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Problems and Mysteries of the Many Languages of Thought

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Abstract

"What is the structure of thought?" is as central a question as any in cognitive science. A classic answer to this question has appealed to a Language of Thought (LoT). We point to emerging research from disparate branches of the field that supports the LoT hypothesis, but also uncovers diversity in LoTs across cognitive systems, stages of development, and species. Our letter formulates open research

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questions for cognitive science concerning the varieties of rules and representations that underwrite various LoT-based systems and how these variations can help researchers taxonomize cognitive systems.

Keywords: Mental representation; Inference; Language of Thought; Comparative psychology; Concepts; Reasoning; Evolution; Vision science; Developmental psychology

1. The re-emergence of the Language of Thought

What is the structure of thought? This question lies at the heart of cognitive science: thought and the faculties that subserve it are the fundamental constituents of the mind. Recent advances in deep neural networks appear to suggest that there is no need for psychological models beyond ones that posit links between neuron-like nodes. But while Artificial Intelligence (AI) research has moved away from transparently interpretable, richly structured internal representations, advances in many disparate areas of cognitive science suggest otherwise. Evidence from animal and infant cognition, Bayesian computational cognitive science, unconscious reasoning, and visual cognition suggests that the mind traffics in representations couched in an amodal code with a language-like structure. In other words, there is a *language of thought* (Fodor, 1975; Quilty-Dunn, Porot, & Mandelbaum, Forthcoming).

A Language of Thought (LoT) is a system with a cluster of distinctive properties:

1. Discrete constituents
2. Predicate-argument structures defined over those constituents
3. Role-filler independence (i.e., syntactic roles like *agent* are independent of the representations that occupy them and vice versa)
4. Logical operators
5. Inferential promiscuity (especially across content domains)
6. Abstract conceptual content (i.e., encoding properties, individuals, and relations as such, independently of low-level modality-specific content)

Evidence from across cognitive science supports the hypothesis: from reasoning with implicit attitudes (Mandelbaum, 2016; De Houwer, 2019; Kurdi & Dunham, 2021), to the structure of object files (Green & Quilty-Dunn, 2021) and the perception of physical relations (Dehaene, Al Roumi, Lakretz, Planton, & Sablé-Meyer, 2022; Hafri & Firestone, 2021), to Bayesian models of cognition (Goodman, Tenenbaum, & Gerstenberg, 2015; Piantadosi & Jacobs, 2016), to the study of thought in infants (Feiman, Mody, & Carey, 2022; Kibbe & Leslie, 2019) and even—surprisingly—many animal species, including arthropods (see Quilty-Dunn et al., Forthcoming for a review of all these areas). These diverse forms of cognition, to varying degrees, operate independently of natural language. In natural language, we find more direct evidence for abstract, compositional, LoT-like structure in syntax and semantics (Levin & Rappaport Hovav, 1995; Pietroski, 2018; Pylkannen, 2008).

Evidence for LoT thus appears to be on firmer footing than ever before. Although language-like structures are just one type of format for thought (alongside iconic and associative representations, inter alia), they appear to be ineliminable. Here, we focus on what we see as two

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central questions for the future of cognitive science: how might LoTs differ both between mental processes in a species (e.g., perception vs. cognition in humans) and also across species?

2. Languages of thought in perception, cognition, action, and beyond

Having a unimodal common code ensures swift communication between different mental faculties. LoT facilitates information transfer through a common *interlingua* (as is needed for natural language semantics; Dunbar & Wellwood, 2016; Dupre, 2021; Harris, 2022). However, that does not entail that all aspects of the LoT stay the same across mental processes. Representational systems may possess all six LoT properties and still differ widely in their primitive representations or in the syntactic rules that combine them; or they may possess some LoT properties and not others.

