Song, Miller and Abbott, Competitive Hebbian learning through spiketime-dependent synaptic plasticity. 
Experience-Dependent Asymmetric Shape of Hippocampal Receptive Fields

Mehta, Quirk and Wilson

* When a rat moves through an environment, neurons in the hippocampus fire in a spatially and directionally selective fashion and provide an accurate estimate of the location of the rat.

* Changes in these fields as a result of experience in novel and familiar environments suggest that mechanisms of plasticity may be involved.

* In this work, it is shown that the hippocampal receptive fields have an asymmetric shape and that this asymmetry is experience dependent.
- Hippocampal pyramidal cells fire significantly more than rest when rat moves through a specific place in the environment.

- "Best place" is the exact location for which the cell fires most.

- "Place field" is the environment around the best place for which cell fires significantly more than rest.
- On a linear track, place fields are asymmetric (or skewed) with respect to the *best place.*
- Asymmetry of place fields depends on rat's experience with a given environment.

- Asymmetry is not just time dependent. Place fields of cells that have acquired asymmetry in one environment are symmetric when rat is first placed in a novel environment in which the same cells are active.
* In previous work experience-dependent changes in place field location and firing rate were reported.

* A 51% increase in the place field size (from 426 to 643 cm × Hz) and a predictive or backward (i.e., in a direction opposite to the direction of movement of the rat through the place field) shift in the location of the center of mass of the place fields by 8.2 cm were observed.

* Further, the location of the peak of the place field shifted backward by 5.5 cm, and the first spike in the place field occurred 9.2 cm earlier, whereas the last spike in the place field occurred 6.5 cm earlier.

* This resulted in an experience-dependent widening of place fields by 7.9 cm.
* Experience-dependent changes of place fields could result from the LTP and LTD of NMDA-dependent synapses.

* NMDA-dependent synapses are strengthened if postsynaptic activity lags behind presynaptic spiking and depotentiated if the converse is true.

* Further, the amount of LTP/LTD is inversely related to the absolute value of the time lag between the pre- and postsynaptic neuronal spike times.

* It is known that pyramidal neurons in CA1 receive excitatory inputs from pyramidal neurons in CA3, which also exhibit place-specific firing. LTP of these CA3 CA1 connections has been shown to be NMDA dependent.
A very simple computational model
Place cell recordings

Built-in, symmetric place fields

CA3

CA1

Plastic place fields acquired via CA3

Modifiable synapses

Enco

Hippocampus

CA3

DG

Entorhinal cortex

Association neocortex
Built-in, symmetric place fields

Plastic place fields acquired via CA3

Modifiable synapses
The diagram illustrates the interaction between CA3 and CA1 regions in the brain, focusing on the impact of a rat's movement on synaptic strength.

1. **CA3 Tuning Curves**: These represent the specific responses of neurons in the CA3 region to different locations (x).
2. **All-to-All Synapses**: Connections between CA3 and CA1 regions, where each CA3 neuron is connected to every CA1 neuron.
3. **Initial Synaptic Strength**: Symmetrically distributed synaptic weights are shown initially, indicating a balanced connection strength.
4. **Input Calculation**: The input to CA1 is calculated as the sum of presynaptic outputs multiplied by synaptic weights.

The diagram also shows the progression of synaptic strength over time (t0, t1, t2, t3, t4), reflecting a change in synaptic response due to the rat's movement.
CA3 neurons firing at various times (t0, t1, t2, t3, t4) and their corresponding input effects on CA1 neurons, as depicted by the figure.
$x = \text{rat's position}$

