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Commentary Title: “Opportunities and Challenges Integrating Resource-Rational Analysis with Developmental Perspectives”

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Abstract: Lieder and Griffiths present the computational framework “resource-rational analysis” to address the reverse-engineering problem in cognition. Here we discuss how developmental psychology affords a unique and critical opportunity to employ this framework, but which is overlooked in this piece. We describe how developmental change provides an avenue for ongoing work as well as inspiration for expansion of the resource-rational approach.

Main Text: The power of any modeling and analysis approach comes with the degree to which it can speak to, and be informed by, variability. Cognitive development provides a rich source of variability in representation, constraint, and mechanism. This affords a unique opportunity to explore heuristic differences predicted by resource-rational analysis. Below we focus on four areas of development, detailing how each integrates with the resource-rational framework and provides a critical test of the approach.

Lieder and Griffiths’ resource-rational analysis combines rational principles with cognitive constraints. Under this framework, the cost of various heuristics should be sensitive to the structure of the cognitive representations on which they operate. For example, carrying out a specific heuristic (e.g. for categorical inference) could be more costly under certain cognitive representations (e.g. non-overlapping clusters) than others (e.g. taxonomic ones). This representational variability provides a critical test of resource-rational models. While the structure of representations is domain-dependent, cognitive representations within a domain can vary. This variability arises from development (Chi & Ceci, 1987; Kemp & Tenenbaum, 2008). Because heuristic cost depends on the representational structure, changing heuristics and the variability in these representations throughout development can inform the robustness and flexibility of the resource-rational approach.

Cost and availability of heuristics (and therefore their utility) in Lieder and Griffiths’ framework are also influenced by cognitive constraints. Constraints of working memory capacity, executive function, and inhibition change developmentally (Davidson et al., 2006), as does the trade-off between cognitive flexibility (e.g. rule switching), recall accuracy, and processing speed (Crone et al., 2006). This suggests another important avenue for applying the resource-rational framework in development to investigate resulting changes in cognitive heuristics. For example, when older children are presented with an increase in cognitive load (e.g. increased inhibition demands), they display an increase in reaction time and higher recall accuracy, whereas younger children maintain their reaction time at the expense of recall accuracy (Davison et al., 2006). Therefore, the variability seen in cognitive control and flexibility across

development, and the implications it has on the duration and execution of cognitive computations and decisions, makes this a promising domain of research to explore the resource-rational framework.

Emotional and motivational states, factors of “internal” environment, are also critical to the cost function, as well as the availability of heuristics considered. Such affective states can influence information processing strategies adopted by individuals, assuming that cognition adapts itself to contextual requirements (known as the “feelings-as-information” perspective; Schwarz, 2002; 2007). For example, past research suggests that most negative states (e.g. sadness or fear) typically signal problems that foster systematic, bottom-up processing with attention to detail, adaptive to goal-directed behavior (Wegner & Vallacher, 1986). In contrast, many positive states (e.g. happiness) are associated with reliance on heuristics and top-down use of pre-existing knowledge structures (Bless et al., 1996; Griskevicius, Shiota, & Neufeld, 2010). Given that children are perhaps the most variable emoters (Lewis, 2008), this provides another unique opportunity of high variance to employ this analysis, especially as research begins to develop new theory integrating development with the domains of emotion and cognition (Calkins & Bell, 2010).

Finally, and perhaps most critically, variability in early environmental experiences may be particularly informative because it will shape how cost functions are learned and govern which heuristics are more readily employed. At the broad level of development, for instance, theories suggest that the relative security of a protected childhood changes costs associated with “riskier” cognitive exploration in adulthood (Gopnik et al., 2017). Individual differences may also critically influence acquired cost functions -- for example, recent work suggests that the kinds of questions parents tend to ask their children (Yu, Bonawitz, & Shafto, 2019), as well as the quality of explanations parents provide in response to their children’s questions (Kurkul & Corriveau, 2018), systematically vary with several key factors of home life. A child whose parents are less likely to ask questions or provide causal explanations may thus acquire a very different-looking cost function for (e.g.) the heuristic of reaching out to others for information than a child whose parents are more likely to engage in these kinds of behaviors. Indeed, this notion is consistent with recent computational work which suggests that learners may bring expectations about the teaching style of their informant to bear in future learning (Bass, Shafto, & Bonawitz, 2018).

Although development provides special opportunities to employ resource-rational analysis by leveraging variability in the population, challenges remain. First, the *goals* of a developing system may radically vary from those in adulthood. For example, the goals of an adult semantic memory system might be defined by compression and storage for optimal later accessibility (e.g. Anderson, 1989); however, hypothetically, a developing memory system’s goal might be to expand and re-encode for representational restructuring. Because there is significantly less work that has focused on defining goals of the developing mind, resource-rational models will be underconstrained.

Second, variability within a developing child presents a challenge as algorithmic utilities are learned. According to the rational-resource analysis, the max ordered value of a heuristic depends on utilities that will be derived from representation, cognitive constraints, experiences, and rule-discovery. But these are constantly shifting in development, so how might a learner develop a preference for a particular heuristic? Consider a learner whose working memory limitations lead to favoring a “local search” heuristic. Although the learner’s working memory capacity may grow over time, once a particular heuristic has been learned and habitually adopted, it is not clear when or why the system would re-evaluate and discover a more

optimal “global” search heuristic employing newly developed resources. Such considerations suggest that a broader, dynamic framework of resource-rational analysis will need to be developed.

Overall, we think the resource-rational approach presented by Leider and Griffiths will be an important computational toolkit for cognitive psychology. Although there are challenges, we suggest that the variability found in cognitive development in particular will be a critical playground for modelers employing this technique.

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