

Chapter XIII

Modelling Interactive Behaviour with a Rational Cognitive Architecture

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ABSTRACT

In this chapter we discuss a number of recent studies that demonstrate the use of rational analysis (Anderson, 1990) and cognitive modelling methods to understand complex interactive behaviour involved in three tasks: (1) icon search, (2) graph reading, and (3) information retrieval on the World Wide Web (WWW). We describe the underlying theoretical assumptions of rational analysis and the adaptive control of thought-rational (ACT-R) cognitive architecture (Anderson & Lebiere, 1998), a theory of cognition that incorporates rational analysis in its mechanisms for learning and decision making. In presenting these studies we aim to show how such methods can be combined with eye movement data to provide detailed, highly constrained accounts of user performance that are grounded in psychological theory. We argue that

the theoretical and technological developments that underpin these methods are now at a stage that the approach can be more broadly applied to other areas of Web use.

INTRODUCTION

With the rapid increase in Internet use over the past decade there is a growing need for those engaged in the design of Web technology to understand the human factors involved in Web-based interaction. Incorporating insights from cognitive science about the mechanisms, strengths, and limits of human perception and cognition can provide a number of benefits for Web practitioners. Knowledge about the various constraints on cognition, (e.g., limitations on working memory), patterns of strategy selection, or the effect of design

decisions (e.g., icon style) on visual search, can inform the design and evaluation process and allow practitioners to develop technologies that are better suited to human abilities.

The application of cognitive psychology to human-computer interaction (HCI) issues has a long history going back to Card, Moran, and Newell's (1983) introduction of the goals, operators, methods, and selection rules (GOMS) task analysis technique and model human processor (MHP) account of human information processing in the early 1980s. Since then, their cognitive engineering approach has developed into a family of methods (John & Kieras, 1994; Olson & Olson, 1990) which are widely used to produce quantitative models of user performance in interactive tasks.

Another, more recent approach to modelling human performance in interactive tasks has emerged in the last decade from theoretical and technological advances in research into cognitive architectures. Cognitive architectures are theories of the fundamental structures and processes that underlie all human cognition, of which there are several currently in existence including EPIC (executive process / interactive control; Kieras & Meyer, 1997), Soar (Laird, Newell, & Rosenbloom, 1987; Newell, 1990), and ACT-R (Anderson & Lebiere, 1998; Anderson et al., 2004). An important feature of these architectures is that they are all implemented as computer programming systems so that cognitive models may be specified, executed, and their outputs (e.g., error rates and response latencies) compared to human performance data.

Originally ACT-R and Soar were theories of central cognition only and did not explicitly specify mechanisms for perception or motor control. EPIC however, was unique in that from its inception it incorporated processors for cognition, perception, and motor control. Recent adaptations to ACT-R (Byrne & Anderson, 1998) and Soar (Chong & Laird, 1997) have now ensured that both architectures incorporate perceptual motor

components that allow models to include visual attention processes and manual interactions with a keyboard and mouse. This is an important development for the study of HCI as cognitive models can now be *embodied* (Kieras & Meyer, 1997) in the sense that the architectures are now able to simulate perceptual-motor contact with computer interfaces and devices and so capture the complex interactions between the task environment, cognition, and perceptual-motor behaviour.

Modelling interactive behaviour with an embodied cognitive architecture has a number of advantages over the traditional cognitive engineering approach exemplified by GOMS and its relatives. Perhaps the most important of these is that computational models can actually execute the task, allowing a direct test of the sufficiency of the hypothesised processes. Second, although most cognitive architectures contain built-in timing parameters taken from the psychological literature, unlike cognitive engineering models, they do not require prior estimated times for all subcomponents of a task. In addition, some architectures — such as ACT-R and Soar — contain learning mechanisms which allow them to model various effects of practice on performance. This allows cognitive architectures to be used to model novel tasks, novice users, or tasks involving components without prior time estimates.

One of the promises of embodied cognitive architectures is that, once they are equipped with sufficient knowledge, they will begin to provide a priori predictions of user performance and eventually evolve into artificial users that can be employed to evaluate novel tasks and environments (Ritter, Baxter, Jones, & Young, 2000; Young, Green, & Simon, 1989). In this chapter we will describe one of these architectures, ACT-R, and show how it has been used to provide detailed and sophisticated process models of human performance in interactive tasks with complex interfaces. ACT-R is an appropriate choice for this discussion because, in contrast to other cognitive architectures, ACT-R also embodies

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