DAPT: 조종 기술의 예측적 인지 모델

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ADAPT: A Predictive Cognitive Model of Piloting Skill

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Abstract

A comprehension-based computational model of pilot action planning called ADAPT is presented to model pilot performance in a flight simulation context. Individual pilots were asked to execute a series of flight maneuvers using a flight simulator, and their eye-scanning, control movements, and flight performance were recorded in a time-synched database. Computational models of each of the 25 individual pilots were constructed, and the individual models simulated execution of the same flight maneuvers performed by human pilots. The time-synched eye-scanning, control movements, and flight performance of individual pilots and their respective models were compared to test ADAPT's predictive validity.

1. Introduction

Our theoretical premise rests on Kintsch's (1988, 1998) Construction- Integration theory of comprehension. Kintsch's theory has been used to explain a wide variety of behavioral phenomena, including narrative story comprehension (Kintsch, 1988), Algebra story problem comprehension (Kintsch, 1988), the solution of simple computing tasks (Mannes & Kintsch, 1991), and completing the Tower of Hanoi task (Schmalhofer & Tschaitschian, 1993). This approach has also proved fruitful of understanding human-computer interaction skills (Kitajima & Polson, 1995) and predicting the impact of instructions on computer user performance (Doane, Sohn, McNamara, & Adams, 2000; Sohn & Doane, 1997). The breadth of application suggests that the comprehension processes described in Kintsch's model play a central role in many tasks, and as such it may be considered a general architecture of cognition (Newell, 1987; Kintsch, 1998).

The present research extends Kintsch's (1988, 1998) Construction-Integration theory of comprehension to account for pilot cognition in the complex and dynamically changing environment of aviation. In this context, planning and action take place serially and the pilot is working on multiple tasks at any given moment. Thus accomplishing tasks in the present research refers to the successful prioritizing of multiple goals and actions in a dynamically changing task environment.

Specifically, we evaluate whether ADAPT, a construction-integration model of adaptive piloting skill can predict pilot eye-scanning, control movement, and flight performance as a function of flight situation and piloting expertise. This was accomplished by simulating the performance of twenty-five pilots on seven segments of flight, and then comparing human and model performance data to determine ADAPT's predictive validity.

1.1. Construction-Integration Theory

According to Kintsch's view, memory is represented as an associative network where the nodes in the network contain propositional representations of knowledge about the current context or task, general (context-independent) declarative facts, and If/Then rules that represent possible plans of action (Mannes & Kintsch, 1991). The declarative facts and plan knowledge are similar to declarative and procedural knowledge contained in ACT-R (e.g., Anderson, 1993).

When the model simulates comprehension in the context of a specific task, a set of symbolic production rules *construct* an associative network for knowledge interrelated on the basis of similarities between propositional representations of knowledge without regard to task context. This associative network of knowledge is then *integrated* through a constraint-satisfaction algorithm that propagates activation throughout the network, strengthening connections between items relevant to the current task context and inhibiting or weakening connections between irrelevant items.

This integration phase results in context-sensitive knowledge activation constrained by inter-item overlap and current task relevance. Since the present research pursuits the construction of adaptive plans of action rather than retrieval of known routine procedures, the ability to simulate context-sensitive knowledge activation is considered to be most important. Therefore, symbolic/connectionist architectures which use symbolic rules to interrelate knowledge in a network, and then spread activation throughout the network using connectionist constraint-satisfaction algorithms have significant advantages and utilized in this research.

2. Empirical Study

Piloting performance data derived from student and instructor pilots during simulated flight was used to build and test ADAPT model of pilot instrument-scanning and control performance.

2.1. Participants

Twenty-five participants, student pilots and instructor pilots, were divided into three expertise groups: novice, intermediate, and expert groups. These expertise groups had an average total flight time of 50 hr, 480 hr, and 1470 hr respectively.

2.2. Apparatus

A 19-inch monitor displayed the instrument panel with the standard primary instruments (the airspeed indicator, attitude indicator, altimeter, turn coordinator, heading indicator, vertical speed indicator, and tachometer) and a cockpit instruction panel that specified the heading, altitude, and airspeed desired at the beginning and end of a maneuver. Pilots used a sidearm-mounted joystick to provide control inputs such as roll (lateral stick movement), pitch (fore-aft stick movement), and power (push or pull back movement of a button atop the stick).

