Exploring Spaces to Make the Right Choice: The Cognitive Science of Search

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Introduction

One important question in cognitive science is how humans search for useful resources in the environment. Indeed, understanding the search process is often a critical step for studying how an agent learns, adapts, and behaves in an uncertain environment. More generally, search is required whenever an agent faces a problem and there are uncertainties involved during the process of solving the problem. Given its ubiquity, the search process is found to be central in many cognitive activities, ranging from vision, memory retrieval, problem solving, decision making, web navigation, to social selection. However, research on search has a tendency to fragment into multiple areas. The goal of this symposium is to lead an integrative discussion of the over-arching principles underlying the search process, and highlight how search plays a central role in cognition. To this end, participants in this symposium will present research results that show how humans search in different spaces such as information spaces (Wai-Tat Fu), decision spaces (Thomas Hills), motivational spaces (Art Markman), and social and non-social spaces (Peter Todd).

Overview of Presentations

Wai-Tat Fu

Exploratory Information Foraging

Information search has become an important part of human activities as people acquire new information about the world and adapt to the changes. The theory of information foraging analogizes information search with animal foraging, and assumes that the search process can be characterized as an optimization process that maximizes the intake of information while minimizing the costs of switching between information patches. Computational cognitive models based on the theory of information foraging provide good prediction on how people search for specific information on WWW. Recent research, however, shows that information foraging behavior is often exploratory, in which the information goal evolves as new information is discovered and integrated into their internal representations of the environment (Fu, Kannampallil, & Kang, 2009). This dynamic updating of internal representations and search policies is found to be highly adaptive to the characteristics of the environment. Modeling the exploratory information foraging behavior can provide a more complete understanding of emergent patterns of individual and aggregate search behavior in large-scale information spaces.

Thomas Hills & Ralph Hertwig

Individual Differences and Executive processing in Information Search

Recent work on individual differences in information search reveals that people differ in how they mediate local versus global search policies. In other words, people differ in how long they search in a local region of the information space before making a global transition to another local region of the space. This may be a consequence of a general executive search process that mediates search across domains, including spatial search and problem solving (Hills, Todd, & Goldstone, 2008), memory search (Hills & Pachur, in review), and external information search among gambles (Hills & Hertwig, 2010).

We investigated individual differences in local-versus-global search when people were searching for information prior to making a decision between several options. In these studies, individuals were invited to explore several options that each produced different payoff distributions. Following a period of unconstrained information search (participants can explore options as they please for as long as they like), participants make a decision about which option they will choose for real, and then receive its associated payoff. Across multiple studies, we consistently find that some individuals search one option comprehensively before transitioning to a second option; other individuals frequently transition back and forth between options, using a piecewise search. These different search policies correspond to different final decisions, which are consistent with different cognitive models for how these individuals process the information when comparing the two samples. Moreover, these search and decision differences correlate with working memory span and are consistent with a broader model of a domain general cognitive control of search, which applies for both external and internal patterns of information search.

Arthur B. Markman, Bradley C. Love & A. Ross Otto

Modeling the motivational and environmental factors affecting exploration

Intelligent agents need to resolve the tradeoff between trying new options (exploration) and relying on actions that

have succeeded in the past (exploitation) in a variety of settings. Our research has examined both motivational factors and elements of the choice environment that influence the way this tradeoff is resolved.

The research on motivation examines the concept of a regulatory fit (Maddox & Markman, 2010). Much research suggests that people can have an overall orientation to approach positive states or to avoid negative states. A fit occurs when this overall orientation matches the rewards or punishments that are prominent in the environment. An approach orientation fits with an environment that has rewards (or gains) and an avoidance orientation fits with an environment that has punishments (or losses). Regulatory fit increases people's tendency to explore across a variety of choice and problem solving settings.

On the environment side, exploration is influenced by the stability of the environment. In stable environments, past experience is a good guide to future outcomes. In contrast, in unstable environments, past experience is not a strong indicator of future outcomes. Consistent with this intuition, people's behavior is more exploratory in unstable environments than in stable ones.

A key limitation to advancing research on exploration in repeated choices is that most extant modeling frameworks are purely descriptive. These models illuminate patterns of repeated choices (Daw, O'Doherty, Dayan, Seymour, & Dolan, 2006; Sutton & Barton, 1998; Yi, Steyvers, & Lee, 2009). To expand on this work, we developed an ideal observer and actor model that provides an ideal assessment of the current state of the world to determine the optimal course of action. This model provides important insights into people's performance in repeated choice tasks.

Peter M. Todd, Ke Sang, Robert Goldstone

Exploring (and exploiting) different spaces: How people search for social and non-social resources

Organisms must adaptively trade off between exploring and exploiting their environment to obtain the resources they need. This applies to whatever space the organism is searching: whether the two- or three-dimensional physical environment, looking for patches of food; the social environment, looking for mates; or the mental environment, looking for information in memory. Different spaces and resource types call for different search strategies. How well do humans accomplish the explore/exploit tradeoff in different settings, and what strategies do they use? Here we contrast search behavior in two simplified versions of adaptive spaces: a resource-accumulation setting, where individuals make a series of decisions whether to explore to find a new resource or exploit a previously-encountered one; and a mate search setting, where individuals explore a sequence of potential mates and must decide whether they are interested in each (the "exploiting" decision), without being able to return to any previously seen. In the first, we boil search down to a minimal setting in which the explore/exploit tradeoff must be made. Individuals aim to accrue as many points as possible over a 20-turn search, at each turn either exploring by flipping over a card from a deck and receiving the number of points (1-99) shown on it, or exploiting a previously-found card by pointing to it on the table and taking (again) the number of points it has. With this accumulation of resources during both exploration and exploitation and the ability to return to previously-found items, this search resembles a non-competitive foraging task with non-depleting resources. The optimal strategy in this case is to use a decreasing threshold, switching from exploration to exploitation whenever the best card seen so far exceeds the current threshold level. In the second task, individuals encounter a sequence of potential mates and must decide in each case whether they are interested in this person, without being able to go back and re-evaluate or change their mind about anyone previously seen. For this competitive social search, without knowledge of the range of values available, where reward only comes from the choices made and not during exploration, and there is no returning to previous options, the optimal strategy is to set a threshold based on a brief period of initial exploratory search and use that to guide the further exploitation choices. We show how close people come to the optimal strategy in each case, and how their strategies differ between the settings, in both cases finding simple strategies that work very well.

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