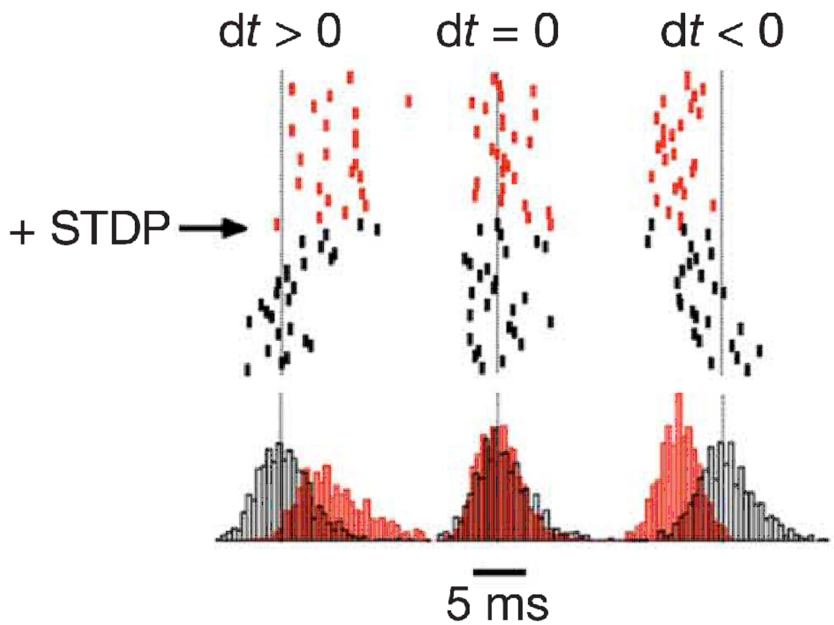
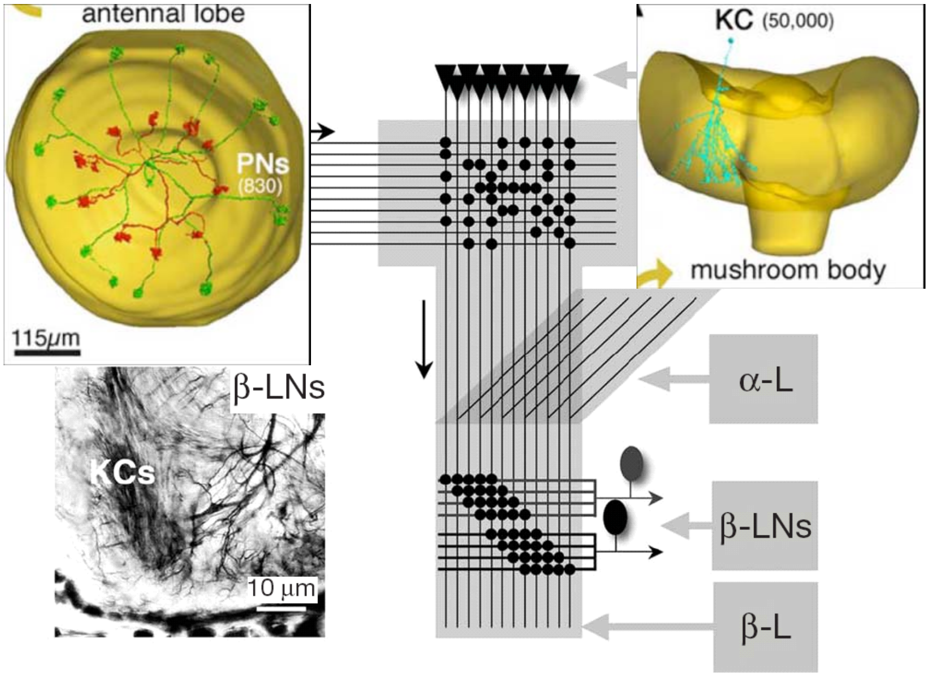
STDP enhances synchrony in feedforward network



STDP strengthens/weakens synapses onto 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.

