COMPUTER TECHNOLOGY

A computer-controlled system for training and testing primates

SAMUEL L. MOISE, JR., *and* LEONARD E. JARRARD,
CARNEGIE-MELLON UNIVERSITY, Pittsburgh, Pennsylvania 15213

The hardware and software for a computer-controlled training and testing system for primates are described. The computer (DDP-116 in the Computer-Controlled Psychology Laboratory at Carnegie-Mellon University) controls all stimulus presentation, reinforcement, and records data in a form ready for analysis on a larger computer.

This paper describes a system for the computer-controlled training and testing of primates. The main components of the system are diagramed in Fig. 1 and are described in the following sections.

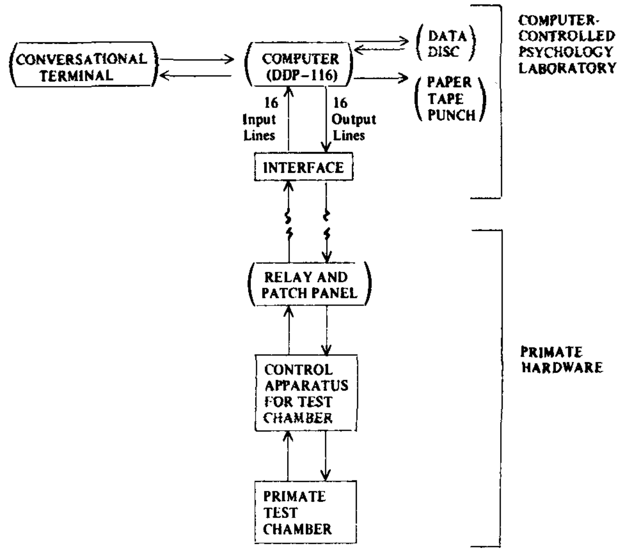

Fig. 1. Schematic of main components of the Computer-Controlled System for Primate Testing.

Computer Hardware and Software

The computer is a 16-bit Computer Control Company DDP-116 (Honeywell), with 16K core storage, located in the Computer-Controlled Psychology Laboratory.[2] It is fast (1.7-μsec memory cycle time) and has proven to be a highly reliable machine.

A number of peripheral devices are interfaced with the main frame; one of the most useful is a disc drive utilizing removable discs (Data Disc Company, Palo Alto, California). The discs serve as primary storage devices for all system software and user programs. Other peripherals include a Friden 7100 Conversational Terminal for interacting with system software (for example, loading, storing, or editing programs), a Friden eight-column paper tape punch for outputting data, and an interface containing input-output connections to both human and animal experimental areas. Full input-output capability from the computer to each experimental area is permitted by the interface logic.

Experiments can be run in up to eight experimental rooms at once under the auspices of a time-sharing monitor. Each active program under monitor control receives $1/N$ ($N \leqslant 8$) of the available time. Execution time is allotted in 10-msec blocks so that the maximum wait time for any program is on the order of 70 msec. This is a negligible delay for many real-time control applications. There is also a priority interrupt system that permits programs requiring immediate attention to be serviced first.

In addition to basic policing and scheduling functions, the monitor also serves as an executive input-output controller and provides numerous specialty routines useful to the psychologist-programmer. For example, there are routines to facilitate the measuring of latencies, wait a specified length of time, and output information to experimental areas.

Primate Hardware

Animals trained with the Computer-Controlled System are tested in a Lehigh Valley Primate Test Chamber (Model 1488). The chamber has a removable aluminum intelligence panel that can be equipped with various stimulus displays and manipulanda depending on the nature of the experiment. For our present research, the panel has three circular display holes arranged in a triangle with the apex at the top and a rectangular pellet feeder opening located below the base of the triangle. Behind each circular opening is an IEE (Industrial Electronic Equipment, Inc.) one-plane digital readout projection unit that permits presentation of 12 different visual stimuli. Between the readouts and the panel are translucent plastic rectangles hinged to microswitches that serve as response manipulanda. The pellet dispenser, together with all wiring, is located behind the intelligence panel and is connected with the outside of the chamber through a 32-pin feed-through connector. Shielded cable joins this connector with the control equipment located in an adjoining room. Included in the control equipment are IEE digital readout projection units that correspond to the display units in the test chamber and digital counters for monitoring the progress of the experiment.

A 12 x 12 in. guillotine door with one-way glass, slides up to permit animals to enter the test chamber. For the greatest flexibility in testing, the chamber is arranged with a false floor that can be removed to permit a restraining chair to be placed in the box.

Since the output lines from the computer operate with different power requirements than the control equipment for the test chamber, a patch board containing a bank of relays (Potter and Brumfield, No. MLIID) was constructed. Computer output lines activate the relays, which in turn activate the test chamber control components. Input to the computer is patched on the same board. The patch-board arrangement has proved to be practical since any output line from the computer can be easily made to operate any piece of equipment merely by changing connectors.

