A SYSTEM FOR PROGRAMMING EXPERIMENTS AND FOR RECORDING AND ANALYZING DATA AUTOMATICALLY¹

ROBERT M. HERRICK² AND JOHN S. DENELSBECK

U. S. NAVAL AIR DEVELOPMENT CENTER, JOHNSVILLE, PA.

A system designed for use in complex operant conditioning experiments is described. Some of its key features are: (a) plugboards that permit the experimenter to change either from one program to another or from one analysis to another in less than a minute, (b) time-sharing of permanently-wired, electronic logic components, (c) recordings suitable for automatic analyses. Included are flow diagrams of the system and sample logic diagrams for programming experiments and for analyzing data.

Many workers in operant conditioning perform experiments in which behavioral measures are, or can be, classified into several categories, *e.g.*, categories of inter-response times, of durations of presses, of forces of presses. We desired to classify presses automatically into categories on the basis of the maximum displacement of a lever handle resulting from each press. As an outgrowth of this goal, an integrated system was developed for automatically (a) programming experiments, (b) recording the behavioral data and the experimental conditions, and (c) analyzing the data. Since these functions are required in all experiments, an outline of the solution may interest others.

To keep the discussion more concrete, the description will refer to specific behavioral measures associated with a particular response lever (Herrick and Karnow, 1962). Moreover, for a clearer exposition, the integrated programming, recording, and analyzing systems will be considered separately.

A block diagram, Fig. 1, pictures both the programming and the recording components of the system.

Programming

The electronic logic elements section consists of 80 electronic circuits—flip-flops, AND

¹Opinions and conclusions in this report are those of the authors. They are not to be construed as necessarily reflecting the views or the endorsement of the Navy Department.

²Reprints may be obtained from Robert M. Herrick, Head, Experimental Psychology Branch, Aviation Medical Acceleration Lab., U. S. Naval Air Development Center, Johnsville, Pa.

gates, OR gates, inverters, relay drivers, multi-vibrators, binary-to-decimal decoders, binary counters, *etc.* Inputs and outputs of these circuits are permanently wired to a plugboard receiver.

Electrical connections from the animal test chamber lights and reinforcement device go directly to the plugboard receiver. Outputs from the response lever go to the data measurement and recorder control section, which consists of 90 permanently-wired logical elements. Here is detected the maximum displacement of the T-bar handle of the response lever resulting from each press. At the completion of a press the maximum displacement information is transmitted, in binary code, to the plugboard receiver. From the plugboard receiver, outputs go back to the test chamber to control the lights and the operation of the reinforcement device.

The removable plugboard (6¼ by 10¾ in) that mates with the receiver contains 680 independent electrical terminals. Plugwires inserted into these terminals interconnect the components mentioned above and thereby pro-

Fig. 1. Flow chart of system for programming experiments and for "on-line" recording. Shaded flow lines interconnect program sections.

gram the experiment. A new set of experimental conditions is created simply by replacing a plugboard with another pre-plugged plugboard.

Recording

In addition to sending the binary-coded, lever-displacement information to the plugboard receiver, the data measurement and recorder control section transmits the same data to a tape perforator, which punches the code in paper tape. Through the same section, the displacement of the T-bar during a press is converted to a voltage analogue and plotted, as a function of time, on an oscillograph. A related part of the data measurement section measures the duration of each press, cumulates these durations, and presents the results on a counter. Another part of the recorder control classifies each press into one of eight categories (eight Lever Positions) with respect to the maximum displacement of the T-bar and energizes a relay representing that category. The contacts of the relay operate additional recorders.

Analyzing

As a result of the "on-line" recording system just described, the data are summarized and displayed in a variety of forms: displacement versus time plots, cumulative records of lever-presses, durations of presses, *etc.* However, for more complex analyses, the data should be in a form suitable for automatic processing. This is the function of the perforated tape records. A row of tape represents eight channels—the first four containing the binary-coded, lever-displacement measurement, the others containing additional information, such as whether a chamber light was on or off, and whether a reinforcement was received for the lever-press. A 1000-ft roll of tape contains 120,000 rows of data.

Figure 2 gives a block diagram of the system used for the more complex analyses. A tape reader detects the punched holes in each row of the tape and transmits this information to the permanently-wired control and storage unit. This unit consists of 90 electronic logic elements. The control section determines the stepping rate and the number of steps taken by the reader. It also monitors the operation of both the reader and the storage unit. By means of three registers, the storage unit

Fig. 2. Flow chart of system for analyzing data automatically.

temporarily retains the information provided by three consecutive rows of tape. The outputs of these registers terminate in the plugboard receiver.

The electronic logic element section, which terminates in the receiver, has been described above. Also represented in the plugboard receiver are outputs to a bank of 30 electromechanical counters and to a graphic plotter, such as a cumulative recorder. These latter devices provide, in numerical and graphic form, the results of the analyses. For a specific analysis, interconnections among the components of the system are achieved by plugwires in plugboard. For a novel analysis, developed any time in the future, another plugboard can be prepared. All plugboards with their interconnections are filed for later use. A fairly complex analysis of, say, 10,000 presses can be performed in about 5 min.

