A PROGRESS REPORT ON COMPUTER APPLICATIONS IN COMPUTER DESIGN

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Introduction

The subject of utilizing computers for designing other computers has been popular for several years. This subject generally brings to mind the reduction, or even the generation, of design logic through the use of Boolean algebra or similar methods. These complex and difficult problems are ones which the authors of this paper have considered only superficially. Instead, consideration was given to the mechanization of several other phases of development work which represent probably the greatest portion of the effort that goes into the development of a new computing system. This paper summarizes the progress that has been made to date in the development and use of mechanized methods for checking design logic and for the performance of processes of detailed design. The latter is exemplified by the planning of component arrangement and preparation of manufacturing tabulations for constructing the equipment. These methods involve the use of a general purpose computer: in this case, a Univac Scientific, Model 1103.

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 Building Blocks

The particular building block chosen for the design program is a one- microsecond magnetic switch developed at the St. Paul laboratories of Remington Rand Univac. This element performs three-level "and-or-not" logic and provides one bit of temporary storage in each 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

The first problem in utilizing a computer for design work is one of communication; that is, communication between the machine and the people using it. 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.

To illustrate the form of representation being used, a logical equation, representing the contribution of a single building block to the system design, is shown in Figure 1(a).

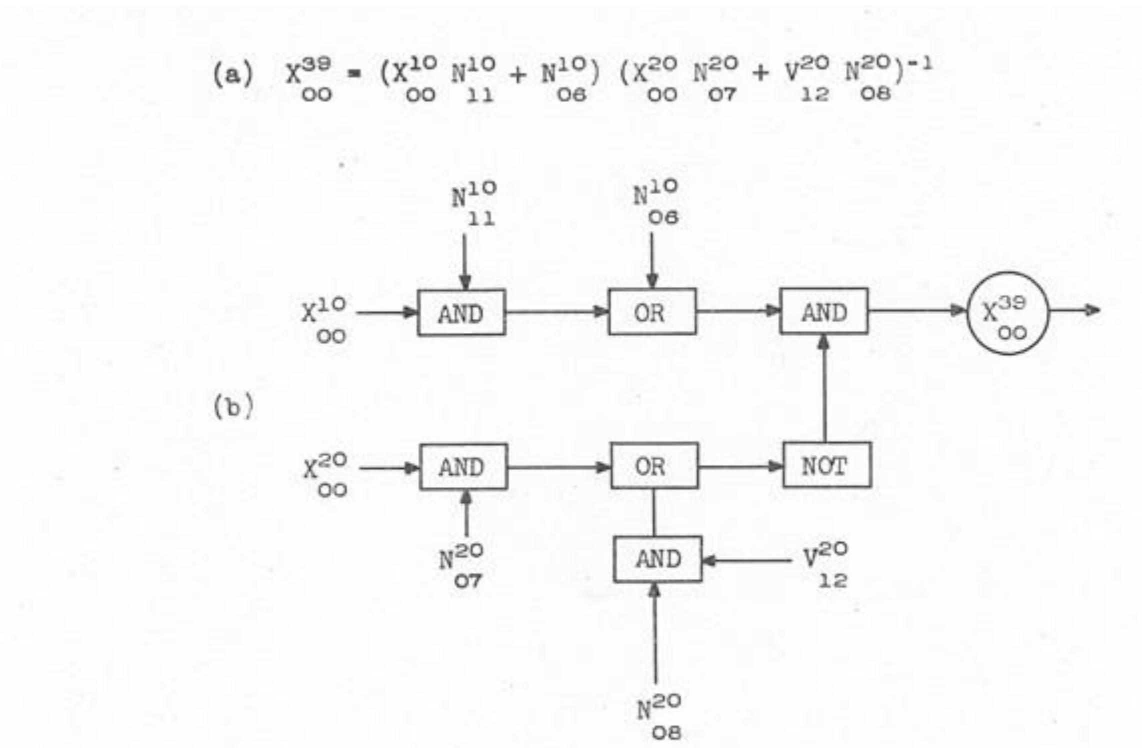

Figure 1. Typical Logical Equation with Diagrammatic Representation

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 Figure l(b). The physical package which implements this function is shown in Figure 2.

