Experimental control programs for the UNIX operating system

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The software described runs on Version 7 UNIX, although most run on earlier versions. Using the curses package requires two program libraries from the Fourth Berkeley Distribution (CURSES and TERMLIB). Using any of the functions requires knowledge of programming, preferably in C (Kernighan & Richie, 1978), but the sample experimental control program is usable by nonprogrammers. Because no special hardware is assumed, the resolution of timed presentations and reaction time recordings may not be accurate enough for some purposes. Functions for stimulus presentation have a resolution of 1 sec, and those for timing responses are accurate to about 17 msec.

This paper may serve as an organizer and reference for existing software useful for programming psychological experiments on the UNIX operating system. UNIX offers hundreds of system calls that have varying applicability to experimental control programming. Many of these system calls are hard to find and, even if they are found, the usefulness of a function is not always apparent. In this paper, I give examples of their use.

This paper also offers some software tools for writing programs for controlling experiments. While the software UNIX offers is useful, it is not specifically suited to the needs of psychology experimenters. Some higher level functions, however, make use of low-level functions supplied by UNIX.

The paper serves as a tutorial on writing experimental control programs. Concrete examples showing where and how software tools can be used are necessary if they are to be used at all.

The software is written in C (Kernighan & Richie, 1978), a structured algorithmic language similar to ALGOL and PASCAL. C is the systems programming language of the UNIX operating system (Richie & Thompson, 1974, 1978), developed at Bell Laboratories and licensed by Western Electric. The University of California at Berkeley (UCB; Joy, 1980) releases an

enhanced version of UNIX that includes software described in this paper. While the functions are written in C, UNIX allows programs written in FORTRAN 77 (Katzan, 1978) and PASCAL (Jensen & Wirth, 1974) to be used in function calls.

UNIX has become popular in the experimental psychology community because of its availability for DEC PDP-11 and VAX computers¹ and because of its versatility for program development and text processing. One use of UNIX is the control of psychological experiments; many experiments can be run using UNIX-supplied functions without special hardware. Stimulus randomization, stimulus presentation at a specified location on a screen, and collection of timed responses are all possible with a character CRT terminal.

This paper is an organizer and reference to functions useful for experimental control developed at Bell, UCB, and the Cognitive Science Laboratory (CSL) at the University of California at San Diego (UCSD). The sources of functions are mentioned as they are introduced and can be referred to in the appendix. The structure of the first part of the paper follows that of an experimental control program. Functions are discussed for (1) stimulus randomization, (2) for stimulus presentation, and (3) for timed response collection. In the second part of the paper, a general experimental control program that uses all the functions is described. It is practically useful, as it can run a variety of paradigms. The control program also serves as a model for writing new programs; for that reason, in the second part of this paper I discuss practical considerations in writing experimental control programs.

Functions used within C programs are called system calls or utility functions. These are described in sections 2 and 3 of the UNIX programmer's manual (Joy, 1980) if they are from Bell Laboratories or UCB, or in documentation available from the author. In a few cases, reference is made to UNIX level programs, which

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are used at the same level as commands for text editing or reading mail. (The convention is to capitalize the names of UNIX programs and systems programming functions, although in practice, they would be lowercase.)

EXPERIMENTAL CONTROL FUNCTIONS

The basic components of an experimental control program are: stimulus randomization, stimulus presentation, and response collection. (Although the functions available and examples are provided in this discussion, the UNIX programmer's manual should be used as the final reference.)

STIMULUS RANDOMIZATION

Two types of stimulus randomization are considered: randomization of stimulus files before the experiment begins and randomization of stimuli stored inside an experimental control program. I will assume each stimulus occupies one line in a stimulus file. If each stimulus is presented just once, experimental programs can be made more compact because stimuli can be randomized outside the program and only one stimulus need be stored at any time. Internal randomization allows more freedom but requires more stimulus storage space.

File Randomization

PERM is a CSL program for randomizing stimulus files that reads in a file and prints the file's lines in random order. PERM is used at the UNIX command level, and so can be used without programming expertise. For example, if stimuli are stored in a file called "stim," the command

```
PERM stim mixed
```

puts a random ordering of stim's lines in "mixed." The lines in this randomized file can then be presented in order, since the order is random.

