COMPUTER TECHNOLOGY

"Basic Black" in computer interfaces for psychological research

WILLIAM R. UTTAL, *THE UNIVERSITY OF MICHIGAN, Ann Arbor, Michigan*

In this paper we present the specifications of a set of interface components able to connect a digital computer to any of a large number of psychological experiments. We believe this set to be nearly inclusive of most of the needs of current computer controlled psychological research. The function and special requirements of each of the devices is described and a block diagram presented. Specific details of electronics construction are not discussed.

It has often been said that the very first people to line up at the doors of a newly opened computing center are psychologists. It is easy to understand this phenomenon for it is well established that the high speed statistical analyses and the complex simulations of cognitive processes which can be carried out at the central computing centers have had profound effects on the last decade of psychological research. Another trend which has been becoming equally evident in recent years has been the contribution of the small, real-time computer to the control and manipulation of parameters in a wide variety of experimental efforts. The practical effects of introducing real-time, on-line computers into the laboratory have been realized in the execution of experiments which had literally been impossible in previous times. Perhaps more important, however, has been the forced draft development of new points of view as expressed in theoretical models as well as new methods of analysis and procedure. Certainly prior to the real-time, on-line computer the more complex decision-making psychophysical procedures (see Green & Swets, 1966) were extremely difficult to implement and the elaborate and efficient PEST rules formulated by Taylor & Creelman (1967) could not be applied in their full power. Keith Smith (1967) has summed up this notion when he pointed out that modern experimental psychology is now for the first time, under the influence of the laboratory computer, developing a statistical methodology better suited to its needs than those of the agricultural heritage out of which the latin square and other similiar procedures evolved.

The purpose of this paper, however, is not to discuss these modern developments in statistical experimental design. Rather, in this paper we should like to take for granted the notion that the computer and the psychologist, both individually and in combination, are here to stay and present the technical details of what has developed in our laboratory as a standard psychological interface package. Like the basic black dress which, as every girl knows, can be worn any place in great taste, this package of interface components represents a basic set which allows almost any kind of psychological or psychophysiological experiment to be run under the control of an appropriate computer program.

By an interface package we are referring to that group of devices which collect information from and transmit information to the external environment. The external environment for the computer in the case of a psychological experiment, of course, is the S or animal preparation itself. Interface devices are required to transform the patterns of signals within the computer into a pattern usable by the S and vice versa. The representation of a given pattern within a computer may be in a form which is not usable by a S simply because of power levels. But more fundamentally this incompatability may be due to a difference in the languages used by the computer and by the S. In addition, the time scales of the two patterns of information may be so disparate that it is necessary to synchronize the one to the other by slowing down or speeding up the flow of information. In general, therefore, the interface acts as a communication link which not only allows information to flow but also translates codes or languages, amplifies or reduces power levels, and alters the basic time units of the S and the computer to accommodate the real-time base of the other.

Our approach in this brief paper is to present the logical characteristics of the devices discussed rather than the specifics of any single commercial line of computer modules. We also will leave to a more complete discourse (Uttal, 1968) the discussion of how the components work. It is hoped that a specification of the interface devices which we have found useful will be valuable to those of our colleagues who also are preparing to take advantage of the remarkable control capabilities of the small laboratory computer.

No claim to originality of design or configuration is implied. Many other researchers have utilized similar devices and the design of these devices is what the patent office calls a simple engineering extension of the state of the art. The general nature of the devices we have added to our computers, however, may suggest to some, novel ways to run their experiments which they had not previously considered.

