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ABSTRACT

The engineering and programming aspects of the Berkeley COBWEB system are described. COBWEB is a system of Franckensteins and Measuring Microscopes on-line to an IBM-7044 computer. Outlines of the system hardware and software are presented. A brief example illustrating the operation of an on-line Franckenstein is given.

INTRODUCTION

Lawrence Radiation Laboratory at Berkeley is now connecting bubble chamber film-measuring machines to an IBM-7044 computer. These machines will be put on-line one-by-one with an initial goal of five small Franckensteins (MPI's, Fig. 1) and two measuring microscopes. In addition, an on-line teletypewriter will be located at each measuring machine.

Our primary objectives are to increase the overall efficiency of our existing measuring machines, while improving the "quality and completeness" of the data collected for final analysis. In this light: (1) the computer will acquire, arrange, and disseminate data to magnetic tape units. (2) During this process the parameters and measurements will be checked, and the measurer immediately informed of the quality and completeness. The measurer can then make any necessary corrections or remeasurements while the film is still clamped in position on the measuring-machine stage. (3) Fiducials and events will be automatically sequenced and located by having the computer act as an integral part of each measuring machine's stage servo system. For example, the computer will automatically move a measuring machine's stage from one fiducial to another by periodically sampling the X-Y coordinates while the stage is in motion and feeding back updated velocity commands. (4) The computer will also generate and transmit parameters and instructions to personnel, and initiate event-bookkeeping operations.

The measuring machines will be tied to the computer through a "multiplexer/interface" connected to the 7044's "direct-data connection". The multiplexer is arranged to accept up to sixteen "blocks" of four devices each (i. e., - a total of 64 measuring machines or other devices). Each block can be located up to 3000 feet from the multiplexer. Devices other than measuring machines can be connected to the computer through the multiplexer/interface, provided they are compatible with our input/output format, data-rate capabilities and existing software organization.

After data has been entered through the direct-data connection, an interrupt routine moves the data to a software table associated with each measuring machine. The processing portion of the program then cycles through each machine's table, operating on the data only when new data has been placed in the table. When this computing is completed, or when a response is required from a measuring machine, a commutator routine is entered. The commutator routine first saves computer registers in the table associated with the particular machine being processed. It then switches control of the processing section to another machine's table. The same coding can be used in the processing of data from the different measuring machines because of the software-table structure. If additional types of equipment are added to the system, they can be programmed in independent sections, connected to the already existing program via the commutator.

ON-LINE MEASUREMENT EXAMPLE

A brief example will help to illustrate what can be gained by putting our measuring machines on-line.

All film to be measured is first scanned to locate and identify events. This is done by scanners using our conventional scanning tables. The scanning data is then punched into IBM cards. These data include film-roll number, frame number, event type, approximate locations of event vertices, and other information necessary for film measurement and bookkeeping.

The IBM scan cards for all measuring machines are fed into the system through the card reader at the 7044. The measurer at a Franckenstein, for example, first puts his machine on-line by pressing the machine's "start" button. He then uses the teletype at his machine to sign-in and receives instructions from the computer. These instructions include the roll number and frame number of the first event to be measured.

After the measurer has properly positioned the film to the first view of the frame to be measured (Fig. 2), he then pushes the "go" button. "Go" signals the computer that the measurer is ready to begin an event measurement. The computer then automatically moves the Franckenstein stage, upon which the film is clamped, to the approximate position of the first fiducial to be measured. The measurer in turn accurately positions the fiducial on the cross-hairs and pushes the "Record" button. This causes a computer interrupt, and the X-Y coordinates of the first fiducial are entered. The computer responds by automatically moving the stage to the approximate location of the second fiducial. The measurer centers the second fiducial and pushes "Record". The stage automatically moves to the third and final fiducial. The measurer again centers and records, and the stage is automatically moved to the approximate location of an event vertex.

The accuracy of the fiducial measurements is checked as they are measured. One check is to compute the distances between the three fiducials to insure that they fall within certain tolerances. If the computation shows an error, the automatic stage motion is immediately stopped and the measurer notified on his teletype. A second check is made by having the measurer observe that the stage is moved to within a reasonable proximity of its destination by the computer-controlled stage motion.

Errors can be deleted by the measurer depressing one of three "Error" buttons: (1) "Track Error" deletes the last fiducial (or track) that was measured. Successive button depressions delete fiducials (and tracks) in the reverse order of their measurements. The stage automatically moves back to the approximate location of the last fiducial (or track) deleted. The deleted fiducials (or tracks) are then remeasured. (2) The "View Error" button deletes the entire view, and (3) the "Event Error" button deletes the entire event.

After the three fiducials have been measured and accepted, the vertices, tracks, and in some cases track end points must be measured. After measurement of the third fiducial, the stage is positioned under computer control at a point near the first vertex. The measurer centers and measures the first vertex, then measures along the first track. Each measurement causes a computer interrupt, and X-Y coordinates are entered. Upon completion of the first track measurement, the measurer depresses "Track Complete". The stage is then moved, under computer control, back to the vertex. The measurer again centers and measures the vertex, and then measures coordinates along the second track. "Track Complete" is again depressed, and the stage automatically returns to the vertex.

