Beginning with biology: “Aspects of cognition” exist in the service of the brain’s overall function as a resource-regulator

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TARGET ARTICLE:

Resource-rational analysis: Understanding human cognition as the optimal use of limited computational resources

Falk Lieder and Thomas L. Griffiths

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RESPONSE:

Advancing rational analysis to the algorithmic level

Falk Lieder and Thomas L. Griffiths

Lieder, Falk, and Thomas L. Griffiths. “Advancing Rational Analysis to the Algorithmic Level.” (2020). *Behavioral and Brain Sciences* 43. <https://doi.org/10.1017/S0140525X19002012>.

Abstract: Lieder and Griffiths rightly urge that computational cognitive models be constrained by resource usage, but they should go further. The brain's primary function is to regulate resource usage. As a consequence, resource usage should not simply select among algorithmic models of "aspects of cognition." Rather, "aspects of cognition" should be understood as existing in the service of resource management.

In their target article, Lieder and Griffiths suggest that efficient use of resources (e.g., psychological, neurobiological, and metabolic) must play a central role in computational models of cognition. We strongly agree, but in our view, the authors could go even further. Lieder and Griffiths suggest that resource-rational models should first identify “an aspect of cognition, formulated as a problem and its solution,” and subsequently select an algorithm that “optimally trades-off resources and approximation accuracy” (Box 2). We suggest that “aspects of cognition” are not productively studied in isolation. Instead, “aspects of cognition” are best understood as a means to the functional end that brains evolved to serve: regulating the distribution and delivery of resources throughout the body – a balancing act called allostasis (Sterling 2004; 2012; Sterling & Eyer 1988; Sterling & Laughlin 2015). Resource usage, then, should not simply adjudicate among algorithms; rather, regulating resource usage is the brain’s overall computational goal.

Centering computational modeling around “aspects of cognition” propagates an assumption that “aspects of cognition” can be separated and studied in isolation (Barrett 2017b; Barrett & Satpute 2019). In the nineteenth century, when psychology emerged from the tradition of mental philosophy as independent science, it inherited a list of mental faculties, or “aspects of cognition.” Such “aspects of cognition” include categories such as attention, memory, and language, and in parallel, “aspects of emotion” with categories such as fear, anger, and sadness. An aspect of emotion like “fear” is thought to arise when dedicated survival-relevant mechanisms are implemented (Cook & Mineka 1989; Fanselow 2018; Fanselow & Lester 1988; Mineka et al. 1984); yet, researchers have generally failed to identify any consistent neural architecture implementing these mechanisms (Barrett 2017b; Clark-Polner et al. 2016; Guillory & Bujarski 2014; Westermann et al. 2007). If the goal was only to solve a computational

problem (e.g., how best to store and retrieve memories in a computer) then isolating “aspects of cognition” would be no issue. However, resource-rational analysis is ambitious *precisely because* it aims to do more: it aims to leverage resource limitations to better model how human brains solve problems. Considering “aspects of cognition” separately (e.g., language separate from memory; memory separate from attention; and attention separate from perception) is counterproductive, as the promise of resource-rational analysis is that it might allow these “aspects of cognition” to be compared on the common currency of resource usage (ideally, a measurable resource; e.g., metabolic costs of neuronal signaling; Attwell & Laughlin 2001; Niven & Laughlin 2008; Zénon et al., 2019). “Aspects of cognition” must be recognized as parts of a whole, and modeled in the context of the brain’s general function within organisms.

Research in neuroanatomy, neurophysiology, and signal processing converges on the hypothesis that the brain’s general function is to regulate metabolism and energy balance within an organism (Barrett & Finlay 2018; Chanes & Barrett 2016; Kleckner et al. 2017; Sterling 2012; Sterling & Laughlin 2015). Regulating energy balance is difficult: it requires that an organism uses “aspects of cognition” to find and extract resources from its environment, that an organism redirects and trade-offs resource usage within itself, and that an organism predicts what resources are needed to keep itself alive. A brain implements these processes and behaviors. An organism’s brain uses perception to identify and navigate toward resources in the environment (while avoiding predators who are hunting for resources also); an organism’s brain uses memory to revisit resource-rich locations and avoid resource-poor ones; and an organism’s brain uses attention to prioritize sensory signals that are relevant to survival. A brain manages energy tradeoffs within the various systems of its body – for example, during peak effort, cardiac output is diverted away from some organs (e.g., liver and kidneys) to others (e.g., heart, lungs,

skeletomotor muscles; Sterling & Laughlin 2015; Weibel 2000), investing energy in pressing concerns (e.g., escaping a predator) and divesting energy from concerns that can wait (e.g., digestion, immunoregulation). Finally, a brain manages resources efficiently by predicting what resources will be needed later and preparing to satisfy those needs before disruptions arise – for example, an organism should be motivated to drink (or seek water) before internal supplies are exhausted (Sterling 2012). These predictions require a major investment: the brain must continually run an internal model of the organism’s body in its niche (i.e., the sensory aspects of the world that are relevant to its survival; Barrett 2017a; 2017b; Barrett et al. 2016; Chanes & Barrett 2016; Clark, 2013; 2015; Denève & Jardri, 2016; Friston, 2010; Friston et al. 2017; Hutchinson & Barrett, in press; Rao & Ballard 1999; Seth 2015; Shadmehr et al. 2010). However, *even this predictive model is cost-effective*: by issuing predictions, and by encoding only prediction error, organisms can limit resources spent on neuronal signaling (Sengupta et al. 2013; Theriault et al. 2019; Zénon et al. 2019), encoding only signals that the predictive model did not already anticipate (i.e., prediction error; Shannon & Weaver 1949/1964). Like “aspects of cognition,” a predictive brain is a means to a regulatory end: animals are not motivated to reduce prediction error, but instead, are motivated to optimize the return on their energetic investments, a task well-suited to a predictive brain (Barrett 2017a; 2017b; Barrett et al. 2016; Chanes & Barrett 2016; Hutchinson & Barrett, in press; Kleckner et al. 2017; Theriault et al. 2019).

“At its biological core, life is a game of turning energy into offspring” (Pontzer 2015), meaning that if Lieder and Griffiths wish to model how a brain works, then resource usage must be a central (if not *the* central) computational concern. Brains did not evolve for animals to think or see or feel – they think, see, and feel because doing so regulates a body with resource-hungry systems. A resource-rational approach can set researchers in the right direction – constraining

computational models using a common currency of resource usage – but the journey will be long unless computational goals are formulated using the empirical trail blazed by biology and neuroscience.

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