DIGITAL RECORDING OF SIMULTANEOUS EVENTS IN MULTIPLE OPERANT CHAMBERS^{1,2}

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The use of solid state digital elements (modules) for the programming of behavioral research has been described by Herrick and Denelsbeck (1963) and by Weiner (1963). These have been concerned primarily with the programming and recording of the behavior of a single experimental subject. Less well known are the applications of digital logic techniques to the recording of events taking place within several simultaneously operating experimental chambers. The present report describes a data recording and retrieval system appropriate for use with multiple chamber operant conditioning research. The system is able to maintain the integrity of all events occurring within five experimental chambers utilizing a binary coded format for encoding data before it is punched on paper tape.

METHOD

General Considerations

In operant behavior research, time, responses and reinforcements constitute three basic classes of events that must be recorded. A punch tape system was chosen as the recording medium since a number of input sources may be multiplexed onto punched tape to share the high-speed capability of the tape mechanism. Ordinary punch type systems employ a 1-in. tape able to record 255 character combinations on eight input channels utilizing a binary coded format. This data capacity is sufficient for the most commonly-used reinforcement schedules.

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²The tape punch and reader as well as logic components and circuitry were supplied by BRS Electronics, Beltsville, Md.

The specific problem was to maintain the integrity of responses, reinforcements and time in each of five experimental chambers while minimizing the amount of necessary encoding and decoding equipment.

Specific Considerations

A. Time. The time between successive events taking place within each of the five chambers is quite simply recorded. A time base is generated on the punch tape by utilizing pulses from a precision clock ($\pm 0.1\%$ accuracy) as the punch signals to advance the tape. The only problem to be considered is how fast this time base should be. Two considerations determine this: (1) economy in the utilization of tape; and (2) capability of recording all data. Since the maximum response rate observed in rats averaged 2 to 3 responses per sec (Ellen and Powell, 1962), a tape advance or punching speed of 5 characters per sec was determined as optimum. This permitted 5 responses per sec to be recorded from any chamber. With this punching speed, $\frac{1}{2}$ in. of tape per sec or 150 feet of tape per hour is produced.

B. Responses and Reinforcements. Since all five chambers may have a response coupled with a reinforcement, 10 data input channels would be required if each response and each reinforcement were to be directly punched on the tape without prior encoding. Because only eight channels of data input could be used, it was necessary to encode either reinforcements or responses before they were punched on the tape. Regardless of which is coded, the uncoded data require five input channels, leaving three channels available for receiving a coded input.

Since responses, rather than reinforcements, are more likely to occur simultaneously when all five chambers are operating, reinforcements are simpler to display on the tape than

are responses. The display of simultaneous events, where the coded data character of an event can occupy any combination of the available data channels, requires an elaborate system for isolating simultaneous signals from each other and delaying their appearance on the tape. We therefore chose to record the responses from each of the chambers directly onto the tape without coding. These occupy five of the available data input channels and are punched immediately upon occurrence.

This left the problem of identifying the reinforcements in each of the five chambers and linking a reinforcement with the response that produced it by multiplexing the reinforcements on the three remaining data input channels. Starting from the fact that a reinforcement could never occur without a response, it was merely necessary to store the occurrence of a reinforcement in any chamber, detect its presence, and assign a code to it.

Figure 1 shows the recording arrangement. A reinforcement signal from each chamber is applied to the input of a bistable multivibrator element (flip-flop) associated with each chamber. This provides for memory storage and erasure of an event, such as a reinforcement, that occurred within a chamber. A scanning device (pulse generator) was incorporated into the system which scans the outputs of these memory flip-flops. The scanner "looks" every $\frac{1}{5}$ th sec at each of the five memory flip-flops at a "look" rate of 10,000 per sec,

with the flip-flop corresponding to the lowest numbered box being the first one scanned, and the flip-flop corresponding to the highest numbered box, the last one scanned. If a reinforcement signal is present on the output of a memory flip-flop during the "look" period, a coincidence gate (AND gate) is enabled and the signal is passed into the encoding network. In the encoding network the signal is coded into the binary equivalent of its source. This is accomplished by passing the signal through a system of coincidence gates. A binary three code is sufficient to handle the five possible reinforcements that must be recorded at any moment in time. Thus, utilizing this code, a reinforcement occurring in any chamber has its own characteristic pattern of punches on the reinforcement section of the tape. This coding arrangement is illustrated in Fig. 2.

One further consideration was imposed on the recording of reinforcements. The system was required to handle the possibility of reinforcements occurring simultaneously in any combination of up to three chambers in the same $\frac{1}{5}$ th sec. By staggering the starting time of a schedule, the likelihood of this occurring can be reduced. Nevertheless, when CRF or FR schedules in particular are employed, staggering the start-up of a schedule does not prevent it.

Since the reinforcement code can occupy any two of the three reinforcement channels

Fig. 1. Block diagram of recording arrangement.

Fig. 2. Sample of tape showing binary coding of reinforcements for the five chambers. The punch pattern for Chamber 1 is 100 binary; Chamber 2, 010; Chamber 3, 110; Chamber 4, 001; and Chamber 5, 101.

on the punched tape, it is necessary to delay the punching of simultaneously occurring reinforcements. After the reinforcement signals are encoded into their binary equivalents, they are immediately transferred into the first stage of a buffer storage sub-system. The buffer system functions primarily to isolate the reinforcement signals from each other by storing them until they can be transferred to some other point in the recording system. It is de-

signed to allow each binary character (signal) to proceed to the first buffer storage stage of a three-stage storage system not occupied by a prior reinforcement character. The presence of characters and transfer commands is automatically handled by transfer controls.

