Title
A General Model For Simulating Information Processing Experiments

Journal
Proceedings of the Annual Meeting of the Cognitive Science Society, 4(0)

Authors
Hunt, Earl
Plxton, Pollyanna

Publication Date
1982

Peer reviewed

A General Model for Simulating Information Processing Experiments

Earl Hunt and Pollyanna Pixton
The University of Washington

Psychologists who study cognition have followed two approaches. One is to isolate elementary processes of thought and study them in laboratory settings. Most of experimental psychology follows this tradition. Alternatively, one can study complex thinking directly, by developing descriptions of the processes of chess playing, mathematical problem solving, medical diagnosis, and the like. This tradition is dominant in Cognitive Science. The experimental psychology approach has produced a set of reasonably concise concepts applicable in restricted settings, but it is not clear how these concepts are to be combined during complex reasoning. The descriptive approach has produced concepts that describe thought, but the concepts are so flexible that it is often difficult to test them. The widely used production notation, for instance, is a way of thinking about thinking rather than a testable model of thought processes.

Our research attempts to unify the two approaches. Instead of trying to build up from elementary processes to complex acts, we have taken a "top down" approach. We assume that the production notation is an appropriate language for describing thought, and then use it to construct a unified model of information processing that is applicable to several laboratory paradigms.

If production notation programs ("production systems") can be written to model any thought process, then the mind, in general, must be an interpreter for such programs. We have written such interpreter, using concepts derived from experimental psychology in its construction. The interpreter contains sections dealing with the input of information over multiple "sensory" channels (Broadbent, 1971), the manipulation of information in working and long term memory (Baddeley, 1976), the activation of distinct coding systems within long term memory (Posner, 1978), and the execution of information processing steps by a cascade rather than a linear process (McClelland, 1979).

Overview of the Model

The basic programming construct, a production, is a two part rule,

pattern ——→ action

where "pattern" refers to a set of conditions that must be met for a production to be activated, and "action" refers to the steps to be taken when the production's pattern conditions are met.

Time in the interpreter is divided into cycles. Within each cycle the following events take place, functionally in parallel. Assume that stimuli are present in the sensory channels and in working memory and that each production in long term memory has associated with it a number indicating its "level of activation". The interpreter compares the stimuli to the pattern half of each production. The comparison produces a numerical value that will be called the "strength" of the match. A production is considered "active" if the strength of the match exceeds a threshold associated with the pattern. A new activation level is then calculated, which is monotonically increasing function related to the difference between the strength of the match and the threshold value. (In most of our work, we simply use the difference). The activation level is then either increased or decreased by the activation level of other productions linked to it. This process, which constitutes "spreading activation" is referred to as priming. Finally, at the end of each cycle all activation levels are reduced ("decayed") to a proportion of their previous values.

When the activation level of one production exceeds the activation level of all competing productions by a preset criterion, the action half of the production is initiated. The action may be an external response, alteration of an internal parameter in the model, or generation of a stimulus in working memory. If no external response is made, "time" is incremented and the program continues cycling through the set of productions, now using the new stimulus or the old stimulus with new parameters, if they have been altered. Firing and cycling continues until an action terminates the program or the program exceeds the allowed processing time.

The program imposes psychologically justifiable constraints upon production execution. This is done in such a way that production processing will produce the phenomena observed in laboratory studies of mechanistic information processing. These constraints are described in more detail in the next section.

Details of the Program and Model

The program, which we call MIND, is written in standard Pascal and contains about 1000 lines of code. Production pattern-action pairs are currently represented in an internal symbol code rather than brief English statements.

A. Initialization

The input to the program consists of a set of productions, the threshold levels for each production and an association matrix which links the productions to each other in a negative, positive or null manner. Other program parameters read during initialization are the decay rate, the decision criterion (DR), an internal noise scale factor and a maximum processing time.

Information (a stimulus) is presented over two external classes of sensory channels: visual and auditory. Associated with each of these external classes of channels is a special channel which is referred to as an immediate memory for information of that class. In addition there is a special class of channels referred to as "semantic" channels. The semantic channels and the immediate memory channels are collectively referred to as "working memory" (WM). Each production is associated with a channel or channel class. Only stimuli from external sources can be placed in the external channels. The working memory channels can be written to only by the action side of a production.

