Multilevel Computational Modeling of Human Attentional Networks

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Suppose a student S was asked to solve the equation "2x + 3 = 9". After 2 seconds, he gave the answer "x = 3". Both cognitive scientists A and B were interested in understanding how S did it. Scientist A recorded S's detailed verbal protocol, based on which, and other relevant behavioral measures, A hypothesized the possible knowledge structure underlying S's problem solving and developed a symbolic computational model that simulated the process. On the other hand, scientist B adopted sophisticated brain imaging techniques including electroencephalograph (EEG) and functional Magnetic Resonance Imaging (fMRI) and acquired a high-resolution recording of S's brain dynamics during problem solving. Based on some well-supported neural computing principles, B then developed a biologically realistic connectionist model to simulate the brain activities underlying S's performance. Though both models fitted the data well, the two models are clearly different. While the symbolic model offers a description of the process with psychological plausibility and high behavioral relevance, the connectionist model emphasizes the process' biological realism and brain foundations. One question is, do we, cognitive scientists who endeavor to discover unified theories of cognition, have justifiable reasons to prefer one to another?

This question and similar others have led to a long debate in the rather brief history of cognitive science (e.g., Newell, 1990; Squire & Kandel, 2000). Although it has long been recognized that mind is a multilevel construct, single level analysis has been the dominant methodology in cognitive science. The so-called "hybrid" models, in which components from different levels of analysis are pieced together, are typically ad hoc and trivialize the problem.

Here we argue that we need a multilevel modeling approach (see also Wang et al, 2003). That is, we need to develop well-fitted computational models at multiple levels for any given cognitive phenomenon. Because mind manifests itself at multiple levels, each level is real and tells a story of mind on its own. When we develop models for a specific phenomenon at multiple levels, we would be able to compare them, contrast them, and more importantly, mutually justify them. By doing so, we expect that a more complete picture of the function of mind would emerge.

We demonstrate our approach by presenting a multilevel model we developed to model human attentional networks. Recently at least three attentional networks, for alerting, orienting, and executive control, have been distinguished at both cognitive and neuroanatomical levels (Fan et al., 2002; Posner & Raichle, 1994). However, how to understand the connection between attentional networks in the brain and cognitive performance raises a question. Our model included a symbolic submodel in Act-R (Anderson & Libiere, 1998) and a subsymbolic submodel in leabra (O'Reilly & Munakata, 2000). While the symbolic model captured the psychological plausibility of phenomenon, the subsymbolic model emphasized the biological realism and neuroimaging finings. Both submodels fitted the data well. Most importantly, we could then cross-validate the submodels. For example, the model illustrated interesting relationships between production rules and underlying neural computation. As demonstrated in the Act-R model, rules are fundamental units of psychological reality and typically proceed serially. However, the underlying neural networks process information in parallel. The parallelism of neural computation and the serial nature of rule firing can be mapped against each other along the time line. Since both types of models decompose the cognitive performance into sub-units that occur at tens of millisecond scales, the mapping may be able to tell how rules are implemented in neural level computation

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References

Anderson, J. R., & Lebiere, C. (1998). *The atomic components of thought*. Hillsdale, NJ: Lawrence Erlbaum Press.

Fan, J., MaCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience, 14*(3), 340-347.

Newell, A. (1990). *Unified theories of cognition*. Cambridge, MA: Harvard University Press.

O'Reilly, R. C., & Munakata, Y. (2000). *Computational explorations in cognitive neuroscience*. Cambridge, MA: MIT Press.

Posner, M. I., & Raichle, M. E. (1994). *Images of mind*. New York: Scientific American Library.

Squire, L. R., & Kandel, E. R. (2000). *Memory: From mind to molecules*. New York: Scientific American Library.

Wang, H., Johnson, T. R., & Zhang, J. (2003). *A multilevel approach to unified theories of mind*.Unpublished manuscript.