A multiprogram approach to real-time experimentation*

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A technique for implementing real-time experiments utilizing several separate and independent programs is discussed. The technique can be employed when the experimental procedure is divided into real-time and nonreal-time program units. These program units are executed in the most appropriate computing environment, and the resulting output is directed to a sequential file. The nonreal-time program issues commands to the real-time program by means of keywords that are inserted in the sequential file output at those points where real-time operations are required. These commands are interpreted by the real-time program which processes the sequential file. While the nonreal-time program is experiment-specific, the real-time program is independent of the particular experiment performed. The applications of this multiprogram approach to real-time experimentation are considered.

The Computer Laboratory for Instruction in Psychological Research must simultaneously support several real-time experiments. The laboratory must do this with limited resources. The most precious of these resources is central processor memory, while the least precious is sequential file storage. Thus, when designing and implementing a new real-time application program, the minimization of memory requirements is of major importance and the use of sequential file storage is of minor importance.

A simple and efficient programming technique has been developed to achieve a maximum utilization of real-time resources. This technique employs several independent programs to implement a single experiment. These programs are serially executed at different times and in the most appropriate computing environments. All output from these programs is directed to sequential file storage, such as disk or tape. One of the programs issues commands to the other by means of keywords which are inserted in the sequential file output. Thus, the simple keyword-command system is used to "explain" the output to the program processing it. Since this technique is adaptable to any computing facility that possesses some type of sequential file storage device, and since it seeks to solve the common problem of limited real-time resources, it is of possible interest.

The successful implementation of a real-time experiment is possible only if the programs designed to execute the experiment efficiently utilize the resources available. This can be accomplished by employing a multiprogram approach in implementing the real-time experiment. The operations necessary to conduct an experiment are of two types: (1) those operations which do not require a real-time environment, and (2) those operations which do require a real-time environment.

The greater part of most programs designed to implement real-time experiments does not require a real-time environment. This part is present only to execute experiment-specific tasks, such as specialized input and output, material generation, and data acquisition. This nonreal-time part of an experimental program requires much of the available real-time resources. Since the nonreal-time part of an experimental program processes information much like a typical batch program, a discussion of its basic operations will be unnecessary. However, a detailed analysis of the basic operations performed by the real-time part of an experimental program will aid in the identification of what should or should not be executed in real time.

BASIC REAL-TIME OPERATIONS

The real-time part of most experimental programs can be characterized by 11 basic operations, which are repeatedly performed and which are independent of the particular experimental paradigm being executed. These basic operations can be organized into four sets of operations. For the purposes of this presentation, these operations will be given keyword names, which will serve to identify their functions. The keywords will have the form "!" followed by some word which is indicative of the operations represented.

Acquisition of Information

The first basic real-time operation is the acquisition of information used to control the real-time experimental processes. This information typically consists of timing parameters, solution criteria, and various limits placed on the number of trials and the duration of an experiment. This operation can be represented by a single keyword, !VALUE. The !VALUE keyword represents a command to acquire all information that is actively used in the real-time environment. This

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KEYWORD	ARGUMENTS	OPERATION PERFORMED
1. !VALUE	(value 1,..., value n)	Acquire some arbitrary number of values for use in controlling real-time processes.
2. !(BLANK)	(some information)	Output the argument to the subject's terminal.
3. !OUTPUT	(some information)	Output the argument to the permanent data file.
4. !ANSWER	(some information)	Output the argument to the subject's terminal after making it contingent on the subject's actions.
5. !RESPONSE	(observation 1,..., observation n)	Output the value associated with each of the observation requested.
6. !DELAY	(some amount of time)	Maintain the output currently on the subject's terminal for the time period specified.
7. !PAUSE		Maintain the output currently on the subject's terminal until some arbitrary response is made. (A degenerate case of !WAIT)
8. !WAIT	(action 1=meaning 1,..., action n=meaning n)	Maintain the output currently on the subject's terminal until some specific action with the meaning indicated occurs.
9. !BREAK	(end of single task)	Indicates end of a single task.
10. !STOP	(end of set of tasks)	Indicates end of set of tasks.
11. !FINISH	(end of all tasks)	Indicates end of all tasks.

