Russell Ackoff Fellowship Proposal

Quantitative Analysis of Belief Updating in a Dynamic Environment

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People and animals base decisions on subjective estimates of the probability and utility of various outcomes (Glimcher, 2003). These subjective estimates, or beliefs, are often updated dynamically as new pieces of information arrive over time. For example, advertisers know that repeated exposure can slowly shape beliefs about a product. However, little is known about the brain mechanisms that govern dynamic belief updating. My proposed research will establish a novel experimental paradigm to measure and quantitatively analyze dynamic belief updating in human subjects. This work will then be adapted for use with monkeys to study how and where in the brain this process is implemented.

Previous work into belief updating has focused on information collected in a stable environment. Under such conditions, optimal belief updating can be described using a relatively straightforward probabilistic framework based on Bayesian decision theory (Hirshleifer and Riley, 1992). Using this framework, it has been noted that human subjects deviate consistently from the optimal strategy and tend to overweight extreme or surprising information when updating beliefs (Tversky & Kahneman, 1974).

Preliminary data from my work in the Gold lab suggests that this kind of suboptimal belief updating may be explained by assumptions about the environment in which the subject is operating. In particular, subjects seem to assume a lack of stability in the environment, possibly reflecting evolutionary pressures to quickly identify potentially disastrous changes in dynamic variables like the location and prevalence of food, potential mates, and predators. In a changing environment, the optimal strategy for updating beliefs given uncertain information is to discount prior information that is unlikely to still be true. The predictions of such a strategy appear to match well with psychological data in that extreme evidence can trump even very deeply rooted beliefs.

To examine how people update beliefs in a dynamic environment, I have developed a novel parameter estimation task. The task requires subjects to indicate their belief about the mean of a distribution that sequentially generates random numbers. The subject is allowed to update his belief after each new number is generated. To simulate a dynamic environment, the mean of the generative distribution changes at unpredictable intervals. By modulating the frequency of these changes and the variance of the generative distribution, we can control the different types of uncertainty that a person or animal encounters in a natural environment.

I will use this task to answer the following questions:

1. Is the influence of new information on an updated belief greatest when the new information is suggestive of an environmental change?
2. Can subjects detect such change-points even in the face of noisy information?
3. Will subjects preferentially use information after a task-irrelevant change-point?
4. How do individuals differ in their belief updating strategies?

I plan to recruit 30-40 subjects to participate in four sessions each. The four sessions will use slightly different task designs that will address each of the four questions above.

Analysis of the behavioral data will include determining the extent to which the subjects do and do not make optimal use of incoming information to make accurate estimates. An ideal observer model has been developed in collaboration with Robert Wilson (U. of Penn, bioengineering) to simulate optimal performance on the task. Preliminary analyses suggest that this model, like human subjects, is highly influenced by extreme pieces of information, which often indicate a change in mean.

The answers to the above questions may yield insights into real-world examples of belief changes in response to new information, such as the rapid change in public opinions about foreign policy after September 11. In addition, my findings will help to elucidate the kinds of neural computations that might underlie a belief updating system. For example, if subjects rely heavily on information after change-points (as is predicted by the ideal-observer model), then they must have system to detect change-points and to increase the influence of information collected after change-points. If subjects are influenced by task-irrelevant change-points, then one or both of these processes are likely to be accomplished through a relatively non-specific neuromodulatory system rather than specific cortical circuitry. Such insight will help to guide the remainder of my thesis project, investigating the neural substrates of the belief updating system.

These later investigations will involve recording from individual neurons in rhesus macaques performing parameter estimation tasks similar to those described above. I will target neurons in brain areas that have been shown to be involved in signaling dynamic aspects of the environment but whose role in belief updating has not been examined. For example, neurons in an area of the brain known as the Locus Coeruleus respond to surprising events, but these responses have never been related quantitatively to behavioral measures of belief updating. We plan to target the Locus Coeruleus in our first electrophysiological studies in monkeys.

I hope to present the results of the proposed behavioral study at the annual conference of the association for NeuroPsychoEconomics. This would be a great opportunity to take my neuroscience research and apply it to real-world problems faced by economists. Additionally, I hope that a dialogue with those approaching similar questions from an economic perspective will help direct the development of my thesis project.

References:

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Tversky, A. and D. Kahneman, *Judgment under Uncertainty: Heuristics and Biases.* Science, 1974. 185(4157): p. 1124-1131.

Hirshleifer, J. and J.G. Riley, *The analytics of uncertainty and information.* 1992, Cambridge; New York: Cambridge University Press.