

If one important aspect of learning is how one might store relevant information and retrieve it for later use (as in last week's discussion), perhaps an even more fundamental challenge for learning is how one might acquire relevant information in the first place. The Schulz paper advances the analogy between a child and a scientist and proposes that the inferential abilities characteristic of scientific practices are, in fact, fundamental properties of the human learning mechanism. In this regard, one of the main questions that arise from this week's reading is whether there's something fundamentally different in the way human children explore and learn about the world, from the way other animals do. Is there a uniquely human aspect in the learning mechanism that promotes hypothesis generation and theory-driven explorations, or is this capacity deeply rooted in a other evolutionarily ancient mechanisms involved in simple motor sequence learning (e.g., songbirds in Fee paper) or foraging decisions (e.g., monkeys in Hayden paper)?

There are simpler kinds of human learning that seem genuinely similar to the way in which songbirds learn songs and monkeys weigh the options to stay or to explore (e.g., playing music instruments, riding bicycles, slot machine behaviors, etc.). However, these cases of learning are fundamentally limited in their explanatory power to capture the full scope of the human ability to construct hypotheses, generate evidence, and move in hypothesis space based on evidence.

(1) The Fee paper puts forward an extremely interesting proposal about a learning mechanism in songbirds that has a clear end state (e.g., producing a song that sounds like the tutor song) and well-defined neural structures that support this learning. Not only is the idea of a learning mechanism that generates "noise" in behavior that is "biased" in a direction that is more likely to produce the correct behavior conceptually intriguing, but the precise details known about each one of these neural structures that perform these computations is amazing. However, despite its awesomeness, I think the kind of learning discussed in this paper is strictly constrained to cases where there is a "correct behavior" or a template to which the behavior is matched and reinforced. Human children's tendency to show more variability in play when there is ambiguity or uncertainty (thus higher potential informational gain) may seem superficially similar to Fee's birds, but their exploration gets the causal structure right even when the initial evidence observed is sparse and far from the "right template". Part of what's special in human exploration seems to be the ability to *generate* hypotheses about causal structures and perform effective interventions to yield informative evidence. The Ullman paper proposes a mechanism by which the correct can be generated via stochastic search – which seems to operate at a fundamentally different level from behavioral variability in the songbirds.

(2) The Hayden paper suggests how firing rates of neurons in dACC may represent the relative value of (a) staying and exploiting the current resource and (b) incurring a cost to move to a different resource. In this foraging decision task, monkeys were presented with precise information about the expected rewards for staying (constant depletion

rate) and for switching (visual representation of length of delay and fixed magnitude of reward from replenished source). While the Hills paper suggest a striking (to the extent that it's almost unbelievable) relationship between spatial search and search in conceptual space, such foraging model in the Hayden paper seems to be way too simplified to account for foraging in hypothesis space where information is harvested and hypotheses are revised accordingly. Critically, it does not explain how humans select or generate "*where* to forage next". In order to apply this framework in explaining human exploration and learning, we need to understand how value of information (e.g., evidence generated by an intervention) can be calculated with respect to the learner's uncertainty in the current hypothesis, probability of observing such evidence, and the costs for generating such information. Despite these limitations, I think there is real potential in understanding how these variables are represented in the brain, and dACC, along with a few other areas in the prefrontal cortex, is an interesting region that may serve as the final destination where all these decision variables are integrated to generate a behavior.

Animal models of learning are important in their own right, and can explain a lot in human learning as well. However, there are at least three aspects of human learning that set us apart from non-human animals, and thus cannot be captured in these models. First, humans possess a powerful mechanism for making inductive inferences. Second, human species have unprecedented ability to represent abstract (even unobservable) variables and construct hypotheses to guide their behavior. Finally, humans seem to have the *motivation* to learn about causal structures in the world, which perhaps might be what makes humans most distinct from other animals.

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