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Cognition: A Study in Mental Economy

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Abstract

In this letter, we argue that an economic perspective on the mind has played—and should continue to play—a central role in the development of cognitive science. Viewing cognition as the productive application of *mental resources* puts cognitive science and economics on a common conceptual footing, paving the way for closer collaboration between the two disciplines. This will enable cognitive scientists to more readily repurpose economic concepts and analytical tools for the study of mental phenomena, while at the same time, enriching our understanding of the modern economy, which is increasingly driven by mental, rather than physical, production.

Keywords: Attention; Memory; Resource-rational analysis

1. Introduction

When a peacetime economy abruptly transitions to a war footing, existing capabilities built up for the production of consumption goods ("butter") need to be repurposed for the production of military ones ("guns"). As documented in historical analyses of Liberty Ship building during World War II (Thompson, 2001) and other examples of learning by doing (*c.f.*, Arrow, 1971), production is initially slow and costly, but becomes ever-more efficient over time as the economy adapts to its new martial stance (Yelle, 1979).

An analogous process occurs when the brain confronts a novel, complex task. Upon first playing the video game Tetris, for example, the brain recruits a diversity of cognitive

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resources, but, much like an economy producing warships, learns to operate both better and more efficiently with experience (Haier et al., 1992). Similar to the butter-to-guns transition, this process often involves shifting *mental production* away from general-purpose but scarce cognitive resources (such as working memory) to high-throughput, specialized capacities (such as perception; Schneider & Shiffrin, 1977). Indeed, one of the features that distinguishes chess experts from novices is that they learn to *see* the relative strength of positions, enabling them to focus their slow, rate-constrained cognitive capacities—for example, forward simulation—on only the most promising lines of play (Chase & Simon, 1973; De Groot, 2014).

Such analogies between adaptive resource allocation in economies and brains are, we argue, no mere coincidences, but rather reflect the deeper fact that both are, at their core, productive systems that must flexibly reallocate scarce resources in pursuit of ever-changing goals. In this letter, we propose that viewing cognitive systems in terms of *mental production* and *mental resources* represents one of the most promising paths forward for cognitive science. Conceiving of the mind as a steward of scarce mental resources opens up new opportunities for intellectual cross-fertilization between cognitive science and economics, and underlies many of the most promising areas of contemporary research in cognitive science, a few of which we outline below.

2. The economics of the mind

2.1. Attention

To the degree that our cognitive capacities can be flexibly applied to competing ends, they constitute mental resources that must be allocated, implicitly or explicitly, by what William James called "selective interest," his way of characterizing the concept of attention (1890). Indeed, the most common metaphors used to describe attention—the bottleneck, spotlight, and zoom lens—all highlight the idea that our limited capacity for information processing implies the need for allocative selectivity (*e.g.*, Eriksen & Yeh, 1985; Posner, 1980; Tishby, Pereira, & Bialek, 2000) Attention's natural interpretation as an economic resource has driven much research on the subject, including Kahneman's (1973) "resource pool" model and, even more explicitly, Navon and Gopher's (1979) application of microeconomic techniques to derive an attentional theory of dual-task performance.

Although people certainly do have the capacity to direct attention explicitly—and often must, especially in situations where habitual patterns of action conflict with one another (Norman & Shallice, 1986)—deliberating about how best to direct the mind consumes the very cognitive resources one seeks to deploy. Accordingly, the brain features many mechanisms to ensure that much, if not most, of attention allocation occurs automatically. These include bottom-up processes, such as visual salience and reflexive orienting to loud sounds, that happen without—and often in spite of—conscious volition. Our mind also includes a special class of feeling states—principally boredom, flow, curiosity, and mental effort—that serve as an interface between deliberative and automatic attention allocation, a topic we explore more fully in the next subsection.

2.2. Feeling states that direct cognition

Herbert Simon, a pioneer of both cognitive science and economics, was also among the first to analyze the mind's architecture explicitly in terms of mental resource allocation. In an article on the "Motivational and Emotional Controls of Cognition," for example, he proposed that emotions exist to redirect precious serial information-processing capacity away from the narrow pursuit of existing goals when pressing new concerns arise (Simon, 1967).

In recent years, the fundamental insight that a subset of feeling states exist to help allocate cognitive resources has stimulated a broad range of theoretical and empirical work, including proposals that mental effort encodes information about the opportunity cost of maintaining attention (Kurzban, Duckworth, Kable, & Myers, 2013) or exerting cognitive control (Inzlicht, Schmeichel, & Macrae, 2014; Shenhav et al., 2017; Shenhav, Botvinick, & Cohen, 2013; Westbrook & Braver, 2015), and that boredom, curiosity, and flow help to direct attention without drawing upon it excessively (Wojtowicz, Chater, & Loewenstein, 2019; Wojtowicz & Loewenstein, 2020).