Programming

Programming the DDP-116 is similar to programming other single-address binary computers using two's complement notation. A symbolic language, ZAP, for programming in the machine code of the DDP-116 has been the primary programming language.

We are now training and testing primates in a delayed-matching-from-sample task with a titrating delay. The length of the delay depends on how well the S is performing, i.e., the delay is increased when the animal performs correctly and decreased when mistakes are made. A series of seven programs to train monkeys to perform this task was written by the senior author. These programs follow a procedure similar to that used by Drachman and Ommaya (1964) in training animals.

The monkeys *(Macaca speciosa)* are first taught to press any one of the three lighted displays in order to obtain 190-mg banana pellets. Since this preliminary training frequently necessitates the use of successive approximations, the displays are illuminated and pellet reinforcements are delivered manually by the E. When the animal is responding to the lighted displays with short latencies, the testing equipment is put under complete control of the computer in the following progression:

Program 1–One of the three displays is randomly selected for presentation. The animals must respond correctly by pressing the lighted display within a limited time period.

Program 2–The two lower displays are used for red-green discrimination training. After reaching a certain level of performance, several reversals are carried out.

Program 3–The upper display (sample) is illuminated with either red or green and the S must press the sample to turn on the lower displays (the sample stays on). The lower display matching the sample must be pressed. If an incorrect response is made, the sample remains on and the animal is allowed to correct the response by pressing the sample and the correct match. The sample is either red or green for a number of trials until a certain level of performance is reached; then the other color is presented.

Program 4–The procedure is identical to that in Program 3 except that incorrect responses are followed by termination of all displays thus ending the trial.

Program 5–The sample color varies randomly on each trial, otherwise the procedure is the same as in Program 4.

Program 6–After the sample is pressed, a delay is introduced before the side displays are illuminated. The delays start at 0 sec and increase in the sequence ¼, ½, and 1 sec as criteria for correct responding are met. Otherwise, the program is the same as Program 5.

Program 7–In this program, the delay starts at 0 sec and, after a predetermined number of successive correct responses, the delay is increased by a certain amount. If a number of consecutive errors is made, the delay decreases by a certain amount. In this way the S is able to work up to his maximum delay capacity.

The flow chart in Fig. 2 shows the basic outline around which the programs are written. While testing an animal, the programs keep track of the number of trials on which there was no response, the state of the criterion, and the number of trials

```
5 G SC, 29,  1567, 2  C, 1837, 3, 3
5 G SC, 30,  1628, 2  C, 4295, 1, 1
5 G SN, 31
5 G SC, 32,  8580, 2  C, 2563, 1, 1
6 R SC, 33, 14718, 2  C, 1202, 3, 3
6 G SC, 34,  2284, 2  C, 1489, 1, 1
6 G SI, 35,    80, 3
6 R SC, 36,  1584, 2  I, 1461, 3, 1
```

Fig. 2. Basic functions of primate training-testing programs.