Tuning curves

CA3 firing

CA3 neurons

CA1

$w$
Tuning curves

CA3

CA1

CA3 neurons

firing

Input

w

x

t0 t1 t2 t3 t4
Tuning curves

CA3 neurons

Input

CA1 Firing
Tuning curves

CA3 neurons

CA1 neurons

CA3 firing

Input

Firing
Before the post event, the CA3 neurons show increased firing with input. The tuning curves for CA3 and CA1 are depicted with arrows indicating pre and post events. The graph on the right illustrates the change in firing time, \( \Delta t = t_{\text{pre}} - t_{\text{post}} \), with time on the x-axis and firing change on the y-axis. The notation for pre before post is indicated with a downward arrow, while post before pre is noted with an upward arrow.
CA3 neurons

pre before post

post before pre

Δt = time_{pre} - time_{post}

Δw

CA3 neurons
\[ \Delta t = \text{time}_{\text{pre}} - \text{time}_{\text{post}} \]

**CA3 Tuning Curves**

**Input Firing**

**Firing**

**Δw**

**CA3 Neurons**

**Pre before Post**

**Post before Pre**

\[ w_{\text{new}} \]

\[ w_{\text{old}} \]
Because of the spike-timing dependent plasticity rule, the place fields tend to move to earlier positions and become asymmetric as the rat moves through the track more and more often.
Tuning curves

CA3

CA1

CA3 neurons

Δt = time_{pre} - time_{post}

Δw

CA3 neurons

pre before post

post before pre
Distribution of synaptic weights becomes asymmetric.

Place fields move to earlier positions and become asymmetric.
Intracortical mechanism of stimulus-timing-dependent plasticity in visual cortical orientation tuning

Yao, Shen and Dan
Figure 8. Visual input to the brain goes from eye to LGN and then to primary visual cortex, or area V1, which is located in the posterior of the occipital lobe.
Adapted from Polyak (1957).
Figure 14. The signals from each eye are segregated within the LGN and go into different ocular dominance columns within area V1, layer 4C.
Fig. 15. The ocular dominance columns in area V1 can be visualized by using markers. When the marker is injected into one eye it is transported via the LGN nucleus to the cortex. The light bands in this tangential section show the places where the marker was located and thus reveal the ocular dominance columns.
From Olavarria & van Essen, 1997.
Figure 8. Visual input to the brain goes from eye to LGN and then to primary visual cortex, or area V1, which is located in the posterior of the occipital lobe. Adapted from Polyak (1957).

Figure 20. The unfolded striate cortex has a shape like a pear. It would be a quarter sphere if the visual fields were equally represented everywhere, but instead it is greatly distorted by the disproportionate representation of parts near the center of gaze (fovea), a feature termed “cortical magnification.” In contrast, the far periphery is greatly underrepresented.
Figure 21. A tuning curve and corresponding polar plot obtained from two macaque V1 cells in response to drifting luminance bars of systematically varied orientation and direction. The responses of one orientation selective cell and one nonselective cell are provided for comparison. Histograms surrounding the polar plots demonstrate the cellular response as a function of time. Orientation bias (OB) and direction bias (DB) are measures of how selective a cell is, where >0.1 is significant, and 0.3 is approximately an 8:1 maximum firing rate to minimum firing rate ratio. From Schmolesky et al. (2000).
Figure 23. The ice-cube model of the cortex. It illustrates how the cortex is divided, at the same time, into two kinds of slabs, one set of ocular dominance (left and right) and one set for orientation. The model should not be taken literally: Neither set is as regular as this, and the orientation slabs especially are far from parallel or straight.
1) Measure orientation selectivity of cell in response to stimulation of each eye. This results in an orientation tuning curve for each cell with an optimal orientation $S_0$. 

Figure 1. Conditioning stimuli used to induce shift in orientation tuning. (a) Orientations of conditioning stimuli (arrows) relative to tuning (curve) of the cell. $S_0$, optimal orientation; $S_{+15^\circ}$ and $S_{-15^\circ}$, 15° clockwise and counterclockwise from optimal. (b) Four types of conditioning stimuli. For interocular transfer experiments, only $S_0$ and $S_{\pm15^\circ}$ (according to tuning measured through the conditioned eye) were used. To measure orientation specificity of the effect (Fig. 6), other orientations were also used.