Figure 3 shows the first buffer and associated transfer control of the logic circuitry for the buffer section. When the system is initially cleared, the three memory flip-flops (FF-1) are

Fig. 3. Circuit diagram for first stage of the buffer storage.

all OFF; the combined effect through the OR-gate (OG-2) and the Inverter (INV-1) is to permit the three input gates to pass pulses representing the binary input from the encoder into the three memory flip-flops. Since the flip-flop in the transfer control is also reset, the output gates likewise pass the information from the memory flip-flops in the first buffer to the memory flip-flops in the second buffer, thence, to the third buffer, and then to the Punch Control Unit. If the second buffer is occupied with previous data, the flip-flop in the transfer control will disable the output gates of the first buffer. The information then is stored in the three memory flip-flops until the second buffer is reset, at which time the flip-flop in the transfer control changes state, transferring the information from the memory flip-flops of the first buffer into the memory flip-flops of the second buffer and, after a short delay, resetting the flip-flops in the first buffer. Thus, the three stages of the buffer section act to pass incoming data from the encoding network to the highest order buffer storage not occupied. As data is punched from the third buffer stage, any data in the lower order stage is automatically moved into the next higher order buffer stage, freeing the lower order buffer stage for new data.

Figure 4 illustrates a sample of tape when three reinforcements occur simultaneously. On the response section of the tape a hole is punched in the channel corresponding to Chambers 1, 3 and 4. The scanner "looks" first at the reinforcement flip-flop correspond-

ing to the lowest numbered chamber and then proceeds to the highest numbered chamber. Thus, the scanning order is Chamber 1, 3 and then 4. Assuming that nothing is in the buffer storage system when these three chambers received their reinforcements, the reinforcement signal occurring in Chamber 1 is coded into its binary equivalent and immediately transferred to the third or final stage of the buffer storage and thence to the punch mechanism. The binary coded punch thus appears on the reinforcement section of the tape at the same time that the response punch appears in the response section of the tape. The reinforcement that occurred in Chamber 3 is encoded but proceeds only as far as the second stage of the buffer storage, while the coded reinforcement from Chamber 4 proceeds only as far as the first stage in the buffer storage at the beginning of the first punch cycle. As soon as the reinforcement from Chamber 1 is punched, the third stage of the buffer is emptied and the coded reinforcements from Chambers 3 and 4 advance to the next open stage in the buffer storage. Thus, the reinforcement from Chamber 3 is punched $\frac{1}{5}$ th sec after its occurrence. At the end of that punch cycle, the coded signal from Chamber 4 advances to the final stage of the buffer storage and is punched. In this manner the three simultaneously occurring reinforcements are recorded with no more than $\frac{2}{5}$ th-sec delay from the time of their occurrence to the time of their being displayed on the tape. The priority of their occurrence on the tape is

Fig. 4. Sample of tape illustrating delayed punching of simultaneously occurring reinforcements.

simply determined by the order in which the scanner "looks" at the reinforcement flip-flops. By increasing the number of buffer storage stages, reinforcements occurring simultaneously in all of the chambers could be recorded with a maximum delay of only $\frac{1}{5}$ th sec. However, the likelihood of all five chambers receiving a reinforcement in exactly the same $\frac{1}{5}$ th sec is highly improbable, and this additional capability was not included in the system.

It should be pointed out that by using the binary code to identify reinforcements, and a buffer storage to isolate and delay their appearance on the punch tape, a great flexibility has been introduced into the system. It is not actually necessary for all five chambers to be working on the same reinforcement schedule. In fact, the schedules may be completely different from chamber to chamber since the binary coded reinforcement character and buffer network provide identification of a reinforcement with the response that produced it.

C. Data Retrieval. An integral part of any recording system is the means by which the data are retrieved. No matter how efficient a recording system may be, if data retrieval takes longer or is equal to recording time, no benefit will be realized.

Data recorded in the manner described above can be readily retrieved merely by means of a photo-electric tape reader capable of reading characters at a rate faster than the characters were punched onto the tape. With our photo-electric tape reader, characters may be read at a rate of 100 per sec. This enables real time to be compressed by a factor of 20, since real time is recorded at the rate of 5 characters per sec. Thus, the data from a 1-hr run in one chamber can be read by a tape reader and totalized on counters in only 3 min. With relatively simple logic circuitry (ring counter) the signals from the tape reader may be gated into counters or other automatic recording equipment to record either interresponse time distributions (IRT's) or the distribution of events in time (DIT's) as would

be required on DRL or FI schedules, respectively.

COMMENT

A data recording system of the type described can readily be used with existing behavioral equipment; the mere contact closure of a switch is sufficient to make an appropriate interface with the digital elements. The major costs of the system are for the punched tape mechanism and tape reader (\$3300.00). In the present system, the associated logic necessary to store the data and display it appropriately on the tape costs approximately \$800.00. This latter cost will vary widely depending upon such things as the use of front or back panel wiring and the number of logical elements on each module.

The system described is relatively inexpensive compared to the cost of the five separate electromechanical systems and cumulative recorders which would be needed to provide the same information. There are also additional benefits. In the first place, all of the data rather than merely the cumulative totals are present on the tape. Secondly, the data are in a format readily available for further electronic processing.

The system was subjected to a rigorous test in which 20 animals were run daily for six weeks on a CRF schedule, with each animal responding 200 times per day. Recalling that only three simultaneously occurring reinforced responses could be detected on the tape by virtue of the limits in the buffer system, less than 2% of the reinforced responses failed to appear.

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