After all tracks associated with a particular vertex are measured, the computer automatically moves the stage to a new vertex. If there is no new vertex, or after all vertices and tracks have been measured, the stage is automatically moved back to the first fiducial measured. This fiducial can then be remeasured and compared by the computer with its original measurement, to check the reliability of the Francken-stein digitizers.

During track measurements, the "monotony" and "smoothness" of the tracks are checked. Repeated measurements of a vertex are also checked against each other. The measurer observes, as he did during fiducial measurement, that the stage is moved to a reasonable location when it is moved and positioned under computer control. If any of these checks fail, the measurer must make the appropriate deletions and remeasurements in much the same way that deletions and remeasurements are made for fiducials,

The net results are that: (1) computer-controlled stage movement saves time by automatically sequencing the measurements, and by immediately and rapidly moving the stage to new locations for measurement. (2) Since all measurements are checked and the measurer immediately notified of errors, required remeasurements can be made while the film is still clamped and positioned. In some cases a single fiducial or track can be remeasured, but with the machines not on-line, the complete event may have to be remeasured at a later date. (3) Any measuring-machine malfunctions are detected immediately. We have had experiences where several days of measurements have had to be redone because of a machine malfunction. (4) An important by-product is gained in the form of "measurer training". For example, if a measurer has some quirk in his measuring technique that consistently causes errors, immediate feed-back makes him aware of this.

SYSTEM HARDWARE ORGANIZATION

General Organization

All measuring machines are tied to the 7044 direct-data connection through a multiplexer/interface (Fig. 3), built at Lawrence Radiation Laboratory.

The multiplexer is organized to accept up to 16 blocks of four on-line devices each, the initial devices being Franckensteins and measuring microscopes. We have chosen to facilitate this by arranging the 36-bit data words (both input and output) in the format shown in Fig. 4. The six most significant bits are used to designate a particular on-line device. The next six bits designate a "function" at the device. For example, in the case of a Franckenstein, the function codes for a computer input word designate a particular push button, the teletype, or that coordinates are being transmitted to the computer for computer-controlled stage movement. During computer output, a function code is used to designate a specific data register at the addressed Franckenstein. The remaining 24 bits are reserved for data that may be associated with a particular function code.

Data Output

Figure 5 illustrates how a direct-data connection output word is distributed by the multiplexer/interface and transmitted to Franckenstein registers. The block code is decoded and used to select one of 16 blocks of devices. Device code, function code, and data are then gated to the selected block. The device number is checked at each device within the selected block and used to gate the function code and data bits into one of four devices. The function code is then decoded and used to distribute the 24 bits of data to one of 64 possible locations. For an on-line Franckenstein we distribute the data to one of only four registers.

The four registers at each Franckenstein (Fig. 5) are used as follows:

(1) Individual bits of the Miscellaneous Register are used to light indicator lamps, initiate audible signals and alarms, and enable or disable particular Franckenstein functions.

(2) The Display Register is used to provide data for numerical displays such as Track Number, View Number, etc.

(3) The Teletype Register is used to receive an 11-bit teletype character and serially shift it into the teletypewriter.

(4) The Servo Register is used during computer control of the Franckenstein stage movement. During a typical servo operation the computer first transmits a data word into the servo register with "one's" in the "servo mode" and "immediate reply" bit locations (Fig. 5). The Franckenstein replies by sending X and Y stage coordinates back to the computer. Once the stage destination and its present location are both known, the required X and Y distances and direction of motion are computed. The desired X and Y velocities of stage motion are determined

from the respective computed distances. Three bits designating X velocity and three bits designating Y velocity along with respective direction bits and a "one" in the "delayed reply" bit location are then transmitted back to the Franckenstein servo register. The velocity vectors in the servo register are used as inputs to the X and Y servo amplifiers, and the delayed-reply bit is used to fire a one-shot. When the one-shot times-out (in 10 to 100 msec depending on the measuring machine), new X-Y coordinates are sent to the computer. The velocity vectors are then updated and transmitted back to the servo register. This loop is repeated until the Franckenstein stage is positioned to within a specific tolerance of its destination.

Data Input

The format of the 36-bit input word to the direct-data connection is identical to the format of the output word.

A sequential system is used to collect data from the various devices connected to the multiplexer interface (Fig. 6). A "load pulse" must be transmitted to the on-line devices before any data can be gated into the multiplexer. This load pulse is transmitted to all on-line devices simultaneously. If one or more functions requiring computer interrupt (e.g., depression of a "record" push button, typing of a teletype character, etc.) have occurred at any of the devices, the load pulse stores the fact of the occurrences in an associated "function flip-flop". If any of the function flip-flops are in the set state in any of the blocks, the "interrupt request" for the respective block will designate this. The "enable data input" is then set and propagated through a gate chain, each gate in the chain being associated with a particular device block. The second input to each of the gates is the "not" of interrupt request from the associated device block. The enable data input is, therefore, propagated from block to block until an interrupt request is encountered, thus selecting that block for data input to the computer.

