COMPANY CONFIDENTIAL

PROJECT STRETCH

FILE MEMORANDUM #7

SUBJECT: Automation of Design
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Logical design is one of the important areas to which automation can be applied. Included in the work done in this area has been Mr. William Starbuck's project in which he prepared by machine a Boolian statement of the logical circuits of the printer buffer of the Type 702 system. This was essentially the inverse of design, since it produced a description of a machine which had previously been designed. However, it revealed several aspects of the problem. It also demonstrated that a machine statement could be prepared which was much easier to understand than the conventional circuits from which it was taken.

A logical system is made up of two classes of elements. The first of these is a series of base or reference points which provide the system with memory and perform the timing function. The second class of elements is logical circuitry through which the condition of certain base points is caused to modify the condition of others.

Base Points

A base point is any point which identifies for a specific period of time a logical condition or combination of conditions. Following are some of the mechanisms which are used as base points:

- Triggers
- Blocking oscillators
- Relays
- Delay lines
- Single Shot multivibrators
- Clock impulses
- Cams
- Manual Keys
- Machine operated contacts
- Electromagnets

Signal Lights
Input cable connections
Output cable connections
Plugboards
Memories of all kinds

Whenever these devices appear in a circuit, it is possible to describe their operation in terms of the following:

1. The logical conditions which will turn the device on.
2. The logical conditions which will turn the device off. (The sum of 1 and 2 is the meaning of a base point.)
3. The time duration or range of time duration of the on and off conditions. (When presented diagrammatically, this is a timing chart.)

Each kind of base point has specific limitations which govern its use in the circuit. However, all can be defined within the above context. This applies as well to a manually operated key as to the more rigidly controlled devices.

When a machine is divided into several parts, as is the case with the 702 printer, printer buffer, and ALU, the division may have been made in such a way that a base point is contained in a different cabinet from its logical controls. To this extent, the several cabinets must be considered as a single mechanism.

Logical Switching

The second part of a control system is the logical switching. Conventionally, this consists of a series of AND and OR devices connecting the outputs of two or more base points to the input of one or more others. The impulse which passes through the logical circuit may turn the receiving base point on, turn it off, or reverse its setup. In special cases, such as signal lights, it may perform more specialized functions.

In all cases, one of the inputs to the logical network must be a timing pulse, for it is timing requirements which justify the existence of all those base points which do not serve as basic input and output. In some cases, the timing is crudely stated, as with a signal light controlled directly from a manual key. In others, the timing may be a reflection of the control of an input base point. This is the case in a logical circuit controlled by the turning on or turning off of a trigger acting as an input base point. Here the circuits which control the trigger provide the timing.

Secondary Elements

In addition to base points and logical devices, the circuit may contain secondary devices which serve to match the individual circuit parts to one another. This is true of amplifiers, which do not ordinarily qualify as base points because they do not provide memory. A clipping amplifier, or any amplifier controlled by two logical conditions in combination does qualify as a logical element, since it serves to replace logical elements while at the same time amplifying the signal. Cathode followers are obviously neither base points or logical elements, but are implied by the load requirements of the logical circuit. Inverters are logical NOT elements as well as amplifiers.

Timing

A machine of the type with which we are concerned is actuated by a complex series of input signals representing the data input. In response to these signals, it is required to provide complex sequences of output signals, representing the data output. The first purpose of base points is to provide memory of sufficient duration to juxtapose in time the several controls which must determine each output event.

If we were to ignore the resulting complexity of logical circuitry, it would be possible to design our machines using no more base points than the sum of the required input and the output conditions. However, the complexity of such a machine would be very great. In order to reduce this complexity, the logic is divided into a series of individually time sequenced parts which by repeated use can be made to achieve the desired result. A machine with the least possible number of base points is a completely parallel machine. Dividing it into parts of less complexity makes it more serial.

An example of this process is multiplication. It is obviously possible to describe a device which would multiply in a single pulse time. This device would be completely parallel. It requires as base points a series of triggers or similar devices to express the factors (the factor registers) and a similar set of base points to receive the result. (The result registers.) Between them lies the logical network expressing the multiply function. One additional base point is required, the multiply control which tells the circuit when to operate (the timing).

We know that the same function of multiplication can be achieved with less logical mechanism if more than one time interval is employed to accomplish it. That is, if it is made more serial. A first step in simplification is to execute one digit of the multiplier at a time. Another is to avoid generation of multiples of the multiplicand. Then one can perform the additions a decimal digit at a time instead of a field at a time. Finally, one can perform the additions a bit at a time. At this point we are near the least common denominator in terms of logical circuitry.