Each pattern in a production is an ordered string of features. A stimulus consists of one or more patterns. The initial stimulus (patterns and pattern features) is read into the program along with stimulus feature noise levels. Noise levels are used when comparing the stimulus features with the production pattern features. The initial stimulus is placed in specified external channels.

B. Response Queue

The response queue contains all the actions which have been initiated during the previous program cycle. At the beginning of each cycle, the queue is examined and the appropriate action is executed. Details of possible actions are explained in section E.

C. Production Activation

A match is computed between the pattern part of each production and the stimulus on the appropriate channels. A pattern always specifies that it is to be matched to a channel class, and may specify a particular channel within that class. The matching function uses the confusion matrix to weight heavily the most likely pattern matches and to weight lightly the least likely patterns. "1", a most likely pattern would be:

see "1" ——→ recognize "1"

and a least likely pattern would be:

see "2" ——→ recognize "2"

Stimulus "7", being somewhat similar to "1", would be an intermediate case. Within the pattern part of each production, stimulus features are weighted by their importance for that pattern.

The strength of the match plus a noise term (a random number that is scaled by the internal noise input parameter) determines the activation level, y[i], of the ith production. If the activation level is greater than the threshold level, the production is considered active and is placed in a set of active productions, {act(y[i])}. If it is not greater than the threshold, the activation level is set to zero.

In this process, all stimuli are compared to all productions in the appropriate channel class.

D. Decision Rule

When production activation processing has been completed, all the active productions are searched to identify the highest activation level. If this most active production exceeds all the other productions by some decision rule variable, DR (an input parameter), the action half of the production is placed in the response queue.

E. Actions in the Response Queue

Actions either:

1. Make an external response. A response will terminate production processing.
2. Place an effective stimuli in one of the channels in working memory.
3. Alter an internal parameter of the program (such as altering the threshold level of a production).

Actions are seen as taking place in stages that extend over time. Once the action is initiated, it proceeds, one stage during each time cycle, in parallel with any other actions that may be being executed at the same time. Actions can not contain any branches or decision points.

F. Priming

After the decision rule has been processed, the activation levels of all the productions are "primed". Using the link formed between the productions by the association matrix, y[i] is either increased (when the link is positive), decreased (when the link is negative) or not affected (if there is no link). Essentially, a weighted sum of the activation levels of the other productions is added to the ith production's activation level, y[i].

G. Decaying

The activation level is also reduced by a delta value, D, another input parameter. Delta is always greater than zero but never greater than one. The decay rule is:

$$y[i] = D * y[i]$$

H. Time Cycling

After the priming and decaying of the activation levels has occurred, time is incremented. If the time then exceeds the maximum processing time specified during initialization, Production processing halts. Otherwise the program checks the response queue and continues processing the productions.

Preliminary Results

The MIND program has been used to recreate several of the most reliable findings observed in laboratory studies. As the purpose of the simulation experiments was to evaluate the psychological reasonableness of the interpreter, we sought situations in which the production systems to be interpreted were, at the program level, as simple a psychological model as possible. The logic of this approach is similar to the logic behind use of very simple programs to test the arithmetic capabilities of computer hardware. As is well known, there are probably no situations that dictate the use of one and only one possible model for human behavior. We do feel that the laboratory situations we have studied approach this ideal in varying degrees.

The approach will be illustrated by a study of the "choice reaction time" (CRT) paradigm. A participant's view is shown in Figure 1. The task is to press the button whose number matches the number appearing on the screen. The task as shown is a two choice task, four and eight choice tasks are constructed on the same principle. It is well known that the time to make a choice in a CRT experiment is a logarithmic function of the number of alternative stimuli that may appear (Hick's law).

Figure 2(a) shows a production system for executing a two choice CRT task. Figure 2(b) shows the associated production activation network. The figure illustrates an important principle that is used in constructing our networks. If two productions, A and B, are in the same channel class and are mutually exclusive alternative interpretations of a stimulus, then the productions inhibit each other. However, if production A produces, as its action, a stimulus that might trigger production B, then A primes B. The priming relation may hold for productions in the same or in different channel classes.

Figure 3 presents the results of a simulation of CRT experiments with varying numbers of choices. Two results are shown, for two different values of the DR parameter. Data from an actual experiment (Taylor, 1982) are also shown. The number of cycles required by the MIND program was approximately a linear function of the logarithm of the number of choices, but departed from linearity slightly at the 8 choice point. Reaction times from the psychological study showed the same pattern.