The function flip-flops within the selected block are serviced in serial order. That is, all function flip-flops in the first device are serviced, followed by those in the second device, etc. If more than one function flip-flop is set per device, they are serviced in the same serial manner.

By servicing a function flip-flop, I mean that the output of the first set function flip-flop encountered is used to generate a device code and function code, and to gate any associated data onto the 24 data lines. The block code is generated in the multiplexer/interface. After all these data have been put into the computer, the associated function flip-flop is reset (by "advance to next function"), and the next one in the series is serviced. This servicing procedure is repeated until all function flip-flops within the block are serviced. At that time the interrupt request for that particular block is removed and the enable data input level is allowed to propagate down the gate chain until the next interrupt request is encountered.

This servicing procedure is continued until all function flip-flops in all device blocks have been serviced. An "end-of-record" is then sent to the computer.

SYSTEM SOFTWARE

Introduction

The first generation of software has been designed and is now being coded. IBM's programming system IBSYS is being utilized. The coding is in the FORTRAN IV language, except for input/output and bit-manipulation routines. This program, when running, does not share the computer with any other program. When this first program is operational and somewhat stable, we plan to translate it into machine language for economy of memory space and speed. This will involve examining the FORTRAN-generated instructions and eliminating redundant coding.

The output from this IBM 7044 program will be processed through an editing program on our CDC 6600. This editing program will translate complete events back into the data format currently generated by the particular measuring machines, so that larger existing programs need not be modified. In addition, the output tapes from the "44" program will likely contain the data for more than one measuring machine, and this will need to be separated.

Organization

The program can be thought of as consisting of three logical sections–interrupt, control, and the commutator. Communication between these sections is via the software tables (see Table I), with one table per measuring machine. The interrupt routine dispatches data just entered into the computer from various measuring machines to data storage areas, these being specified by pointers in the relevant machine's table. The control section really constitutes the basic operation of the program. This involves responding to input data from a given measuring machine by specifying the logic that defines the measurement procedures and analogous processing. The commutator is simply a switching mechanism to get the control section to work on different measuring machines.

Interrupt

The IBM 7044 has several data channels which logically connect the central processing unit and core memory to the input/output devices. The computer multiplexer/interface designed for COBWEB is considered to be one input/output device in this connotation. The data channel to which the interface is connected(in the future, channel will mean this particular one) operates asynchronously with the central processing unit. The computer program normally keeps the channel in the read mode, so that the interface is free to input data to the computer at will. When the multiplexer/interface determines that enough data has been transmitted to the computer, an "end of record" signal is generated. This causes a "program interrupt" to take place in the computer and the read mode is turned off. This means that the executing software is stopped, computer registers are preserved for a later resumption of this software, and the interrupt section of the program is called into operation.

The interrupt section can determine the number of data words transmitted into memory during the last "read" cycle of the interface. Each word of input data is then scanned for machine block and number designations. This determines which software table is to be used in the ultimate destination of the data word. If the data word reveals that one of the measuring-machine buttons has been depressed, the data word is then appended to the measuring machine's input buffer. If the data word indicates that the operator pushed the "record" button, the "record" word is added to the input buffer. Since the data word is a X or Y "record" function, it is also appended to the measuring machine's track-coordinate buffer. Because the Y "record" function comes last, it triggers the updating of the "number of track points" counter.

With regard to moving the stage of the measuring machine, the control program tells a servo subroutine the desired destination of the stage. An algorithm is then applied to determine the velocity vectors of the stage, these being sent through the interface as the servo word with a delayed reply requested. Thus, when the interrupt section recognizes an input "servo coordinate" data word, the servo routine must calculate either a new direction and velocity or stop the stage. Care is taken within the servo routine to insure that it is "program interrupt" protected. If this were not the case, the servo routine could be entered both by the control and interrupt sections at the same time, causing an undesired reentrant coding problem.

The interrupt section also handles the teletype data. If the input data word indicates that the teleprinter is ready for another character, the next character, if any, is extracted by using the measuring-machine's software table. If the teletype has had a keyboard character depressed, that character is added to the input message. Only the first 72 characters are allowed in an input message; all subsequent ones are ignored. A carriage-return character is considered an "end of message" delimiter. A line feed is used as a "message erase" delimiter.

Control

The control section defines the actual logic flow of the measurement sequence. One can think of this section as handling just one measuring machine. The multiplicity of machines is accomplished by using software tables for the storage of measuring-machine parameters and variables, with one such table per machine. Another way to visualize the ease of implementing this machine multiplicity is via the Fortran language, where every machine-oriented parameter or variable takes on an added dimension, that of a number of measuring machines.