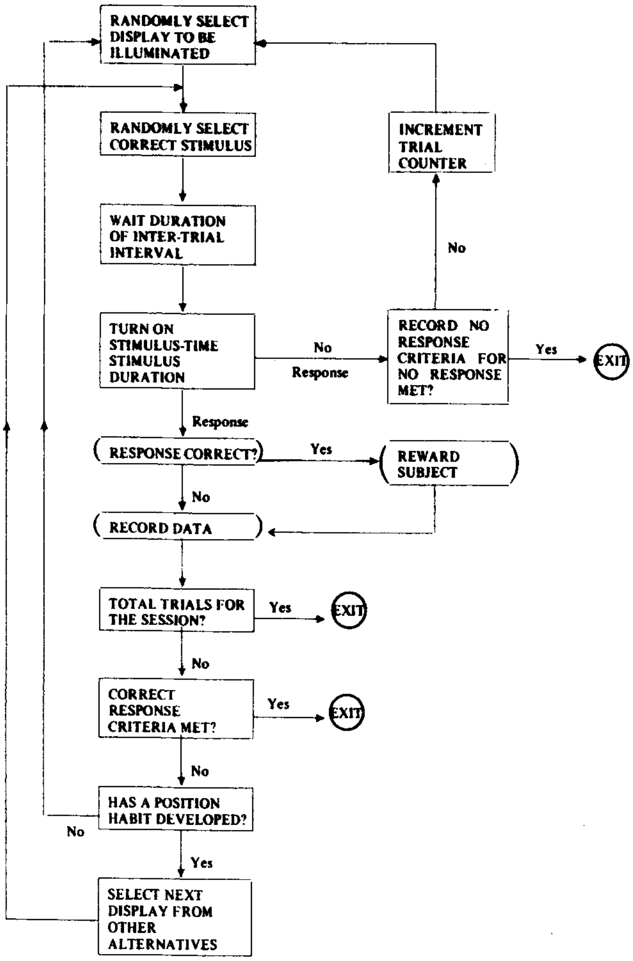

Fig. 3. Printout excerpt from an experimental run controlled by Program 7. The information printed from left to right is: length of delay, color of the correct sample for the trial, response to sample (SC = sample correctly pressed, SI = incorrect response to lower displays, SN = no response during sample presentation), trial number, latency of response to the sample (in milliseconds), response of the S to presentation of sample (Display 2 is located at the top of the triangle and must be pressed to get sample correct, Displays 1 and 3 are located at the lower left and right, respectively), response to matching stimuli following the delay (C = correct response, I = incorrect response, N = no response during stimulus presentation), latency of response to matching stimuli, identification of correct matching stimulus and response to the matching stimuli, identification of correct matching stimulus and response to the matching stimuli (the last two entries are the same in the case of a correct matching response).

presented. Of particular importance for our purposes are routines that determine if the animal has formed a spatial position habit. Since we are training animals to learn nonspatial matching it is important that position responding be extinguished. The programs check for position habits according to a criterion set by the E. If a habit forms, the correct stimulus is presented in other locations until the animal responds correctly for some given number of trials.

On each trial the programs punch out information relevant to that trial. Special symbols are recorded to indicate such events as reaching of a criterion or termination of the experiment after a given number of trials have been completed. The information output on each trial consists of the following:

(1) trial number

(2) response correct or incorrect (C or I)
(3) latency of response
(4) which display was "correct" (i.e., should have been pressed)
(5) which display was pressed

In addition, when the matching-from-sample programs (Programs 3-7) are being run, information is obtained indicating whether the sample was correctly or incorrectly pressed and the latency of that response. The programs that involve color discrimination or matching also punch out which color is correct for each trial. Programs involving a delayed match punch out the length of the delay. If no response has been made within the stimulus duration, this is signified by punching, "N," as well as the display that had been presented. Figure 3 shows a sample printout from an experimental run controlled by Program 7.

Experimenter control over the test session is handled largely in the computer room. However, push-button switches are provided in the primate equipment control room to permit some control over the running experiment. These illuminated push-button switches also provide information about the status of the testing from signals generated by the computer. The switches are lighted to signify reaching criterion (Switches 1 and 2), completing the number of trials for the session (Switch 2), or delaying too long with no response (Switch 1). By pressing Push-button 2 the E can halt the experiment at any point. He can also restart it by depressing Switch 1. Successive presses of Switch 1 keeps the experiment at the same point in the program while generating new randomly selected displays (one selection for each press). In addition, the E can keep track of number of trials and number of reinforcements given via the mechanical counters located on the control rack.

The programs are written so that changing a parameter is a simple matter of altering one or two words in the program. Prior to run time the E can make changes in, for example, the number of trials to termination of the session, criteria for correct responses, criteria for determining and breaking position habits, length of intertrial interval, stimulus duration, etc. It is this flexibility that makes the computer-controlled system so versatile and useful.

Of course, a major advantage of the computer-controlled system is its flexibility. Experimental design or parametric changes are often simply a matter of altering a few program instructions. For example, after running the first pilot monkey on Program 2, it was decided that our criterion for a position habit was not sufficiently restrictive. In the few minutes it took to remove one monkey from the test chamber and put in another, two program instructions were changed and the next animal was run under the new criterion.

Our computer-controlled system offers another time-saving capability that we do not use at present. Even when time sharing with other programs, there is some time available to do preliminary data analysis while the experiment is being run. Analysis routines could be appended to the programs to manipulate the data as it is collected. At the present time our more involved data analysis is done by reading the data tapes into a UNIVAC 1108 computer[3] where the data is analyzed by an Algol program.

The apparatus described in the section on primate hardware can easily be converted to run primates on a number of different tasks. Other intelligence panels can be prepared with various configurations of digital readouts, manipulanda, pellet dispensors, and drinkometers, and programs written to control them. Even with the present panel design a number of different experiments could be programmed. Examples of alternatives are delayed response, oddity learning, sequential responding tasks, and learning set problems.

Although it is felt that the advantages of employing computers to control experiments far outweigh the disadvantages, there are certain limitations with our current system. The DDP-116 mainframe and interface have been trouble free. However, the disc that stores programs and system software has caused trouble occasionally, resulting in several lost days of testing each month. This is to be expected in a situation where there is rewiring of peripheral equipment and other changes designed to improve the overall system We anticipate higher reliability in the near future as several wiring projects are completed and a fixed head disc (Data Disc) is being installed.

REFERENCE

DRACHMAN, D. A., & Ommaya, A. K. Memory and the hippocampal complex. Archives of Neurology, 1964, 10, 411-425.

NOTES

1. This research was supported in part by an NDEA Fellowship to S.L.M. and National Science Foundation Grant GB-8044 to L.E.J.

2. Supported by a grant from the United States Public Health Service, NIMH 07722.

3. The 1108 is located in the computer center at Carnegie-Mellon University.