identical to those in our on-line system. Although we feel continually pressed for space—in core-memory size and in the number of stimulus and response lines per station—the system is running well (down-time this year averaging only about 1 day every 2 months) and is in general delivering the promises of the company's most recent advertising. It suits our research purposes rather nicely, despite the fact that the original SCAT designers probably had conventional operant conditioning research in mind, and it

seems likely to exceed our initial expectations as we become more skilled in realizing the full potential of an on-line computer.

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Using the PDP-12 in verbal learning and short-term memory research*

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In this paper, we would like to do four things: (1) discuss the rationale for using an on-line computer to conduct research in the verbal learning and short-term memory area; (2) describe our operating system; (3) list the experiments currently in progress or planned; (4) evaluate our progress to date. Of necessity, all sections will be brief.

RATIONALE

An issue of some general concern is whether an on-line computer is a necessary laboratory device for the experimental psychologist. Prospective purchasers and funding committees often weigh heavily the issue of whether the research is of such a nature as to be impossible without a computer. A related question, often asked by those fortunate (or unfortunate) enough to have a computer in their laboratory, is whether they are making full use of its capabilities. Given the power and flexibility of a computer, is the psychologist really exploiting it to the full?

In our opinion, this is the wrong question to ask. It loses sight of the purpose of psychological experimentation. The purpose of

experiments is to test theories and extend our empirical knowledge. The question that should be asked by the prospective or reflective user is whether he will do more and/or better experiments with a computer than without a computer. The purpose of doing experiments is *not* to utilize our equipment; it is to expand our knowledge.

As a simple example, if one has a multifactorial analysis of variance to do, one can spend hours or days at a desk calculator doing it by hand. Alternatively, one can run an ANOVA program on the university computer. In so doing, one is using a multimillion-dollar device as a simple adding machine. Considering matters of time and efficiency, there is little doubt which alternative most psychologists would prefer.

Further, while everything else is going up in price, on-line or "mini" computers are coming down, dramatically. The lowest-priced computers are not even necessarily the most expensive device one might have in a psychological laboratory, and even medium-priced laboratory computers are comparable to the salary one would pay a good technician over a period of several years. However, software costs are something else again, in terms of either trained personnel and/or the investigator's time required.

OPERATING SYSTEM

We have developed an operating system (OS12) to run experiments in verbal learning and memory using a

PDP-12A (Duffy, 1970). Originally, our machine had only 4K of core, and the operating system requires about half of it. We have expanded to 8K of core to use FOCAL-12, but have not yet finished modifying the operating system. The general purpose of OS12 is to facilitate the writing of programs to run experiments. It is in modular form so that additions, deletions, and modifications will be relatively easy. The ultimate goal is to write a program using only call statements to subroutines, but at present the programs must be written using some assembly language in addition to OS12.

The four principal features of OS12 are the use of FORTRAN-like input/output statements, nested interrupt levels, debugging aids, and provision for chaining and overlays. The read statement is of the general form, READ;DEV;DATA, where DEV is the input device and DATA specifies a starting location. The input devices may be core, the Teletype, buffered Teletype, LINC tapes, sense switches, keyboards (not yet operational), or the A/D converter. For output, the general statement is WRITE;DEV;DATA, where the devices may be core, the Teletype, buffered Teletype, display (the CRT), LINC tapes, relays, or the speaker. A typical format statement might be TEXT%(4A2"—"4A2)%, where 4A2 permits up to eight alphabetic characters to be displayed and the quotation marks are for literals. If the device for this format statement was the display, then the paired associate, GALLANT—LEGEND, might be shown on the CRT. Provided formats are alphabetic, binary, octal, decimal, and free.

For the interrupt, at the higher level, a counter is incremented to keep track of real time and to determine when the lower level is to be entered. At the lower level, the display is refreshed and other device routines are entered. The clock is the only device that can cause program interrupts. We have our own hardware clock with a normal frequency of 200 Hz. The slow interrupt is entered every 25 msec and the fast interrupt every 5 msec. The software can handle clock rates up to 5,000 Hz.

