Modeling Cognitive versus Perceptual-Motor Tradeoffs using ACT-R/PM

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Abstract

Information stored *in-the-world* is retrieved from external memory via visual perception as rendered by the appropriate saccades and fixations. Recent research has suggested that when information in-the-world is readily accessible, internal storage is not needed. Perceptual-motor strategies will be deployed to reacquire information as needed. However, Fu & Gray (2000) found that when the cost of information access was increased from a simple key press to a one-second lockout time, the perceptual-motor strategy was replaced with a strategy that placed task-relevant information into working memory. This suggests that the decision to store information in-the-head versus in-the-world is sensitive to effort considerations. In this paper, we present our work-in-progress report on modeling the data using ACT-R/PM.

Introduction

If information in the external environment can be considered as an external memory store, the cost in searching for the relevant information in the external environment can be taken as the "memory" search cost. If the only cost associated with internal and external memory were a search cost, then we would expect that in most situations internal search would be faster than external search. However, for internal memory a significant additional cost is internal storage (encoding).

Compared to a memory strategy that includes encoding plus retrieval, a saccadic eye movement to a known location has a much lower time cost. However, when the cost of information access from the external environment is high enough, the expected utility of external memory would be lower than that of internal memory. In this case, one would expect a shift from external memory to internal memory. In other words, people would be more likely to adopt a memory strategy than a perceptual-motor strategy.

In this paper, we describe a ACT-R/PM model of this kind of cognitive versus perceptual-motor tradeoffs. Specifically we attempt to model the phenomenon that an increase in the perceptual-motor cost of information access will induce a shift from an external to an internal memory strategy.

The Task

The task is to copy a pattern of colored blocks shown in the *target* window to the *workspace* window, using the colored blocks in the *resource* window (for our version see Figure 1). All three windows were covered by gray boxes. Throughout the task only one of the windows could be uncovered at a time. The resource and workspace windows were uncovered by moving the mouse cursor into the window. They were covered again when the mouse cursor left the window. The effort required to uncover the target window varied between each of our three conditions.

To access the information in the target window participants could adopt either a predominately perceptual-motor or a predominately memory strategy. The predominately perceptual-motor strategy would entail one uncovering at the target window to obtain color information and another to obtain position information. In contrast, a predominately memory strategy would entail one uncovering at the target window to obtain both color and position.

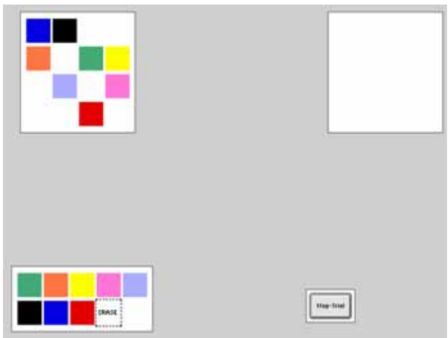

Figure 1. The blocks world task. In the actual task all windows are covered by gray boxes and at any time only one window can be uncovered. The window at the top left is the target window, at the bottom the resource window, and at the top right the workspace window.

Design and Procedure

The three conditions were designed to vary the cost of uncovering the target window. In the *low-cost* condition, participants had to press and hold down a function key. In the *control* condition, all three windows were uncovered when the mouse cursor entered the window. In the *high-cost* condition participants had to move the mouse cursor inside the target window and endure a one-second lockout before the target window was uncovered.

Empirical Results

An ANOVA on the number of times the target window was uncovered showed a significant main effect of condition (F (2, 45) = 10.17, p = .0002, MSE = 159).

(See Figure 2). ANOVA on the time subjects spent looking at the model showed that there were significant main effects of conditions (F (2, 45) = 20.6, $p < .0001$, MSE = 300).

