Modeling Individual Difference Factors in a Complex Task Environment

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Abstract

Cognitive models are often used to predict the average performance of a population. For many purposes, however, generating predictions of individual performance is crucial. We propose a methodology in which the ACT-R architecture is extended, through the setting of architectural parameters that represent individual differences, into a model of individual behavior. This approach can provide a vast range of predictive and diagnostic capabilities from a modest initial investment of resources.

Introduction

Cognitive models often produce results that model those of a typical individual, or the average of a population of individuals. For many purposes, however, it is desirable or even necessary to model individuals.

We describe here a methodology in which data from subjects performing simple tasks are used to parameterize a cognitive-level model so as to model each individual. These models can then be used to predict individual performance in more complex tasks. Those models can inform pure scientific investigations or serve as a low-cost diagnostic procedure in applications such as low-cost evaluation of personnel, in task analysis, or interface design.

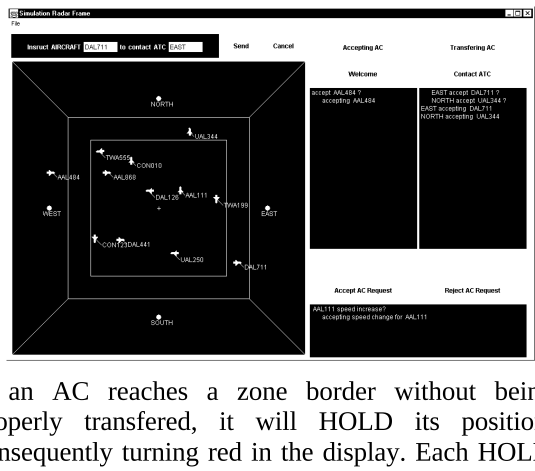
Lovett, Reder & Lebiere (1997) showed that ACT-R's *W* parameter that describes working memory capacity can be set to values that describe individual ability, yielding models that predict individual performance. The work described here extends that foundation by testing a two-parameter model of individual differences utilizing both *W* and a parameter describing psychomotor ability. Individual values for these parameters can be determined via easily administered tests. We have begun comparison of individual and model performance in the moderately complex AMBR air-traffic control (ATC) simulation (Gluck & Pew, 2002).

The AMBR Task

AMBR is loosely based upon air traffic control. It calls for the subject to process aircraft (AC) as they enter and leave a central airspace zone, for which the subject is responsible. As an AC moves to or from the central airspace zone to any of the four neighboring zones, the subject must issue commands, via a graphical interface, that transfer responsibility for the AC from one controller to another. Each transfer, whether it is into or out of the central zone, requires two commands (one to make initial contact, one to verify transfer). The same AC must thereby be issued a total of four commands if it passes into and subsequently out of the central zone during a scenario. In addition, a fifth type of command is required if an AC requests a speed change, which requires the subject to make a trivial judgement as to whether or not the AC is on course to catch, from behind, any other AC; if so, the speed change request should be denied, and otherwise, it should be accepted.

The need to issue most commands (four of the five types) is prompted by a text message that appears in one of the message windows on the right side of the display. These windows also provide feedback messages when a command has been issued. The need to issue the first command that transfers an AC out of the central zone is not prompted by a message; this command must be issued when the subject notices, in the simulated radar display, that the AC is departing the central zone. A static image of the AMBR display is visible in Figure 1.

Figure 1: The AMBR Display



If an AC reaches a zone border without being properly transfered, it will HOLD its position, consequently turning red in the display. Each HOLD is scored as an error. AC can never crash, nor do they take off or land.

It should be noted that AMBR is not highly faithful to the task that professional air traffic controllers face. (Notably, real ATC involves voice communication with aircrews and changing aircrafts' routes and altitudes.) Our goal is not to study expert behavior, but rather the behavior of novices who thoroughly understand the AMBR task, the rules of which subjects come to understand in a matter of minutes.

Parameters and Individual Differences

The ACT-R architecture provides a well-developed core around which to build specific cognitive models (Anderson & Lebiere, 1998). Certain work in the ACT-R community has pursued values for some architectural parameters, based on the assumption that those values are roughly universal across subjects and situations (ibid, p. 217). In contrast, Lovett, Reder & Lebiere (1997) posited that the *W* parameter, governing working memory capacity, may be thought of as an individual difference variable, and that varying *W* can tune an ACT-R model to the abilities of an individual. This has been empirically borne out by comparing individual performance on pairs of memory tasks (Daily, Lovett & Reder, 1999).

Working memory capacity is a very important individual difference variable (Kyllonen & Christal, 1990), suggested by some to be identical to Spearman's *g* describing general intelligence (Conway, Kane & Engel, 1999). Individual models, however, in order to achieve even modest fidelity, require extending the *W*-only paradigm via a parameter, *Pm*, describing general psychomotor ability. This two-variable model of individual differences has been incorporated into an existing ACT-R model of the AMBR task (Lebiere & Biefeld, 2002) to create a model of individual performance.

Methodology

In our methodology, subjects begin by participating in tasks that allow us to estimate each subject's individual *W* and *Pm* values. The subjects then go on to participate in several AMBR scenarios. Individual values for *W* and *Pm* are plugged into the ACT-R model of the AMBR task. Each subject's individual model can then be run on the same scenarios in which the subjects participated. Subject and model performance are then compared on a wide range of measures, from the coarse to the fine. This phase aims to establish that we have a model that predicts individual behavior to a high degree of fidelity.

Subsequent phases of the research will pursue application-driven goals, using the model to predict performance as a function of individual abilities, variations in workload and interface, and across a variety of tasks. During all phases, fidelity of the model will be evaluated and refined. This will be particularly important if we wish to extend the methodology to tasks that, unlike AMBR, invite a large degree of strategic differences between subjects. Previous work has empirically sought correlations in individual behavior between unrelated tasks (Ackerman & Kanfer, 1993; Joslyn & Hunt, 1998). Our aim is to show that modeling can replace intensive empirical testing. Preliminary work suggests that our model has much of the hoped-for validity and points the way towards more accurate and more complete models employing this methodology.

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