problem to determine the types of flights to be flown in order to reduce the cost for operating these flights. The latter is merely determining the probability distribution function for the various variables involved and producing a table which would indicate, based on a given assumption, what are the revisions in terms of the number and type of flights and flight assignments that have to be eliminated from the assignments already constructed in Phase II.

It is in Phase II where the most difficulty is encountered. The basic problem is simply this: The trip schedules represent the workload *W*, which has to be perfomed in any given month. To accomplish the task of Phase II, *W* has to be broken down into individual work assignments subject to the constraints which were enumerated above; moreover, in doing so, the total amount of layover time had to be minimized and the total number of hours assigned per month up to the maximum hours allowed by constraint (a) had to be minimized. The reason for this latter objective is that a flight crew member's pay is the sum of a monthly base pay and an hourly rate times the number of hours flown in that month.

The solution to this problem was also written and coded for *650* and the final results, particularly in Phase II, have not been obtained. Nevertheless, certain conclusions can be made even at this stage. First, an over-all improvement over the hitherto existing way of accomplishing this task will be of the magnitude of 5 to 10 per cent, a very worthwhile achievement considering the money and costs involved. Secondly, a great deal of this improvement is a consequence of the results obtained in Phase I and to some extent, Phase III. However, there was a decided lack of technique available which would enable the computer to improve in terms of reducing costs, etc., an earlier decomposition of the workload, *W*. More precisely, there was no systematic way to improve an existing decomposition by an iterative procedure which was in the realm of practicality and economically feasible. The only other course of action was to produce another decomposition and select the one which was more efficient than all the previous ones made. Surely, this is nothing more than an elaborate trial and error procedure.

Concluding Remarks

The solutions to the three problems which have been discussed were to a large extent elaborate trial and error schemes. No doubt, the computer serves a very important function in this respect for the basic operations research problem is, to a large extent, initially divorced from a mathematical model. Consequently, any method which assists the analyst in deriving a mathematical model for his problem is a step in the right direction. Nevertheless, it is also true that this primitive approach is relied upon to such a large extent because of the state of the art. The problems that remain as a challenge to the computer user are much more complex than those which are presently being solved. They will require a more efficient utilization of the capabilities and capacities of the computer in use today.

On the other hand, the management of large businesses and industrial companies should realize that, in less than a decade, the computer specialist has gone from deriving mathematical tables and doing standard accounting work to solving operational and managerial problems of enormous magnitude and complexity. If management is to derive a greater utilization from its computing facilities, it must broaden its perspective and give to the computer specialist the challenge that the latter is willing to accept.

Reference

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A Progress Report on Computer Applications in Computer Design

S. R. CRAY R. N. KISCH

THE subject of computers designing other computers has been a popular one for several years. This subject generally brings to mind Boolean algebra reduction or generation of design logic. This is a difficult problem which the authors of this paper have investigated only superficially, and is not the subject of this paper. Another aspect of computer development work, however, lends itself to mechanization and represents the greatest portion of the time, money, and manpower consuming business of developing a new computing system. This paper summarizes the progress which has been made to date in writing, debugging, and placing in production a general purpose computer program (ERA *1103*) for handling this portion of the development work. This is a program for processing the logical design engineer's work through simulated operation of the proposed equipment to the production of detailed wiring tabulations for manufacturing purposes.

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The mechanization program described in this paper necessarily is based on a particular computer building block and particular type of cabinet design. It is independent, however, of any specific computer and any logical design can be processed which uses the selected building blocks and cabinet structure. The program takes into account all of the physical as well as electrical factors in planning component placement and in computing wire lengths and cable paths in tabulations for manufacture.

The Building Blocks

The particular building block chosen for the design program was a 1-microsecond magnetic switch developed at the St. Paul laboratories of Sperry Rand Corporation. This element performs 3-level "and-or-not" logic and provides one bit of temporary storage in each package.

(a) $X^{39}_{00} = (X^{10}_{00} N^{10}_{11} + N^{10}_{06})(X^{20}_{00} N^{20}_{07} + V^{20}_{12} N^{20}_{08})^{-1}$

(b)