OS12 has a small monitor which is useful in debugging. It permits the command G to start a program, C to continue from a STOP (judiciously inserted at various points in a program), O to load into core ODT (Octal Debugging Technique, a standard software package), S to start ODT, D to return to DIAL (Display Interactive Assembly Language, an excellent editor and assembler particularly suited for the PDP-12),

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and W to write a core image as a binary file in the workspace of Tape 1. This monitor considerably simplifies the job of making small changes in programs.

OS12 also facilitates chaining and overlays. Chaining is used when a program can be split into a sequence of steps such as data collection and data analysis with no interaction between them. Program sections are limited to 1,024 words each. Overlays are used when a particular routine is only required occasionally during the running of a program. In OS12, overlays are restricted to 256 words. As an example, the command GET;QUAD brings in as an overlay QUAD, a subroutine to manipulate four locations as one. QUAD is useful, for instance, in randomizing the word pool, which consists of common English words not more than eight letters long.

EXPERIMENTS

For our experiments, testing is completely automated and the S interacts only with the computer. He comes in, turns the computer on, mounts his tape, loads DIAL, loads his program, types in his S, session, and start numbers (which load the random-number generator), then starts the program. The computer CRT functions as the display device, and responses are either typed in on the Teletype or a bank of Telegraph keys is used. The data are either printed out immediately or stored on LINC tape for later analysis. At the end of the session, summary statistics may be typed out. The S then signs off and leaves. This procedure will be simplified still further, but so far, we have had good luck running Ss from the undergraduate S pool.

To date, we have six general types of experiments. RCMT is a recognition-memory test where, on each trial, a list of words is presented, then followed by a test which is either a yes/no or a confidence-judgment procedure in which both responses and their latencies are recorded. Twice as many words are tested as are presented, and old and new items are equally represented. Composition of

the lists and lag (number of items intervening between presentation and test) is randomly determined, though in the current version, a constraint is imposed such that $\text{lag} > 7$. List length, presentation rate, and number of lists per session are parameters specified in the program.

STERN is a reaction-time test where, on each trial, some number of digits from 1 to 4 is presented then followed by a probe to which the S responds yes or no. Our experience has been that several sessions suffice to generate linear functions for individual Ss of the type reported by Sternberg (1966). The PA series is a recognition memory-probe test for paired associates very much like those reported by Murdock (1965). The MELTON program uses the distractor technique introduced by Peterson and Peterson (1959) but varies the number of letters presented in the n-gram (Melton, 1963).

Finally, we have two sets of interactive experiments which are almost ready. IPAL will require Ss to learn a set of paired associates, with the selection of each pair presented contingent on past performance. As a start, very simple rules will be used, but work on optimization (Atkinson & Paulson, 1972) suggests that powerful techniques exist to speed the learning process.

IAFR is an extension of a study on interactive free recall reported by Murdock, Penney, and Aamiry (1970). In multitrial free recall, presentation of the items on Trial $n+1$ is contingent on some aspect of the S's performance on Trial n . In the study noted above, recalled items were either presented first, last, or randomly on the next trial. More powerful manipulations will be possible with IAFR, and it may help to document and clarify the role of chunking and organization in free recall.

EVALUATION

To date, our experience has been that one does fewer but better experiments with an on-line computer. Of course, if one runs a series of experiments on the same problem, one may recoup on the later experiments

the time spent on program development for the first. Our intent, however, has been to bring a variety of experimental tasks under computer control rather than restrict our efforts to one particular problem. On the other hand, we have no intention of running a laboratory that is completely computer controlled. Many experiments do not call for computer control, and some could not be implemented even if we wished.

Originally we had hoped to involve a fair number of graduate students in this project. To date, we have not been very successful. Even with OS12 and FOCAL-12, writing an experiment on the computer is not easy. Our students are understandably reluctant to make a large investment of time in acquiring these skills given the pressures of graduate training. What is necessary (and a project we are currently undertaking) is a specialized and tailor-made training course which will introduce students to the use of on-line computers in verbal learning and short-term memory research which will teach them both the specific details of the installation and the fundamentals of assembly-language programming. Once they get started in computer-controlled experiments, they can extend and perfect these skills as they wish.

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