When the control section must wait for something to happen, such as a measuring-machine operator action or the completion of a servoing sequence, it transfers control to a routine named DELAY. DELAY is a part of the commutator section and eventually returns control for that measuring machine to the computer instruction (or flow-chart box) located physically immediately after the transfer to DELAY.

The basic measurement procedure has already been described. An operator must sign on via the teletype. Having done this, there are two choices of measuring procedure--automatic and manual.

Automatic Mode. The automatic mode presupposes the existence of punched cards, generated from the visual finding of an interesting interaction during the film-scanning operation. These punched cards are entered into the computer via an on-line card reader. Each set of scan cards is identified with a measuring-machine number. The cards can either add to the current list of scan cards for the machine, or replace them. The scan cards contain such information as roll and frame numbers, event type, etc. This indicates the number of measurable (charged) tracks per vertex, and the number of vertices in the event.

The fiducials are measured and checked in each view using the automatic mode. Then the various tracks are measured and the coordinates examined for monotony and smoothness. No longer does the operator need to set up a data panel by hand to indicate such things as roll, frame, view, vertex, and track numbers. These are remembered and updated by the program, and then displayed back to the operator. The operator need not digitize the vertices anymore. All tracks are measured from the vertex outward, thus the program can take the first track coordinate as a vertex.

Each scan card contains the approximate position of the vertices. After measuring the first track in a vertex, the program knows the purported position of that vertex. Since the measuring machine has the facility for computer-controlled stage motion, the stage can be returned to the proper vertex after measuring a track in the automatic mode. The absence of a manually set data panel and the automatic stage motion are the two most important factors in dramatically increasing the number of measured events per hour.

The operator will switch from view to view. When the event is complete, the next scan card, if any, is typed to the operator. He must then position the film at the proper frame and view.

Manual Mode. The manual mode of operation is designed to allow any operation one can presently do with a measuring machine connected to a card punch. This mode does not require any artificiality to accomplish something that is natural in the present off-line environment.

The operator types in codes indicating view, vertex, track, and (or) fiducial numbers. All of the operator's actions involving the measuring machine are put on the measuring machine's output tape for later processing, perhaps involving special routines within the editing program.

Operator Options. The operator has other logical operations he can exercise via the teletype. He can type in a "system control" message. This may indicate such things as a operator sign-on, operator or maintenence sign-off, manual or automatic mode for measuring, event unmeasurable, altering the measuring machine's output data tape, removing the machine's output data tape, status, and debug. Status tells the operator precisely where in the program's logic he is when the "status" message appears, and then returns to that point in the processing. Debug enables the programmers to examine and alter memory locations. This is used only during debugging phases.

A single log tape is generated during one day's measuring. It gives an indication by time of day of when events were started, completed, why rejected, and eventually, some statistics on when portions of an event need to be remeasured.

Commutator

The commutator section switches the control section from the processing of one measuring machine to another. The DELAY portion saves the hardware index registers in the measuring-machine's software table. An index register points to the next desired value of the instruction counter for that machine. The remainder of the commutator simply cycles the measuring-machine number to give the next higher numbered measuring machine a chance to be processed. Thus all measuring machines have the same priority, and the control section processes them in a circular fashion. Thus it would be very straightforward to implement a meaningful priority scheme for the measuring-machine processing.

CONCLUSION

We should have our first measuring machine on-line and operational before the end of 1966. Other measuring machines will follow in succession. There is also a good possibility that scanning-table data to be used with the on-line measuring machines will be collected through the COBWEB system.

In the programming area it is likely that spatial reconstruction and kinematics will be added. This would serve as a more definitive check on the data. These calculations can be made using only a few selected track points.

