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Integrative computational modeling of physiological and cognitive systems, and their interactions

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Introduction

The mind is embodied, physically and chemically, receiving and passing information to the body in myriad physiological feedback loops. The mind-body interface induces connections between different cognitive functions, and is an integral part of cognition. Understanding how physiological and cognitive mechanisms interact to influence behavior will require exploring the representative and systematic ways we can connect systems on the physiological and cognitive levels. As physiological sensors continue to become cheaper, more pervasive, and more accurate, computational cognitive modelers will have a unique opportunity to predict and explain human behavior using process models with representations on both the physiological and cognitive levels. This shift will result in models that more realistically operate over longer periods of time, allowing modelers access to more mechanistic models and predictions of behaviors given moderators like sleep deprivation, caffeine, or stress.

The ACT-R cognitive architecture (Anderson, 2007) can be used to model cognitive processes and their effects on behavior. However, ACT-R lacks a comprehensive way to simulate the effects of several cognitive moderators (Ritter et al., 2007) and the interactions of these moderators. The architecture has had its module functionality associated with certain areas of the brain and brain networks (e.g., see Anderson et al., 2008), this can make it more straightforward to understand where in the architecture certain moderators should affect behavior.

HumMod (Hester, Brown, et al., 2011) is a physiological model that simulates physiological systems from a middle-out perspective (i.e., see Hester, Iliescu, et al., 2011). The model integrates multiple tissue and organ level submodels along with a responsive cardiovascular system modulated by hormones and the autonomic nervous system. This allows one to explore the consequences of physiological perturbations (e.g., activation of nerves in the peripheral nervous system) both on the respective local systems and the overall global physiological system. However, as a stand-alone system, HumMod does not simulate high-level behavior.

ACT-R/Φ is a hybrid physio-cognitive architecture that combines the ACT-R and HumMod systems. The architecture can be used to explore interaction between physiological and cognitive systems and how these interactions modulate human behavior. A *physio* module controls the communication between the ACT-R and HumMod system, controlling the synchronization of the timing and also any bottom-up physiological modulation of cognitive processes. ACT-R/Φ has been used to explore several aspects of the physiology-cognition connection, including homeostatic drives (Dancy & Kaulakis, 2013), stress (Dancy, Ritter, Berry, et al., 2015) and sleep deprivation (Dancy, Ritter, & Gunzelmann, 2015).

In this tutorial, we will discuss physiological and cognitive processes, and interactions between systems at these levels, that are useful for modeling and simulating behavior on both the physiological and cognitive levels. We will use two representative systems (HumMod and ACT-R) as well as an integrated version of the two systems (ACT-R/Φ) to ground the discussed connections and interactions to a computational system. Tutees will then have the opportunity to build a hybrid computational physio-cognitive model, run the model in a simulated experiment, and interpret the predicted physiological and cognitive output against existing behavioral data.

About the Authors

Christopher L. Dancy is an assistant professor in computer science at Bucknell University and chair of the Behavioral Representation in Modeling and Simulation (BRiMS) society. His research interests focus on studying how physiology, affect, and cognition interact and what these interactions mean for memory, decision-making, and interfacing with systems. He uses computational process models and simulations, as well as experimental methods, to study these interactions and predict consequences for behavior.

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