As these successive downward steps in the complexity of logical circuitry are taken, the number of time steps and the number of base points expressing them increases in number. At first, a large reduction in logical complexity is obtained with a small additional number of base points. However, as the process proceeds the ratio becomes less favorable until a point is finally reached where large amounts of additional time buy very little in reduction of logical circuitry. The Turing machine is at this extreme. The change from completely serial operation in the TPM to parallel by character operation in the 702 is a case where the greater logical complexity was almost fully offset by the reduction in the number of base points, with the result that higher speed was obtained at virtually no net cost in equipment.

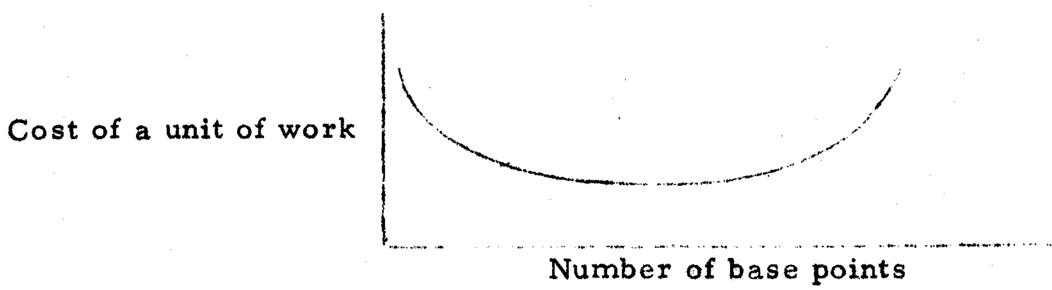
How to describe a Logical Circuit

Any complex logical circuit can be described by enumerating its base points and defining in Boolian terms the conditions which govern the turning on and turning off of each. As already noted, a given function can be accomplished with circuits employing varying numbers of base points, with the complexity of their Boolian description in general becoming less as the number of base points increases.

Moreover, a given logical situation can be expressed in turns of a family of related Boolian statements built around a single set of base points. For each member of a family, a circuit diagram can be drawn up. Each will perform the same function in the same time by using its components in a different way. Because of the large amount of labor involved in drawing circuit diagrams for complex logical circuits, the unability of circuit diagrams to clearly convey the logic which they imply, and the large family of circuits which can be used to perform the same function, it appears that the circuits of a machine can best be described in Boolian terms at least until the time that the machine is fully designed. An example of how this would be done for a part of the adder is included in Stretch Memorandum #6.

The Great Plateau

We have already considered the fact that the number of base points and the amount of operating time which they imply can be varied over wide limits. At one extreme lies great logical complexity and high speed and at the other logical simplicity and very low speed. If one plots for a machine the cost of each unit of work against the number of base points, the usual result is a curve of the following form.



When the number of base points is small, the machine operates very fast but at a prohibitively high cost due to the complexity of its logical circuitry. At the other extreme, the number of base points and the slowness of operation make the machine equally costly in terms of work done despite the simplicity of the logical controls.

It is significant that between these extremes there usually lies a wide plateau over which many solutions exist which are of nearly equal value. Commonly, a single best solution may not exist, and machine evaluation of the relative merits of solutions may do no more than identify an area within which a choice can be made. For reasons which lie completely outside the bounds of cost and efficiency, one of these solutions may be much more desirable than the rest. The reason may be completely subjective, it may relate to the ease with which the circuit can be understood, (which recommends use of circuits like those with which the student is familiar), or it may be required by standardization as would be the case in using the same code as in an earlier machine even though another code were as good or better.

Series-Parallel Operation

Up to this point, the discussion of the relationship of the number of base points and the complexity of logical circuits to operating time has related only to systems in which one thing is done at a time.

When a succession of circuits operate in sequence upon a given unit of input data, each circuit may operate in succeeding time periods upon different units of the same kind of data. As a result, all circuits can be in constant use and a new result obtained each pulse time. For this to be possible, the input base points of each logical network in the series may not include as base points the output base points of any other network other than those of its immediate predecessor. (This is in effect a matter of logical orthogonality).

Moreover, the principal is of value only when the same series of operation is to be performed upon successive units of data, as is the case in addition. The number of pulse times for the operation as a whole is equal to the number of successive units of input data plus the number of successive stages of logic minus one.

Conclusion

It is the writer's belief that the logical requirements of the Stretch computer should be set down in Boolian terms as rapidly as they are developed, and a machine procedure worked out to obtain an optimum configuration of each part of the circuit. This will avoid a large amount of early labor in circuit drafting, and will keep the machine logical statement in the fluid state necessary for application of new data on components as it is developed.