LOGICAL SYMBOLS

Before we discuss specific interface devices, it is necessary to present a brief nomenclature for the logical symbols we will use in our drawings. It is not well appreciated by the novice when he first looks at the superficial complexity of a digital computer that computers are, in fact, simple concatenations of a very small number of different components. It is well known to mathematical logicians and computer logical designers that it is possible to build a computer out of a set of components consisting of no more than two different devices. It is further realized that there are several different sets of these pairs of components which will do the job. In the practical case, however, it is usually a fact that a wider variety of components are used for secondary reasons of economy and convenience, but even then the number of different units in the set of logical elements is typically quite small. The basic units used in most computer design are four in number. The first of these units is the inverter which is capable of multiplying a signal by minus one, i.e., inverting negative voltage to positive voltage and vice versa. The second unit, the basic storage element, is variously called a flip-flop, trigger or bistable multivibrator. This device has two stable states either of which can be set by activating one of two inputs. Usually, the flip-flop also has two outputs, one of which is activated when the flip-flop is in the "1" state and the other of which is activated when the flip-flop is in the "0" state. The third and fourth devices are actually different utilizations of a single physical unit. This single unit, usually called a gate, can be implemented in a number of different ways with transistors alone, transistors in combinations with diodes, or special multiple base transistors. In any case, however, a gate is characterized by multiple inputs which must be activated or asserted in a particular way to produce an active output. The two functions to which it can be applied are logical "and-ing" and logical "or-ing." The "and" operation is defined such that the output signal of a gate will be asserted only when all of the inputs to the diode gate are themselves asserted simultaneously. The "or" operation is defined such that the assertions of any single input will result in the assertion of the output. Figure 1 shows the standard symbols for the four basic functional units.

There are a number of other complications about the design of logical circuits which are more or less special to each particular commercial line of components. Voltage levels, in particular, must be of the appropriate polarity as defined by the electronics of the logical unit. For the purposes of this paper we shall ignore these special details and concentrate only on the functional utilization. We shall assume that an activated input will result in an activated output without reference to what the signal characteristics (rise time, voltage level, or polarity) would have to be. There are also a number of specially designed units which are required for special functions at one point or another in our circuits. These will be described as they are encountered.

It is generally the case that small computers are connected to the interface equipment which we shall describe in two ways. There is usually a parallel set of signal lines coming from some buffer register which conveys an entire memory word of coded information to the external equipment. These we shall refer to as data signals. There are also, usually, a series of pulse lines which can be used to select or initiate a given operation. These pulse lines are activated by the execution of a specific input-output instruction by the computer and are otherwise dormant. The data signals on the other hand may be present continuously. The data signals are usually, therefore, gated by "and-ing" them with a control pulse into a secondary storage buffer when needed. In addition signals entering the computer from the outside world are also able to indicate their need for service by means of an interrupt signal. Each of the various computers has its own special means of generating these input and output pulses and in this brief article we shall also ignore these details. The reader is directed to the promotional materials of each of the manufacturers for the specifics concerning their machines. An especially useful general introduction, however, is the *Small Computer Handbook* published by the Digital Equipment Corporation of Maynard, Massachusetts which while naturally emphasizing the special characteristics of their own line of computers does contain a great deal of general information about the computer side of the interface. Now let's turn to the specific interface devices themselves and discuss their use, special requirements, and present a simple logical diagram showing how they can be constructed from the standard set of logical components.

STIMULATOR TRIGGERS

Purpose

In many psychological experiments some special peripheral instrumentation is necessary to create the desired stimulus condition. This stimulus might be a flash of light, an acoustic click or a cutaneous constant current stimulus pulse. The critical function of the computer in this case is not to produce the stimulus itself but to emit a trigger pulse at the correct time to activate the external equipment.

Special Requirements

The brief control pulses emitted by a computer will, in general, not be suitable in either duration, polarity or amplitude for the triggering of external equipment. It is, therefore, necessary to extend them in time and amplify them in voltage to meet the input needs of the external equipment. The elongation of the pulses is accomplished by means of a device called a single shot or monostable multivibrator. This device, when triggered, emits a pulse, the duration of which, like the all or none response of a neuron is independent of the characteristics of the triggering signal. The duration of this pulse is usually adjustable over wide ranges. The output of this single shot is then amplified, typically by means of a special voltage amplifying inverter, to meet the input criteria of the peripheral equipment. Figure 2 shows a schematic block diagram of a convenient stimulator trigger. We have found that at least a pair of these are always needed and in some cases four to six have been used simultaneously.