File Randomization from Inside a Program

C provides a function to execute UNIX-level commands from inside programs. The `SYSTEM` function executes the string `COMMAND` as though it were typed at the UNIX command level:

```
system(command);
```

This function can be used for randomizing stimulus files from within a program.

```
system("PERM stim mixed");
```

Randomizing Presentation Order

PERMUT randomly permutes the elements of its array argument. It takes three arguments: the name of

the array to be permuted, the size of the array, and the size of each array element. In this way, the same function can be used to randomize arrays of characters, integers, pointers, and so on. For example, if `STIMULUS[I]` contains the *I*th stimulus, `ORDER` is an array of integers suitably large, and *I* is a loop index, instead of using *I* to access stimulus array elements, as in:

```
printf(stimulus[i]);
```

a permuted `ORDER` array can be used to randomize presentation order by indirection. In the following example, assume that the array `ORDER` contains the integers from zero to one less than the number of stimuli, `NSTIM`. (In C, array indexing begins with zero, not one, as in other languages.)

```
permut(order, nstim, sizeof(int));
```

```
...
```

```
printf(stimulus[order[i]]);
```

The C primitive, `SIZEOF`, can be used to determine the size, in bytes, of any data type.

`RANDOM` is a function that returns randomly selected, uniformly distributed integers. The returned value is between `MIN` and `MAX` inclusive, and may be used for presenting randomly selected practice stimuli.

```
random(min, max);
```

```
nrandom(min, max);
```

A function related to `RANDOM`, `NRANDOM`, returns an integer between `min` and `max` inclusive that is normally distributed.

STIMULUS PRESENTATION

Ordinary Printing

Stimuli may be printed using standard C printing procedures; a common one, `PRINTF`, can print strings in complicated formats, though it is used here in a simple way. For example, the following statement would provide a short debriefing for subjects:

```
printf("The experiment is over. Thank you.");
```

If more efficient stimulus presentation is necessary, the more primitive UNIX function `WRITE` can be used instead, though the savings are not great for simple strings.

```
write(1, "The experiment is over. Thank you.", 34);
```

Screen Printing

A powerful generalization of `PRINTF` is `PRINTW`, which prints at any coordinate on a terminal screen. `PRINTW` is part of the `CURSES` screen controlling package developed at UCB (Arnold, Note 1) and uses the `TERMCAP` data base that contains information on

terminal's capabilities. CURSES allows programmers to print text at any location on a screen without knowledge of details about individual terminal characteristics. For example, the following program fragment prints a stimulus indented 20 spaces below the 10th line of a clear CRT screen:

```
clear()
move(10,20);
printw(stimulus[i]);
refresh()
```

The CLEAR function clears the terminal screen, and the MOVE function moves the cursor to the specified line-column coordinates. REFRESH is called after PRINTW to tell CURSES to update the screen. The CURSES package is too large to discuss in this context, but documentation of this well-designed package is available (Arnold, Note 1).

Timed Presentation

Sometimes stimuli or instructions are to be presented for a fixed duration. This is possible with the UNIX SLEEP function. The following call presents a notice for 60 sec:

```
printf("Rest for a minute");
sleep(60);
printf("Begin Block II");
```

In other cases, subjects may be allowed to rest as long as they like, but no more than some maximum duration. An interruptable pause is possible with the CSL TIMEGETC function that uses the UNIX ALARM and SIGNAL functions to wait a specifiable maximum number of seconds for a response. In the following example, TIMEGETC will wait at most 2 min for a key-press to continue:

```
printf("Press any key to continue");
timegetc(120);
printf("Begin Block II");
```

Both SLEEP and TIMEGETC have a maximum resolution of 1 sec, so they are useful only for presentations of greater than a few seconds.

RESPONSE COLLECTION

Ordinary Response Collection

One function for reading from the keyboard is the UNIX GETCHAR, which returns one character from the keyboard each time it is called. For example, the following statement sets response to the next character typed:

```
response = getchar();
```

Whole strings can be read using the UNIX GETS func-

tion. GETS obtains a string from the keyboard and stuffs it into its argument. GETS assumes that string is pointing to enough space to hold whatever is input:

```
gets(string);
```

Single-Character Response Collection

UNIX normally hands characters to functions like GETCHAR and GETS only after a whole line is input and followed by a new-line character (RETURN or LINE-FEED). This is called "cooked" mode. In cooked mode, functions like GETCHAR will not allow recording response times for the first character typed, because they wait for a new-line character. Then there is an unread new-line character in an input buffer, and a possibly unwanted character (the one pressed by the responder) on the terminal screen.