Figure 3 is a diagram of a tape duplication and preparation system. After an experiment is completed, a duplicate of the tape obtained during the experiment is made. It is used if

Fig. 3. Flow chart of system for duplicating tapes automatically and for punching tapes manually.

the original tape is lost or damaged. Manually-prepared test tapes are made to evaluate the operations of the system.

Figure 4 pictures the complete system.

Although the system described above uses electronic logic, the same logical functions could be performed with electro-mechanical relays. In fact, in an earlier system, relays were used. They performed the programming and recording functions satisfactorily. However, the millions of operations to which the relays were subjected in the analyses necessitated frequent replacement of relays.

Illustrations of plugboard circuitry

All of the components shown in Fig. 5 and 6 are from the electronic logic elements section (Fig. 1 and 2), and all of the interconnections among the components are made by plugwires inserted into a removable plugboard.

Programming. Consider a program under which an animal is to be reinforced only for presses of a certain displacement (Lever Position 5) when the chamber light is on (S^D). A press to any of the other seven Lever Positions (Positions 1, 2, 3, 4, 6, 7, 8), causes the light to go off (S^A) and remain off for 10 sec. Any press in S^A delays the onset of S^D until 10 sec after the press. (See Fig. 5.)

When a press is completed, the maximum lever displacement information is sent to a binary-to-decimal (B-D) decoder. If the press was to Position 5, the B-D decoder operates AND gate 1 which actuates the reinforcement device. If the press was to any other Position, the B-D decoder, via the OR gate, operates a flip-flop that (a) "disables" AND gate 1, (b) turns out the chamber light, and (c) "enables" AND gate 2. AND gate 2 allows pulses from a precision clock to feed into a pulse counter

Fig. 4. Integrated system for programming experiments and for recording and analyzing data.

Fig. 5. Logic diagram of operand conditioning program. All interconnections among the components are made by plugwires in a removable plugboard.

that counts off the 10-sec S^A period. If a press is made during the 10-sec period, a signal from the data measuring section resets the counter to zero and, via an inverter, disables AND gate 2. When the S^A press is completed, AND gate 2 is enabled and the clock pulses to the counter resume. The termination of the S^A period resets the flip-flop that turns the chamber light on and enables AND gate 1.

Analysis. In this sample analysis the goal is to obtain two frequency distributions. One distribution will include each press immediately preceding a reinforced press to Position 4; i.e., the number of times a reinforced press to Position 4 was preceded by a press to Position 1, by a press to Position 2, by a press to Position 3 . . . , by a press to Position 8.

The other distribution will yield similar information on the press immediately following a reinforced press to Position 4. (See Fig. 6.)

Binary-coded information on three consecutive rows of tape is provided by the three registers. Three binary-to-decimal decoders convert this information to decimal form. The B-D decoder associated with the first register gives the displacement of the $(N+1)^{th}$ press, i.e., the press following the N^{th} press. This information is fed from the B-D decoder to one leg of one of eight two-leg AND gates (A_F), namely, the AND gate representing the displacement of the $(N+1)^{th}$ press. Each of the eight A_F gates feeds into a counter. Analogous circuitry originating in the third register provides a signal on the $(N-1)^{th}$ press, i.e., the press preceding the N^{th} press, to one leg of one of the eight A_P AND gates. Each A_P gate also feeds into a counter.

When the information is in the three registers an "interrogate pulse" is sent to AND gate 1 (A_1). If, at the time of this interrogate pulse, the second register indicates that the N^{th} press (a) was to Position 4 and (b) was reinforced, AND gate 1 sends a pulse to the flip-flop. The flip-flop, in turn, provides a pulse to each of the 16 two-leg AND gates. Since one leg of one of the eight A_F gates already is enabled, that AND gate operates its associated counter and thereby indicates, for example, that the press following the reinforced Position 4 press was to Position 5. Similarly, one A_P AND gate, representing the $(N-1)^{th}$ press operates its associated counter and indi-

Fig. 6. Logic diagram of an analysis of operand conditioning data. All interconnections among the components are made by plugwires in a removable plugboard.

cates that the press preceding the reinforced Position 4 press was, say, to Position 2.

After this process is completed, a pulse from the control section resets the flip-flop. Next, (a) data from register 3 is discarded, (b) data from registers 1 and 2 shift to registers 2 and 3, respectively, and (c) the next row of data from the perforated tape is entered in register 1. Then the process described above is repeated.

Sources of System Components

The plugboard, its receiver, and the plugwires were purchased from the Mac Panel Co., High Point, N. C.; the electronic logic elements, from BRS Electronics, Beltsville, Md.; the tape perforator, tape reader, and the tape, from the Tally Register Corp., Seattle, Wash.;

the oscillograph, from Consolidated Electrodynamics Corp., Pasadena, Calif.; the coding keyboard, from Information Products Corp., Cambridge, Mass.; the relays, from Potter and Brumfield, Princeton, Ind.; the counters, from Landis and Gyr (Sodeco), N. Y., N. Y., and from Photocon Research Products, Pasadena, Calif. Most of the data measurement and recorder control section was designed and assembled by BRS Electronics.

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Received May 16, 1963