OPERANT PROGRAMMING WITH TRANSISTORIZED DIGITAL ELEMENTS

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Development and utilization of transistorized digital elements for the programming of operant conditioning contingencies has been under study in the Experimental Psychology Laboratory at Saint Elizabeths Hospital. The logic associated with reinforcement contingencies can readily be converted into electronic circuits by the substitution of appropriate digital printed circuits for required logical operations. Digital elements and networks have numerous advantages, namely: rapid assembly and disassembly into any desired configuration; compactness; low power requirements; reliability and durability (no moving parts); noiselessness; relative immunity to temperature variations; and, high speed operation which provides maximum switching and gating capability. These features are not generally characteristic of the standard electromagnetic devices (relays, counters, timers, *etc.*) currently being employed to program operant conditioning experiments. The cost of the digital elements is less, when total programming capability is considered, than comparable operant programming equipment. When necessary, standard operant equipment can be made to control inputs to digital elements (and *vice versa*) by separating the common conductive paths between the two systems.

Digital Networks and Schedules of Reinforcement

Reinforcements in operant conditioning experiments are usually made contingent upon the emission of a fixed or variable number of subject-produced and/or clock-produced

events which are converted into electrical impulses and fed into some programming system. This programming system must, in general, be able to "count" these events, provide reinforcement (positive or negative) before or after a critical number or sequence has occurred, and "erase the memory" of these events once reinforcement (positive or negative) has occurred or been avoided.

The digital elements and networks which can be used to program these operations are: (1) several bistable multivibrator digital elements called "Flip-Flops" (FFs) which can be connected in series to form a Binary Counter. A Binary Counter can provide individual outputs for any value (count) up to 2^n , n being the number of FFs in the series. FFs generally consist of two transistors which are set up to conduct in a mutually exclusive way. Positive-going impulses to the bases (inputs) and steering circuitry of the two transistors (which in a Binary Counter are connected together as a "T" unit) reverse consecutively the conducting and non-conducting states of the two transistors, changing their respective output potentials. These two output potentials are analogous to the rest and operate positions of common relays. Unlike the states of common relays, however, both of the two different output potentials of an FF remain "locked up" following a single input pulse until a second pulse is introduced. Memory storage and erasure is thus obtained with minimum power and circuitry. (2) A single FF (Memory FF) acts like a latching relay to provide positive or negative reinforcements after a specified number of these events have been counted by the Binary Counter. (3) A diode AND gate (AG-1) which, acting like a connector of a latching relay in series with another set of contacts from the subject's manipulandum, switches or translates a poten-

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tially available reinforcement into an actual positive or negative reinforcement; and (4) an RC AND gate (AG-2) which resets the Binary Counter (erases the count) before or after a positive or negative reinforcement has been delivered. Occasionally, the outputs of certain digital elements may require amplification by Emitter-Follower (EF) networks before they can drive other digital elements or trigger reinforcement mechanisms.

Figure 1 presents a digital logic diagram for a basic fixed-interval (FI) schedule. For simplicity, digital elements are presented in symbolic form. The Binary Counter is shown in block form for "n" stages. All FFs are shown schematically as having two sides—a 0 side and a 1 side. Both the 0 side and the 1 side contain a transistor and associated circuitry, which provide differential output potentials depending upon the conducting and non-conducting states of the transistors. In Fig. 1, positive-going outputs are obtained from conducting transistors.

In presenting Fig. 1, it has been assumed that the reinforcement mechanism: (1) has adequate amplification to enable it to be triggered from the digital elements shown; (2) runs through a self-timed cycle of operation;

and, (3) can, if needed, provide a positive-going pulse at the end of its operating cycle. Changes in reinforcement frequency can be effected by changing the multivibrator clock (MV) pulse rate or by taking the output (count) from different stages (for 2^n counts) or combinations of stages (for intermediate counts) in the Binary Counter.

The Binary Counter in Fig. 1 is shown tallying pulses from the MV digital clock. When a critical number of clock pulses (i.e., the interval requirement) have been "counted," the Binary Counter sends a positive-going output to the 0 side of a Memory FF, turning off its transistor. The transistor in the 1 side now begins to conduct, sending a positive-going output into one leg of an AG-1. Positive reinforcement is now contingent upon the emission of a response by an experimental subject. When this response occurs, a positive-going potential is put on the second leg of the AG-1 by the manual pulser (MP) of a digital pulse generator (CX). The output potential of the AG-1, amplified by an EF, dispenses the positive reinforcement. The completion of the positive reinforcement provides a pulse which resets the Memory FF to its 0 side. An output from the 0 side of the

Fig. 13 Digital Network for an FI Schedule.

Memory FF is sent through an AG-2 to reset the FFs (erase the count) of the Binary Counter.

Only simple modifications of Fig. 1 are required to program other schedules of reinforcement. For example, a DRL schedule can be programmed by: (1) taking an output from the CX (in inverse phase with output pulse going to the AG-1) and running it through the AG-2 to reset the Binary Counter each time the subject emits a response; and, (2) resetting the Memory FF from the output of the AG-2.

The DRL schedule can be modified for an avoidance-escape schedule by triggering the negative reinforcement directly from the outputs of the 1 side of the Memory FF, thus eliminating the AG-1 and EF networks. An avoidance schedule without escape contingencies can be programmed by removing the connection to the reset of the Memory FF. An escape schedule without avoidance can be effected by disconnecting the reset line from the CX to the Binary Counter.

For an FR schedule, pulses to be counted by the Binary Counter are fed from the subject's key through a CX rather than from an MV network. This removes the need for the AG-1 and EF.

Circuits for all of the common fixed-event schedules mentioned above as well as their variable-event counterparts (*e.g.*, VI, VR) have been developed. All of the common schedules of reinforcement require the same few basic digital elements (*e.g.*, FFs, AG-1s, AG-2s) in fairly similar configurations (*e.g.*, Binary Counters). It becomes readily apparent, therefore, that rapid manual or automatic switching between a maximum number

of different reinforcement schedules is not only easier with digital elements (compared to standard operant equipment), but is also far less expensive.

Trouble-shooting is also a relatively simple matter with digital elements. An oscilloscope, multimeter, and a few other standard testing devices are usually all that are required to test most digital components. The replacement of components is seldom necessary. When replacements are needed, however, they can be readily effected due to the small number of digital parts involved, their solid state nature, their small size, and their usual accessibility on printed circuits.

A final feature of digital elements which has proved to be important is their low power requirements. Serious disruptions to experiments due to power supply failures have been avoided by substituting dry cell batteries as a temporary stop-gap measure. The low operating voltage and current requirements of the digital elements have also removed the possibility of serious electrical accidents. Electric shocks are virtually impossible. This fact, together with the simplified circuitry required to program schedules of reinforcement when digital elements are employed, markedly reduces the problem of training technicians.

The development of digital techniques for the programming of operant schedules of reinforcement must be considered to be in its early infancy. Nevertheless there seems to be little question that digital elements and techniques represent a major step forward in programming simplicity, flexibility, and efficiency.

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