corresponding group of four words.
This may seem wasteful. It should be pointed out however, that no additional identification
of each spark address word is needed. This identification is already contained in the
location of the word in each block of 336 words. This simplifies the processing of the
Vidicon data of course, very much.

Another kind of spark chamber readout is the use of wire spark chambers in combination
with a core store. The wire spark chamber discharges takes place between planes of
parallel wires or between a plane of wires and a metal surface. Each wire is strung
through a ferrite core. In this way, it is possible to store at the same time, all infor-
mation of wires hit by sparks. Apart from the spark chamber wire, two "half-current"
wires, and a sense wire are strung through each core, in very much the same way as a
normal core memory. The total memory has a capacity of 4096 bits and it is organized in
words of 32 bits. After the event is over, the complete memory is read out, whereby the
stored information is destructed, which means that the memory is cleared. The readout
procedure is organized as follows:

Each word of 32 bits is read out and inspected for possible bits
that equal to 1. If all bits are Zero, the next word is read
out. If one or more bits are equal to 1, the word is stored into a
32-bit register which is scanned from one end to the other by a
word scanner. The word scanner will stop at every "1-Bit", registering
the location of that bit in the word. The location in the word can be

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expressed in 5 bits. The location of the word in the core stack can be expressed in 7 bits. This information is assembled in a 12-bit wire address word.

The address words are stored in a 3 word buffer which signals the PDP-5 when it holds three addresses. The PDP-5 then reads the buffer and after the completion of the data transfer, the wire core scanner searches for more "1-bits"; until the core memory is exhausted, which fact is also signalled to the PDP-5.

The complete readout takes about 2 milliseconds, depending on the number of wires hit by a spark. In contemporary experiments 2,000 wires are read out. The wires are distributed over 6 wire planes.

In the following, an essential outline is given of the interfacing used between the PDP-5 and the data sources. The first group of units is formed by the databreak control, datasource control, and datamerger. It serves as a fast data channel between the data sources and the computer. The complete databreak interface performs the following functions:

1. It brings the PDP-5 from the Program Mode into the Databreak Mode, in which all memory-cycles are available for data transfer to the memory.

2. It specifies the memory address for each data word to be stored.

3. It guards against memory overflow.

4. It recognizes flag signals and assigns priority to data sources.

5. It controls the sequential data gathering in words of 12 bits at a time by a scanning mechanism.

The databreak control and datamerger form standard pieces of equipment. The
Datasource control is tailored to the specific needs of each experiment and is therefore not a standard piece of equipment. Figure 6 shows the flag scanning procedure. The Vidicon has the highest priority because it has the weakest memory, being the image face on the camera. As Figure 7 shows, the data sources, like the Vidicon and the Wire Core Scanner, produce two flag signals; namely, the long and the short flag. Due to the nature of these data sources, the data arrives in groups of several words, separated by pauses in the transmission. The availability of such a word group is signalled by the short flag, which will be cleared after the word group is stored. The long flag, however, stays up as long as word groups may be expected and will be cleared after all data of the particular data source is transmitted.

In Figure 8, an example of data format is shown. Each event has an identification word of 36 bits, in which among other things, it is indicated which sources supplied data. The Vidicon supplies a constant number of words as do the counter logic and the Analog-to-Digital converters. The amount of data from the wire core scanner is dependent however, on the number of wires hit by sparks in a particular event, so that it is necessary to insert a flag word (77778) to indicate the beginning of the counter data.

Other interface equipment consists of an oscilloscope display control (provided by DEC), a tape transport control, and a general purpose facility called the "Utility Bin".

The tape transport used is the D2020 from Datamec. The character transfer rate is a 16.6 KC at a density of 556 characters per inch.

All functions necessary to write and read records, to time the proper gap delays, to write "End of File", etc., are software controlled by a program of 125 instructions.

The Utility Bin provides control logic for the paper tape reader and punch, an incremental magnetic tape unit and also a read-in facility for a virtually unlimited number of 10 Megacycle scalars. Furthermore, it has five interrupt flag inputs and 15 program
controlled pulse outputs for general use.

To keep a complicated system as this one running, it is necessary to organize effective operations and maintenance procedures. During a run, at least four programs are available. (See Figure 9.) The program of highest sophistication is called "Monitor", and occupies more than three-quarters of the available memory space, being 4096 words of 12 bits. Monitor therefore does not produce much data on tape; but is mainly used to closely investigate experimental parameters during the set-up time or after a change set-up or for a limited amount of time during the normal run. It affords the experimenter to scrutinize the incoming events with statistical means.

The next program is of lower sophistication and is called "Single". This program only occupies one-quarter of the memory space so that much is available for data accumulation before the tape record is written. It only allows for two modes of display.

Syp-13 and Syp-15 are maintenance oriented programs. Syp-15 affords the operator to produce a useful amount of data and to make some performance tests of the system simultaneously. Syp-13 is more elaborate — it has facilities to test the interfaces, the tape unit, and some particular circuits. It also contains a Debug package and a set of 16 input-output sub-routines to facilitate the construction of a new test program in a matter of minutes.

There are now several PDP-5's being used at the Lawrence Radiation Laboratory in Berkeley, of which three are assigned to the Counting Physics experiments. Figure 10 shows a diagram of the control area and the "cave" of an experiment now running in the Bevatron in Berkeley. All the interfaces, with the exception of the oscilloscope display control, were constructed by facilities in the Lawrence Radiation Laboratory.
Figure 1
MANAGEMENT SCIENCE LABORATORY SYSTEM

FIG. 2.
```
DB

EVENT? Yes

IDENT.WORDS

VIDICON? No

VIDICON WORDS

WIRE CHAMBER? No

WIRE-WORDS

COUNTER? No

COUNTER FLAG

COUNTER AND ADC WORDS

RESET SCANNER

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```
S0
S1
S2
S3
S4
S5
S6
S7
S8
S9
S10
S11
S12
S13
S14
S15
S16
S17

MAIN EVENT NUMBER

EVENT NUMBER

VIDICON

WIRE CHAMBER

ALL "ONES"

COUNTER WORDS

ADC WORDS

ALL "ZEROS"

DATA SOURCE CONTROL

SCANNING PROCEDURES

FIG 6
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DOUBLE FLAG SYSTEM FOR DATA SOURCES

BATCHES OF 6 WORDS

ABOUT 1500 μsec

BATCHES OF 3 WORDS

V_2

ABOUT 10,000 μs

V_M

V_S

FIG 7
VIDICON DATA
112 WORDS OF 36 BITS

WIRE CHAMBER DATA
N WORDS OF 36 BITS

72 BITS COUNTER DATA
ADC I    ADC II

DATA FORMAT OF ONE EVENT (VWC)

FIG 8.
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