Another characteristic of CRT experiments is the "speed-accuracy trade off". For a given individual and condition, the faster a response is made the more likely an error is to occur. When accuracy is plotted against reaction time the function is almost invariably negatively accellerated (Pachella, 1974). Figure 4 shows a speed-accuracy curve obtained from MIND by varying the value of the DR parameter, while keeping all other parameters and the number of choices constant. The program clearly matched the function found in human data.

The speed-accuracy tradeoff describes the relation between accuracy and latency for a given individual and condition. When one changes either the individuals being tested or the experimental conditions, speed and accuracy are often positively correlated. For instance, older people tend to perform more slowly in CRT tasks, and to make more errors (Welford, 1977). This result was simulated by holding DR constant constant, and varying the internal noise parameter. The results are shown in Figure 5. Again the pattern is similar to that obtained in the laboratory.

MIND has been used to simulate a number of other results from the literature in experimental psychology. These include the Stroop phenomenon (Stroop, 1935), the effects of repetition of the same stimulus over trials in CRT paradigms, and interference effects when two tasks are done simultaneously. These results will be reported in a larger paper. While we do not claim to have modeled the microstructure of all these phenomena perfectly, the initial results are encouraging. The ranges of parameter values that are adequate to simulate one task overlap considerably with those required in other tasks. This is a particularly encouraging finding. It appears that the values of the parameters of this model must be held to a rather tight range if the model is to work at all, but that within this range reasonable results can be obtained.

ACKNOWLEDGEMENT: The research reported here was supported by the Office of Naval Research, Contract N00014-80-C-0631, to the University of Washington. We are glad to thank Dr. Marcy Lansman for her constructive comments and criticisms.

REFERENCES

Baddeley, A. D. The Psychology of Memory. New York: Basic Books, 1976.

Broadbent, D. E. Decision and Stress. New York: Academic Press, 1971.

McClelland, J. L. On the time relations of mental processes: An examination of systems of processes in cascade. Psychol. Rev., 1979, 86, 187-330.

Pachella, R. G. The interpretation of reaction time in information processing research. In B. H. Kantowitz (ed.) Human Information Processing: Tutorials in Performance and Cognition. Hillsdale, N. J. Lawrence Erlbaum Associates, 1974.

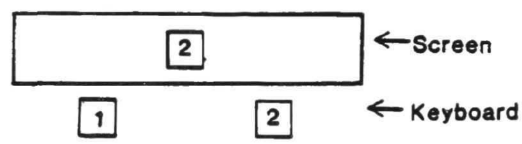
Posner, M. I. Chronometric explorations of mind. Hillsdale, N. J.: Lawrence Erlbaum Associates, 1978.

Stroop, J. R. Studies of interference in serial verbal reactions. J. Experimental Psychology. 1935, 18, 643-662.

Taylor, J. The effects of benzodiazepines on cognition and performance. U. of Washington Ph. D. thesis (Psychology). 1982.

Welford, A. T. Motor performance. In J. E. Birren and K. W. Schaie (ed.) Handbook of the Psychology of Aging. New York: Van Nostran Reinhold, 1977, pg. 450-477.

FIGURE 1



CHOICE REACTION TASK

Production Rules

Visual	**Channel 1 = 1**	→	**Put S1 in Semantics**
	Channel 1 = 2	→	**Put S2 in Semantics**
Semantic	**S1**	→	**Make response 1**
	S2	→	**Make response 2**

