INSTRUMENTATION & TECHNIQUES

A technique of "spatial" coding to program rapid temporal sequences¹

HARRY A. MACKAY,² Joseph P. Kennedy, Jr. Memorial Laboratories, Neurology Service, Massachusetts General Hospital, Boston, Mass. 02114

A technique for programming rapid temporal sequences of events is described. A slide projector is used to selectively illuminate a 6 by 4 matrix of photocells so that a single slide codes up to eight different serial events. The scheduling of the eight individual events in serial order is accomplished with solid-state gating and a ring-counter. Correct key-selection in a task analogous to the digit-span illustrates the application of the technique.

There is a need to program and record rapid sequences of events in many behavioral experiments. When the sequences are short and repetitive, the necessary sequential programming can be carried out with direct connections (e.g., to stimulus lamps) from successive contacts of a stepping relay or counting circuit (e.g., a ring counter). This method of programming becomes cumbersome and inflexible when a large bank of stepping switches is needed to program a lengthy sequence of events such as might be required in vigilance experiments or in studies of probability learning.

Described below is a system which not only has considerable flexibility for scheduling long series, but is well suited also to applications which require a large number of short sequences which differ one from the next, and which may be changed readily by the E during the course of an experiment. "Spatial" photoelectric coding is used to program rapid temporal sequences of stimuli and to schedule the response key which is correct at any given time.

The circuitry was designed to provide automatic control and

recording in experiments in which monkeys and humans are taught a task similar to the digit-span problem. The S is taught to press ("observe") a series of lighted keys presented individually in a predetermined sequence and then to "report" the sequence by going through the series again without the use of cue lights. Within each trial the S is required first to "observe" and then to "report" as many as eight different keys in sequence. The particular sequence changes from trial to trial.

Figure 1 shows a segment of a recording obtained on an Esterline Angus operations recorder which continuously monitors the scheduling of correct keys and the S's behavior. The sequence shown in Trial 1 is used throughout the following discussion to illustrate the programming technique.

Key 8 is scheduled as correct at the start of Trial 1. This is indicated by the upward movement of the recorder pen (8) from its normal line. When Key 8 is pressed the pen returns to its normal line. This is followed immediately by a pen deflection indicating the scheduling of Key 5 was correct. The response on Key 5 is in turn followed by the selection of and responses on Keys 1, 4, 6, 2, 3, and 7. The response on Key 7 completes the "observing" phase (OBS) of the first trial. The sequence is then repeated for the reporting phase (REPT) of the trial. The "observing" and "reporting" of three other sequences is also shown in Fig. 1.

Although the programming technique is described in the context of the procedure described above, its flexibility allows ready adaptation to other experiments in which the programming of series of events plays a part. Some such adaptations are discussed in a later section of the paper.

CODING

The key that is correct at each serial position in a sequence is programmed by a Kodak Carousel Automatic Projector in conjunction with a 4 by 6 matrix of photoelectric cells (photodecoder) and a solid-state control circuit. The sequence of correct keys is coded on a punched slide, which may be made easily and cheaply with any stiff, opaque paper placed in a standard slidemount. Each slide programs one complete sequence, including both the "observing" and the "reporting" phases. Sequential selection of the individual members of the sequence is carried out by the control circuit.

With a slide in position, a pattern of light spots is projected on the photodecoder. Those photocells on which light falls are turned "on." This condition may be expressed in the binary form "1." Photocells in the "off" condition are represented by the binary "0." A set of three such binary events yields eight possible combinations, each of which stands for a particular response-key. Each unique combination designates Keys 1 through 8 as follows: 000, 001, 010, 011, 100, 101, 110, 111, with the "ones" representing illuminated photocells. A different set of three photocells is required to code the correct key at each sequence position. In Fig. 2 note the representation of the photodecoder illuminated by a slide coded for the key-sequence 8, 5, 1, 4, 6, 2, 3, 7. The first member of the sequence is coded by photocells numbered 1, 2, and 3, the second member by photocells numbered 4, 5, and 6, etc. Such a sequence of eight members requires eight

Fig. 1. Segment of recording showing four trials in which different sequences, each eight members long, were "observed" (OBS) and "reported" (REPT) by the S. Each upward deflection of a pen from its normal line represents the scheduling of a given key as correct and the return of the pen follows a correct key press. Dots mark the last response in each "observing" phase. Reading from right to left, the key sequence for Trial 1 is 8, 5, 1, 4, 6, 2, 3, 7. For Trials 2 through 4 the sequences are Keys 6, 7, 2, 8, 4, 5, 1, 3, Keys 4, 1, 8, 7, 2, 5, 3, 6, and Keys 4, 6, 3, 7, 8, 2, 5, 1.

and a pattern of outputs which coincides with that of the particular set of SERIES I AND-gates currently allowed by the ring-counter.