Fig. 1. Basic real-time operations and associated keywords.

command has some arbitrary number of arguments and can be written as

!VALUE (Value 1, Value 2, ..., Value n).

Output of Information

The second basic set of real-time operations concerns the output of information. This output is typically directed either to a permanent data file or to a S's terminal. Further, this output is either contingent or noncontingent on a S's actions. Thus, there are four output operations, which are represented by the keywords !(BLANK), !OUTPUT, !ANSWER, and !RESPONSE.

The !(BLANK) keyword represents a command to output a message to the S's terminal which is predetermined and which is not contingent on any action by the S. This keyword can also be thought of as the "default mode" of the real-time program. That is, if no other operation is specified, output is directed to the S's terminal.

The !OUTPUT keyword represents a command to direct information to the permanent data file. This output is not contingent on a S's actions and is predetermined.

The !ANSWER keyword represents a command to direct output to the S's terminal which is contingent on the S's actions. The !ANSWER command requires one argument which is to be the reply to S's actions. This argument may be modified prior to being directed to the S's terminal, so that it reflects the S's actions. This command can be written as

!ANSWER (response to S's action).

Finally, the !RESPONSE keyword represents a command to direct output, which reflects a S's actions, to the permanent data file. This command has an arbitrary number of arguments which specify what observations about a S's actions are to be output. This command can be written

!RESPONSE (Observation 1, ..., Observation n).

Timing of Output

The third basic set of real-time operations involves the timing of output directed to a S's terminal. This timing can be done in three ways. It can be done such that the output is maintained for a predetermined amount of time, or until a S makes an arbitrary response, or until a S makes a specific response. These operations are represented by the keywords !DELAY, !PAUSE, and !WAIT.

The !DELAY keyword represents the timing operation used to maintain output for a predetermined amount of time. The keyword !DELAY requires a single argument specifying the amount of time to maintain the output. This command can be written

!DELAY (time period to maintain output).

The !PAUSE keyword represents the timing operation used to maintain output until the S makes some arbitrary response. It requires no arguments and is simply a degenerate form of the !WAIT operation.

The !WAIT keyword represents the timing operation used to maintain output until the S acts in a specific way that has some relation to the output. The !WAIT keyword requires some arbitrary number of argument pairs which specify the acceptable actions and their meanings. This command can be written:

!WAIT (Action 1=Meaning 1, ..., Action n=Meaning n).

Termination of Operations

The fourth basic set of real-time operations involves the control of program execution. Real-time programs can control the presentation of a single task or sets of tasks. Thus, programs must identify the end of a single task, or the end of a set of tasks, or the end of all tasks. These termination operations can be represented by the commands !BREAK, !STOP, and !FINISH.

The !BREAK command represents the end of a single task, the !STOP command represents the end of a set of tasks, and !FINISH represents the end of all tasks.

A summary of all of these 11 basic operations and their associated keyword commands is contained in Fig. 1.

IMPLEMENTING A REAL-TIME EXPERIMENTAL PROGRAM

Once the separate real-time and nonreal-time parts of an experimental program have been isolated, optimization of each can be considered. To clarify this, a

The nonreal-time part often consists of the following: (1) the acquisition of experimental parameters, stimuli, and instructions, (2) the construction of the stimuli according to predetermined criteria, and (3) the identification of stimuli and their rules of classification. These operations can be performed by a single batch program, which would be executed in a nonreal-time environment. This program would generate all material to be presented to a S, assuming no solution was obtained. This nonreal-time program will be called the "generation" program. All of this output would be directed to a sequential file to be interpreted and processed by the real-time part of the experiment. However, wherever a real-time operation is required, a keyword command would be inserted. These keywords

