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RESEARCH ARTICLE

A cognitive model fleshes out Kahneman's fast and slow systems

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Abstract
Daniel Kahneman (2011) posits two main processes that characterize thinking: ''System 1'' is a fast decision making system responsible for intuitive decision making based on emotions, vivid imagery, and associative memory. ''System 2'' is a slow system that observes System 1's outputs, and intervenes when ''intuition'' is insufficient. Such an intervention occurs ''when an event is detected that violates the model of the world that System 1 maintains'' (Kahneman, 2011, p. 24). Here, we propose specific underlying mechanisms for Kahneman's Systems 1 and 2, in terms of the LIDA model, a broad, systems-level, cognitive architecture (Franklin et al., 2014). LIDA postulates that human cognition consists of a continuing, overlapping iteration of cognitive cycles, each a cognitive ''atom,'' out of which higher-order processes are built. In LIDA terms, System 1 employs consciously mediated action selection in which a stimulus is acted upon within one or two cognitive cycles. In contrast, System 2, which LIDA posits to operate according to James' ideomotor theory (James, 1950), requires more cognitive cycles in its deliberative decision making. Thus, we suggest that System 2 employs multiple occurrences of System 1 in its operation. To test the proposed mechanisms, we perform an *in silico* experiment using a LIDA-based software agent.
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Introduction

As human beings, we interact with our environment and integrate implicit and explicit knowledge for decision making. Many researchers in psychology and neuroscience have suggested models for decision making (Pfeiffer, Whelan, & Martin, 2000; Scott & Bruce, 1995; Shiv & Fedorikhin,

1999). However, the main target of these models is the functional level process of decision making, rather than their underlying mechanisms. Some other questions that have been discussed in the literature are: Would our brains use implicit or explicit knowledge or a combination of both to make a decision (Peters & Levin, 2008)? How can we explain the underlying processes that affect errors of judgment? Or choices under pressure? What are the prerequisites, such as training, required to have a clear enough understanding of a given situation to make appropriate decisions? How can professional training improve an expert's decision making?

Kahneman's Thinking, Fast and Slow (TFS) (2011) discusses all the aforementioned questions. The book postulates that two systems are responsible for decision making; namely, ''System 1,'' a fast system, which is responsible for intuitive decisions based on emotions, vivid images and associative memory and ''System 2,'' a slow system, which observes System 1's output, and intervenes when the output is considered to infringe on decision making rules. In order to pay attention to the output of System 1, System 2 requires a great deal of extra energy, and also can sometimes be ''lazy'' (see below). In order to understand the decisions we make, it is necessary to understand such mental processes underlying decision making.

The Learning Intelligent Distribution Agent (LIDA) model is a broad, systems-level, cognitive architecture that attempts to model how minds work (Franklin, Madl, D'Mello, & Snaider, 2014). LIDA conceptually and computationally implements the Global Workspace Theory of Baars (1988). Global Workspace Theory (GWT) is perhaps the most widely accepted psychological and neurobiological theory of the role of consciousness in cognition (Baars, 2002). LIDA postulates that human cognition consists of a continuing, overlapping iteration of cognitive cycles, each acting as a cognitive ''atom,'' out of which higher-level cognitive processes are built. We suggest that Kahneman's fast System 1 is characterized by decision making in one to three cognitive cycles, while the slower System 2, implementing James' ideomotor theory of decision making (William James, 1950), employs more than 3 cognitive cycles in its deliberative decision making.

In the next section of this paper, we will give a brief review of Thinking, fast and slow. We then present what we take to be the conceptual core of the book, and describe how the LIDA model and its cognitive mechanisms implement that core. In particular, we will describe how Kahneman's two systems are implemented by two forms action selection in LIDA. To begin validating LIDA as a model of the underlying processes of Systems 1 and 2, using a LIDA agent, we replicate some of the experiments described by Kahneman in TFS.

Kahneman's fast and slow systems

The focus of Thinking, Fast and Slow (TFS) is on two systems of decision making. ''System 1'' is the fast system, which is responsible for intuitive decisions based on emotions, vivid imagery and associative memory. ''System 2'' is the slow system, which observes System 1's output, and intervenes when the output is considered to either infringe on more rational decision-making rules, or when an agent's intuition[1] is insufficient in handling a situation. For example, a person feels thirsty and immediately reaches for a glass of water on the table (System 1 in action). Or, he considers having a beer instead, but thinks that it's too early in the morning for that, and decides to drink orange juice instead (System 2 in action). In the former example, the person had an immediate need, which could be satisfied by an action based on intuition alone. No alternative possibility needed to be accounted for. In the latter, it was initially intuitive for the person to consider having a nice, refreshing beer. However, the time of day was sufficient context to provoke an inconsistency involving this initial impression and the long-term consequences of consuming beer so early. In order to address inconsistencies between one's intuitive impressions about how to decide and evaluate, and aspects of our situation conflicting with those impressions, System 2 becomes vigilant and resolves the issue.

Relevant to the above, humans have to adapt to both fast-paced, chaotic environments and to slower-paced, more stable environments. Evolutionarily, we needed quick, heuristic decision making when there was no time for long-term planning in such fast-paced situations. Dealing with present opportunities for short-term gain is an example, much like the beer-versus-water dilemma above. Another is when there was no time to deliberate in the rational sense (System 1) (e.g., with an immediate threat). However, we also need a slower system for long-term planning, which would best fit ''slower,'' more stable situations. Examples would include planning for the winter, when there is less food available, or choosing what to order in a restaurant. We would have to make rational (System 2) predictions, and reason about multiple consequences, all over extended periods of time. System 1 is incapable of such long term processing. Likewise, it would be disastrous if System 2 interfered when time was of the essence. It is imperative that these two systems collaborate to deal with these conflicting demands. Kahneman's account of Systems 1 and 2 involves many circumstances in which such collaboration occurs, whether culturally enforced or built-in by evolution.

TFS, discusses attention and effort, cognitive ease and strain, norms, surprise and causes, causal versus statistical reasoning, expert intuition, intuition verses formulas, associative coherence, attribution substitution, the availability heuristic, availability cascades, the affect heuristic, the halo effect, the representativeness heuristic, and the anchoring effect. It also mentions some of Slovic's work (2000) regarding human judgment of risk. In this paper, from the above list, we will give a brief description of attention and effort, cognitive ease, expert intuition, associative coherence, the availability heuristic, the affect heuristic, the representativeness heuristic, and the anchoring effect and then in the Kahneman's Systems 1 and 2 à la LIDA section we will discuss them in the subsection below.

Attention and effort

The effort described by Kahneman refers to what a subject is doing, instead of what is happening to him (Kahneman,

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[1] The act or faculty of knowing or sensing without the use of rational processes; immediate cognition (Freedictionary.com).