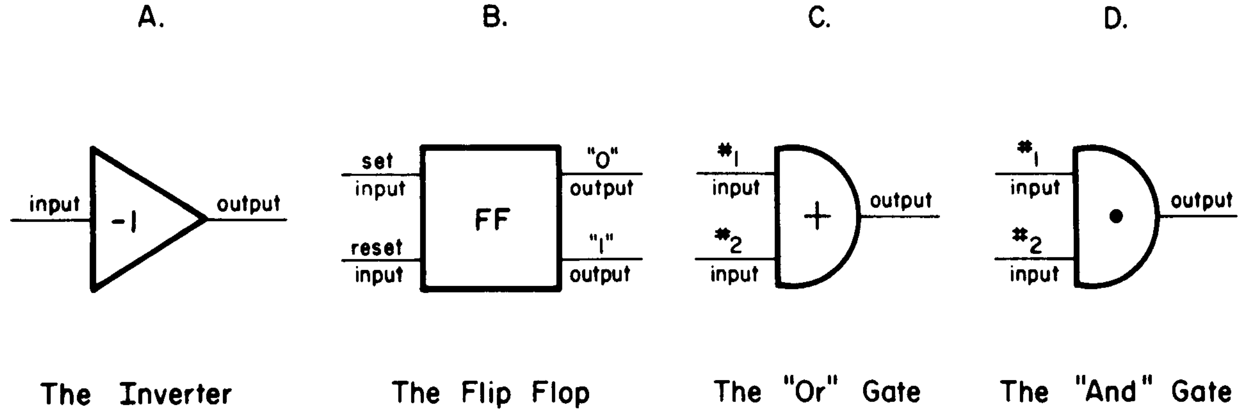

Fig. 1. Symbols for the four basic components used in computer logical design.

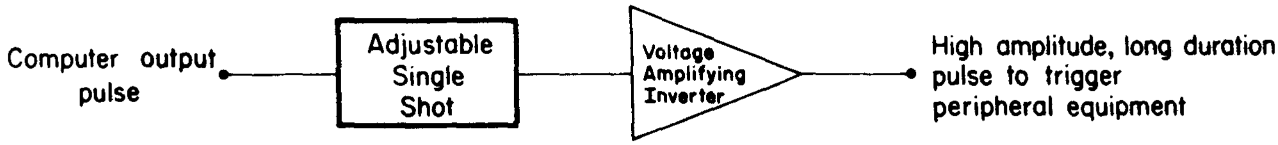

Fig. 2. A simple pulse stretcher and voltage amplifier which can be used to trigger peripheral equipment.

RESPONSE SWITCHES

Purpose

One of the most often used forms of response in psychological experiments is a simple key press. If the number of switches which might be depressed is large, some standard coded keyboard would be most appropriate. If, on the other hand, the number of switches is small or if there is some other special requirement it is usually convenient to construct a special set of switches. These devices may be mounted at great distances from the computer.

The meaning assigned to the depression of a given switch is, of course, a function of how the computer is programmed so a single set of switches can serve many different purposes.

Special Requirements

Electromechanical switches produce a jagged and noisey output signal when they are depressed which is so slow that a single key depression could cause multiple operations by the very high speed computer. Most switches are therefore buffered with a switch filter—a passive resistor-capacitor circuit, which integrates the jagged response from the switch into a monotonically rising one. The rise is still slow, however, and this is usually compensated for by the use of a device which has a sharp amplitude threshold for its transition between two binary states. Such a threshold controlled flip-flop is called a Schmitt Trigger after its designer. The high speed transition of its output is usually used as the signal that a key has been pressed rather than the slow rise of the switch filter. A conventional flip-flop is necessary to remember that this transition has occurred until such time as the computer is able to service the action stimulated by the switch closure. The output of the flip-flop may be used also as an indicator of which switch was depressed. It may also be combined through an "or" circuit to activate the interrupt input to signal the computer that something has happened. Figure 3 is a schematic diagram of a usable set of response switch inputs.

A MILLISECOND REAL-TIME CLOCK

Purpose

There are very few psychological experiments which do not in one way or another involve the measurement of time. There exist a number of techniques whereby a real-time computer can measure time. These techniques include program loops and complete external hardware clocks which actually contain a complete statement of real-time in units varying from milliseconds to days. In many psychophysical and human performance experiments, however, it is possible to use a very simple piece of hardware which only emits a periodic interrupt signal to the computer in place of those previously mentioned more complicated or time consuming procedures. A simple regulatable oscillator can be connected to the computer in such a way that every time it emits one of its periodic pulses the computer stops whatever it had been doing and increments one of its regular core memory registers. When this register counts up to a certain value—that value multiplied by the basic period of the oscillator is a precise measure of elapsed time. We have found that setting the oscillator to 1 kHz (1 msec between pulses) is a most useful value for measuring a wide variety of psychological and neurophysiological times.