Figure 2 (a) Simulation of CRT experiment

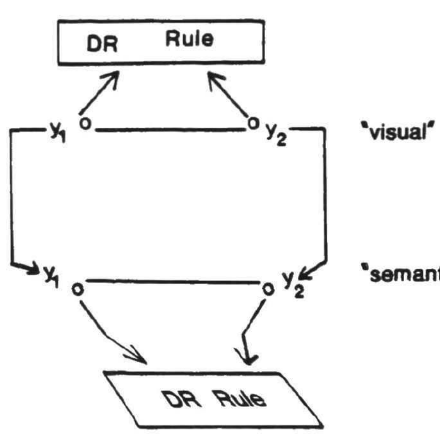
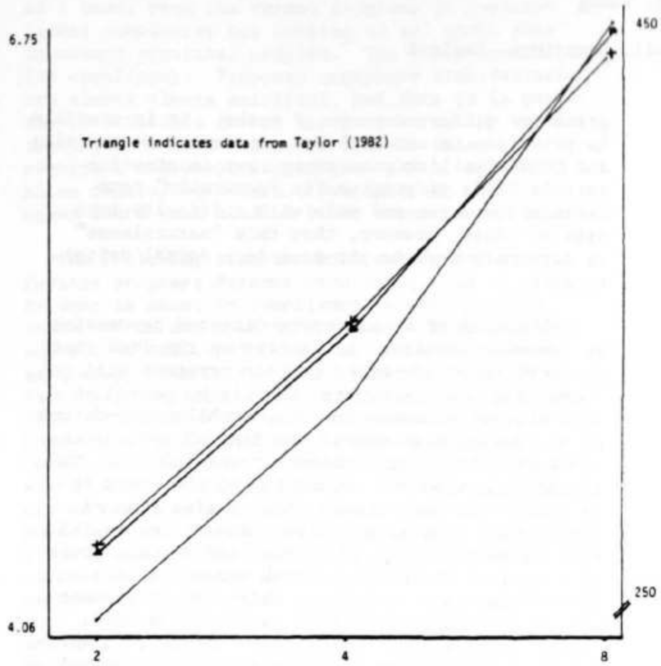


Figure 2(b) Association Network For

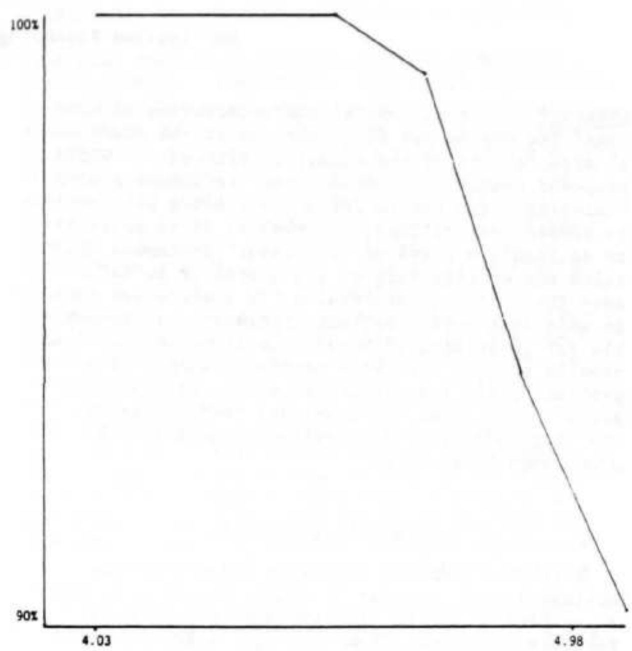
2 choice Task

Figure 3



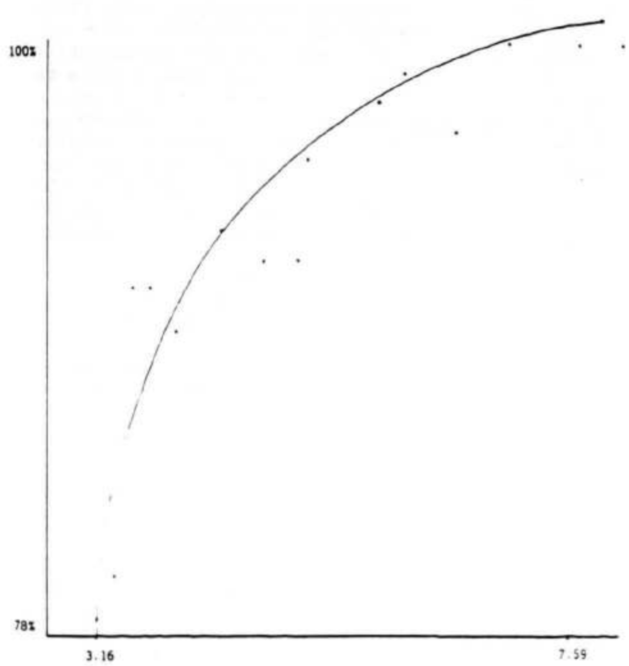
Number of cycles to decision point (left ordinate) or reaction time (right ordinate, in milliseconds) as a function of the number of choices

Figure 5



Accuracy of choice (ordinate) vs. number of cycles (Abelssa). Each point representa a different value of the internal noise parameter. Two choice task.

Figure 4



Accuracy of choice (ordinate) vs. number of cycles required to reach a decision. Each point represents a different value of the DR parameter.