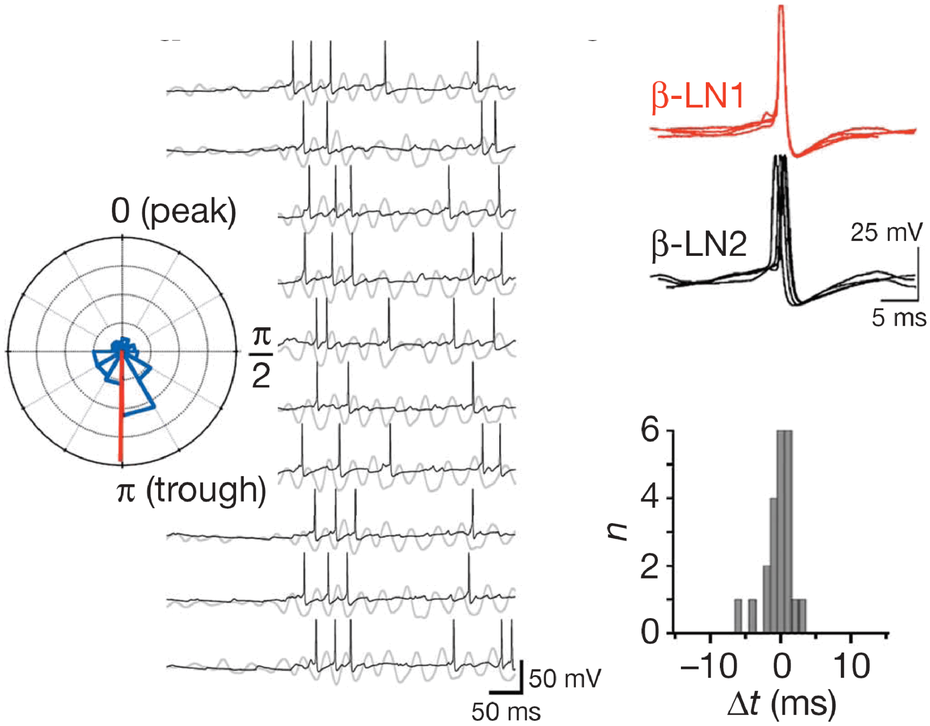
Memory retrieval requires the output from its intrinsic neurons, the Kenyon cells.

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.

