Towards a Constraint Analysis of Human Multitasking

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Introduction

When people conduct multiple tasks in tandem, they often interleave the various operators of each task. Just how these basic cognitive, perceptual and motor processes are ordered generally affords a range of possible multitasking strategies. We briefly outline how a cognitive constraint approach can potentially be used to explicitly explore a range of multitasking strategies, within the theorized constraints that operate on the human cognitive architecture. The power of this approach lies in the task description language, which allows higher-level task performance to be constrained by information requirements and resource demands of lower-level tasks. In general, this approach could provide an *a priori* method for identifying possible multitasking strategies.

Consider while you are driving in your car, it is sometimes not too difficult to direct your attention away from the road, in order to complete a secondary task, such as dialing a number on a cell phone. In this example, there are obvious tensions between the two tasks; suspending attention from the primary task of driving for too long a time period might result in a collision, but completing the secondary task in a rapid and timely manner is probably also important. We briefly outline how an approach called Cognitive Constraint Modeling (CCM: Howes et al., 2004), can be used in a multitasking context to identify the optimal points at which to interleave a primary task, such as driving, in order to complete a secondary task, such as dialing a number on a cell phone.

One of the aims of the cognitive modeling community is to provide an account of human performance on complex real-world tasks. Cognitive architectures (e.g., ACT-R: Anderson et al., 2004) allow models to be developed within a unified framework that integrate assumptions about the time course and information processing constraints that operate on the human system.

For multitasking scenarios, like that described above, most previous models have tended to rely on a *customized executive*, which strategically controls the interleaving of the various task operators (see Salvucci, 2005, pp. 458-460). In response, Salvucci (2005) has proposed a *general executive* for controlling multitasking in the ACT-R cognitive architecture. The general executive assumes that control between two or more primary tasks is passed through a queuing mechanism. The queuing mechanism allows for the interleaving of the various operators that make up each primary tasks. In other words, the multitasking general executive provides a domain independent mechanism for integrating separate ACT-R task models.

Salvucci (2005) has applied the multitasking general executive to the problem of integrating the control and monitoring required for driving, with the completion of secondary in-car tasks, such as dialing a cell phone number. The model was able to account for the increase in dialing time required while driving compared to baseline, and also the degraded steering that resulted from the introduction of the secondary dialing task. The multitasking general executive accounted for these results by assuming that a central cognitive bottleneck operates to limit performance, and that cognitive control must be sequentially ceded between the two tasks.

However, a limitation of this approach is that the modeler has to make additional assumptions regarding the possible range of points in a task that control could be ceded. In other words, the precise operators in a task, at which control can be temporarily given up to a secondary task, must be specified by the modeler. This is a problem because performing one or more complex tasks in tandem affords the cognitive architecture a range of possible strategies with which to order the basic cognitive, perceptual and motor processes required for each task. Here, we briefly outline how an alternative approach, called CCM (Howes et al., 2004), might be used explicitly explore a range of possible strategies for multitasking.

Cognitive Constraint Modeling

The CCM (Howes et al., 2004) approach provides a framework for directly reasoning about the optimal bounds on skilled behavior, given the constraints imposed by the task environment, by strategic knowledge, and by the cognitive architecture. The CCM approach relies on a task description language, called Information-Requirements Grammar (IRG). IRG is motivated by the theory that higher-level task performance is constrained by the information requirements and resource demands that operate on lower-level task processes (see, Howes et al., 2005). Predictions in CCM are then made using a Prolog-based tool, called CORE, which expands the task description specified in the IRG to determine an optimal schedule of the start times for each low-level process. Previously, this approach has been used to account for dual task performance limitations in the psychological refractory period (PRP) paradigm (Howes et al., 2004), and more recently has been scaled up to account for more complex tasks (Eng et al., 2006; Howes et al., 2005).

