Associative Memory on Complex Networks

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The ability of store and recall information based on associations between objects is considered a characteristic trait of intelligent systems. In biological neural networks, learning is believed to take place at a synaptic level by modification of synaptic connections. Learning and associative memory are understood as emergent phenomena resulting from interactions between a complex network of neurons. In physics, the study of such complexity emerging from many interacting elements is studied with the tools of statistical mechanics.

Associative memory is the ability to remember relationships between objects. When presented with partial information, a subject recovers the complete information of associated items stored in its memory. In this thesis project, we study the statistical physics of memory and learning through the Hopfield Model of Associative Memory. We computationally simulate the model in Python and devise an algorithm to find the critical memory capacity of a Hopfield Network.

However, unlike magnetic systems, the structure of wiring in brain is far from homogeneous. The synaptic wiring in brain is far from random like that in spin glasses or regular like that in an ising lattice and instead follows evolutionary favourable organizing principles. To study how the collective function of the brain and neural systems depends on the structure, we use tools from graph theory and generative network models to simulate the Hopfield Model on a Watts-Strogatz (WS) small world network which interpolates between regular and random network structures.

We devise a set of open source Python codes that simulate the Hopfield Network on any given network structure and numerically estimates the memory capacity as a function of various parameters. Finally, we understand how changes in the network structure affects the function by varying the rewiring probability of a WS network and study the overlap with the desired state using an algorithm of ensemble averaging over multiple initial states with random and sequential noise to characterize the recall quality of the network.

We find the small world networks achieve performance as good as a random network but for a fraction of total wiring length, and are thus favourable. Our findings support the experimental evidence for existence of small world characteristics in biological networks in literature. For example, the connectome of nematode worm C. Elegans or in-vitro evolution of a culture of neurons are shown to have small world characteristics.

There has been some earlier work on implementation of the Hopfield Model on WS networks. Our study further extends the scope of existing work by characterizing performance by probing various configurations of local connectivity based on estimates of memory capacity.