ACKNOWLEDGMENT

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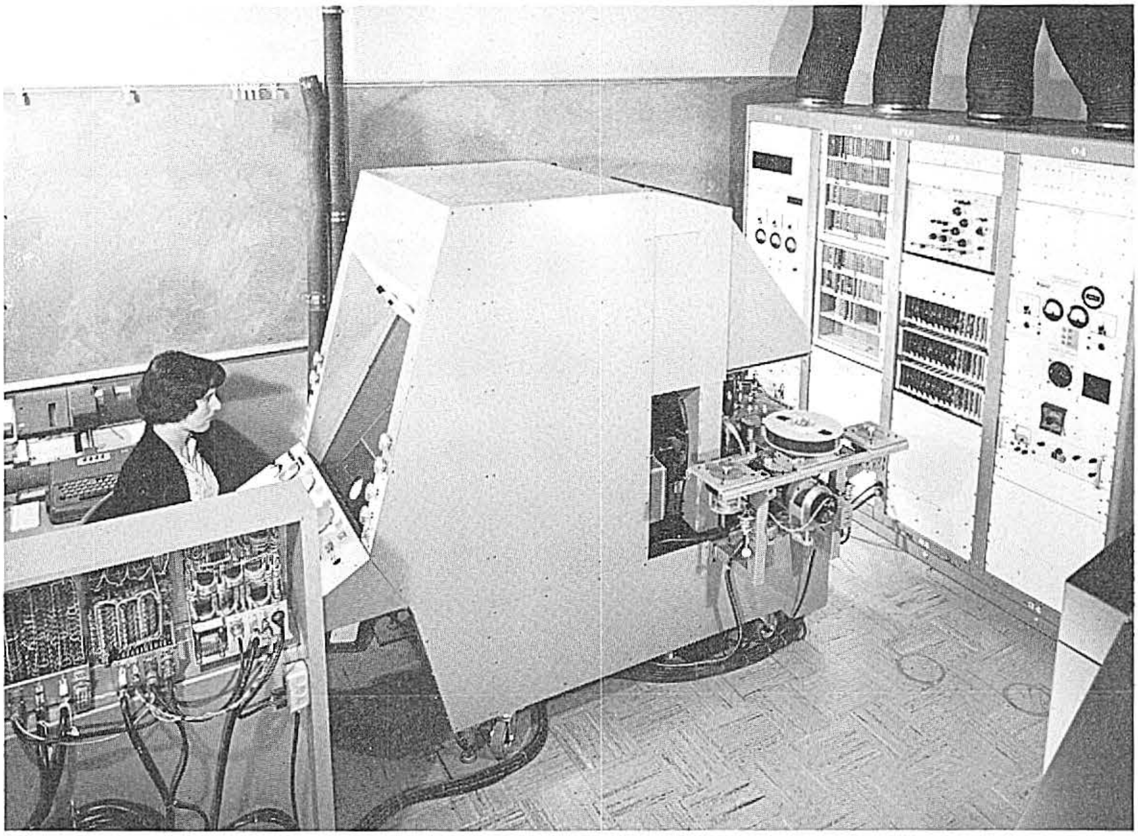

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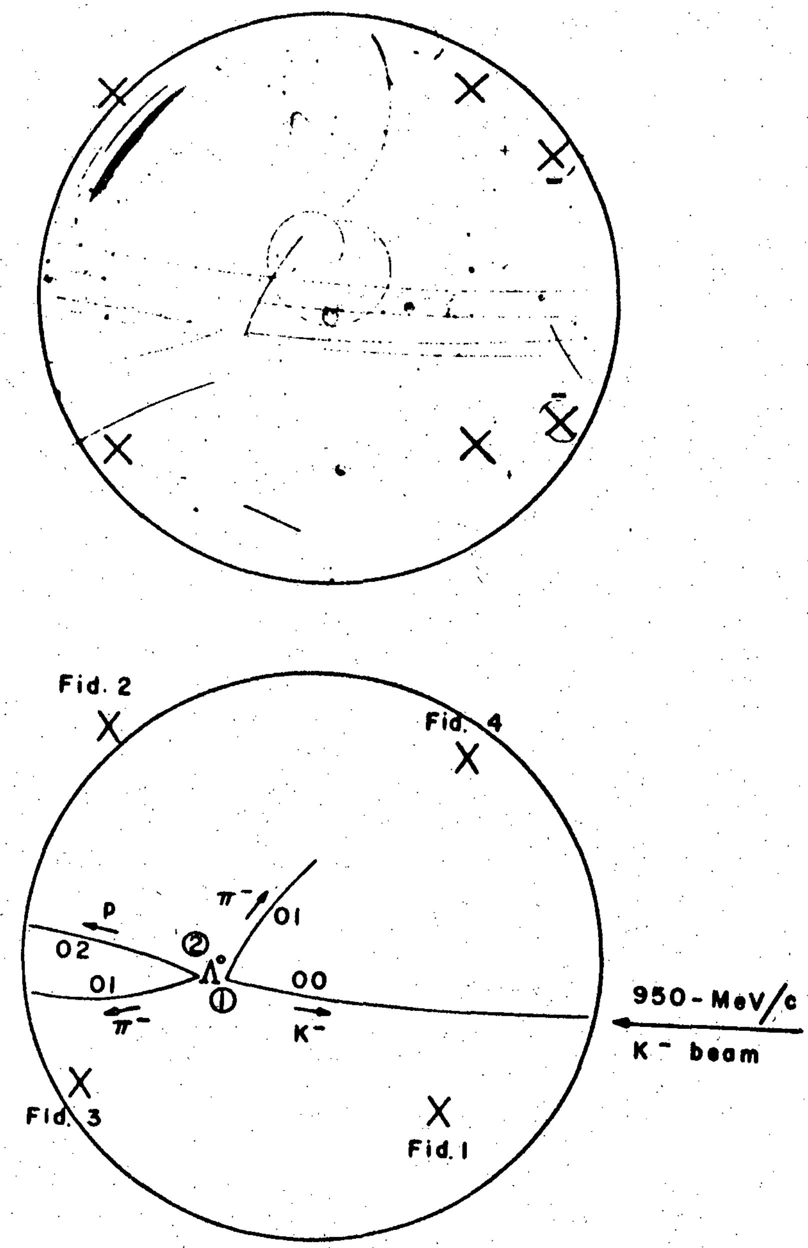
Fig. 1. Franckenstein measuring projector (MPI-E).