DECODING

The decoding of the outputs of the OR-gates is performed by the AND-gates of SERIES II. These provide the eight unique outputs which determine the correct key at each successive position in a sequence.

Since the AND-gate function requires that all inputs be at ground level before an "on" output is obtained, the reciprocals (A_0 , B_0 , C_0) of the OR-gate outputs (A_1 , B_1 , C_1) are obtained through the use of inverters. When the OR-gate output is "off" ($-V$), the inverter output is "on" (gnd) and vice versa. The SERIES II AND-gate which is on at any given moment is determined by the configuration of direct and inverted outputs of the OR-gates. The selection of each OR-gate configuration as inputs to the SERIES II AND-gates is indicated by the labelling of these gates in Fig. 2. Thus, the AND-gate marked 001 is turned "on" when A_0 , B_0 , and C_1 are at ground level.

As indicated above, these SERIES II outputs determine which key is correct. They also drive recorder pens and prime the circuits which supply ac voltages to the key lights. Those circuits however are shown in Fig. 2 only in block form since the switching involved is specific to the apparatus used for the "memory-span" experiments.

EXAMPLE

To illustrate the operation of the system with an example, note the slide illustrated in Fig. 2. When power is applied to the circuit, the first stage of the ring-counter allows SERIES I AND-gates 1a, 1b, and 1c. Since the slide has been punched in the appropriate three places, the outputs of these AND-gates are turned "on." Consequently, OR-gates A, B, and C will be turned "on" to provide ground level outputs A_1 , B_1 , and C_1 . Since the only SERIES II AND-gate receiving all of these inputs is that marked 111, it will be the only one allowed. Key 8 is thus programmed as the initial member of the sequence.

When the ring-counter is stepped, its first stage is turned "off." This disallows AND-gates 1a, 1b, and 1c, and the second stage is turned "on." The second stage allows AND-gates 2a, 2b, and 2c. In this case, only AND-gate 2a is turned "on" since only the "a" photocell is illuminated. In turn, only OR-gate A is turned "on." Since OR-gates B and C are in the "off" condition, the inverters associated with them are turned "on." Because the outputs A_1 , B_0 , and C_0 are the only ones providing ground level signals to the SERIES II AND-gates, only AND-gate 100 is allowed. The second member of the sequence is thus Key 5.

The third and subsequent members of the sequence follow in the same manner as allowed by successive stages of the ring-counter.

Upon the eighth input, the ring-counter cycle automatically resets to Stage 1 and the same sequence is programmed again. These two cycles represent the "observing" and "reporting" phases of the procedure described initially. At the end of the trial, a signal is delivered to the projector advance. The new slide illuminates the photodecoder appropriately for the next sequence.

ADAPTABILITY AND COST

The system described has been in reliable operation for two years as part of a larger circuit which provides precise control of the brightness of the key lights, reinforcement functions, recording, etc.

In the present instance correct key-presses by the S provide the inputs which advance the ring-counter (STEP INPUT in

Fig. 2. Schematic diagram of circuit showing the projector (PROJ) and the selectively illuminated photodecoder. See text for explanation.

sets of three photocells. Each of these sets corresponds to a particular sequence position but can read out the code for any of the eight keys at that position. Sequential readout of each set of three photocells is accomplished by a scanning unit (see below).

The outputs of the photodecoder are a pattern of logic-level voltages which correspond to the coding punched into any slide. Photocells that are "on" provide an output of 0 V (gnd). Those in the "off" condition supply an output at -12 V ($-V$). As shown in Fig. 2, these outputs are transmitted to the control circuit. The output of each of the photocells is fed into an AND-gate in SERIES I such that three AND-gates (1a, 1b, 1c) carry the key-position code of the first member of the sequence, and other separate sets of three gates (2a, 2b, 2c; 3a, 3b, 3c; etc.) represent the additional sequence-members. The binary number representing the state of each photocell in the example shown is marked on the appropriate PHOTO-DECODER-AND-gate connection under the heading "CODE."

SCANNING

The set of three gates sampled at any individual point in a sequence is determined by an eight-stage ring-counter which selectively allows the sets of AND-gates of SERIES I in serial order. As the diagram indicates, the first stage of the ring-counter allows only the three AND-gates (1a, 1b, 1c) for the first member of the sequence and the second stage allows only those (2a, 2b, 2c) for the second member, etc.

The a, b, and c outputs of the SERIES I AND-gates are combined, respectively in OR-gates A, B, and C. These OR-gates provide electrical isolation of their multiple inputs

Fig. 2); the S is self-paced. However, the inputs to the ring-counter may be programmed in other ways to suit other experimental requirements. For example, the use of a timer to perform this function would provide an externally paced condition.

Although the present system limits the maximum length of each sequence to eight members, shorter sequences are programmed by means of a binary-counter which counts correct responses. The selectable output of the counter then recycles the ring-counter and advances the projector at the point desired. The control circuit also performs these functions when the S presses an incorrect key—errors terminate a trial and advance the projector. These characteristics of the control circuit are not shown in Fig. 2.