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

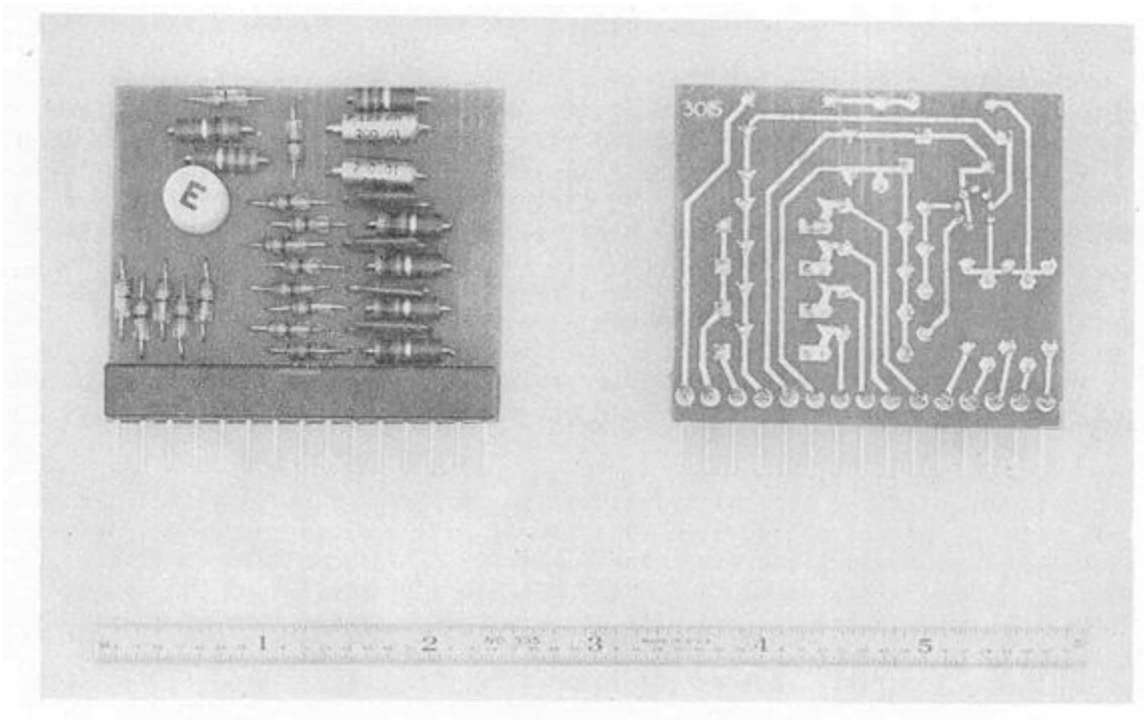

Figure 2. Magnetic Switch Package

A Three-Phase Program

Phase One

In the first phase of a design effort using the magnetic switch elements, the designer decides on an overall 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 this 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 overall 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 the logical and clerical errors is not much better than that of preparing all 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 a Model 1103 computer, and a permanent equation file is established on one of the computer's 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 instead is 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. The equation in Figure 3, for example, would be rejected because the clock-phase numbers on the symbols $X^{28/10}$ 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.

$$Q^{00}_{10} = X^{20}_{10}\ N^{11}_{16} + Q^{30}_{11}\ N^{32}_{21}\ N^{31}_{02}$$

Figure 3. Equation with Clock Phase Error

Since the number of outputs from a 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 in various ways and preparing printed copies of the equations and other information appearing in the magnetic tape file. These first mechanized procedures are executed to make sure that nothing appears in the design logic that cannot be physically implemented. 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, usually several hours 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 pro- posed 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 register, 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 the equation shown in Figure 4(a) the symbol $M^{-3/56}$ represents a push button which provides a manual input to stage 03 of the X register.

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

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

Figure 4. Equations showing Manual Input and Indication Functions

The equation of Figure 4(b) is written to provide indication of the contents of the same register stage. The superscripts and subscripts associated with the L and M symbols have a special meaning in that they represent coordinate locations on the control panel whereon 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 already planned the layout of the control panel.

To initiate the simulation of the various operations, the designer, using .a special coordinate paper representing the control panel, marks the coordinate positions which correspond to buttons he would depress on the actual panel. He might proceed, for example, by entering certain operands into the arithmetic registers 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 Model 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 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 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 rapidly discover 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 pro- posed 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.

Figure 5 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 which contains 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 operating times and specific examples of register contents before and after execution.

Indicator Panel 002104

B^1	B^5	Q	F		O
000000000000000	000000000000000	000000000000000111111111	000000000000000		0000000
B^2	B^6	A	K	C	I
000000000011100	000000000000010	000000000000001010101010	000000	00000	0000000
B^3	B^7	X			
000000000000001	000000000000000	000000000000000111111111	000100000000		0000000000
B^4	S	Z			
000000000000000	000000000000	000000000000000000000000	000000	0000000	00000000
G	P	U		D	
000000000000000	000000000000	010011000000000000000000	0000 0000	0000	0001

Figure 5. Control Panel showing Register Contents after Simulation

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, 2000 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, in tolerable 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 Model 1103 compute, 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 Figure 6 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.

Simplicity of Utilization

In order that the use of the computer for design assistance be made as simple as possible for the people involved in design work, a method of interpretive programming for the execution of the various mechanized procedures been worked out. A master file of all available programs is maintained on magnetic tape which is placed on a computer tape unit at the beginning of production run. The user is provided with a catalog which lists an identification 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 the detection of equation errors which must be corrected before proceeding.

The development of a computing system with this mechanized program runs 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 completely investigate a number of approaches to a system design. Several design approaches can be processed to completion so that component inventories and operating time be compared for the completed equipments.

WIRE TABULATION	Remington Rand Univac DIVISION OF SPERRY RAND CORPORATION 1902 WEST MINNEHAHA AVE. ST. PAUL W4, MINNESOTA	DRAWING IDENTIFICATION PREFIX | SIZE | NUMBER | REV.

TITLE	NOTE
GEMINI UNIT 10 INTRA-UNIT TABULATIONS	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

Figure 6. Example of Automatically Prepared Wiring Tabulation