2.3. Procedure

Participants flew seven different flight maneuvers that required airspeed, heading, and/or altitude changes. The first three maneuvers of the simulation required a change in only one flight axis; airspeed, heading, or altitude (the other two values were to be maintained at starting values). The fourth through sixth maneuvers required changes in two flight axes, and the seventh maneuver required three axes changes.

3. Simulation Study

The data derived from empirical study were used to measure the match between human and model performance. Prior to comparison, we will outline the ADAPT model of piloting skill.

3.1. Knowledge Representation

ADAPT represents human memory as an associative network where each proposition representing knowledge constitutes a single node. ADAPT represents the three major classes of knowledge proposed by Kintsch (1988): world knowledge, general knowledge (e.g., declarative facts), and plan element knowledge (e.g., procedural knowledge represented as If/Then rules).

3.1.1. World Knowledge

World knowledge in ADAPT includes the pilot's knowledge of the current and desired states of the airplane, determined relationships between the current and desired states (e.g., altitude is higher than desired value), and flight segment goals.

3.1.2. General Knowledge

General knowledge refers to factual knowledge about piloting. In ADAPT, general knowledge represents facts about the relationships between control inputs and plane performance, and knowledge of flight dynamics, display instruments, and control movements.

3.1.3. Plan-Element Knowledge

Plan elements describe actions that can be taken in the world, and they specify conditions under which actions can be taken. Thus, pilots have condition-action rules that they can consider and execute if conditions are correct Plan elements are three-part knowledge structure that include a name, preconditions, and outcomes. When preconditions are satisfied in the order for the plan to fire, the outcome is added to the world knowledge if the plan is executed.

ADAPT contains two major classes of plan elements· cognitive and action. There are three forms of cognitive plan elements (i.e., monitor-status, determine, and change) that represent mental operations and two forms of action plan elements (i.e., monitor-display and control plans) that represent explicit behaviors.

3.3. Constructing Knowledge Bases

Twenty-five individual knowledge based were constructed to represent individual pilots who participated in the empirical study. This was done through observations of a small portion of the pilot's eye-scanning, control movement, and airplane performance data. 56 sec of empirical performance sample was collected to build individual knowledge bases that were used to predict approximately 11 min of pilot behavior during simulated flight maneuvers. Overlay method (see VanLehn, 1988) was used to determine what pieces of knowledge would be included in the individual's knowledge base.

3.4. ADAPT Simulations

The model operates in a cyclical fashion, firing the most activated plan element whose preconditions exist in the knowledge base. For plans to be selected for execution, they must be relevant to the current and desired flight status (as dictated by the world knowledge) and their preconditions must exist in the world knowledge. The outcome propositions of the fired plan element are added to the world, and construction begins again with the modified knowledge base. Following construction, the modified and associated knowledge is integrated and a subsequent plan element is selected for execution. This process continues until the goals are accomplished. The model is working on multiple goals at a time and multiple plan elements compete for activation. There are no apriori constraints on the order of plan element firing in ADAPT.

3.4.1. Construction

During construction, ADAPT computes relationships between propositions in the knowledge base (k) to compute a task-specific network of associated knowledge. The model uses low-level rules to construct a symmetric task connectivity matrix (c), where each node (c(i,j)) contains a numeric value corresponding to the calculated strength of the relationship between k(i) and k(j). The resulting network represents the unconstrained relationships between knowledge brought to bear to accomplish this specific task.

ADAPT uses the construction relationships and weights devised by Mannes and Kintsch (1991), including positive and inhibitory argument overlaps of 0.4 and −0.4 respectively, a proposition embedding of 0.8, plan-element precondition and outcome mapping of 0.7, world knowledge and plan-element outcome mapping of −10.00, and maneuvering goal and plan-element name mapping of 1.5.

3.4.2. Integration

The constructed network of knowledge represents unconstrained relationships between knowledge elements. To develop a situation model (e.g., Kintsch, 1988), this knowledge must be integrated by using constraint-based activation to spread activation throughout the network. This process essentially strengthens the activation of knowledge elements consistent with the task context and the environmental situation of flight, and dampens the activation of others. Computationally, integration constitutes the repeated post-multiplication of the constructed network (matrix) by a vector.

