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Deciding when to switch tasks in time-critical multitasking

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Abstract

While cognitive modeling has begun to make good progress in accounting for human multitasking behavior, current models typically focus on externally-driven task switching in laboratory-task settings. In contrast, many real-world complex tasks, particularly time-critical ones, involve internally-driven multitasking in which people themselves decide when to switch between tasks. In this paper, we propose an adaptation of the ACT-R cognitive architecture that incorporates a notion of elapsed time for the current goal and uses time to determine when to switch away from the current task. We demonstrate the usefulness of this mechanism in an application to a dynamic, time-critical dual search task, showing how an ACT-R model can account for various aspects of human subjects' multitasking behavior.

Keywords: Multitasking; Cognitive architectures; ACT-R

1. Introduction

In the push to generalize to increasingly complex real-world tasks, cognitive modeling and cognitive architectures have begun to address several important challenges, including direct interaction with realistic environments and complex integration of lower-level performance with higher-level planning and decision making. One of the most important challenges today involves making the leap from single-task laboratory experiments to real-world, time-critical situations in which a person performs several tasks together – in other words, addressing the fundamental yet ill-understood skill of human multitasking in time-critical tasks.

Recent modeling work on multitasking has focused primarily on situations where external cues are provided as a signal initiating switching between tasks. Such situations provide an excellent framework for analyzing the dynamics of reaction time, and thus the distribution of attentional

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resources, at the time when switching between tasks takes place. For instance, the analysis of switching-time costs (STC) and psychological refractory period (PRP) has been done for various types of tasks, discrete and continuous, successive and concurrent (Kieras, Meyer, Ballas, & Lauber, 2000). However, it has been argued (e.g., Burgess, Veitch, De Lacy Costello, & Shallice, 2000) that relying on external signals for switching between tasks is less common in real-life multitasking situations. Instead, many real-life scenarios, particularly in time-critical environments, involve internally-driven multitasking in which the person *decides* when to switch between tasks (e.g., the tasks of driving and dialing a cell phone), instead of simply reacting to a signal to do so. While the environment may indirectly define certain parameters of task switching, reliance on direct environmental feedback as a signal to switch would imply processing that is too slow for time-critical situations (Rasmussen, 1983). In addition, environmental feedback is not even always available in real-life situations; it may also be significantly delayed and thus only useful for adjusting future, but not current, behaviors. For this reason, the ultimate distribution of task switch points under time-critical conditions must be signaled by processes internal to the human cognition.

Modeling of internally-driven multitasking proves to be an interesting challenge for current cognitive architectures such as ACT-R (Anderson et al., 2004), EPIC (Meyer & Kieras, 1997), and Soar (Newell, 1990). One critical component of internally-driven multitasking in time-critical contexts is the ability to implicitly reason about time and the temporal aspects of each task. Intuitively this can be understood in terms of the increasing "pressure" over time that a person working on one task may feel to switch to another task. Possibly, this psychological phenomenon is what allows people to effectively balance cognitive resources across tasks. However, the current major architectures do not incorporate time-sensitive mechanisms that affect behavior on the scale of single-task execution.

To address this issue, we turn to the ACT-R cognitive architecture (Anderson et al., 2004) and show that relatively minor changes to mechanisms already built into ACT-R allow us to implicitly reason about time and capture task-switching behavior in time-critical tasks. We evaluate the proposed architectural changes in the context of a simple experimental environment whose task demands are based on our analysis of the available neuropsychological tests (see Burgess, 2000). In developing an ACT-R model that incorporates the proposed changes, we found that the model nicely captured several aspects of people's temporal sensitivity in the task and their resulting behavior of when to switch tasks.

2. Deciding when to switch tasks in ACT-R architecture

As a step toward modeling internally-driven task switching in time-critical environments, we first examine some of the neuropsychological bases of real-world multitasking and explore the mapping of these concepts onto the ACT-R architecture. Given this insight, we then propose a small but powerful change to the current architecture that incorporates time into the task-switching decision and thus account for empirical phenomena such as those described in the subsequent sections of the paper.

2.1. ACT-R and neuropsychological bases

Analysis of the demands that real-life multitasking situations place on the individual allows identifying three major skill sets whose involvement is crucial for satisfactory multitasking performance (Burgess et al., 2000):

- The ability to create and schedule future intentions.
- The facility to remember/maintain those intentions, as well as prioritize them.
- The ability to switch from carrying out one intention to another when the appropriate moment in time is finally reached.

In identifying those brain structures that are expected to be most significantly involved in producing these types of skills, we note two important