For example, although there is evidence that perceptual representations traffic in LoT structures, perception may lack the full representational scope of natural language, including limits on properties (e.g., *color* but not *democratic*; Green, 2020) as well as syntactic features like logical operators, modality, aspect, and tense. Canonical human cognition, on the other hand, is not so restricted. There is little consensus on the compositional structure of motor representations, but some have supposed that a subset of them have language-like structure (Mylopoulos, 2021; Shepherd, 2021). Whether motor systems, like perceptual systems, exhibit some LoT properties (e.g., predicate-argument structure and role-filler independence) and not others (e.g., logical operators) is a question cognitive science is only beginning to tackle. In the same vein, it is unknown how many of the concepts used by one system (e.g., compositional shape representations in vision) can interface directly with other systems.

The variability in LoTs broadens as we leave human psychology and turn to growing evidence for LoTs throughout the animal kingdom. To take just one example, some insect species perform logical (Tibbetts, Agudelo, Pandit, & Riojas, 2019) and numerical (Howard, Avarguès-Weber, Garcia, Greentree, & Dyer, 2018) inferences. But the difference between their LoTs and ours might be considerable. The ability to compute such simple inferences imposes few constraints on a creature's stock of primitive concepts and syntactic variation may be even more dramatic between species than across an organism's subsystems.

Human cognition utilizes operators, such as negation and universal quantification. How widespread are such operators among LoTs? Evidence for sentential operators of any kind in perception is thin; there is some evidence for disjunctive syllogism in olive baboons (Engelmann et al., 2021), parrots (Pepperberg, Gray, Cornero, Mody, & Carey, 2019), chimps (Ferrigno, Huang, & Cantlon, 2021), and infants (Cesana-Arlotti et al., 2018). Elsewhere, we know next to nothing: for example, do any nonhuman species use quantifiers? If so, do they respect rules that would be familiar to us from existing formal and natural languages, or do they have some totally different syntax? Might some operators be usable just for domain-specific reasoning (Camp, 2009)?

The generative capacity underlying natural language appears to require recursion (Chomsky, 1995; cf. Futrell, Stearns, Everett, Piantadosi, & Gibson, 2016). *Pace* the claim that only human thought supports this (Hauser, Chomsky, & Fitch, 2002), we can ask if it occurs in other LoTs or is restricted to a few rare clades of the phylogenetic tree (Sablé-Meyer et al., 2021)? Within human minds, is recursion limited to specific mental processes or is it cognitively fundamental?

We still know little about the specific syntactic principles of thought and even less about their origins. Are there any core shared syntactic features across LoTs, and if so, are these the result of some shared evolutionary history or merely convergence due to the benefits of LoT-like cognition? Similarly, are the potential neural underpinnings of LoT (Frankland & Greene, 2020; Gallistel, 2021; Gershman, 2022; Roumi, Marti, Wang, Amalric, & Dehaene, 2021) part of convergent evolution or are they shared homologous structures? Turning to artificial cognition, do apparent successes of neural networks owe in part to implementing LoT-like structures (Manning, Clark, Hewitt, Khandelwal, & Levy, 2020; Tenney et al., 2019; cf. Grondahl & Asokan, 2022; Miller, Naderi, Mullinax, & Phillips, 2022), and if so, exactly what symbols and rules do they implement?

Chomsky (1976; 2013) distinguished problems and mysteries in cognitive science. Problems were difficult issues whose progress may be slow, but were steadily improving; mysteries were questions whose answers are not graspable given our contingent human conceptual machinery. Questions concerning (e.g.,) consciousness and the frame problem may still appear to be in the land of mysteries, but some crucial questions about the structure of thought are now firmly in the problem category. The future of cognitive science is, in part, an investigation into how human minds differ from other agential thought, both animal and artificial. Future research can distinguish kinds of cognition within and across species by uncovering continuity and diversity in syntax and expressive power in LoTs. Pursuing this (partly taxonomical) project will allow us to trace evolutionary paths for biological cognition of all stripes, from the ability of seemingly simple creatures—perhaps even more humble than insects—to represent and reason, to the complex and powerful machinery that underwrites human thought.

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