The UNIX functions GTTY [get terminal (tty) status] and STTY (set tty status) solve these problems. Rather than describe the obscure syntax of these functions, I will discuss the CSL function, EXPMODE, that uses both. EXPMODE takes one integer argument and puts the terminal into CBREAK and NOECHO modes if it is nonzero (true for C) and back to normal mode if it is zero (false for C). In CBREAK mode, in contrast to cooked mode, characters are passed to programs as they are received; new lines are unnecessary. (This mode is new to Version 7 UNIX; the old version counterpart is called "RAW" mode.) EXPMODE also changes the terminal mode so that typed characters are not displayed (NOECHO mode). A side effect of calling EXPMODE is that the input buffer is flushed. This is useful for discarding keypresses made by subjects between trials.

Timed Response Collection

The UNIX function FTIME allows reading the system clock that ticks at a 60-Hz rate, allowing a maximum resolution of about 17 msec. It is used in the CSL PRESENT function, which presents a stimulus and records a timed response not greater than a specified maximum (using TIMEGETC) while in EXPMODE. PRESENT briefly goes into a privileged mode to receive extra CPU attention.

Because UNIX is a timesharing system, the CPU response a program normally gets is inversely proportional to the load of the system. Rather than restrict access to the computer while collecting data, it is possible to increase the priority of a program so that it gets extra CPU cycles. The UNIX function NICE, created to reduce the load of a particular program (to be nicer to other users), can be called with a negative niceness (if the program is owned by the super-user) to receive extra attention. Since other users suffer while a program is negatively niced, use negative niceness for short periods (e.g., while the program is presenting stimuli and timing responses) and return to normal (zero) niceness for other tasks (e.g., randomizing or storing data).

AN EXPERIMENTAL CONTROL PROGRAM

A general experimental control program, EXP, uses all the functions discussed so far. To use EXP, no knowledge of its inner workings is required, although it is useful for modification. The main program of EXP uses components for initializing and setting options, presenting instructions, running trials (present stimuli, collect and store data), and cleaning up loose ends. Many of the functions are useful for other programming tasks because they are self-contained; these functions are discussed in following sections.

Initialization

Initialization involves: (1) setting the values of variables that cannot be set automatically (such as arrays); (2) calling any functions that do further initialization (e.g., the CURSES screen package requires that the functions INITSCR be called); (3) making sure that the program dies gracefully if interrupted (e.g., catching BREAK or DEL characters with the UNIX SIGNAL function); and (4) seeding the random number generator RAND, with SRAND called with the time and date (found with TIME).

Setting Options

Options can be set by assigning values to variables in an option file read by EXP. A sample option file is shown in Table 1. Each of the variables are described in following sections. EXP gets the name of the option file from a UNIX call like:

EXP options

These variables are read and interpreted by a set of CSL functions, collectively called VARPAK, that form a stand-alone variable-handling package. The function READVAR sets the names and values of the variables found in its file argument. If the option file in Table 1 is called "options," the following line sets the variables.

```
readvar("options");
```

After variables are set, their values can be determined from names using the GETVAR function. GETVAR returns the string value of the name it is supplied if the

name matches that of a set variable; otherwise, it returns a null pointer. Continuing the example with the variables from the option file, the interstimulus interval (ISI) can be set by using the UNIX ATOI (ASCII to integer conversion) function that returns the integer value of a string:

```
isi = atoi(getvar("isi"));
```

Similarly, the name of the file in which data are to be stored can be set.

```
datafile = getvar("datafile");
```

Often, it is useful to let variables have truth values, such as "true" or "yes" or some nonzero integer value. For this, the function TRUEVAR is provided. If a variable called varname has any of the values

```
true yes 1 t y (null)
```

then

```
truevar(varname);
```

returns one (true in C); otherwise, it returns zero (false in C). This can be used to set an option that has one of two values. For example, the CLEARSCREEN option (to tell EXP to clear the screen between trials) is set to true in the option file in Table 1. This can be used to set an internal variable:

```
clearscreen = truevar("clearscreen");
```

The VARPAK package also includes functions for interpolating strings containing variables, for setting individual variables, and for printing all the variables set. These functions can simplify setting options and trying many configurations of experimental control programs with EXP.