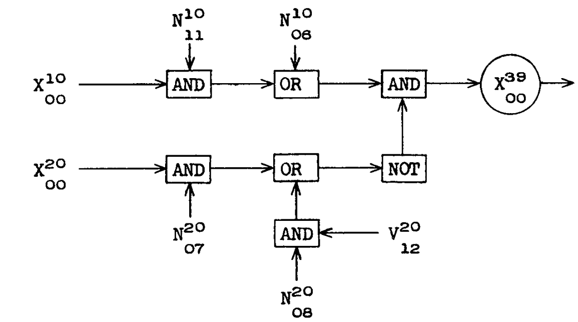

Fig. 1. Typical logical equation with diagrammatic representation

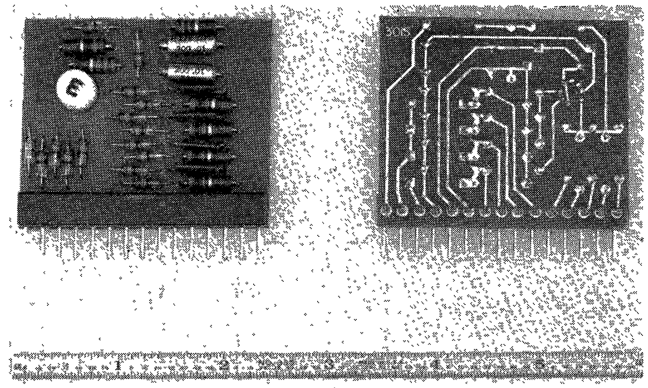

Fig. 2. Magnetic switch package

It is particularly well adapted to mechanization because of the simplicity of its logical structure and the inherent storage at each logical step.

Expression of Computer Logic in Equation Form

Communication with the machine is the first problem in utilizing a general purpose computer for design purposes. In this program an electric typewriter with attached paper tape reader and punch was chosen as the off-line communication unit. Seven-level paper tape is the medium for data transfer from printed page to computer and from computer to printed page. With this choice of input-output equipment, the design information must be reduced to symbols and combinations of symbols which can be typed on the electric typewriter.

A logical equation, representing the contribution of a single building block to the system design, is shown in Fig. 1(a). A base letter together with its two superscripts and two subscripts represents the signal from the unique building block. The equation represents the combination of signals from a number of building blocks which are combined in the indicated logical function to form the input to the building block symbolized by the left term in the equation. The same logical function is indicated by the schematic diagram of Fig. 1(b). The physical package which implements this function is shown in Fig. 2.

Communication between the building blocks is synchronized by a 4-phase clock source. To aid memory, the first superscript in each magnetic switch symbol designates the phase time at which the building block is read. This numeral, then limited to the values 0, 1, 2, and 3, is an aid in determining the timing of pulses occurring in the "and" and "or" circuits.

A Three-Phase Program

Phase One

In the first phase of a design effort using the magnetic switch elements the designer decides on an over-all general logic and then proceeds to generate a system of equations which describe how the building blocks should be connected to accomplish the desired operation. For a system of average size and complexity, from several hundred to several thousand of the building block packages are required; therefore, an equivalent number of equations must be prepared. This part of the program requires several weeks or months to perform. As yet no serious attempt has been made to mechanize the operation.

When this initial effort is completed the equipment designer is faced with a tremendous checking task. He is interested in examining the equations individually and collectively to ascertain that none of the combinatorial rules regarding numbers and relative timing of the inputs and outputs of each magnetic switch have been violated. He is interested further in learning whether or not the over-all performance of the system represented by the equations will be as planned. This task ordinarily is difficult and time consuming and the probability of detecting all of the logical and clerical errors is not much better than that of preparing all of the equations correctly in the first place. It is at this time that mechanized methods are brought into use.

A perforated paper tape copy of the equations is prepared by typing them on an electric typewriter-perforator. A typed copy is thus also obtained which can be used for reference purposes. The paper tape information is then entered into an *1103* computer, and a permanent equation file is established on one of the computer magnetic tapes. A part of the loading operation is a preliminary check of the equations to ascertain, for example, that each symbol in an equation is composed of the proper kind and number of characters. If an equation does not meet the format requirements, it is not entered in the magnetic tape file but is instead sent back out of the computer via punched paper tape. At the end of this initial loading operation the designer has a paper tape containing all of the equations having format errors. Corrections are then made, and the revised equations are entered and added to the magnetic tape file.

Next, the individual equations are subjected to more complete verification regarding the number and types of inputs and the relative timing of these inputs. It is a requirement, for example, that there shall be no more than four "or" inputs per magnetic switch and that each "or" input shall consist of no more than four "and" inputs. Furthermore all "and" inputs to each "or" must occur simultaneously, and there are restrictions regarding the timing of these inputs with respect to the read-out time of the switch. Improper equations are printed out on the monitoring typewriter attached to the computer. Equation 1, for example, would be rejected because the clock-phase numbers on the symbols X^{20}_{10} and N^{11}_{16} do not correspond. In this way many of the minor logical errors and transcription errors are detected. A number of computer programs are available for facilitating the alteration or replacement of equations in the magnetic tape file, so that the process of making the necessary corrections is made extremely simple.