3 of 10

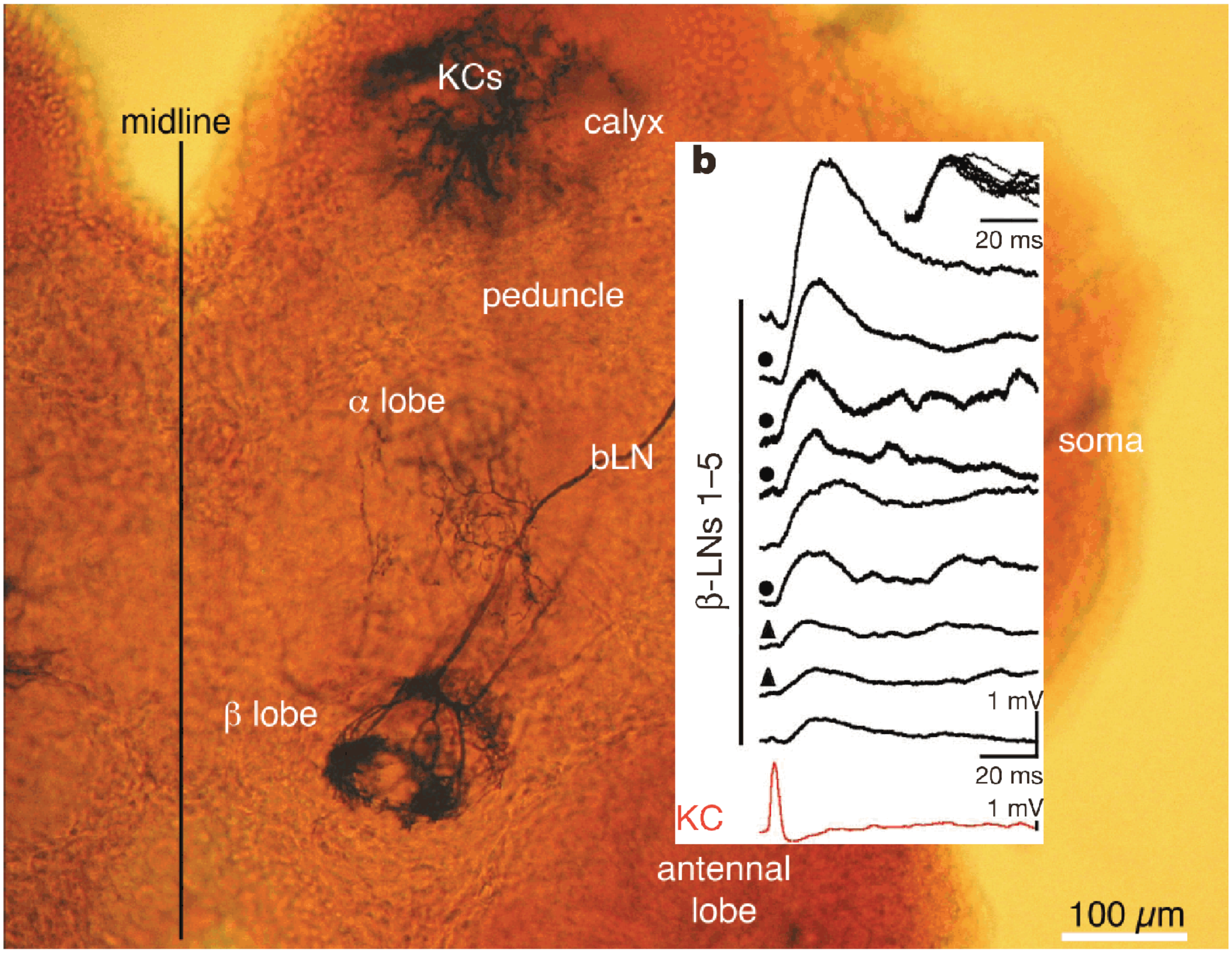
β-lobe neuron synchrony



Odor-evoked spikes occur at trough of LFP (~20Hz) in tight synchrony (~2ms) [Laurent07].

| ⏮ ◀ ▶ ⏭ | 4 of 10 |

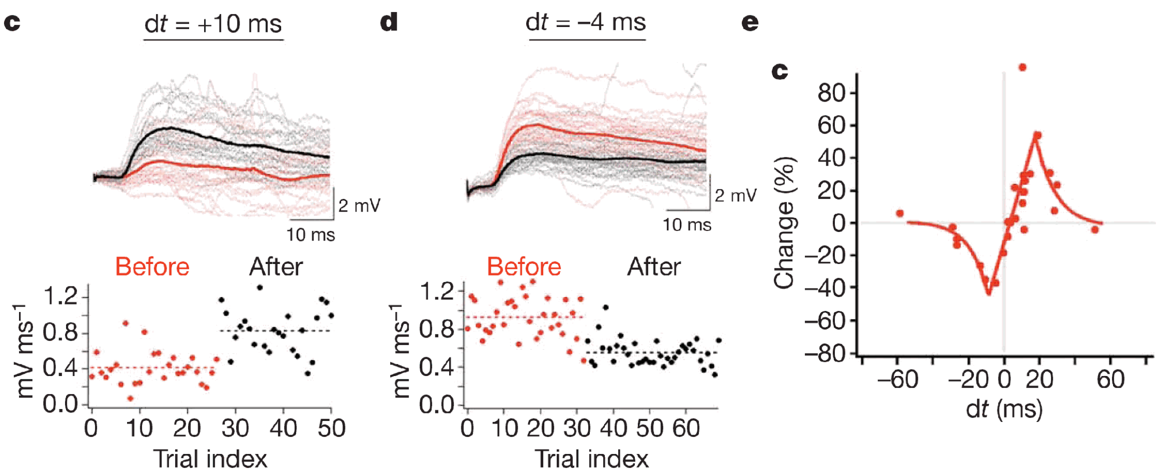
Kenyon-cell → β-lobe-neuron synapse



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.

