A Dynamical Account of Probabilistic Inference

Eran Agmon and Randall D. Beer, Cognitive Science Program, Indiana University

Living systems are embedded in complex environments, which are full of uncertainties in the eyes of the organism. Despite this, organisms are able to reliably recognize their contexts and enact appropriate actions. Given that information at their sensors is generally insufficient to completely infer the context, organisms must somehow fill in the missing information with prior knowledge. Multiple scientific approaches have been used to investigate and describe this ability. Bayesian approaches use statistical inference engines to run through large databases of knowledge representations (Tenenbaum et al. 2011). Though this approach is powerful, many argue that heuristic approaches are more biologically plausible because they require fewer, yet more reliable sensory cues for directing decision making (Gigerenzer and Gaissmaier 2011). The project presented here attempts to create a dynamical systems alternative to the study of inference. This is motivated by our belief that the processes of living systems are best understood as dynamical, distributed interactions between the many components of the brain, body, and environment, rather than statistical engines that run through databases of symbolic representations. Can a dynamical system produce successful probabilistic inference that is truly Bayesian? Would it use a heuristic mechanism? Or is it best understood as something altogether different?

We explore these questions by evolving continuous-time recurrent neural networks (CTRNNs) to optimize probabilistic inference tasks, and then analyzing their resulting strategies. These dynamical, deterministic systems are embedded within a probabilistic sensory environment within which they must make decisions about appropriate actions. By creating such tasks in which agents use incomplete information to make decisions, we were able to successfully evolve dynamical systems that perform some form of inference. In preliminary experiments, agents were evolved to perform a minimal form of numerical Bayesian estimation. Agents were put in one of two contexts and received probabilistic evidence about the context from two inputs. Their fitness function was to minimize the distance between two CTRNN output values and Bayesian posterior probabilities that were separately calculated as evidence was generated. Though the resulting CTRNNs did not perform as accurately as an ideal Bayesian estimator, they were able to predict the posterior probabilities within a reasonable margin of error. Pending dynamical and information-theoretical analysis will investigate how these agents arrive at these values, and how the dynamical systems strategy found in these agents compares to Bayesian and heuristic approaches.

A second experiment aimed to create more situated and embodied agents that perform inference by moving through a probabilistic environment. Agents were provided with two effectors that allowed them to rotate around 360 degrees. Their task was to point as close as possible to a resource in the environment. They could sense this resource in a probabilistic manner that was a function of their distance from it. A 3rd CTRNN effector executes decision making if it reaches a certain threshold. By passing the threshold, it locks in the agent's angle as the final decision for the trial. The distance of this angle from the resource's true direction is the agent's fitness value, and was minimized by the genetic algorithm. Agents that evolved for this task are able to successfully infer the position of the resource. They require a period of time in which they test the environment by moving around in the circle and receiving input. After sufficient investigation they make a decision by increasing their decision-making effector past its threshold. It is our hope that by analyzing the dynamical mechanism used by these agents, we will uncover some insights into how real organisms, with self-organizing dynamical brains, might solve the task of probabilistic inference.

References: Tenenbaum J. B., Kemp C., Griffiths T. L., and Goodman, N. D. [2011]. How to Grow a Mind: Statistics, Structure, and Abstraction." Science 331 (6022): 1279-1285.

Gigerenzer, G., and Gaissmaier, W. [2011]. Heuristic Decision Making. Annu. Rev. Psychol. 62: 451-82.