Special Requirements

Other than the fact that a special oscillator is necessary to serve as the clock itself, the most important functional requirement for the millisecond real-time clock is that it is possible to turn it off when it is not being used. This is easily accomplished by gating the signal from the clock through an "and" circuit which is conditioned by a flip-flop which can be either turned off or on by control pulses from the computer. Figure 4 depicts the general organization of this controllable millisecond real-time clock.

DUAL DIGITAL TO ANALOG CONVERTERS

Purpose

Interfacing a computer to a psychological experiment often requires patterns of information which are quite different than the bit structure of an internally stored digital word. Psychologists are likely to be requiring signals which are spatial patterns for visual experiments, temporal patterns for acoustic experiments, or amplitude modulated analog information of other kinds. The device which can convert the digital information as it is encoded within the computer into equivalent analog values is called a digital to analog (D-A) converter. D-A converters can now

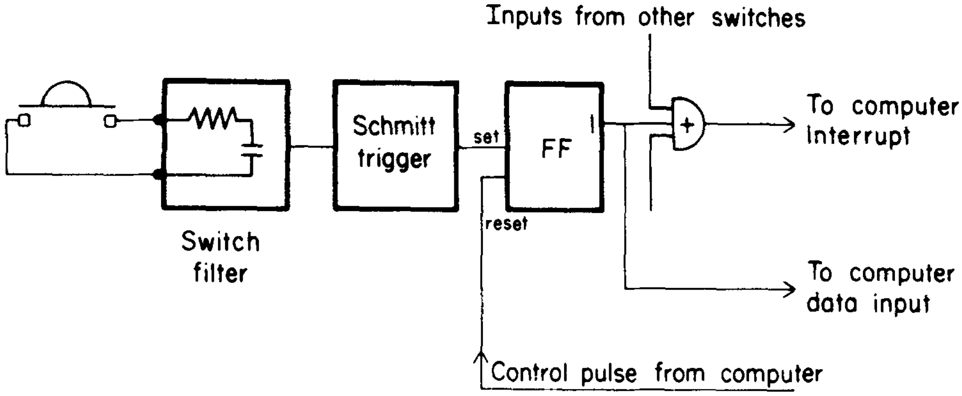

Fig. 3. The logical design of an interface device capable of handling switch activations as response inputs from the S to the computer.

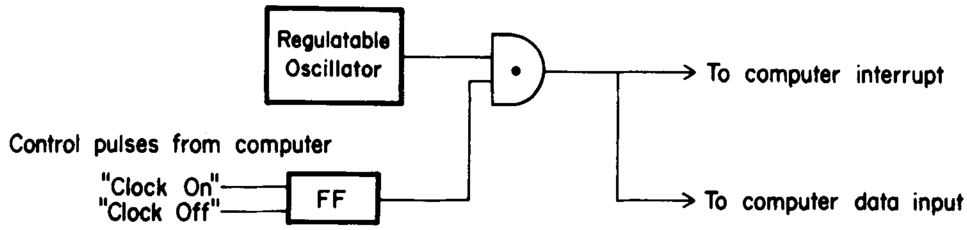

Fig. 4. A simple controlled real-time clock capable of interrupting a computer at precisely defined intervals.

be purchased as completely packaged units or constructed from the logical units we have already described. In general, they operate by adding a series of voltages proportional to the significance of the bit combination representing the signal level desired.

Two independent channels are necessary to drive a two dimensional display such as a cathode ray tube or any one of the various kinds of plotters. Once connected, these devices can then be used to represent almost any geometrical pattern including rows of alphabetic figures or even cartoon-like motion pictures. One channel of D-A conversion is sufficient to drive an audio system although both could be used to generate stereo effects. We have presented speech sounds to Ss which were stored in the computer in this manner with a relatively high degree of fidelity even though the speech sounds had undergone an A-D conversion, a D-A conversion and the resulting approximations of digital storage.

Special Requirements

The output voltages of D-A converters are usually standardized in magnitude and level by the particular equipment utilized. It is often necessary, therefore, to further amplify these signals. This can be easily accomplished with any one of the many operational amplifiers now manufactured by several different companies. The output of the D-A converter is fed into the input of the amplifier. The amplifier is then adjusted for the required gain and level and its output sent to the peripheral device being driven. In Fig. 5 we indicate the signal flow but not the complete details of the dual D-A converter. Also indicated in Fig. 5 is an additional pulse stretcher and amplifier which can be used to produce a signal capable of modulating the intensity of the dot of light on the face of a cathode ray oscilloscope. By intensifying the beam only after the beam has been positioned on the face of the scope, those ghost images created during beam movement can be suppressed. This third dimension is usually called a Z-axis control.

