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An integrative account of memory and reasoning phenomena

Sébastien Hélie [a, *], Ron Sun [b]

[a] Purdue University, United States
[b] Rensselaer Polytechnic Institute, United States

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ABSTRACT

There is growing consensus that human memory is mediated by multiple qualitatively different systems co-evolved to function in a complementary way. As a result, memory should be studied not only using direct tests of memory but also using other tasks that naturally require memory access. This article presents an attempt at using the declarative memory systems in CLARION (termed the Non-Action-Centered Subsystem or NACS) to account for a wide range of psychological phenomena involving both the direct and indirect use of declarative memory. We advocate an architectural approach, which is broad-based (rather than depth-based). As such, the explanations presented herein, from psychological domains as diverse as human memory, deductive reasoning, inductive reasoning, and heuristic reasoning, were based on architectural properties of CLARION and most of them did not require the adjustment of any numerical parameter. This article concludes with a comparison of CLARION with alternative views of memory systems.

1. Introduction

There is growing consensus that human memory is mediated by multiple qualitatively different systems (Ashby, Alfonso-Reese, Turken, & Waldron, 1998; Rolls, 2000; Squire & Schacter, 2002; Tulving, 2002) that have co-evolved to function in a complementary way (e.g., Klein, Cosmides, Tooby, & Chance, 2002; Schneider, 1993; Sun, 2002). As a result, dissociations among memory systems may exist under some circumstances, so that different memory systems may serve different purposes, but dissociations may not be prominent under some other circumstances, so that multiple memory systems may be brought together to bear on one task.[1] Investigating the evolutionary problems faced by each memory system may help to achieve a better understanding and delineate the design features of each memory system. Thus, it can be useful to take a careful look at memory systems from a non-memory-centered, broader perspective (Sun, 2012). In the process, we advocate an *architectural* approach toward memory systems (and cognitive systems in general), which is broad-based rather than depth-based and almost parameter-free and simulation-free.

1.1. Theoretical dichotomies

When focusing on the type of tasks (functions) that can be achieved by different memory systems, the declarative/procedural dichotomy immediately appears as a useful concept. The distinction between procedural and declarative memories has been proposed by, e.g., Anderson (1983), Squire (1987), and others (although some details vary across these proposals). Procedural memory contains knowledge that is specifically concerned with actions in various circumstances, that is, how to do things. Declarative memory contains knowledge that is not specifically

* Corresponding author. Department of Psychological Sciences, Purdue University, 703 Third Street, West Lafayette, IN 47907-2081, United States. Tel.: +1 765 496 2692.

E-mail address: shelie@purdue.edu (S. Hélie).

[1] Note that memory systems may, alternately, be viewed either as functional modules or as physiological modules (for more discussions of this and other distinctions, see Fodor, 1983). However, our main focus here is on functional modules.

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concerned with actions, but more about objects and events in generic terms. For example, declarative memory may contain propositions about the state of the world with a measure of their support (or truth value). The major factor that distinguishes procedural and declarative memories seems to be the action-centeredness or the lack thereof (that is, the procedural versus non-procedural nature of knowledge; Sun, Zhang, & Mathews, 2009). Evidence in support of this distinction includes voluminous studies of skill acquisition in both high- and low-level skill domains (e.g., Anderson & Lebiere, 1998; Hélie, Waldschmidt, & Ashby, 2010; Kanfer & Ackerman, 1989).

Another (alternative) dichotomy is concerned with memory accessibility (i.e., explicit versus implicit). Specifically, a theoretical distinction between accessible and inaccessible processing has been proposed (for a review, see, e.g., Eichenbaum, 1997). According to this framework, explicit knowledge is based on conceptual (consciously accessible) processing and implicit knowledge is based on (consciously inaccessible) subconceptual processing. This distinction is also supported by many empirical results (for reviews, see, e.g., Hélie & Sun, 2010b; Sun, Slusarz, & Terry, 2005).