$$Q^{00}_{10} = X^{20}_{10} N^{11}_{16} + Q^{30}_{11} N^{32}_{20} N^{31}_{02} \quad (1)$$

Since the number of outputs from a

```
Indicator Panel  002104

       B¹                B⁵                      Q                        F               O
000000000000000  000000000000000  0000000000000000111111111  000000000000000  0000000

       B²                B⁶                      A                  K          C        I
000000000011100  000000000000010  0000000000000001010101010  000000     00000  0000000

       B³                B⁷                      X
000000000000001  000000000000000  0000000000000000011111111  00010000000  0000000000

       B⁴                 S                      Z
000000000000000     000000000000  0000000000000000000000000  000000  0000000 00000000

       G                  P                      U                           D
000000000000000     000000000000  0100110000000000000000000   0000  0000  0000  0001
```

Fig. 3. Control panel showing register contents after simulation

single magnetic switch is limited by electrical and physical considerations a check must be made to assure that the designer has not used more outputs in his logical design than are physically available from a given switch. This check, which is again handled automatically by computer program, involves the scanning of the entire list of equations and noting where the outputs from one switch appear as inputs to other switches. The information relative to the number and destination of the outputs from each switch is recorded, for future reference, in the magnetic tape file along with the equations. Any illegal usage is immediately described on the monitoring typewriter. This process of verification is repeated, with intervening correction procedures, until a functionally sound set of equations is obtained.

Other computer programs are available which accomplish such tasks as sorting the equations by the various elements of the symbols identifying them and preparing printed copies of the equations and other information appearing in the magnetic tape file.

When a set of several thousand equations is considered it is obvious that the previously described procedures, when conducted manually, would require several weeks of effort. With the mechanized methods, several hours usually are sufficient to complete the task.

Phase Two

In the second phase of the program the designer has an opportunity for testing the logic of his design in a manner which simulates the method he would use if the equipment were actually constructed. The control panel for the proposed equipment is created, on paper, by laying out and identifying all of the push buttons and indicator lights which will appear on the actual panel. The push buttons include those used for setting and clearing the stages of arithmetic and control registers, those used for initiating the various sequences of operation, and miscellaneous operating controls. The indicator lights are those used for indicating the contents of the registers, the state of control elements, etc. The push buttons and lights which appear on this panel are incorporated into the design by adding special symbols to some of the equations of logic to represent the manual inputs and by the preparation of some additional equations to express the indication functions. For example, in equation 2a the symbol M^{-3}_{56} represents a push button which provides a manual input to stage 03 of the "X" resister. Equation 2b would be written to provide for the indication of the contents of the same register stage.

$$X^{00}_{03}=X^{20}_{03}N^{21}_{14}+A^{20}_{03}N^{23}_{16}+M^{-3}_{56} \quad (2a)$$

$$L^{-3}_{56}=X^{00}_{03} \quad (2b)$$

The superscripts and subscripts associated with the L and M symbols have a special meaning in that they represent co-ordinate locations on the control panel where the buttons and lights which they symbolize are located. Ordinarily most, if not all, of these special symbols and equations will be included from the outset, since the designer is aware of their function and probably has a fair concept of the control panel for the equipment he is designing.

To initiate the "simulation" of the various operations, the designer, using a special co-ordinate paper representing the control panel, marks the co-ordinate positions which correspond to buttons he would depress on the actual panel. He might proceed, for example, by entering certain operands into the arithmetic resisters and then initiating an operation such as "multiply." A paper tape is then prepared by typing on the electric typewriter-perforator a pattern of "1"s in which each "1" represents a depressed button, and its location, determined by the number of horizontal and vertical spaces from a printed index point, indicates which button is being depressed. The paper tape is entered into the *1103* computer, which contains the completed magnetic-tape equation file, and the information is automatically interpreted and recorded. The simulation is then initiated and involves the simultaneous solution of the system of equations for each clock cycle of the simulated operation. After a certain number of clock

WIRE TABULATION — *Remington Rand* — Engineering Research Associates Division

DRAWING IDENTIFICATION: PREFIX | SIZE | NUMBER | REV.

TITLE: GEMINI / UNIT 10 / INTRA-UNIT TABULATIONS

NOTE: THE TITLE, PREFIX, SIZE AND REVISION OF THE DRAWING APPEAR ON SHEET 1 ONLY.

