A Declarative Approach to Modeling Interactive Cognition

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We have constructed a prototype software tool, called CPM-X, for predicting the time course of interactive cognitive skill. The tool calculates a prediction of an operator schedule, given a declarative description of the task and psychological constraints. In this respect, the tool shares similarities with the syndetic modeling technique developed by Duke and Duce (1999) and can be contrasted to simulation-based approaches to modeling cognition such as ACT-R (Anderson and Lebiere, 1998) and EPIC (Kieras and Meyer, 1997). Predictions are derived by reasoning about constraints on cognitive processing rather than by simulating transitions through a state-space.

The task constraints are described in terms of a hierarchal analysis of the interaction between a person and the task environment. The psychological constraints are described in terms of a distributed set of processors each with its own processing capabilities. In this respect, CPM-X is influenced by the Model Human Processor (MHP; Card, Moran, Newell, 1983). Each processor is defined in terms of a set of properties. For example, a processor might typically execute an operator once every 50ms.

Following Gray, John and Atwood (1993) operators are defined in terms of their processor requirements and dependencies. (In contrast to a simulation architecture, the state changes caused by operators are not represented.) Dependencies specify the preconditions for operator scheduling. For example, a dependency may specify that a vision operator which is for perceiving words must be preceded by a cognitive operator that attends to the appropriate modality. Similarly, given the task to type ‘ab’, the operator which is for initiating ‘type b’ is dependent on the completion of the operator for initiating ‘type a’.

In CPM-X no commitment is made to a particular set of processors or operators. Instead, within the declarative description language, it is possible to define the set of processors and operators that correspond to the required theory of the human cognitive architecture. The modeling language therefore provides a means of expressing the class of theories in which human cognition is conceived of as an interacting set of simple information processors.

In the models that we have built in CPM-X we have used a set of processors that were derived from the CPM-GOMS approach to modeling cognition (Gray, John, Atwood, 1993). These include a cognitive processor, one or more motor processors, and one or more perceptual processors. The operators that are executed by the motor and perceptual processors are dependent on control operators executed by the cognitive processor, reflecting a central-bottleneck theory of mental processing. However, it should be possible to express alternative theoretical viewpoints.

In addition to a description of the psychological processors and their operators, CPM-X also requires the description of strategies by which the processors work together to produce desired behaviors.

For a particular description of the task and psychological constraints there are usually many possible ways in which the cognitive, perceptual, and motor operators can be scheduled. CPM-X uses a heuristic method to calculate an operator schedule that is consistent with the specified constraints and which, given the heuristics, takes as little overall time as possible. Following Vera, Remington, Matessa, John, Freed (2003) the schedule is presented as a PERT chart.

The CPM-X prototype is implemented in Prolog and has been applied to a handful of toy Human-Computer Interaction problems. Our initial findings indicate that the technique can be used to make millisecond accurate predictions of skilled interactive behavior.

References

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