While these dichotomies are often merged (e.g., the claim that procedural memory is implicit while declarative memory is explicit), Sun et al. (2009) argued that the dichotomies may be better treated as orthogonal, with procedural memory being either (or both) explicit and implicit, and declarative memory also being either (or both) explicit and implicit. This is the approach advocated in the CLARION cognitive architecture (Sun, 2002; Sun et al., 2005). In CLARION, procedural and declarative memories are represented as separate modules, and each of these modules is further subdivided into an implicit and an explicit component (thus decoupling the two dichotomies). So far, most of the published work on the CLARION cognitive architecture (e.g., Sun et al., 2005; Sun, Merrill, & Peterson, 2001; Sun & Peterson, 1998) has focused on the interaction of explicit and implicit processing within the procedural system (called the *Action-Centered-Subsystem* or *ACS*). However, the declarative system (called the *Non-Action-Centered-Subsystem* or *NACS*) has not received as much attention (with some exceptions; e.g., Hélie & Sun, 2010b; Sun & Hélie, 2013). This article aims at filling this gap. We present a more detailed presentation of the NACS and show how the interaction between explicit and implicit processing within the NACS can be used to account for a variety of psychological phenomena in memory and reasoning. This is important because, as argued in more detail below, memory serves an important function in supporting intelligent behavior, and testing models/theories using only memory-centered tasks and functions does not inform us on the role of memory in other intelligent behaviors. This is done by first assessing the CLARION NACS as a model of declarative memory, and then showing that it is sufficient to support a wide range of reasoning activities in humans.

1.2. An architectural approach to cognition

In the present work, we advocate an architectural approach toward cognitive modeling, which means that we are advocating a broad-based account rather than depth-based (in the same way as architectural sketches, necessary before buildings are constructed). It is our view that this is especially important for the advancement of psychology because it allows for the exploration of how the different component models interact and fit together (instead focusing on individual smaller-scoped computational models that focus on smaller details). The study of architectural issues provides new insight, and narrows down possibilities to delineate the processes involved in cognition (Helie & Sun, 2014).

The architectural approach is also what Newell (1990) argued for: more data could be used to constraint a cognitive theory if the theory was designed to explain a wider range of psychological phenomena. In particular, these 'unified' (i.e., integrative) psychological theories could be put to the test against well-known (stable) regularities that have been observed in psychology (e.g., the power law of practice, the serial position curve in free recall, etc.; Murdock, 1962; Newell & Rosenbloom, 1981). We would add that one advantage of using such a broad-based architectural approach is that it allows for accounting for data with (almost) parameter-free explanations by deriving or numerically estimating mathematically predicted outcomes from intrinsic properties of the architecture. This is accomplished by not focusing our work on overly fine-grained modeling attempting to capture all the nuances of data involved in the selected phenomena, but rather on general psychological 'laws'. This is justified because (1) finer-grained data can sometimes represent noise (Pitt & Myung, 2002), (2) minute details can usually be captured by adding some minor activation mechanisms within the same components (e.g., for short-term priming, etc.) and, (3) abstracting away from the details facilitates the exploration of the interactions of architectural components in explaining empirical data. The main objective of this article (and of the CLARION cognitive architecture) is to select and include only a minimum set of mechanisms, structured in a parsimonious but effective way, to account for a maximum set of psychological data and phenomena to explore the interaction between the architectural components of memory.

In this article, we review a range of psychological phenomena, and present explanations of the phenomena using the CLARION NACS. The first set of phenomena considered is related to human memory, to ensure that the CLARION NACS can account for basic declarative memory phenomena. Then we build on this model by showing that the CLARION NACS is a model of declarative memory sufficient for supporting other cognitive functionalities, such as deductive reasoning, inductive reasoning, and heuristic reasoning. Newell (1990) pointed out that it was unclear whether most memory models available in the research literature could support intelligent behavior. The issue of the functionality of memory was taken up again in Anderson (2007), who argued that studying integrative cognitive architectures was a good means of addressing this issue.

With such a wide area of applications, the list of phenomena included in this article is obviously not exhaustive. The phenomena were selected based on (1) their historical