EFRI-COPN: Optimal decision making:
How do rats and humans solve the traveling salesman problem?

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Project Summary and Intellectual Merit: The goal of this ambitious and transformative project is to reverse-engineer optimal decision-making in the mammalian (human and rat) brains via collaboration among internationally renowned systems engineering, neurophysiology, psychology, and recording technology researchers. This research will be framed in the context of "Traveling Salesman Problem (TSP)", which is a common benchmark problem in these fields. Particular research questions include 1) how does the brain choose a strategy, 2) can the choice of a strategy be understood at the neural level, 3) can we understand the choices the brain makes on the basis of engineering principles? To address these questions, we propose to conduct human and rat experiments. First, we propose to test normal human subjects in a computerized version of the TSP in a virtual reality environment that depends on learning via reinforcement feedback. Second, in the rat, we propose to simultaneously record the activity of the ventral tegmental area (involved in reward processing) together with hippocampal place cells (involved in spatial learning) or striatal cells (involved in making plans and decisions) while the animals are learning a TSP task similar to that used in the human studies. We will use the hyperdrive technique, which is capable of recording from up to 100 neurons simultaneously. Data will be obtained at all stages of learning, so that comparisons can be made at several points between the naïve and proficient stages. The behavior of the rat will be compared to optimal trajectories and we will determine the extent to which recorded neural activity correlates with rat behavior. Based on our findings and inferences from the experiments, we will reverse-engineer the algorithms used in a unified computational framework involving a Markov decision process and Belief-Desire-Intention (BDI) framework. This reverse-engineering will be driven by an effort to map the functional modules of the BDI framework to what will be learned from the neurophysiological recordings. We will use a modified connectionist network formalism to bridge the gap between these two levels of description. The temporal dynamics and functional interactions between the modules will be based on the intrinsic and cross-correlational activity of the brain areas being recorded during the task.

Broader Impact: The proposed project is transformative and will allow a significant leap and paradigm shift in fundamental engineering and neuroscience (one of the grandest national challenges) knowledge. The outcome of this research (algorithms capable of learning to perform optimization in the face of severe complexity, nonconvexity, and nonlinearity) will improve the operation of large-scale dynamic systems, which constitute the bulk of modern society. Therefore, the proposed project has a strong potential for long-term impact on economic prosperity and human welfare (urgent national needs) of our nation. In addition, it will have a significant positive impact on participating faculty and graduate student ethos for interdisciplinary research. Such opportunities for collaboration will produce a new cadre of students and researchers who will be able to communicate research across the divide between engineering and neuroscience. The impact of such workforce development does not happen without a catalyst, and the proposed project will serve as such a catalyst. Finally, we should comment that the University of Arizona is a leading institution in systems engineering and neuroscience, and has a vibrant student body, with a long history of participation from minorities. We expect that this project will attract some of the brightest minds to the systems engineering approach to neurosciences, which will advance the competitive capabilities of our nation on the grandest national challenges. As such, the broader impact of this project is quite significant.