The circuit may be adapted readily for use in experiments requiring lengthy sequences of responses, as in studies of probability learning. If the "0" position of the rotary slide tray is used, 81 slides yielding 648 individual response-key selections can be preprogrammed since each slide permits eight selections from the eight keys. This adaptation described by Siegel (1964) also provides a direct method for continuously recycling the slide tray.

Before applying this system to programming other experiments, consideration might be given to the following characteristics. The interval between slides, the change cycle of the projector, is approximately 1.5 sec. The space required by the photodecoder and the projector is 48 x 15 in.

The photodecoder (\$495) and the logic modules for the ring-counter and gating (\$300) are commercially available.³ The operating voltage of these units is 12 V dc. The additional cost of a slide projector (Kodak Carousel, Model 550, \$110) should be added to that of the photodecoder and logic to obtain the total cost of the system described here. The expense involved with an alternative system using a paper tape reader and punch varies widely. A hand punch available in most dime stores is sufficient for preparing slides, and the punching can be done quickly. Tolerances are sufficiently large that high accuracy in locating programming holes is not an important consideration. Slides also offer great ease of manipulation. The order of slides can be quickly changed as can small segments of the total set. The programming of test trials or probe trials, for example, is readily accomplished by the temporary replacement of a single slide.

REFERENCES

SIEGEL, P. S. Addendum to "A technique for automatic recycled, serial presentation of up to 80 unique visual stimuli." *Journal of the Experimental Analysis of Behavior*, 1964, 7, 408.

NOTES

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3. B. R. S.—Foringer, 5451 Holland Drive, Beltsville, Maryland, 20705.

An apparatus for use in 2 by 2 game research¹

ALBERT A. HARRISON, *University of California at Davis, Calif. 95616* and CHARLES G. McCLINTOCK, *University of California at Santa Barbara, Calif. 93106*

This article describes a solid state apparatus for use in 2 by 2 game research. There are two individual player's boards and a control panel for E. Following E's signal, each player chooses one of two responses. Their choices are immediately registered on E's panel, but appear on each individual game board only after both have responded. Provisions are made for E to transmit false feedback.

Recently there has been an increasing number of studies utilizing two-person, interdependent games.² One of the most popular of these is the 2 by 2 game in which each of two players chooses one of two response alternatives. On the basis of their mutual choices, they each receive a payoff.

Conventionally, these games are represented in the form of a 2 by 2 matrix. The first player controls the rows (X and Y) while the second player controls the columns (A and B). Each chooses one of his response alternatives; usually, it is important that neither player be aware of the other's choice until he has made his own response. When both players have responded, the payoffs are disbursed. The payoffs to each are represented in the four cells of the 2 by 2 matrix, "XA," "XB," "YA," and "YB." The designations "XA," "XB," "YA," and "YB" refer to the intersection of columns and rows.

The present article describes an electric apparatus suitable for such two-person, two-choice games. It is preferable to manual versions on several counts. First, it speeds up the conduct of the game. Second, because there is an "override" circuit by which the E can take the role of a simulated other S, the transmission of false feedback is simplified. And thirdly, it

eliminates the need for the E to be in verbal or visual contact with the players.

The apparatus consists of three interdependent units, a game board for each of the players and a control panel for the E. The schematic diagram appears in Fig. 1.

The players' game boards each consist of a play signal (green-lensed lamps L_1 and L_2), two silent momentary depress push-button response indicators (S_1 and S_2 for Player I, controlling Rows X and Y, and S_3 and S_4 for Player II, controlling Columns A and B), and four white-lensed payoff lights corresponding to the quadrants of a 2 by 2 matrix (Lights 7, 8, 9, and 10 for Player I; Lights 11, 12, 13, and 14 for Player II).

The E's panel houses the following controls: (1) a toggle switch (S_{11}) which activates the apparatus and illuminates the play signals; (2) four lights to indicate the response choices of the two players, L_4 and L_6 to represent Player I's choices of Row X or Row Y, respectively, and L_3 and L_5 to indicate Player II's choices of Column A or Column B, respectively; and (3) override controls, S_9 and S_{10} , which serve to cut in or out E-controlled feedback to Player I and Player II, respectively, while override controls S_5 , S_6 , S_7 , and S_8 provide the false information that the "other player" chose "A," "B," "X," and "Y," respectively. As there are separate override controls for the two players, it is possible to give the participants combinations of false and true information. Whether or not the override mechanism is in use, the S, of course, receives correct feedback concerning his own responses.

As illustrated in Fig. 1, eight silicon control rectifiers (SCRs) are used in a matrix consisting of 12 signal lamps. (The play signals, L_1 and L_2 , are directly controlled by the master power switch, S_{11} .) Each SCR is triggered into conduction by actuating a momentary contact push-button switch, wired