ANALOG TO DIGITAL CONVERTER

Purpose

While the D-A converter was required to convert the digitally coded information within the computer into signals which could be utilized by Ss, the analog to digital (A-D) converter is necessary to convert analog signals generated by Ss into the digitally coded information required by the computer. Analog signals of several different kinds typically require this service. The voice messages mentioned above were originally entered into the computer by this means. However, the largest class of signals which require A-D conversion are the bioelectric signals developed by physiological mechanisms. A wide variety of analytical methods have been developed to process bioelectric signals. We spell these methods out in great detail in another source (Uttal, 1968) and they are not germane to the purpose of this article. Nevertheless, all digital computer processing techniques for bioelectric signals require A-D conversion as the initial step. A-D converters can be very fast, so much so that it is not usually appreciated how very quickly one can flood the available

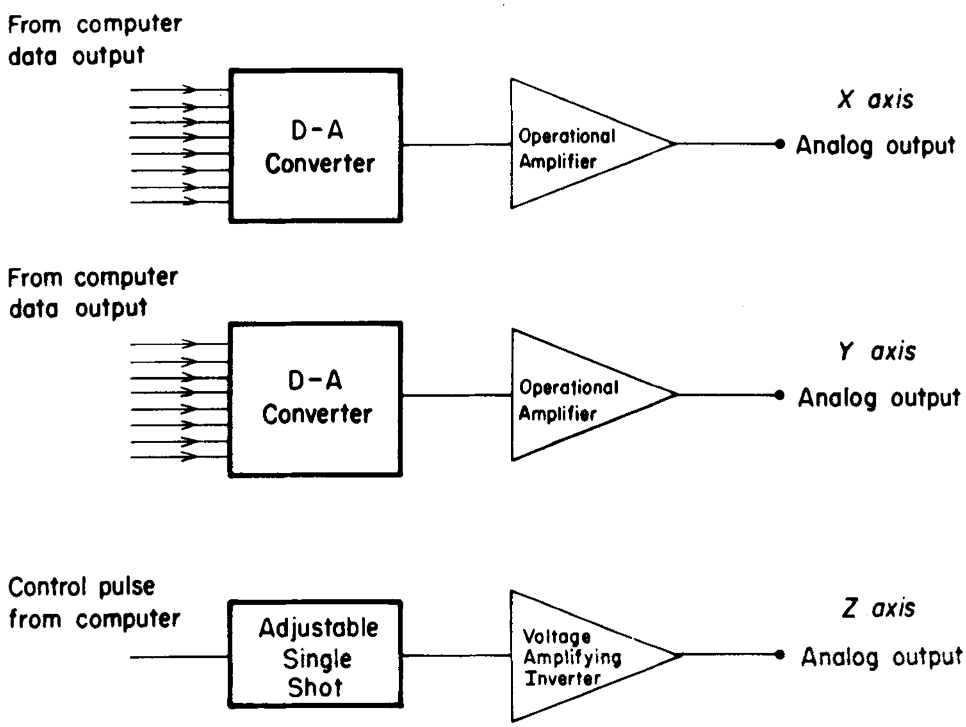

Fig. 5. The dual D-A converter which can be used in many different ways to convert digital signals to analog signals. The Z-axis circuit can be used for CRT trace intensification.

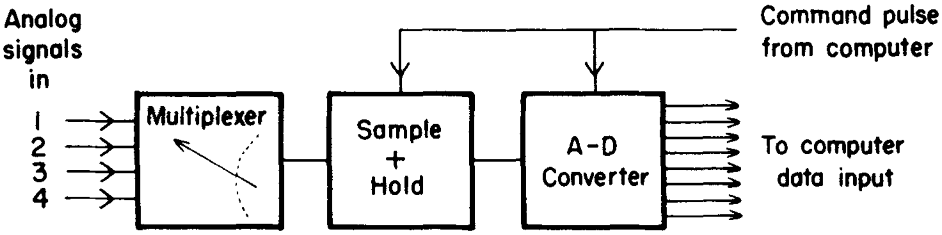

Fig. 6. The A-D converter showing the input multiplexer and the sample-and-hold accessories.

memory resources of a small computer. Another related problem concerns the amount of computer processing which is required to perform some apparently relatively simple process such as a cross correlation. Anyone interested in applying this and related analytical tools might do well to at least consider the use of some analog computation facility instead.