STDP

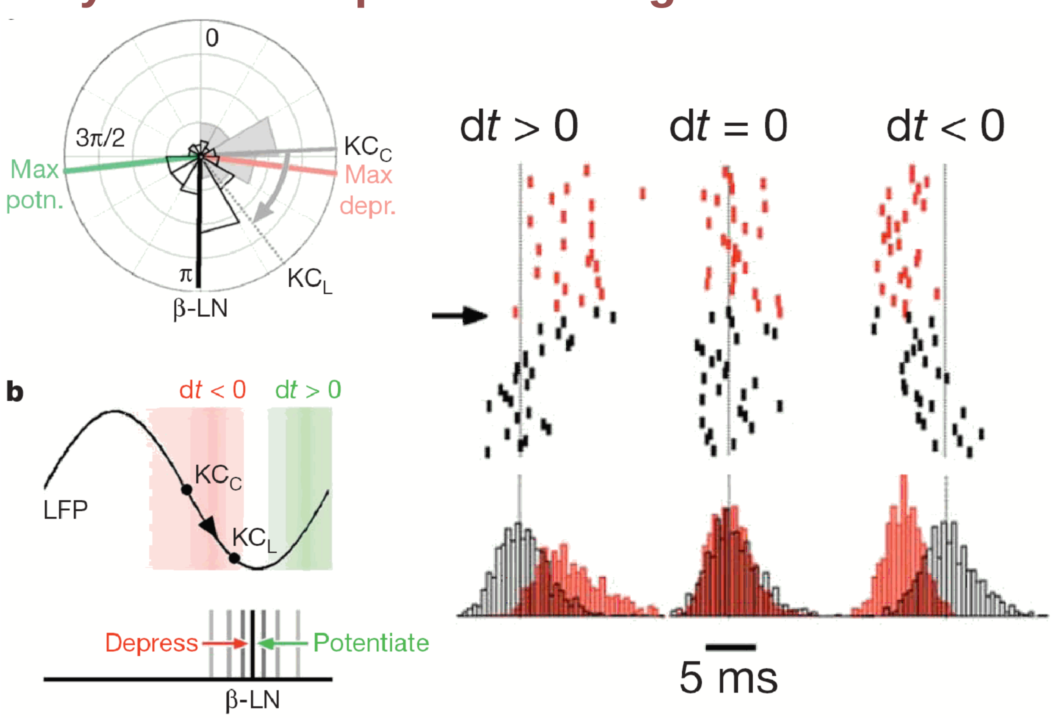


Post-pre pairing produced depression; pre-post pairing produced potentiation [Laurent07].

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

6 of 10

Plasticity enhances phase-locking in model



Synapses onto early/late-firing neurons depress/potentiate ($KC_C \rightarrow KC_L$: calyx-lobe delay) [Laurent07].

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

Synapses onto β-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.

In Laurent's model, kenyon-cell spikes' phases were chosen from measured distribution and synaptic weights were initialized to uniform distributions with different means.

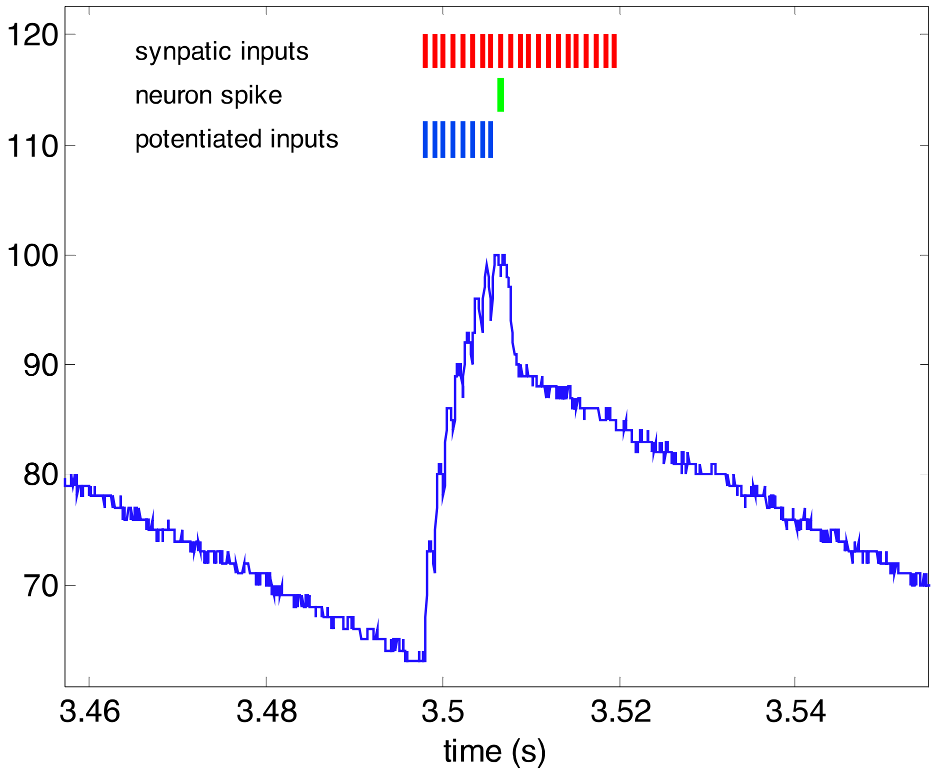
7 of 10

Replicated results

Used binary synapses rather than graded ones.