In a multitasking context, this approach allows parallelism between task operators to be easily defined. This is because IRG does not limit the task description to a sequence of operators, but instead allows resource constraints on lower-level cognitive, perceptual and motor

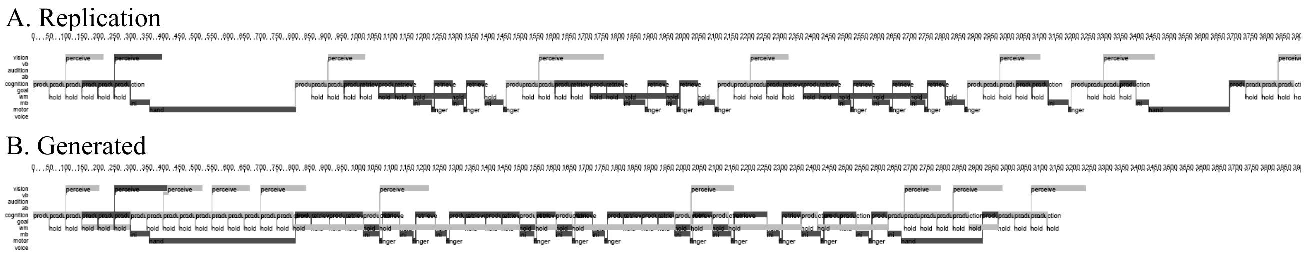

Figure 1. Behavior graphs for dialing a cell phone (dark grey bars) while monitoring a driving task (light grey bars), which (a) replicates Salvucci's (2005) task switching schedule and (b) a greedy schedule generated by CORE that was also consistent with the constraints imposed by the ACT-R cognitive architecture.

processes to determine the sequential orderings of operators. Our explorations of human multitasking performance within a CCM framework is still very much in the early stages of development. Here we present a brief description of some preliminary findings.

Preliminary Results

As a starting point, we reimplemented a model trace from Salvucci's (2005) ACT-R model of driver distraction. As summarized above, this model used a general executive to switch between a primary task (driving) and secondary task (dialing). Figure 1a shows a behavior graph from an IRG description that replicated the original model. In particular, the points at which the ACT-R model could switch between tasks was explicitly represented in the IRG task description. Therefore, this behavior graph is identical to that produced from an ACT-R simulation.

In contrast, Figure 1b removed the explicit task switching points in the IRG and allowed CORE to find a strategy that was consistent with the constraints imposed by the ACT-R cognitive architecture. A greedy scheduling algorithm was used. Comparison of the two outputs suggest that a multitasking strategy could be specified that 1) did more road checks while dialing a cell phone number (7 vs. 5), and 2) could complete the dialing task in less time (3 s vs. 4 s). This difference was partly because the CORE generated schedule exploited slack in the cognitive processor (i.e., the delay between production rule firing) to initiate a new road check, while the dialing task was waiting on the motor processor to execute a key press.

Discussion

We have shown that a CCM approach can potentially be used to directly reason about the space of multitasking strategies afforded within the theorized constraints that operate on the human cognitive architecture. We were able to replicate a previous multitasking model (Salvucci, 2005) by explicitly representing the hypothesized points that control between tasks could be ceded within an IRG task description (Howes et al., 2005). We were also able to use CORE to find a minimal schedule (using a greedy algorithm) that was consistent with the constraints imposed by the ACT-R cognitive architecture and task description. Moreover, this work demonstrates the power of IRG as a task language for describing how the constraints on lower-level cognitive, perceptual and motor processes can determine the sequential orderings of operators, even in the complex case of human multitasking.

Our eventual goal is to identify sets of possible optimal and/or satisficing multitasking schedules. In particular, given the process constraints specified in the ACT-R cognitive architecture, we are interested in identifying a task switching strategy that optimizes the *payoff* between time taken to complete the dialing task and the quality of driver control. In order to specify this payoff function we need to be able to more precisely formalize the quality of driver monitoring, and also the down stream effects of moving attention to a secondary task.

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