Special Requirements

A number of different devices are usually appended to all but the simplest A-D converter. One very often used special facility is an input multiplexer which can switch any one of a number of different inputs into the A-D converter in almost any order directed by the computer. The multiplexer is particularly useful in reducing the number of separate A-D converters required by a single system. However, a surprising thing has been happening. The price of A-D converters has been dropping very rapidly along with their size and complexity. It is now, for example, possible to purchase a complete analog to digital converter manufactured on a single integrated circuit chip. Multiplexer prices are such that in some cases it would be more economical to have a large number of A-D converters rather than a single A-D converter and an input multiplexer.

Another important auxiliary device used with A-D converters is the "sample and hold circuit." There is an inevitable error introduced into all A-D conversions due to the change in the level of the signal which occurs during the conversion period. It is, therefore, usually very helpful to have the signal sampled during a very short temporal "window" and that instantaneous voltage remembered by being stored on a capacitor for what may be a much longer conversion period. Sampling "windows" as short as a few hundred nanoseconds have been achieved even though conversion periods of several tens of microseconds are still typical.

Finally a note about the construction of A-D converters. In Fig. 6 we have block diagrammed the A-D system we have been discussing. But there is a very large variety of different ways to accomplish A-D conversion. Most of the newer ways, however, do depend upon a prior D-A conversion and then a comparison of the voltage so generated with the input analog signal. The variety of ways in which this comparison is effected is so large that no purpose would be served by more detailed logical diagrams of our particular circuit.

MULTIPLE POWER LEVEL BIT CODED DISPLAY CONTROLLERS

Purpose

Along with the development of computer sciences there has also been in the last two decades a very actively developing interest concerning the problem of how humans process binary coded information. This has been expressed in the laboratory in a host of studies in which the stimulus materials are binary coded displays. In some instances the number of these discrete stimuli is small enough so that they may be activated by binary signals from the computer without any preliminary decoding. Thus the output signal lines from the computer which we have mentioned as inputs to the digital to analog converter, for example, might themselves be used to directly light small lamps in some sort of stimulus matrix. The problems remaining once decoding has been

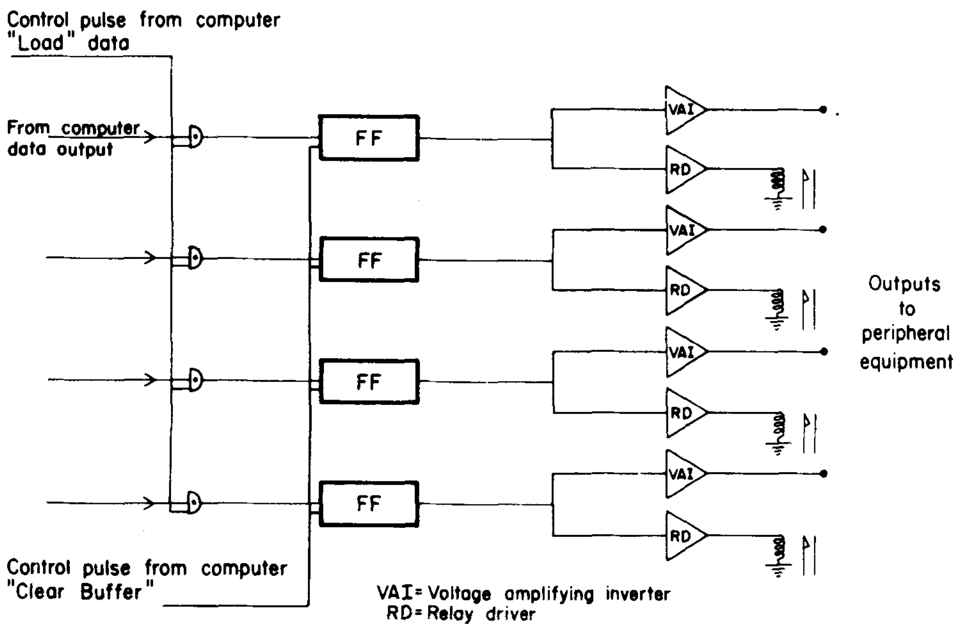

Fig. 7. A typical multiple power level output interface device for binary coded displays from the computer to the S.

eliminated are simply those of time and voltage matching. This can usually be accomplished by the construction of a buffer flip-flop register into which the pattern of bits is loaded directly from the computer.