Figure 9. Visual input to the brain goes from eye to LGN and then to primary visual cortex, or area V1, which is located in the posterior of the occipital lobe. Adapted from Polyak (1957).
1) Measure orientation selectivity of cell in response to stimulation of each eye. This results in an orientation tuning curve for each cell with an optimal orientation $S_0$.

2) Then “condition” the cell by repeatedly presenting two stimuli at 8.2 ms intervals. Two conditioning paradigms were used:
   A) $S_0 - S_{+/15}$ separated by 8.2 ms
   B) $S_{+/15} - S_0$ separated by 8.2 ms.

A) Shifted followed by best orientation
B) Best followed by shifted orientation
1) Measure orientation selectivity of cell in response to stimulation of each eye. This results in an orientation tuning curve for each cell with an optimal orientation $S_0$.

2) Then “condition” the cell by repeatedly presenting two stimuli at 8.2 ms intervals. Two conditioning paradigms were used:

A) $S_0 - S_{+/-15}$ separated by 8.2 ms
B) $S_{+/-15} - S_0$ separated by 8.2 ms.

3) After the conditioning phase, the orientation selectivity was measured again by presenting stimuli to the non-conditioned eye!
a) Shifted followed by best orientation

Before  After

8.3 ms  100 ms

![Graph showing response (spikes/s) vs. orientation with different conditions labeled as control, S+15° → So, and S-15° → So.](image-url)
a) Shifted followed by best orientation

b) Best followed by shifted orientation

8.3 ms  100 ms

Before        After        After        Before

Response (spikes/s) vs. Orientation (°)

- control
- $S_{+15°} \rightarrow S_0$
- $S_{-15°} \rightarrow S_0$
- $S_0 \rightarrow S_{+15°}$
- $S_0 \rightarrow S_{-15°}$
a) Shifted followed by best orientation
b) Best followed by shifted orientation
c) Conditioning leads to similar shifts in orientation tuning in response to stimuli in both eyes.
Human psychophysics

300 ms presentations, 1 sec ITI orientations 1, 2 or 3° from vertical

Test: Percentage of gratings judged to be on left or right side.
Control subjects usually judge an average of 50% to be on either side
Human psychophysics

50 %Right  50% Left

300 ms presentations,
1 sec ITI
orientations 1, 2 or 3° from vertical

Test: Percentage of gratings judged to be on left or right side.
Control subjects usually judge an average of 50% to be on either side
Human psychophysics

Result: Perceptual shifts in agreement with electrophysiological data

300 ms presentations, 1 sec ITI orientations 1, 2 or 3° from vertical
Mechanism?
Mechanism?

- Cell 1 $\rightarrow S_0$
- $S_0 \rightarrow S_{0+22}$
- $S_{0+22} \rightarrow S_0$

- Cell 2 $S_0$
- $S_0 \rightarrow S_{0+22}$
- $S_{0+22} \rightarrow S_0$

8.3 ms

- Cell 1
- Cell 2

pre before post!
\[ \tau_0 \frac{\partial V_k(t)}{\partial t} + V_k(t) = V_k^{ff}(t) + \sum_{j=1}^{j=36} V_{k,j}^{rec}(t), \]

\( V_k(t) \): membrane voltage of pyramidal cell k.
\( \tau \): membrane time constant
\( V_k^{ff}(t) \): feedforward (afferent) input (green arrows)
\( V_{k,j}^{rec}(t) \): recurrent input from other cells.

This equation describes how the membrane voltage evolves in time due to external inputs (leaky integrator).

Remember: \( \tau \frac{dv}{dt} = -v + \text{inputs} \)

In response to a given stimulus orientation, each cell receives a combination of feedforward input, output of other Cells (narrowly tuned) and input of more broadly tuned cells.
Contribution of second spike is suppressed!
Efficacy of nexy spike is suppressed and recovers exponentially.