An economic view of the mind has been indispensable for disentangling the allocative function and specific properties of these states. For example, the opportunity cost model implies that mental effort should reflect one's expectations and features of the current environment, not just characteristics of the task at hand, and that this should be true regardless of whether the underlying limits to cognitive control arise from finite processing capacity, metabolic resource depletion, or interference due to noise (Shenhav et al., 2017). The resource-based perspective has also driven recent efforts to "price" the disutility that participants place on mental effort and how it responds to such features (Kool, McGuire, Rosen, & Botvinick, 2010; Kool & Botvinick, 2014, 2018).

2.3. Foundations of hedonic utility

Economic thinking can also be applied to the broader question of why diverse stimuli—*for example*, the primary reinforcers of water, food, sleep, shelter, and sex, but also the cognitive motivational states of boredom, flow, curiosity, and mental effort, discussed above—all motivate behavior via the "common currency" of pleasure and pain (Cabanac, 1992; Sescousse, Li, & Dreher, 2015). Stylized accounts of economic behavior assume that consumers trade off everything against everything when making choices—for example, today's latte against an incremental investment in the education of one's as-yet unborn child. In reality, however, people simplify such problems by crudely evaluating potential purchase against the marginal utility of money (Baxley & Moorhouse, 1984), or, in a more recent account, the viscerally felt "pain of paying" (Prelec & Loewenstein, 1998).

The brain likewise seems to simplify the problem of maximizing evolutionary fitness by breaking it down into a low-dimensional space of informational signals—for example, thirst, shame, and curiosity—that measure progress on biological, social, and cognitive subgoals in a globally commensurable way (Lewis, Singh & Barto, 2010; Lewis, Howes, & Singh, 2014; MacLeod, 1996; Singh, Lewis, Barto, & Sorg, 2010; Sorg, Singh, & Lewis, 2010). These states reduce an organism's intractable goal of maximizing long-term fitness into more manageable subgoals which can then be traded off against one another on a momentary basis,

similar to how prices enable an economy to reduce the global problem of societal resource allocation into simpler production and consumption decisions made by firms and households.[1,2]

This analogy immediately generates a variety of predictions, for example, that we will only experience hedonic states in connection with things that we have some degree of volitional control over and that hedonic states crudely encode the evolutionary costs and benefits of engaging in alternative actions. It also raises new and interesting questions that are amenable to economic analysis, such as what determines the "price" at which one affective state (*e.g.*, hunger) trades off against another (*e.g.*, the shame of eating alone) or why it is efficient for some information processing to happen "within" the signals and some happen in the market "between" them (which parallels a central problem in economics known as the *theory of the firm*; see, again, Simon, 1991).

2.4. Resource-rational analysis

Rational analysis (Anderson, 1990) attempts to understand the mental and behavioral strategies people employ by formalizing the longstanding intuition that cognition is efficiently adapted to its environment (see also the related proposals of Marr, 1982; Oaksford & Chater, 1994; and Gigerenzer & Goldstein, 1996). *Resource-rational analysis* builds upon this tradition by explicitly modeling how the optimal cognitive strategy changes when mental resource constraints—that is, a cost for attending to each additional piece of information—are added to standard decision-theoretic problems.

Solutions to these expanded problems furnish the modeler with hypothesis about which types of strategies can be considered "resource rational" and are, therefore, likely to be employed. This approach has been productively applied to a range of questions, such as how people plan action sequences (Callaway et al., 2018), where they orient their gaze (Callaway, Rangel, & Griffiths, 2021), and why they exhibit biases, such as anchoring and adjustment (Lieder, Griffiths, M Huys, & Goodman, 2018).

3. The future of mental economy

Spurred by a shared quest to understand biases of judgment and choice, recent years have seen an accelerating convergence of thought between cognitive science and economics. Our hope is that this trend will continue, leading to more explicit collaboration between the two disciplines and further scientific "gains to trade" for both. In particular, economics can offer cognitive science a rich conceptual toolkit for the analysis of scarce mental resources, while cognitive science can offer a variety of computational and functional perspectives on the mind that extend the domain of economic thinking to within the boundary of the skull.

This trend toward tighter integration promises to enrich our understanding of both brains and the economies they create, especially in the digital age. As Simon noted early on (1971), attention and other mental capacities have already become the most important resources constraining many aspects of modern life, making their scientific analysis pivotal to

contemporary economic, social, and political discourse. At the same time, machine learning and other novel digital technologies stand poised to enable the manufacture and widespread distribution of artificial mental resources at scale for the first time in human history. The emergence of mental resources as not just a, but perhaps *the*, driving force in modern economic life means that the joint project of mapping mental production both within and between minds is even more critical than ever.

Notes

1 In this connection, it is interesting to note that Friedrich Hayek's influential arguments for free markets on the basis of their capacity for distributed self-organization drew inspiration from his early work on the neural basis of sense-perception (Hayek, 1945, 1952, 2012).
2 The price system may also provide insight into our ability to flexibly and dynamically distribute processing over cortical areas. Although some work raises the question of how the brain accomplishes this remarkable feat (Just & Varma, 2007), whether the cortex uses something akin to transfer prices (Hirshleifer, 1956) to coordinate mental production is an open question for future research.

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