8 of 10

Enhancing timing precision

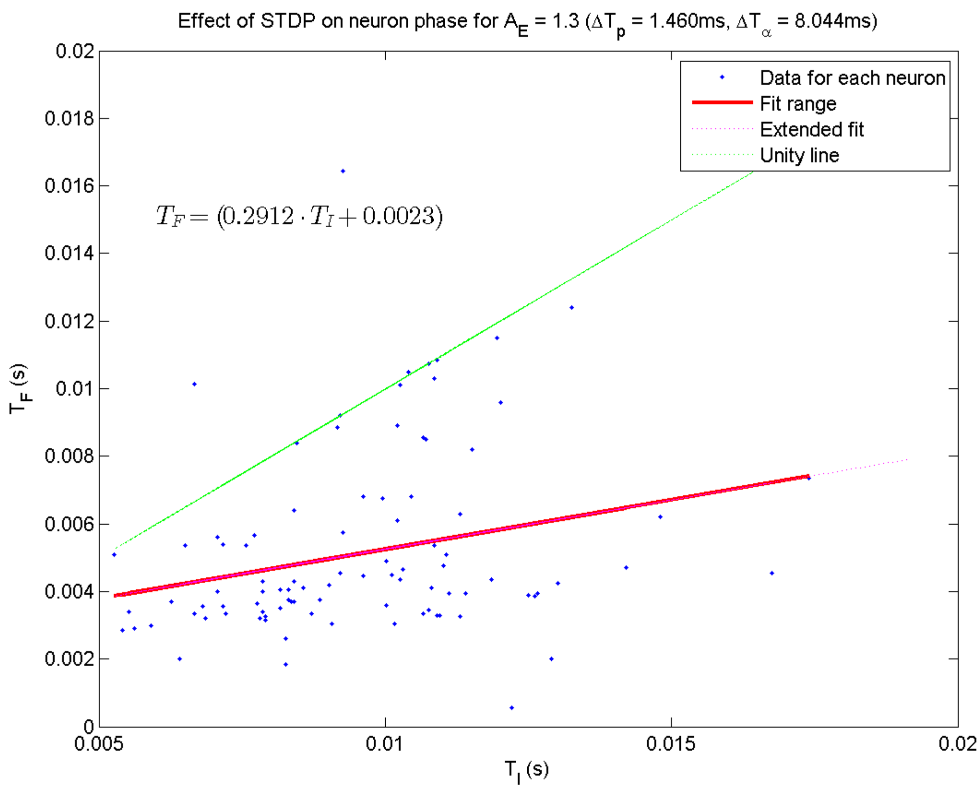


Input and output spike timing (above) and synaptic input received (below) from potentiated synapses (indicated above). The same result was achieved starting with synapses mostly depressed or potentiated.

Input spikes hit the neuron's 21 STDP synapses sequentially, 0.6ms apart; this 21-spike, 12.6ms sequence was repeated every 50ms.

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

Theory



Spike phases before and after STDP are plotted—one dot for each neuron (dashed line: unity slope).

Each potentiated synapse a neuron receives advances it phase by ΔT_P. Synapses activated just before the neuron spikes are less effective, which we account for by adding a delay T_α.

The equations are:

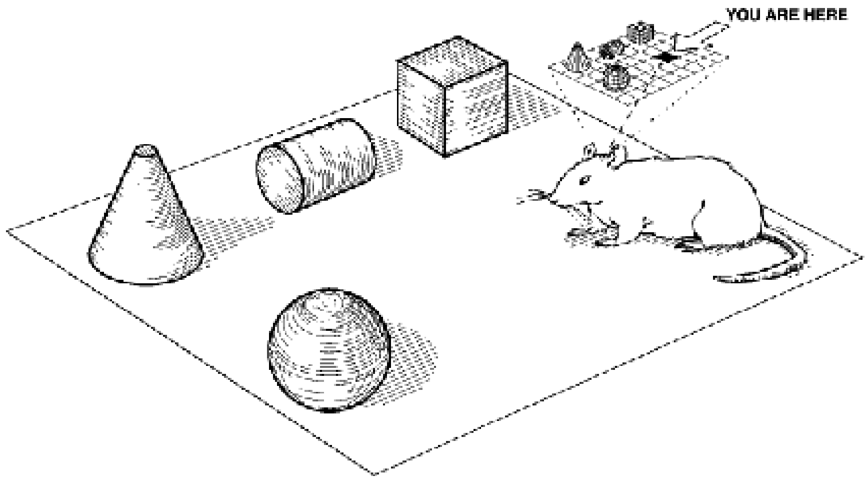
$$T_F = T_I - n_P \, \Delta T_P + T_\alpha$$
$$n_P = 1 + T_F / \Delta T_S \approx T_F / \Delta T_S$$

where n_P is the number of potentiated synapses and ΔT_S is the period at which input spikes arrive, each targeted to a different plastic synapse. Hence

$$T_F = \frac{T_I + T_\alpha}{1 + \Delta T_P / \Delta T_S}$$

10 of 10

Next Lecture: Associative Memory



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