Table 1. Software table (one per measuring machine)

Location of the machine's input buffer
Number of data words in the input buffer
Location of the machine's track coordinate buffer
Number of track points in the track coordinate buffer
Location of the machine's input teletype keyboard message
Location of the machine's output teleprinter message
Number of characters already transmitted in the teleprinter message
Total number of characters to transmit in the teleprinter message
Existence of servo hardware
Name of track-coordinate checking routine
Mode of operation
Permanent data-tape name
Current data-tape name
Sign-on flag--yes or no
Fiducial counter
Fiducial set being measured
Current view, vertex, and track numbers
Number of views left to process in the event
Number of vertices left to process in the view
Number of charged tracks left to process in the vertex
Fiducial check flag
Instruction counter and hardware registers
Etc.



MUB-13343

Fig. 2. Typical bubble chamber view showing fiducials and vertices.

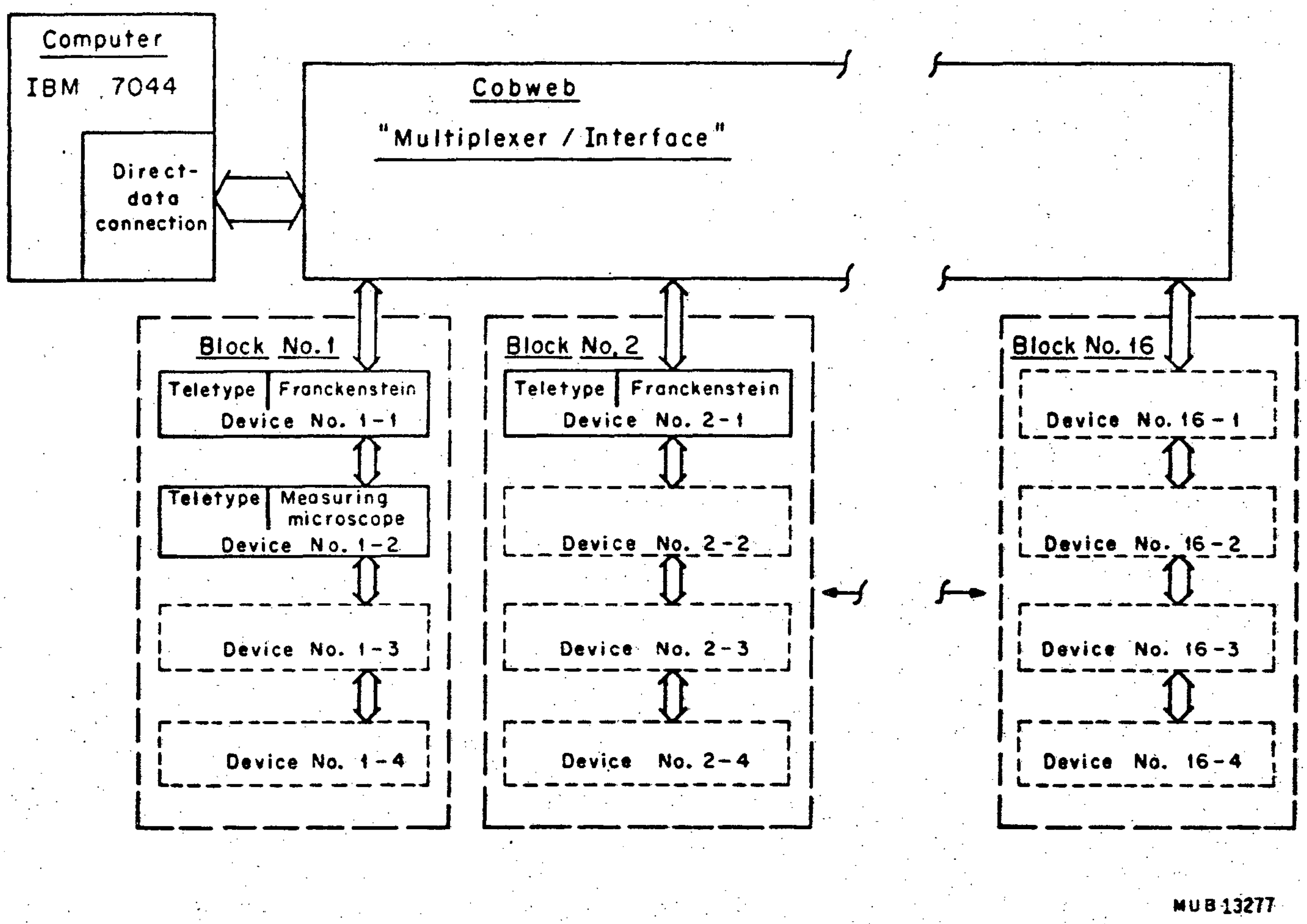


Fig. 3. COBWEB "multiplexer/interface" distribution system.

