Neural and Computational Mechanisms of Conscious and Unconscious Decisions Under Uncertainty

Results:

I am pleased to report a number of successes on the research stemming from this bursary, all on the general theme of quantifying uncertainty and risky decision-making across domains. We have now measured such behavior for conscious and unconscious perception in tasks ranging from intuitive physics in infants and adults, binocular rivalry, and early visual processing. Moreover, we developed a method to discover the structure of neural representations and applied it to visual cognition. This report is structured by the papers that have stemmed in part from this bursary.

[1] We investigated how people forage in an uncertain environment, and found that visual search follows optimal foraging informed by the distribution of the number of targets across displays. This indicates that people learn target distributions from the environment, and integrate this learning with uncertain, sparse measurements of the richness of a given scene, to yield near- optimal foraging behavior.

[2] Here we investigated pure reasoning about physically constrained objects in infants. We showed that a simple kinematic model can account for infants' surprisal in a number of classic, and new, experiments measuring how infants perceive objects. This suggests that even as infants, humans can reason about physical scenarios and can combine uncertainty about object locations and motion, along with constraints from base rates.

[3] Here we asked whether bistability in the visual system during binocular rivalry might reflect optimal inference given uncertainty about the latent causes of visual input. We showed that Gibbs (or Markov chain Monte Carlo) inference in a model that captures the structured dependencies of the visual world yields both the global switching dynamics, as well as the local transition dynamics, of binocular rivalry.

[4] Here we asked whether uncertainty about the timing of rapid sequences of events is combined with expectations about the temporal structure of the world – we find that such an account can explain a number of RSVP perception phenomena, including repetition blindness, the attentional blink, and patterns of errors in those tasks.

[5] Here we proposed an overarching agenda for combining uncertain reasoning with cognitive constraints to yield rational process models. We propose that by considering optimal engineering solutions to implementing inference under uncertainty, we may develop process models of human reasoning.

[6] This is the culmination of many strands of research in which we devised methods to discover the structure of visual representations in the human brain. We applied our data driven 'functional

clustering' to fMRI data to show that we can find which objects are seem to be subserved by similar neural substrates, and to identify neural substrates that seem to have sufficiently homogenous function. This hypothesis-neutral method of discovering functional neural architecture yields strong evidence for the face, place, and body areas, and opens the possibility for discovering new functional regions in the brain.

[7] Here we measured uncertainty in the mapping function between visually presented magnitudes, and self-reported numerical estimates. We find that mapping of magnitudes onto numbers reveals a bilinear function that highlights two regimes of (mis)calibration: small magnitudes are mapped veridically, with considerable stability. However, larger magnitudes (above about 15) are systematically mismapped, and show slow drift over time. We believe this slow drifting mismapping reflects a process of MCMC learning of the uncertain mapping from magnitudes onto our verbal number line.

[8] In this work we measured the sources of uncertainty in human physical reasoning, particularly in the domain of reasoning about physical objects undergoing simple 2D motion. We find that most of the uncertainty in these cases arises from stochastic dynamics: meaning that our forward physical models are not deterministic, but are themselves uncertain. Moreover, this physical uncertainty propagates non-linearly, and yields stable patterns of bias and error in human judgments and decisions.

[9] Here we measured uncertainty and the dynamics of verbal problem solving in a semantic remote associates test. We find that people search through their semantic space via a partially-guided random-walk, consistent with a MCMC chain exploring the semantic space weighted by the constraints of the cues.

Published works:

[1] Cain M., Vul E., Clark K. & Mittroff SA. (2011) Optimal models of human multiple-target visual search., Proceedings of the 33 Annual Meetings of the Cognitive Science Society.Cain, M., Vul, E., Clark, K., & Mitroff, S. (2012). A bayesian optimal foraging model of human visual search. Psychological Science, 23(9), 1047-1054. doi: 10.1177/0956797612440460

[2] Teglas E., Vul E., Girotto V., Gonzalez M., Tenenbaum JB. & Bonatti LL. (2011) Pure reasoning in 12-month-olds as probabilistic inference., Science, 332(6033), 1054-1059

[3] Gershman S., Vul E. & Tenenbaum JB. (2012) Multistability and perceptual inference., Neural Computation, 24(1), 1-24

[4] Reith CA. & Vul E. (2012) Expectations About the Temporal Structure of the World Result in the Attentional Blink and Repetition Blindness, Proceedings of the 34th Annual Meetings of the Cognitive Science Society,

[5] Griffiths TL., Vul E. & Sanborn AN. (2012) Bridging Levels of Analysis for Probabilistic Models of Cognition, Current Directions in Psychological Science, 21(4), 263-268

[6] Vul, E., Lashkari, D., Hsieh, P. J., Golland, P., Kanwisher, N. (2012). Data-driven functional clustering reveals dominance of face, place, and body selectivity in the ventral visual pathway. Journal of Neurophysiology, 108(8), 2306-2322. doi: 10.1152/jn.00354.2011

[7] Vul E., Sullivan J. & Barner D. (2013) Slow drift of individuals magnitude-to-number mapping., Proceedings of the 35th Annual Meetings of the Cognitive Science Society,

[8] Smith KA. & Vul E. (2013) Sources of Uncertainty in Intuitive Physics, Topics in Cognitive Science, 5(1), 185-199

[9] Smith KA., Huber DE. & Vul E. (2013) Multiply-constrained semantic search in the Remote Associates Test, Cognition, 128 64-75

Area(s) of interest:

Human cognition, uncertainty, risk, neuroscience

Researchers' contact:

Edward Vul
Assistant Professor
Dept. of Psychology
University of California, San Diego
9500 Gilman Dr. 0109
01 858 534 4401
evul@ucsd.edu