Special Requirements

This buffer register stores the state of the various bits for a period defined by the computer program. The outputs of the register are amplified to a level sufficient to activate the binary stimuli. This output amplification may be accomplished by a simple transistor with a power output sufficient to drive a small incandescent light. However, some applications may require high power levels (such as the activation of a solenoid operating some mechanical device) and special high current relay and solenoid drivers may be required. The output of these latter units is sufficient to activate an electromechanical relay whose contacts themselves may be able to carry even higher currents. Some alphanumeric character displays, for example, require this sort of power buffering. It has been suggested that a general purpose binary output device can be constructed for multiple uses such that its output may either be a low power-signal or a high-power signal as required. A single buffer register is shown in Fig. 7 which is loaded by the coincidence of a control signal "load register pulse" and the information bits themselves. This register has a dual output. One of the outputs is a simple voltage amplifying inverter providing a signal of the appropriate level to light a small lamp or provide the input to some other similar low power device. The other output is a high current capacity driver which is actually connected to a set of relay coils. Either (or both) of the two devices may be used as necessitated by the peripheral equipment which is to be connected to the appropriate output. The advantage of such a dual output is that a single set of computer instructions and buffer circuitry can be used in any of a number of different experiments at different times with but the simplest switching operation required between experiments. The single buffer register may also be used as the signal inputs to other devices such as the D-A converter which also requires an equivalent function as part of its circuitry. Depending upon the work load on the computer, the amount of simultaneous time sharing by different users and the number of bits of information required, this dual output resister may result in a substantial savings in equipment costs since identical functions which might never occur simultaneously are all served by this single device.

A NOTE ON THE COMPUTER CONTROLLED TYPEWRITER

Perhaps one of the most often used yet most often underestimated devices for human interaction with a computer is the electric typewriter, standard on most computers. A computer-controlled electric typewriter is capable of both transmitting information from the subject to the computer and displaying information from the computer to him. Many experimenters have used typewriters successfully and have demonstrated their wide applicability for communicating alphanumeric information. For the low data rates encountered in alphanumeric interaction between a human and a computer, the typewriter is eminently suitable, not imposing undue restrictions on the computer as do some more powerful all-electronic displays. Many of the alternatives to such a keyboard-driven device also deprive the user of the opportunity to construct alphabetic responses fully.

Some recent innovations are compromises between the typewriter and the cathode ray tube. These new *electronic typewriters* have typewriter-like keyboards, with simple CRT (cathode ray tube) displays replacing the platen of the typewriter. The special CRT's are often very limited in scope in order to maintain simplicity and can only display alphanumeric characters. Electronic typewriters have the advantage of electronic reliability and silence but functionally are indistinguishable from a typewriter. They should, however, be distinguished from the full-capability CRTs, which allow full geometric display.

Summary

In this paper we have presented a discussion of a set of interface components which we have found suitable for a wide variety of psychological experiments. These devices in conjunction with appropriate peripheral equipment such as oscilloscopes, special stimulus generators, switches, etc. offer sufficient flexibility to accommodate the needs of virtually all computer controllable psychological experiments. In conjunction with appropriate control and analysis programs, these devices allow small on-line, real-time computers to efficiently and economically run psychological experiments. In conclusion, we want to emphasize that such an experimental system injects into psychological research a whole new set of capacities which though differing from their predecessors only in quantity actually can be expected to result in differences in the type and quality of psychological research. And since developments in the laboratory are essential to the development of new theoretical points of view, this new psychological technology (as all other new technologies influence their respective sciences) can be expected to have a profound effect on man's understanding of his nature.

REFERENCES

GREEN, D. M., & SWETS, J. A. *Signal detection theory and psychophysics.* New York: John Wiley & Sons, 1966.

SMITH, J. E. K. Dynamic stimulus selection and the effect of computer control on experimental design. Mental Health Research Institute Preprint No. 209, University of Michigan, Ann Arbor, May 1967.

TAYLOR, M. M., & CREELMAN, C. D. PEST: Efficient estimates on probability functions. *J. Acoust. Soc. Amer.*, 1967, 41, 782-787.

UTTAL, W. R. *Real time computers: Technique and applications in the psychological sciences.* New York: Harper & Row, 1968.