STDP enhances synchrony in feedforward network

STDP strengthens/weakens synapses driving late/early-spiking cells [Laurent07]

Olfactory neurons' spikes phase-lock (~2ms) to a 20Hz rhythm. STDP favors firing at a particular phase, promoting synchrony.
Insect olfaction pathway

Olfactory receptor → projection neuron → Kenyon cell → β-lobe neuron [Laurent07]
Ablating the mushroom body abolishes associative odor-learning.
Memory retrieval requires synaptic output from its intrinsic neurons, the Kenyon cells.
Kenyon cells fire sparsely, synchronously and respond selectively, compared to their inputs (projection neurons).
β-lobe neurons, extrinsic neurons of the mushroom body, respond selectively to odors and are sensitive to input synchrony.
Odor-evoked spikes occur at trough of LFP (~20Hz) in tight synchrony (~2ms) [Laurent07].
Kenyon-cell $\rightarrow$ $\beta$-lobe-neuron synapse

EPSPs are potent but vary in size and occur with a 6.4ms delay [Laurent07]

EPSPs amplitudes fell in the range 1.6±1.1mV, with 5.4ms axonal and 1ms synaptic delay.
Post-pre pairing produced depression; pre-post pairing produced potentiation [Laurent07].

STDP curve was fitted with two exponential decays ($\tau_+ = 9$, $\tau_- = 10.4$ ms) flanking a straight-line ($-9 < t < 17.5$ ms).

Plasticity enhances phase-locking in model
Synapses onto early/late-firing neurons depress/potentiate \((K_{C} \rightarrow K_{L}: \text{calyx-lobe delay})\) [Laurent07]

Synapses onto \(\beta\)-lobe neurons that spike before the Kenyon-cell spike arrives depress, delaying spiking in the next trial (red).

Synapses onto \(\beta\)-lobe neurons that spike after the Kenyon-cell spike arrives potentiate, advancing spiking in the next trial (green).

Thus, a stable-fixed point exists at a particular phase, which, due to the delays involved, happens to be at the LFP’s trough.

Phases of kenyon-cell spikes were chosen from measured distribution and synaptic weights were initialized to uniform distributions with different means.

Replicated results
The same phase was achieved starting with synapses mostly depressed or potentiated.

Input spikes hit the neuron's 21 STDP synapses sequentially, 1.1ms apart; this 21-spike, 23.1ms sequence was repeated every 74ms.

A fixed (nonplastic) synapse, driven with an identical sequence, providing background excitation that guaranteed firing even when all the plastic synapses were depressed.
Next Lecture: Recurrent synapses

Hippocampal place cells' rate (middle) and timing (bottom) codes [O'Keefe03]