Chapter 1
A Computational Cognitive Model of the Brain

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ABSTRACT

Recent fruitful progresses on brain science have largely broadened our understanding of the cerebrum. These great works led us to propose a computational cognitive model based on a graphical model that we carried out before. The model possesses many attractive properties, including distinctive knowledge representation, the capability of knowledge accumulation, active (top-down) attention, subjective similarity measurement, and attention-guided disambiguation. It also has “consciousness” and can even “think” and “make inference.” To some extent, it works just like the human brain does. The experimental evidence demonstrates that it can give reasonable computational explanation on the human phenomenon of forgetting. Although there are still some undetermined details and neurobiological mechanisms deserving consideration, our work presents a meaningful attempt to give further insights into the brain’s functions.
INTRODUCTION

The last decades have witnessed an increasingly large effort into the investigation of the brain. No one can deny that research on the brain is now becoming one of the hottest issues in the scientific field. Researchers from various disciplines, including neuroscience, mathematics, psychology, computer science, and so on, dedicate themselves to explore the secrets in the brain, which is considered the most complicated and valuable part of the human being.

Thanks to the higher resolution brain-scan devices, more powerful computers, and fruitful advances in many related areas, such as neuroscience, machine learning, and artificial intelligence, researchers have made significant progress in understanding the structure and function of the cerebral cortex (see Miyashita, 2004, and Wang & Kinsner, 2006, for reviews). Many researchers have developed mathematical models of the neocortex that accord well with experimental results and provide directions for implementation (see, e.g., Elman, 1995; George & Hawkins, 2005; Lee & Mumford, 2003; Rao & Ballard, 1996; Shastri, 2001; Wang, 2006; Wang, Wang, Patel, & Patel, 2006). Although these models vary considerably in details, and some of them just focus on some specific aspects of the brain, for example, the visual system (Lee & Mumford), memory system (Shastri, 2001), or language processing (Elman, 1995), they shed light on the fundamental issues of the cerebrum as well as the corresponding computational cognitive model.

First of all, different from the conventional view that the brain is a passive and stimulus-driven system that simply reacts to outside input, many researchers believe that the brain is an active and adaptive system that interprets external stimuli according to its internal status. Engel, Fries, and Singer (2001) review much evidence demonstrating that “internally generated activity shows distinct temporal patterning against which input signals are matched.” Other researchers (Wang, 2003; Wang & Wang, 2006) also indicate that the perceptual result can be determined by both the external stimuli and the internal status.

Additionally, more and more researchers agree that a cognitive model is a dynamic system where the temporal factor plays a significant role in the model. Wang (2002) developed real-time process algebra (RTPA) to formally describe the cognitive system architectures and dynamic behaviors with a set of new mathematical notations. Rao and Ballard (1996) use a form of the extended Kalman filter to dynamically combine input-driven bottom-up signals with expectation-driven top-down signals to predict the recognition state. Elman’s (1995) dynamic approach to language processing is another example, where the author utilizes simple recurrent networks to predict the following word according to earlier input accumulation. In his model, the hidden layer also receives input from context units that hold the state of the hidden units from the previous step.

The third issue is about the topological structure of the cognitive model. Many researchers have proposed hierarchical structures to describe a reasonable model. For instance, to explain the fundamental cognitive mechanisms and processes of natural intelligence, Wang et al. (2006) developed the layered reference model of the brain (LRMB), where the model of the brain is depicted with six layers, namely, the sensation, memory, perception, action, metacognitive, and higher cognitive layers. Rao and Ballard (1996) also carry out a hierarchical structure to model visual recognition in the visual cortex. Lee and Mumford (2003) adopt a hierarchical structure to illustrate the Bayesian inference in the visual system as well. Yet, the recent research (Achard, Salvador, Whitcher, Suckling, & Bullmore, 2006) has shown that the topological structure of the cerebrum is a small-world network. As a matter of fact, some previously proposed models, for example, the object-attribute-relation (OAR) model (Wang, 2006; Wang & Wang,
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