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=====BEGIN SCREEN 1=====
SUBJECT NUMBER =114
RANDOM BASE =331
CONDITION =001
TRANSFER PARADIGM =001
TRANSFER PROBLEM =004
RULE TYPE =002
DATE AND TIME OF FILE GENERATION:
10/18/73 0954
PRESS EITHER BUTTON TO CONTINUE.
=====END SCREEN 1=====

=====BEGIN SCREEN 2=====
WELCOME TO THE
COMPUTER LABORATORY FOR INSTRUCTION IN PSYCHOLOGICAL RESEARCH
THE EXPERIMENT YOU ARE TO PARTICIPATE IN TODAY IS
DESCRIBED IN THE INSTRUCTION BOOKLET.
PRESS EITHER BUTTON TO CONTINUE.
=====END SCREEN 2=====

=====BEGIN SCREEN 3=====
EYES
CABBAGE
?
(After the subject responds with NUF, the "?" is replaced.)
WRONG, THE CORRECT ANSWER IS VEC.
=====END SCREEN 3=====

=====BEGIN SCREEN 4=====
LETTUCE
EYES
?
(After the subject responds with NUF, the "?" is replaced.)
WRONG, THE CORRECT ANSWER IS VEC.
=====END SCREEN 4=====

=====BEGIN SCREEN 5=====
CABBAGE
EYES
?
(After the subject responds with NUF, the "?" is replaced.)
RIGHT, THE CORRECT ANSWER IS NUF.
=====END SCREEN 5=====

=====BEGIN SCREEN 6=====
YOU HAVE SUCCESSFULLY SOLVED THIS PROBLEM.
THANK YOU FOR YOUR ASSISTANCE IN THIS EXPERIMENT.
=====END SCREEN 6=====

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would be those used to represent the 11 basic real-time operations specified earlier and shown in Fig. 1.

Likewise, the real-time program would be informed of the end of the task and all tasks by the !BREAK, !STOP, and !FINISH commands. The !BREAK command is of special interest here, since it signals the end of a single problem. The !STOP command would be inserted at the end of all tasks for a single S. The !FINISH command would be inserted at the end of all tasks for all Ss.

(Note that when the sequential file is generated, the maximum number of possible trials would be output, not just the criterion number. Once the criterion was

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|VALUE (CRITERION NUMBER OF TOTAL CORRECT=10)
|OUTPUT (114, 11,001,001,004,001,002)
|SUBJECT NUMBER =114
|RANDOM PAGE =331
|CONDITION =001
|TRANSFER PARADIGM =001
|TRANSFER PROBLEM =004
|RULE TYPE =001
|INSTRUCTION TYPE =002
|OUTPUT (10/18/73 0954)
|DATE AND TIME OF FILE GENERATION:
|10/18/73 0954
|PRESS EITHER BUTTON TO CONTINUE.
|PAUSE
| WELCOME TO THE
|COMPUTER LABORATORY FOR INSTRUCTION IN PSYCHOLOGICAL RESEARCH
|THE EXPERIMENT YOU ARE TO PARTICIPATE IN TODAY IS
|DESCRIBED IN THE INSTRUCTION BOOKLET.
|PRESS EITHER BUTTON TO CONTINUE.
|PAUSE
|EYES
|CAMRAGE
|?
|OUTPUT (EYES, CAMRAGE)
|WAIT (NUF=WRONG, VEC=RIGHT)
|RESPONSE( ? )
|ANSWER (_____, THE CORRECT ANSWER IS VEC.)
|DELAY (5 SECONDS)
|LETTUCE
|EYES
|?
|OUTPUT (LETTUCE, EYES)
|WAIT (NUF=WRONG, VEC=RIGHT)
|RESPONSE( ? )
|ANSWER (_____, THE CORRECT ANSWER IS VEC.)
|DELAY (5 SECONDS)
|CAMRAGE
|EYES
|?
|WAIT (NUF=RIGHT, VEC=WRONG)
|RESPONSE( ? )
|ANSWER (_____, THE CORRECT ANSWER IS NUF.)
|DELAY (5 SECONDS)
|(Output continues until maximum number of trials is presented or until
the criterion of 10 correct trials occurs.)
|BREAK (END OF PROBLEM)
|YOU HAVE SUCCESSFULLY SOLVED THIS PROBLEM.
|THANK YOU FOR YOUR ASSISTANCE IN THIS EXPERIMENT.
|PRESS EITHER BUTTON TO CONTINUE.
|STOP (ALL PROBLEMS COMPLETED)
|FINISH (ALL SUBJECTS COMPLETED)

