Cognitive Control: A Symposium

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Abstract

Cognitive control may be defined as the mechanisms or processes invoked in order to engage in goal directed behaviour under system constraints. This symposium explores a range of recent computational approaches to understanding problems of cognitive control. It comprises five presentations which each discuss a different aspect of cognitive control and a discussion session.

Keywords: Cognitive control; executive function; rational adaptation; task switching; monitoring; multitasking.

Introduction

In cognitive science there is a substantial research tradition of studying control problems such as how the cognitive system ensures the selection of a desired action in circumstances where an automated, learned, action might otherwise be selected. Control problems are often understood as arising from the necessity to serialise the multi-threaded processing contributions of a parallel neural architecture, but some work (e.g. Rieskamp, 2008) has tried to extend the application of control metaphors, derived from control theory and reinforcement learning, to a broader range of phenomena, including those associated with higher level decision making tasks. In the most general terms we might define the control problem as the problem of what to do next. A view that, perhaps, encourages an integrative approach to cognition that eschews prior commitments to particular forms of processing mechanisms. Control is about engaging in goal directed behaviour under system constraints.

Questions concerning cognitive control include, for example: how people switch among the short-term goals that govern everyday behaviour (Altmann & Gray, 2008); how people allocate perceptual, motor and cognitive resources in the control of interactive behaviour (Gray et al., 2006); how people adjust architectural parameters in the light of feedback (Botvinick et al, 2001); how people inhibit prepotent but inappropriate or unintended behaviours (Norman & Shallice, 1986); how the cognitive system resolves the problem of producing multiple responses when processing or physical constraints prevent them from being produced in parallel (Howes et al., 2009); how the cognitive system may manage strategies in demanding memory tasks (Juvina & Taatgen, 2007); and how the cognitive system learns to prefer specific strategies in judgement and decision making tasks (Rieskamp, 2008). It is also critical to real world applied problems such as driving (Salvucci, 2006; Janssen and Brumby, in press; Gunzelmann et al., 2009).

The control problem is difficult for a number of reasons:

1. *The temporal credit assignment problem.* Control is adaptive, so the problem of control encompasses the problem of how to make use of feedback. However, multiple actions can contribute to feedback and feedback may be delayed. This raises the problem of which actions should be assigned credit/blame when feedback is received. (cf. Lovett and Anderson's (1996) utility learning within ACT-R).
2. *The uncertainty problem.* Frequently information that we do have (e.g., feedback) is uncertain. We may know that information is uncertain, but how should information about uncertainty be processed?
3. *The scaling problem.* When many choices are available considering them all is computationally expensive. Scaling problems are found in, for example, both reinforcement learning and Bayesian approaches to modelling control and inference (Botvinick, Niv & Barto, 2009).
4. *The bounds problem.* The brain is a physically instantiated neural processing mechanism that imposes limits on what information can be encoded and effectively deployed. Cognitive control involves making efficient use of the neural mechanism subject to these limits (Howes, Lewis & Vera, 2009).
5. *The concurrency problem.* In many situations behaviour is under the control of multiple goals which we work towards concurrently, as in the example of driving while navigating or holding a phone conversation (Salvucci & Taatgen, 2008).

The symposium will explore a range of recent computational approaches to understanding the control problem through five diverse presentations and a discussion session.

Botvinick's recent work emphasises the hierarchical structure of control knowledge: the divisibility of ongoing behavior into discrete tasks, which are comprised of subtask sequences, which in turn are built of simple actions. Botvinick, Niv and Barto (2009) reexamines behavioral hierarchy and its neural substrates from the point of view of recent developments in computational reinforcement learning. Specifically, a set of approaches known collectively as hierarchical reinforcement learning is considered. A close look at the components of hierarchical reinforcement learning suggests how they might map onto neural structures, in particular regions within the dorsolateral and orbital prefrontal cortex. A particularly important question that hierarchical reinforcement learning brings to the fore is that of how learning identifies new action routines that are likely to provide useful building blocks in solving a wide range of future problems.

Cooper will discuss the potential roles of so-called forward and inverse models in cognitive control. Forward models are representations of a future state of a system given its current state and a plan or course of action, while inverse models "invert the causal flow" and allow one to predict, given a desired state and a course of action will should result in that state. Both forward and inverse models have been argued to play important roles in motor control (e.g., Wolpert & Ghahramani, 2000). Cooper will argue that such models, possibly learned through associative and reinforcement learning mechanisms, may equally play a significant role in cognitive control, allowing the cognitive system to predict appropriate processing parameters and thereby configure itself prior to task performance.

Both Howes and Lewis will explore computational and empirical approaches to understanding people as *bounded optimal* control systems (Howes, Lewis & Vera, 2009). They contend that through learning people solve the constrained optimisation problem presented by their architecture. Howes will present evidence concerning bounded optimal control of working memory strategies. The work demonstrates that people do not only adapt strategies to changes in the cost structure of the task environment but rather they adapt optimally. Lewis will present a boundedly optimal control perspective on interference resolution. He will report a computational model of how people adapt strategically to interference in memory.

Taatgen's task will aim to initiate a discussion about asking the right questions; clearly a precusor to the search for answers.The standard way to think about cognitive control in multitasking is that control is needed to schedule the use of resources between tasks (e.g., Kieras, 2007). A different view, prompted by the threaded cognition theory of multitasking (Salvucci & Taatgen, 2008), is that not all cognitive processing can be understood in terms of tasks. As soon as we consider something as a task, some measure of cognitive control is needed to make sure all the steps in the task are carried out to achieve the goal. Miyake's (Miyake et al, 2000) three categories of cognitive control (inhibition, working memory and task switching) are all needed to protect a task from interference, but they are not the whole story. Cognitive modeling can help complete the picture.

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