Coincidence Detection

Towards an alternative to Synaptic Plasticity

Francis Jeanson, PhD Candidate
Carleton University

Motivation

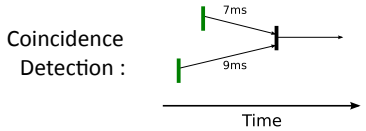
There must be a *rapid* mechanism by which early sensory encoding and processing for motor and higher cognitive responses takes place in somatosensory and associative areas.
Spatiotemporal processes are known to improve propagation speeds of sensory information (Carr & Konishi, 1990), but could similar mechanisms play a role in memory and learning?

Limits of Synaptic Plasticity

- Time to encode sensory information is long (> 500ms), yet echoic and working memory require rapid (< 300ms) encoding times for response and upstream processing (Stevens & Wesseling, 1999).
- The energy expenditure for NMDA and AMPA regulation via BDNF use of ATP is non-negligible.

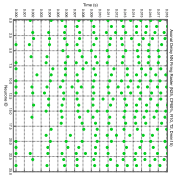
An Alternative

Coincidence detection (CD) is a fundamental mechanism in the brain which results from axonal delays and other cellular time constants (Fujii et al. 1996).
A neuron has a higher chance of firing when a greater number of *simultaneous* action potentials reach its soma.

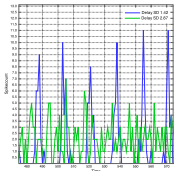


Firing Chains by CD

Coincidence detection leads to a wide number of possible firing sequences based on the initial firing state of cells (Izhikevich 2004).
In a population of N spiking neurons an upper bound of 2^N firing chains exist in the population.



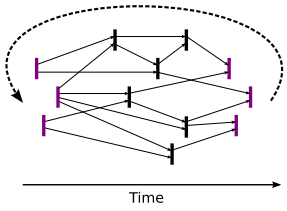
Firing chain spike raster



Spike count comparison for small and large variation in delays

Memory via CD

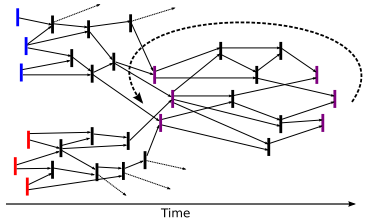
A firing chain which leads to self-sustained activity by re-triggering neurons belonging to its population in the *same temporal sequence* can, in principle, play the role of a small memory.
Such firing chains can serve as an effective "memory scratchpad" without making use of synaptic plasticity.



Memory firing chain

Association via CD

Two or more firing chains that take place simultaneously, have a high probability of triggering one or more alternate firing chains. If such chains self-sustain then a temporary association has been created. Firing chains by CD can thus account for elementary forms of associative learning between inputs.



Associating two firing chains

Current and Future Work

- Currently developing a formalism to describe the probability that a firing pattern emerges given cell and network properties.
- Currently simulating and evolving khepera robots which solely exploit axonal delays for behavioural control.

Future work will investigate:
- The tolerance to noise that these networks possess.
- The functional impact of various connection topologies and delay distributions.
- The mechanisms by which memories can be retrieved and used by simulated agents.