SHEET 10 OF 21

ORIGIN	DESTINATION	COLOR	GAUGE	DESCRIPTION	LENGTH	CHG.
J10 H8- 2	J10 G9- 9	(56)			9-7	r
	J10 L9- 1	(56)			10-2	r
J10 E8- 1	J10 D9- 9	(44)			10-0	r
	J10 C8- 1	(44)			10-0	r
	J10 A8- 1	(44)			14-7	r
J10 D9- 1	J10 L9- 9	(77)			12-4	r
	E10 B-12	(77)			4-0	
J10 J8- 2	J10 L9- 2	(75)			11-6	r
	J10 I9- 9	(75)			8-4	r
	J10 H8- 3	(75)			9-6	r
J10 L8- 2	J10 L9- 3	(05)			4-7	
	J10 K9- 9	(05)			6-7	r
	J10 J8- 3	(05)			9-6	r
	J10 H8- 4	(05)			14-0	r
J10 N8-2	J10 M9- 9	(20)			9-7	r
	J10 R9- 1	(20)			10-2	r

Fig. 4. Example of automatically prepared wiring tabulation

cycles have been completed, an output is provided in the form of a paper tape. The number of cycles simulated may be predetermined or may depend on some selected criteria.

The paper tape output, when processed on an electric typewriter, provides essentially a picture of the control panel with each indicator light represented by either a "0" or a "1" depending on whether or not the light is on. Thus the contents of registers may be examined at the end of an operation and the performance of the "paper" computer evaluated. In this manner all of the operations of the computer being designed can be simulated with various combinations of operands and the complete set of equations verified. When operational errors are detected, sufficient evidence is usually present on the printed control panels to allow the designer to discover rapidly the logical error in the design. Then by using the modification facilities described under phase one he may make the necessary corrections to the equations.

It is also practical, in order to achieve added realism, to prepare some additional equations which simulate several registers of storage in the proposed computer system. Thus actual simple programs may be prepared and their execution simulated for the purpose of checking continuity of control in the new design. The added equations are, of course, removed from the file before further processing is done.

Fig. 3 shows a typical output display resulting from a simulation operation. As previously mentioned, the arrays of "0"s and "1"s represent indicators on the various arithmetic and control registers in the computer being designed. The registers are identified by the letters appearing over the indicators. Each panel is identified by a number appearing at the top, which is automatically advanced for every clock cycle of simulated operation. This number is preset to an arbitrary value at the time of entry of the paper tape containing the push button information initiating the simulation. Each type of operation performed is thus identified with a unique series of numbers. A by-product of this phase of the program is a record of each operation of the proposed system giving exact operation times and specific examples of resister contents before and after execution.

Phase Three

When the design checking process has been completed another formidable operation must be undertaken. Decisions must be made regarding the placement of the magnetic switch packages in the standard chassis assemblies, and manufacturing tabulations must be prepared which completely describe the wiring required to interconnect all of the packages. A standard chassis accommodates up to 180 of the building block packages so that in an equipment using, for example, 2,000 packages, 12 assemblies would be required. Indiscriminate or improper assignments of the various magnetic switch packages to the chassis would result in an excessive number of interconnections between chassis, intolerable lengths of wire on some of the switch outputs and possible excessive unbalance of the loads on the clock pulse driver lines. In view of the number of factors to be considered and the tremendous number of options available for placement, the assignment job is handled by the 1103 computer in a manner far more rapid than it could be done by the designer.

The same is true of the process of preparing wiring tabulations. Several hundred pages of material such as that shown in Fig. 4 are prepared in a few hours by the computer, and freedom from the various types of human errors is assured. The connection points are listed in an order such that subsequent wiring in that order will require a minimum length of wire. The length of wire required is also listed in each case and a color code is assigned. Additional manufacturing and maintenance aids such as component inventories and cross tabulations for signal tracing are also quickly obtained from the computer.

Simplicity of Utilization

In order that the use of the computer for design assistance be made as simple as possible, a method of interpretive programming for the execution of the various mechanized procedures has been worked out. A master file of all available programs is maintained on a magnetic tape which is placed on a computer tape unit at the beginning of a production run. The user is provided with a catalogue which lists an identifying code number for each program, describes its functions, and specifies prerequisite operations. Preparation for a run consists of typing on the electric typewriter a list of these code numbers in the proper sequence for accomplishing the desired task. The resulting paper tape is called the master program tape, and its contents are loaded into the computer at the beginning of the run. All of the subsequent operations are automatically controlled by the master program and the operator's attention is required only in the event of the detection of equation errors which must be corrected before proceeding.

The development of a computing system with this mechanized program requires the same logical design effort, on a system level, as any other approach. However, this method substantially reduces the time and money consuming process of detailed design and physical layout. Because of the great reduction in detailed design time, it is now practical to investigate completely a number of approaches to a system design. Several design approaches can be processed to completion so that component inventories and operating times can be compared for the completed equipments.