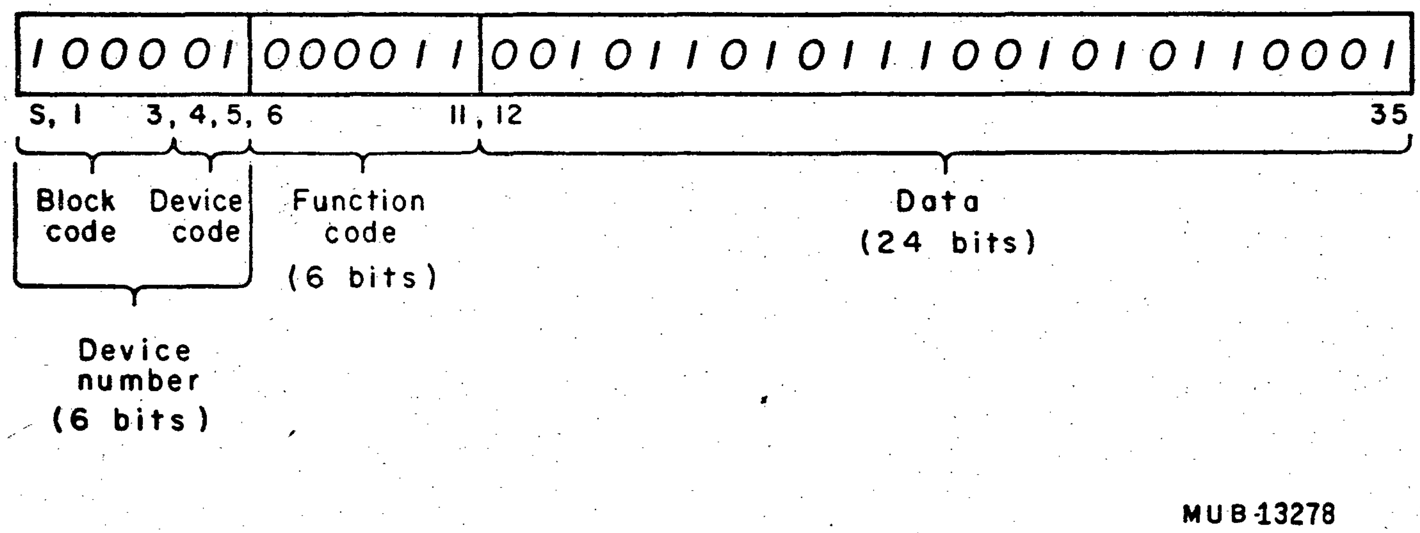


Fig. 4. IBM data word format for COBWEB.

