Simulating Human Multitasking with a Cognitive Architecture

Multitasking -- doing several tasks at the same time -- is one of the most astounding of all human abilities. In some situations, people multitask effortlessly: chatting with colleagues while eating lunch, or helping with a child’s homework while washing dishes. In other situations, people have an extremely difficult time performing two tasks: sending a text message while driving, or reading a book while listening to someone else’s conversation. What makes multitasking so easy, or so difficult, in these different situations? And can we simulate human multitasking with a computational system, predicting whether multitasking will be easy or difficult for some particular combination of tasks?

Over the past five years, we have been making strides toward this goal by studying and simulating multitasking using a cognitive architecture (see Byrne [1]). A cognitive architecture is simultaneously a computational framework and a working theory of human cognition. The architecture allows for specification of running models that simulate both cognition and the perceptual/motor actions that occur in service of cognition; the models often interact with either simulated or real task environments, and thus their behaviors can be visualized and analyzed in much the same way as human behavior on the same tasks. At the same time, the architecture strives to be a faithful representation of cognition, and the models developed within the architecture are generally compared against empirical data collected from human behavior.

Cognitive architectures provide an ideal context in which to simulate human multitasking. We have developed a theory of multitasking, called threaded cognition, which is incorporated into the ACT-R cognitive architecture.[2] Threaded cognition (Salvucci & Taatgen, 2011) states that all people have a core ability to interleave (“thread”) the execution of multiple tasks.[3] At the same time, core limitations in cognitive processing result in interference in certain situations, and for certain combinations of tasks. Its instantiation in the ACT-R architecture means that a user can take models of two different tasks and immediately simulate behavior for the two tasks being performed concurrently.

As a simple example, consider a laboratory dual-task scenario: for one task, a person presses a key in response to a visual stimulus; for another, the person speaks in response to an auditory stimulus. It has been shown for variations on such dual tasks that, even when the modalities of the tasks do not overlap (visual/manual in the first, aural/vocal in the second), people are slower to respond to one of the tasks. Threaded cognition accounts for this interference because of ACT-R’s cognitive processor: in essence, a person can only perform a small “thinking step” for one task at a time, producing a cognitive bottleneck that slows down the second task. Interestingly, the dual-task interference can sometimes disappear with enough training and when the two tasks are not prioritized. This result arises in the threaded cognition account from an ACT-R learning mechanism that reduces each task’s memory load, which eventually interleaves the two (unprioritized) tasks in a way that neither task interferes with the other. The theory also extends to applied, complex, task domains. For instance, we have studied the effects of a driver’s interaction with in-vehicle devices while driving (see Salvucci & Taatgen, 2011). The interleaving of other tasks, especially visual tasks, not surprisingly can produce large effects in a driver’s ability to steer and/or respond to external events. Perhaps more surprisingly, even purely cognitive tasks such as mentally rehearsing a list of numbers can produce observable effects on driver behavior. Again, the combination of ACT-R and threaded cognition helps to account for these phenomena.

Threaded cognition is not restricted to concurrent multitasking, doing multiple tasks at the same time; it can also be used to model sequential multitasking, in which tasks are alternated. More specifically, threaded cognition predicts that alternation between two tasks is much more efficient if the resource demands (especially maintenance of context) of these tasks do not overlap, and that people will try to switch between tasks when the risk of losing context is minimal. The simulation of multitasking behavior by means of threaded cognition and ACT-R thus has two important implications. First, these theories and their associated computational mechanisms help us to better understand the intricate workings of the mind with respect to people’s fascinating multitasking abilities. Second, the computational theories allow us to make predictions through simulation -- e.g., a prediction of the distraction potential of a new in-vehicle device -- thus grounding the theory with the promise of guiding the design and development of applied systems.

References


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