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Population clock models and delayed temporal memory: An information theoretic approach

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The ability to precisely track and tell time is critical towards the learning of ordered motor behaviors as well as the underlying cognitive process, in all living creatures. However, the mechanism by which the brain tells time is still not understood clearly. Although it is still debated whether dedicated or intrinsic mechanisms underlie the timing process, some experimental and theoretical studies have validated the concept of neural circuits being inherently capable of sensing time across time scales. Large recurrent neural networks could be considered as an abstraction of the mammalian cortex. Accordingly Buonomano and Laje, 2010 suggested that population clocks, where in time is encoded in the time varying patterns of activity of neuronal populations emerge from the internal dynamics of the recurrent network. Furthermore in order to account for varying time-scales of input patterns to such networks, classically they have been arranged in hierarchies of networks with different timescales. However monkey experiments (Bernacchia et. al,2011) have shown that individual neurons can have different timescales of reward memory correlated with the actual behavior. As such it is highly plausible that neurons in a single recurrent network can adjust there individual time constants to account for a multi-timescale input in contrast to a hierarchical arrangement with different fixed timescales.

In this work, we describe a single information theoretic framework for adapting the local neuron time constants via it's leak. The recurrent neural network is composed of leaky-integrator neurons, where in, the individual neuronal leak-rate governs the dependence of the current activity of the neuron on the actual net input to it, compared to it's own previous activity. This is adjusted by an active information storage(AIS) measure at each spatial-temporal location of a recurrent neural network. This quantity measures the amount of information in the previous state of the neuron that is relevant in predicting it's future state. Interestingly high AIS regions in the network correspond to significant events in time. Depending on whether this measure is either greater or less than a pre-defined threshold, the leak control parameter is adjusted accordingly with the inverse of this control parameter determining the leakage rate of each neuron. In other words we are able to incorporate a self-adapting non-uniform leak rate in the network that can account for varying timescales in the input stream as well as encode timing of events. Furthermore we combine this with a mutual information driven intrinsic plasticity scheme in order to homeostatically control runaway or highly chaotic activity in the network. We test our network on a physical six legged walking robot for a delayed memory T-maze navigation task. This requires the correct maintenance of variable time delays between turning cue to the robot and the point of memory recall at the T-junction. This mechanism effectively copes with variable time delays (#different T-maze size) and demonstrates that time is not only encoded in the internal recurrent dynamics but also single neurons can adjust their time-constants in order to account for high relevance events in the input data.

References

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