Presenting Instructions

For presenting text to subjects, EXP uses the CSL function, SHOWTEXT, that buffers text for the terminal screen. SHOWTEXT takes one argument, the name of the file containing the instructions, and presents text one screen full at a time until the file is exhausted. Subjects pace their reading by pressing a key for each new page. Instructions can be presented with one line when the INSTRUCTFILE variable is set:

```
showtext(getvar("instructfile"));
```

Running Trials and Storing Data

EXP uses the CSL function, RUNTRIALS, controlling stimulus presentation and data storage. For each stimulus file in the variable STIMFILES (in random order if RANDFILES is true), RUNTRIALS reads all the stimuli and presents them NREPEATS times (in random order if

Table 1
Sample Option-Setting File for EXP

subjid	=	subj10
stimfiles	=	set1 set2 set3
randfiles	=	true
randstim	=	true
nrepeat	=	1
isi	=	2
max_rt	=	5
clearscreen	=	true
beep	=	false
instructfile	=	instructions
debrieffile	=	explanation
datafile	=	data

RANDSTIM is true). On each trial, the screen is cleared if CLEARSCREEN is true and the program sleeps for the number of seconds to which the variable ISI is set. Finally, the single character response and reaction time are collected by the PRESENT function and are stored in the file named by the variable DATAFILE.

PRESENT takes four arguments:

```
present(string, beep, rt, max_rt);
```

STRING is presented, preceded by a beep if BEEP is nonzero, the reaction time is stored indirectly through the double pointer RT, and the obtained character response is returned by the function. PRESENT returns the character typed unless MAX_RT seconds have passed, in which case it returns zero. PRESENT flushes the input buffer so extra keypresses are discarded, and goes in and out of a privilege mode to get extra CPU attention while waiting for a response (see the earlier discussion of NICE).

Finishing Up

After all the data are collected, EXP presents to subjects a debriefing it finds in the file named by the variable DEBRIEFILE. Finally, EXP calls FINISH to clear the screen, say good-by to the subject, and call any functions for normal termination (the CURSES package requires a final call to the ENDWIN function).

Possible Uses of EXP

EXP can be used as is to run experiments that have several stimuli (perhaps divided into blocks) presented on a clear terminal screen for timed single character responses. This includes simple choice reaction time experiments, and reading and reasoning studies, in which critical timing of stimulus presentation is not needed. For example, a reading experiment might have subjects read a story (each story in its own stimulus file) line by line by pressing the space bar to get successive sentences. Sentence reading times can be recorded and then followed by a last line with some other type of stimulus, perhaps to test comprehension. While the class of paradigms possible with EXP is large, the program is relatively easy to modify.

Interfacing with Data Analysis Programs

EXP allows easy interfacing with data analysis programs described by Perlman (1980). Data are stored in a file in random order and can easily be reformatted because of the versatile capabilities of data manipulation programs. If data are stored with a stimulus description (e.g., strings coding levels of experimental factors), data can be analyzed immediately after an experiment with no further specification.

REFERENCE NOTE

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NOTE

1. UNIX is a trademark of Bell Laboratories. DEC, VAX, and PDP are trademarks of Digital Equipment Corporation.

Appendix Sources and Short Descriptions of Functions

PERM	(CSL)	permut lines in a file
system	(Bell)	execute UNIX command at C level
permut	(CSL)	permut array elements
random	(CSL)	uniform random integer generator
nrandom	(CSL)	normal random integer generator
printf	(Bell)	print formatted string
write	(Bell)	print simple string
curses	(UCB)	package of screen printing functions
printw	(UCB)	curses version of printf
clear	(UCB)	curses screen clearing function
move	(UCB)	curses cursor moving function
refresh	(UCB)	curses screen updating function
sleep	(Bell)	timed suspension of processing
timegetc	(CSL)	get a character within time limit
alarm	(Bell)	interrupt processing after time limit
signal	(Bell)	catch or ignore signals
getchar	(Bell)	get a character from keyboard
gets	(Bell)	get a string from keyboard
gtty	(Bell)	get terminal (tty) status
stty	(Bell)	set terminal (tty) status
expmode	(CSL)	put terminal in cbreak+noecho mode
ftime	(Bell)	read the 60-Hz clock
present	(CSL)	present stimulus and time response
nice	(Bell)	set program priority
EXP	(CSL)	general experimental control program
initscr	(UCB)	curses initialization function
rand	(Bell)	random integer generator
srand	(Bell)	seed random integer generator
time	(Bell)	get the time and date
varpak	(CSL)	package of variable handling functions
readvar	(CSL)	varpak: read variables from file
getvar	(CSL)	varpak: get a variable's value
atoi	(Bell)	ASCII to integer conversion
truevar	(CSL)	varpak: return variable's truth value
showtext	(CSL)	show textfile buffered for a screen
runtrials	(CSL)	basic iteration function
endwin	(UCB)	curses termination function

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