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Fig. 2. A sample of output directed to the sequential file by the nonreal-time "generation" program.

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114 331 001 001 004 001 002
10/18/73 0954
EYES CABRAGE
RESPONSE=NUF=WRONG
LETTUCE EYES
RESPONSE=NUF=WRONG
CABRAGE EYES
RESPONSE=VFC=RIGHT

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(This output would continue for the entire solution sequence until the 10 correct trials criterion was obtained or until the maximum number of trials had been presented.)

Fig. 4. A sample of output directed to the permanent data file by the real-time "interpreter" program after processing the sequential file information shown in Fig. 2 and after receiving the S responses shown in Fig. 3.

reached, the "extra" information would not be presented, but would be skipped. Therefore, when the criterion is reached, the real-time program would scan through the sequential file, leaving all commands uninterpreted until the first occurrence of the !BREAK command. Commands would once again be interpreted once the !BREAK command was encountered.)

An example of the type of output that would be directed to the sequential file by the nonreal-time "generation" program is shown in Fig. 2.

Once the sequential file was output by the nonreal-time "generation" program, this file would be interpreted in real time by the real-time part of the experiment. The real-time part of the experiment is called the "interpreter" program, since it will interpret each of the 11 commands inserted in the sequential file by the "generation" program. The "interpreter" will input each record from the sequential file and execute the real-time operation specified by the keyword

command. In Fig. 3, a sample of the output directed to a S's terminal, as a result of processing the sequential file in Fig. 2, is presented. The responses input by the S would be requested by the "interpreter" program and processed as specified.

The "interpreter" program would also direct output to the permanent data file as a result of processing the file shown in Fig. 2 and the S's responses indicated in Fig. 3. A sample of several trials of output is presented in Fig. 4.

APPLICATIONS AND CONCLUSIONS

The multiprogram approach to real-time experimentation has been used to successfully implement a large number of real-time experiments. While many nonreal-time "generation" programs have been developed, only a single real-time "interpreter" program has been developed. Since the "interpreter" program is exceedingly versatile, it has proven to be adequate for most experiments. Because the "interpreter" is small (less than 1,500 locations), several copies of it are simultaneously in operation. The "interpreter" program can be adapted to purposes other than concept identification experiments. Computer-assisted instruction, serial list learning, and virtually any task that stores materials on a sequential file can be implemented. Such implementation only requires a nonreal-time "generation" program to be developed. It is hoped that the reader has acquired some ideas on how to utilize the multiprogram approach to implement new real-time experiments.

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Monitoring experimental results*

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No matter whether an experiment is a success, a failure, or a mixture of the two, the E needs to see his results immediately to be able to plan his next study. For this purpose, he needs a rapid, simple, relevant analysis of the data. We define a version of this data-summarizing problem and describe a monitor program to solve it. One major decision is what search method and data file organization to use: We use the n-dimensional array method. We specify dependent variables in two parts: first, a measure code like proportion correct, reaction time, etc., and second, a series of coefficients to specify what items will make up the desired dependent measure. Our program is interactive and makes extensive use of default options. Some suggestions are made for the implementation of monitor programs on other hardware.

There are three ways an experiment can come out: it can be a failure, a qualified success, or a complete success.

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If the experiment is a complete failure, this may mean, among other things, that all Ss responded at chance, that response times were very long, or that an apparatus failure produced invalid data. A superficial analysis of the overall results will usually reveal such problems, and the E will want to make some change in