Project Summary: Evolution of Time in Simple Neural Architectures

Introduction: The function of the brain is intricately weaved into the fabric of time. Functions such as (1) storing and accessing *past* memories, (2) dealing with immediate sensorimotor needs in the *present*, and (3) projecting into the *future* for goal-directed behavior are good examples of how key brain processes are integrated into time. Moreover, it can even seem that the brain *generates* time (in the psychological sense, not in the physical sense) since, without the brain, a living organism cannot have the notion of past nor future. When combined with an evolutionary perspective, this seemingly straight-forward idea that the brain enables the conceptualization of past and future can lead to deeper insights into the principles of brain function.

Key gap: Most current investigations on the temporal aspects of brain function are focused on specific tasks such as temporal coding or prediction. Therefore, broader questions from an evolutionary perspective are rarely asked, e.g., how can basic building blocks that endow the notion of past and future naturally evolve from simple, reactive neural architectures.

Goal: The goal of this project is to systematically investigate, through simulated evolution of neural networks, conditions for the emergence of past and future in simple neural architectures.

Objectives: The objectives of this project are as follows:

1. Evolution of external memory use in reactive, feedforward neural architectures: Feedforward architectures only support reactive behavior (i.e., they reside in the eternal present). This architecture will be minimally extended, while maintaining the feedforward topology, to allow dropping and detecting markers in the environment, a form of stigmergy. Memory-like behavior is expected to emerge from this simple augmentation. This type of agent-environment interaction is analogous to *olfaction*.
2. Internalized marker interaction: Once external markers are found to be effective in implementing memory, the next step is to test if such external marker interaction can be internalized. This could be analogous to the *neuromodulatory system*.
3. From internal marker interaction to recurrent circuits: The next step is to test if internal marker interaction can lead to actual recurrent circuits that support fully dynamic internal memory, such as in the *hippocampus*.
4. Evolution of predictive dynamics in recurrent circuits: Recurrent neural architectures are generally associated with memory (of the past). Whether such recurrent circuits have the potential to evolve predictive internal dynamics projecting into the future will be investigated.

Intellectual merit: Results from this project are expected to show how neural architectures supporting memory and prediction (and thus the notion of past and future) can evolve, without explicit fitness terms that mandate those functions. The various stages starting from reactive, feedforward architecture to fully recurrent architecture expressing predictive dynamics can be mapped to the evolution of the olfactory system, the neuromodulator system, and the hippocampus, providing a coherent theoretical framework to understand the three subsystems in the brain.

Broader impact: One graduate student will be trained, and undergraduate students (in many cases from the underrepresented group) will be trained through NSF REU and other funding mechanisms at Texas A&M. Software and data resulting from the project will be advertised and disseminated through the internet. Finally, an educational web page will be constructed for K-12 and the general public, including realtime experiments that control the simulated evolution process. The use of mechanistic computer algorithms to show how simple rules can give rise to the evolution of complex behavior can have great positive impact on the public's view of evolution.

Transformative potential: This project can provide an important theoretical framework to understand the olfactory system, the neuromodulator system, and the hippocampus under a singular evolutionary origin.

Keywords: Evolution; Memory; Prediction; Neural architecture