Strategic Adaptation in a Dual-Task Setting

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Unified Cognitive Models of Multitasking

How do people interleave attention when performing multiple tasks, such as writing a paper while listening to music, or dialing a phone number while driving a car? A variety of cognitive models and architectures have been used to understand this interleaving process (e.g., Howes, Lewis, & Vera, 2009; Liu, Feyen, & Tsimhoni, 2006; Meyer & Kieras, 1997; Salvucci & Taatgen, 2008). Most notably, the threaded cognition theory (Salvucci & Taatgen, 2008) has been implemented within ACT-R. This theory is particularly strong in that it provides a unified framework to explain performance across a range of different settings (Salvucci, Taatgen, & Borst, 2009) from concurrent multitasking, where tasks are interleaved within seconds (e.g., listening to a song while writing a paper), to sequential multitasking where tasks are interleaved for minutes or hours (e.g., watching a movie, followed by reading a book).

Treaded cognition theory explains multitasking performance using a minimum control structure (Taatgen, 2007) and without the need for an executive that schedules the interleaving of multiple tasks. Rather, the interleaving is determined in an almost bottom-up manner: stimuli (either external, such as screen events, or internal, such as goals) are processed as soon as they appear and a relevant production rule and buffer is available. If a buffer is not yet available, it will be made available as soon as possible. This process leads to relatively fair sharing of buffers amongst multiple tasks (Salvucci & Taatgen, 2008).

The approach is fruitful – one simple solution (i.e., no executive) applies across a range of settings (see Kieras, Meyer, Ballas, & Lauber, 2000, for some trade-offs in the use of executives). However, interleaving is not always done in a fair manner. Rather, people can dedicate more attention to one task, often at the cost of performance on the other task (e.g., Navon & Gopher, 1979; Norman & Bobrow, 1975). Our research focuses on understanding this more flexible way of interleaving two tasks, which contrasts with the stimuli driven approach as used by threaded cognition. In this paper we explain how we modeled adaptive multitasking, and we raise ideas on how it might be realized in ACT-R.

Adaptive Multitasking

The adaptive character of multiple task performance has been known for at least three decades (e.g., Navon & Gopher, 1979; Norman & Bobrow, 1975). This work has shown that people can adapt their performance when explicitly instructed to dedicate more time or effort to one of the tasks (e.g., spend 25% of your time on task A, and 75% on task B). In our work we do not give explicit instructions on how much time to dedicate to a task, however we do give a priority objective. Participants adapt performance to meet the specified objective, by dedicating relatively more time or accuracy to the task with the highest priority (e.g., Brumby, Howes, & Salvucci, 2007; Brumby, Rosario, & Janssen, submitted; Brumby, Salvucci, & Howes, 2009; Janssen & Brumby, accepted; Janssen, Brumby, & Garnett, 2010). For example, in the case study of manually dialing a phone number while driving, we instruct participants to either focus on safe driving or on fast dialing of the phone number. In the first situation driving performance is relatively good, at the cost of dialing time, while in the latter situation dialing performance is relatively fast, but often at the cost of driving safety.

These trade-offs in task performance are not always made in a straightforward way. For example, when instructed to drive as safe as possible while also dialing the phone number, the safest strategy would be to interleave dialing for driving after every digit. Interestingly, our participants do not adopt this strategy. Rather, they use the task structure of the phone number to guide interleaving performance (cf., Salvucci, 2005), either as given by the way it is memorized (Brumby, et al., 2009), or by the motor cues of the task (Janssen, et al., 2010). However, when cues are not prominent, additional breakpoints are inserted (Janssen & Brumby, accepted). These effects are most prominent when the focus is on safe driving, and almost disappear when the focus is on fast dialing.

Cognitive Models of Adaptive Multitasking

To explain this variety of performance a model (Brumby, Salvucci, & Howes, 2007) was developed using the Cognitively Bounded Rational Analysis framework (Howes, et al., 2009). The benefit of using this framework is that it can easily explore the performance of multiple alternative strategies (or more broadly, action sequences) for performing tasks. In the case of manually dialing a phone number while driving a car, a strategy can be thought of as the number of digits one types before returning attention back to the road. A risky strategy would be to drive for a while, then dial the complete phone number in one sequence, and then drive again. In contrast, the relatively safest strategy would be to interleave dialing for driving after every digit. In between these two extremes are other strategies, for example those that interleave at chunk boundaries (e.g., 123 – steer – 456 – steer – 7890 – steer, for a typical US phone number Salvucci, 2005). In the case of dialing a typical 11-digit UK phone number, there are 10 points at which one can either continue dialing, or interleave dialing for driving. This gives a space of 2^{10} strategies. In addition, at each point of interleaving, more or less time can be dedicated to steering (in our models, typically between 250 and 3000 milliseconds).

The model framework demonstrates amongst other things why people do not interleave dialing for driving after every digit when the objective is to drive as safe as possible (Brumby, et al., 2009; Janssen & Brumby, accepted). Although driving behavior slightly improves with more frequent interleaving, there is a relatively severe cost in the time needed to complete dialing the phone number.

ACT-R Models of Adaptive Multitasking

Threaded cognition is already capable of describing performance in different task settings (e.g., Borst, Taatgen, & Van Rijn, 2010; Salvucci, et al., 2009), but the flexible adaptation to performance objectives as described above is missing. We investigate in what situations people adjust to performance objectives, why they adjust (i.e., do they make performance trade-offs?), and how they adjust their performance. In particular this latter question is still open ended. One option that would be in line with the Cognitively Bounded Rational Analysis framework is that participants try to optimize an objective function, given environmental and cognitive constraints on performance (Howes, et al., 2009). Within ACT-R there might be multiple ways of incorporating this. Some of the options that we consider are optimization to different types of rewards in a reinforcement-learning scheme (cf., Janssen, 2008; Janssen, Gray, & Schoelles, 2008), estimation of time intervals (Salvucci, Taatgen, & Kushleyeva, 2006), and adding an extra thread that coordinates executive functions (Salvucci & Taatgen, 2008).

Conclusion

Within the ACT-R architecture, the threaded cognition theory of multitasking has been successful at explaining default interleaving performance in a variety of settings. An explanation of more deliberate strategic (and not always fair) task interleaving is lacking. Our work tries to describe these situations, and explain them using principles from amongst others ACT-R and threaded cognition.

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