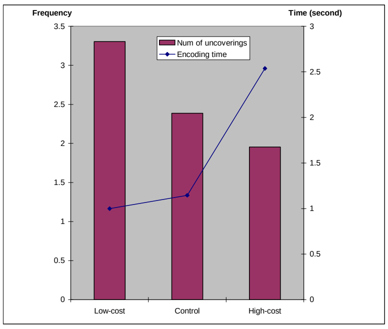

Figure 2. The mean total frequency of uncovering of the target window per trial and time uncovered of the target window.

The Model

The data were modeled using ACT-R/PM, a theory that combines the ACT-R theory of cognition (Anderson & Lebiére, 1998) with a modal theory of visual attention, and motor movement. In so doing, ACT-R/PM permits motor and visual attention processes to be executed in parallel with each other as well as with cognitive processes.

The main goal of the model is to capture the cognitive and perceptual-motor tradeoffs in the *control* and *high-cost* conditions. Perceptual-motor cost was represented by the movement time predicted by Fitts' law, and the one-second lockout time in the high-cost condition. Cognitive cost was represented by the time spent encoding information of the block(s) in the target window. In ACT-R, the total effort C associated with a production is represented by the sum of two parameters: a and b. (C = a + b) The a parameter represents the current effort in executing a particular production; the b parameter represents the downstream effort involved between the time after the current production is executed until the time when the current goal is accomplished (popped). The higher the sum of these values, the less likely the production will be executed. Since it is the sum of these two parameters that determines the result of the production selection, it is possible that the model would choose a production rule that has a high current effort (a), but a low downstream effort (b).

The basic structure of the model is shown in Fig. 3. In the beginning of each trial, a strategy of encoding n blocks (n=1 to 8) is picked. The a parameter (current effort) associated with this production represents the encoding time, and therefore increases with n. The b parameter (downstream effort) decreases with n, since the more blocks one encodes per uncovering of the target window, the fewer number of times one needs to uncover the target window again. Therefore in general, when n is small, a is small but b is large; when n is large, a is large but b is small. Interestingly, when the cost of uncovering the target window increases, a remains unchanged, but the increase in b is much larger for small n than large n (since a strategy with small n entails more uncoverings of the target window). Therefore when the cost of uncovering the target window increases, the total cost (C = a + b) for strategies with small n will be higher than that with large n, producing the basic tradeoff effect as shown in Fig. 2.

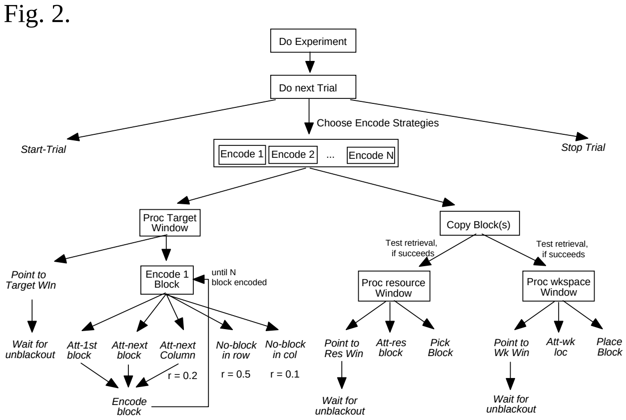

Figure 3. The basic structure of the model.

At this point, we are adjusting the effort parameters to obtain a good fit to the data. Our ultimate goal is to have the model learn the effort parameters and converge to an "optimal" encoding strategy that matches the empirical data in each condition. We believe that this will allow us to further understand the underlying mechanisms for this kind of cognitive versus perceptual-motor tradeoffs.

References

Anderson, J. R., & Lebiére, C. (Eds.). (1998). *Atomic components of thought*. Hillsdale, NJ: Erlbaum.

Fu & Gray (2000). Memory versus Perceptual-Motor Tradeoffs in a Blocks World Task. *Proceedings of the 22nd Annual Conference of the Cognitive Science Society* (pp. 154-159). Hillsdale, NJ: Erlbaum.