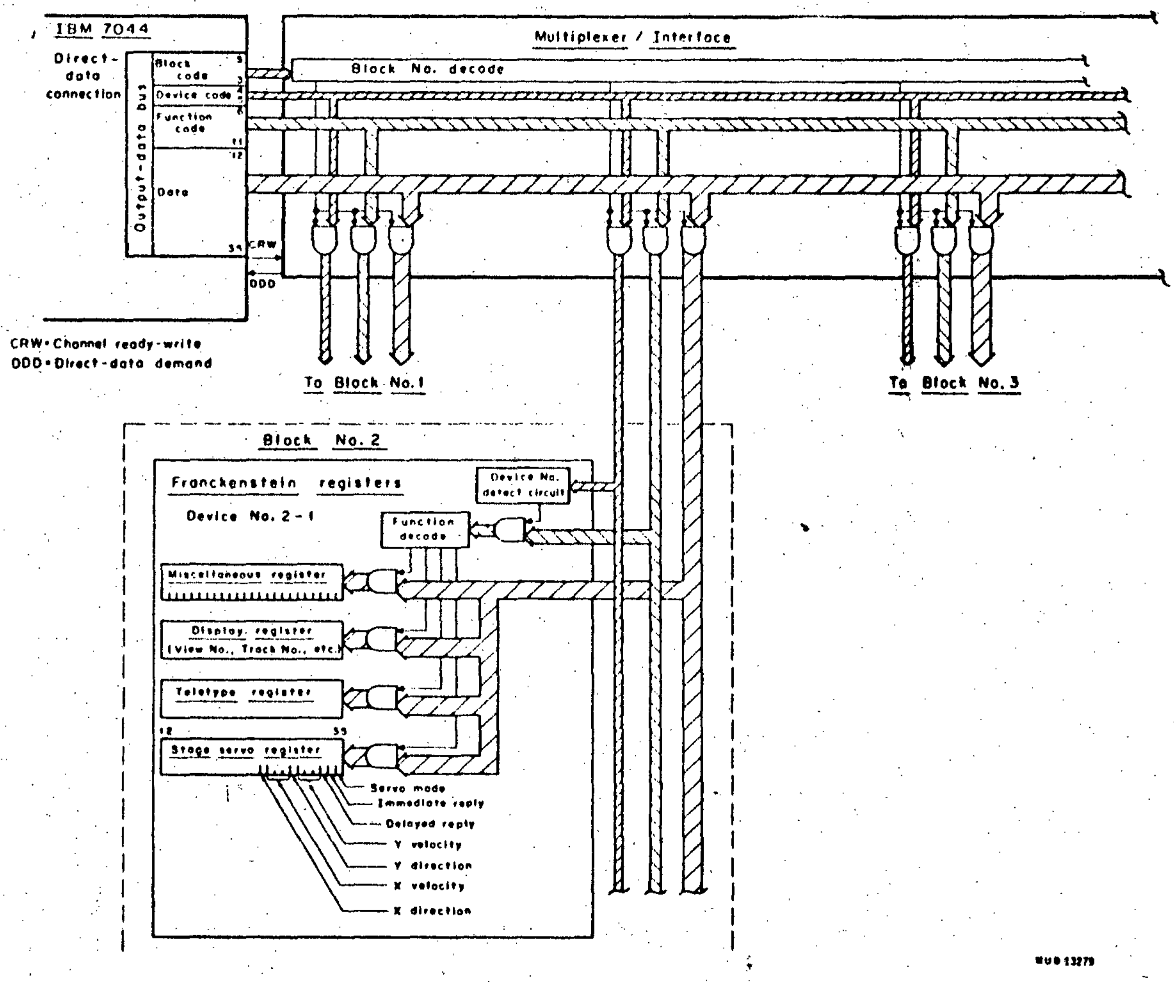


Fig. 5. Data output from the "direct-data connection" to Franckenstein registers.

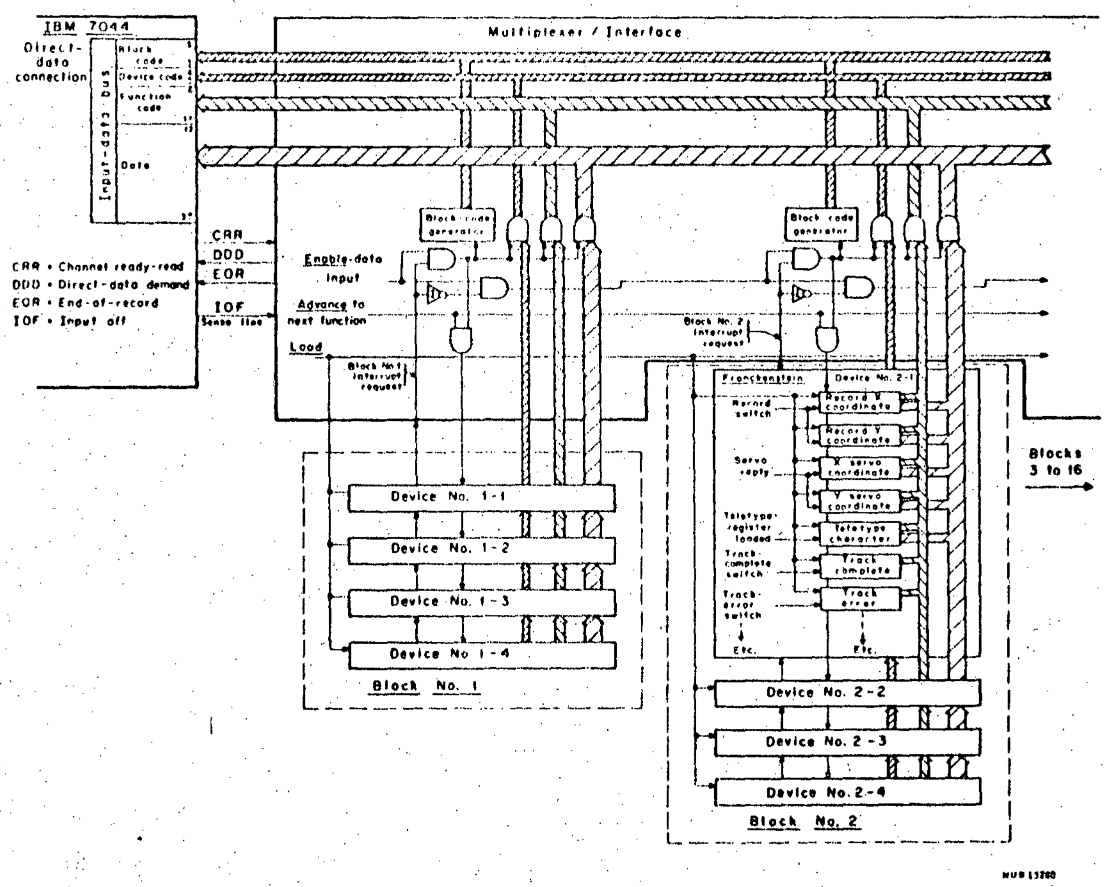


Fig. 6. COBWEB input multiplexing to the "direct data connection."