The vector values represent the current activation of each knowledge element represented (e.g., the value of the first item in the vector represents the current state of activation of the first proposition in the knowledge base, and so on). The iterative integration process stops when the difference between two successive activation vectors is less than 0.0001. At this point the resulting activation vector becomes the final activation and represents the stabilized activation of knowledge. The final activation vector is then used by the model to make executive decisions regarding the next plan element to fire.

3.5. Testing ADAPT

After constructing individual knowledge bases by observing a small portion of empirical performance data, we used automated modeling procedures to simulate, and thereby predict, the unobserved pilot data.

ADAPT was tested by simulating each pilot's performance on the seven flight maneuvers. A given pilot's knowledge base was accessed by ADAPT, and the model was given desired flight goals and beginning airplane status. This information match what was given to individual human pilots at the start of a given flight maneuver. The model executed a Construction–Integration cycle, and selected the most activated plan element whose preconditions were met in either world or general knowledge to fire.

Following knowledge base revision, the model determined if working memory capacity or decay threshold had been exceeded. If so, the model retained the most activated (capacity) and recent (decay) propositions that fell within the limits set for the individual model. This procedure was repeated for each flight maneuver until the model obtained the desired flight goals.

4. Results and Discussion

Of interest is the match between human pilot performance and the corresponding model performance as a function of expertise. Specifically, we analyzed three expertise levels (novices, intermediates, and experts) of human and model flight performance as a function of task complexity, situation complexity, and flight maneuver.

4.1. Analysis of Flight Performance

Prior to comparing human performance with model performance, we synchronized the individual pilot data and modeled data by introducing a goal–based unit of processing time called 'coding time.' Because the individual pilot's behavior was measured as a function of time and the model's behavior is measured in cycles, we needed to devise a way to synchronize time in seconds with time in cycles. To do this we created a goal–based unit of processing time that refers to all activities taking place while a particular cognitive goal is active. Pilot performance on a flight axis for a coding time was scored as correct if the status of the airplane is within the predetermined error limits at the end of the coding time.

4.2. Fit Between Human and Model Performance

To quantify the fit between the empirical and simulation data, RMSDs were calculated based on the percent correct performance. The resulting mean RMSD values, which range from 0.09 to 0.24 for novices, 0.10 to 0.21 for intermediates, and 0.02 to 0.05 for experts. The fit between the empirical and simulation data increased as a function of expertise, though this is due to the attenuated variability of ceiling level performance for experts.

Overall ADAPT matches actual novice and intermediate performance quiet well, although attenuated performance variability for experts made it difficult to compare human and model expert performance. Using each pilot's knowledge base created from very small portion of performance, the model was effective in predicting various aspects of human pilot's action planning as a function of expertise. It strongly supports the validity of ADAPT, one of comprehension–based computational models of human cognition, in understanding aviation pilot's action planning.

5. General Discussion

We have shown how a comprehension–based model accounts for a significant amount of pilot eye–scanning, control movements, and flight performance. Using a model based on the construction–integration theory of comprehension, we developed individual knowledge bases using a small subset of pilot performance data. The knowledge bases were used by ADAPT to fly seven segments flown by individual pilots, and the data derived from both human and model were compared. This procedure allowed us to test the predictive validity of ADAPT and thereby overcome typical weakness of knowledge–based models which provide mere description of the data.

An important strength of the present model is that it has been applied to such a wide variety of cognitive phenomena using very few assumptions and very little parameter fitting. One weakness is that greater parsimony in terms of assumptions and parameter fitting has lead to less than perfect models fits to the human data. There is clearly a tradeoff between parameter fitting and parsimony. In this case, a relatively parsimonious model has provided reasonable fits to highly complex human performance in a dynamically changing environment. In addition, this work highlights the importance and necessity of turning toward the building of predictive individual models of human performance, accounting for differences at the participant level, rather than simply describing for aggregate performance.

In sum, the present work highlights the importance of testing the ability of knowledge–based models to predict individual performance, and to develop standards for evaluative comparisons. Such work would represent an advance over descriptive accounts of aggregated or hypothesized human performance.

6. References

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