The One-and-Thousand lives of the Hebbian Synapse

- Pre-Hebbian Theories
- Hebb’s Postulate
- Post-Hebbian Theories

Hebb’s Postulate

How to build Assemblies

- Donald Olding Hebb (1904-1985)
- The organization of behavior

The first stage of perceptual growth of the assembly:
Repeated stimulation of specific receptors will lead slowly to the formation of an "assembly" of associated neural cells which can act briefly as a closed system after stimulation has ceased: this process is termed Hebbian learning. The structure changes of learning are caused by and constitute the simplest instance of a representational process change in Man. (p. 39) The theory is entirely of a mechanistic, one of the workboard variety.

Making lasting memory possible:
The assumptions, in brief, is that a growth process accompanying synaptic activity makes the synapse more readily transferred. A...
Hebb’s Postulate

At the cellular level

Formula: $\frac{d W_{ij}}{dt} = \alpha y_j x_i$

At the network level

At the behavioral level (Classical Conditioning)

CS: conditioned stimulus
US: unconditioned stimulus
ISI: interstimulus interval

Experimental implementation of Hebb’s rule

Protocols of Hebbian conditioning

Tetanus
Low-frequency Paring

Integrative power:

$$y_j = \sum_{i=1}^{N} w_{ij} x_i - \theta_j$$

Adaptive power (Hebb’s rule):

$$\Delta w_{ij} = \alpha y_j x_i$$

Ideal Synapse and Functional Coupling

A dynamic variable that can change sign, and is network context dependent

Effective connectivity (JPSTH)

from http://www.neuro.mpg.de/research/csn/morphplast/

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Post-Hebbian Theories

Binding by Synchrony

"If adjacent, or nearly adjacent, cells interact when excited, in such a way as to synchronize and perhaps intensify each other’s activity, this could provide the unifying characteristics that tie the elements of a figure together. At subsequent levels of the pathway, impulses from the cells fired by one whole would arrive as synchronous volleys, whereas impulses from different figures would have a random temporal relationship to each other" (Milner, 1974)
Fig. 1. Schematic representation of evoked and induced gamma oscillatory responses. An evoked response (blue boxes).
Post-Hebbian Theories

How to build Synfire Chains
Abeles (1982; 1991)
Vaadia & Aertsen

Biological correlate (Bi & Poo)
in cultured networks

Dynamic Binding
Logogenesis
Milner, 1959, 1974
Von der Malsburg, 1981
Bienenstock, 1991

Graph Matching
Perceptual Invariance

Vertical Binding
Compositionality

The architecture of the graph, defining the relational coding within the assembly, would be independent of the physical location of the activated neurons in the brain.

Fields of Application of Hebb’s Hypothesis

- Reverberating activity in recurrent networks
- Making Memory possible
- New circuits for learned behavior (alpha-conditioning)
- Storing Associations
- Self-organizing the brain (ontogenesis and epigenesis)
- Transient percept formation

Generalized Hebbian Algorithms

- The Covariance Hypothesis
- Spike-Timing-Dependent Plasticity
Generalized Hebbian Algorithms

The Covariance Hypothesis

\[
\begin{align*}
\Delta w_{ij} &= \epsilon \cdot (x_i - F(<x>)) \cdot (y_j - F(<y>)) \\
F(<y>) &= y_0 \cdot (<y>/y_0)^p \text{ with } p > 1 
\end{align*}
\]

Floating threshold

Bienenstock - Cooper - Munro (1982)

The temporal interval between the presynaptic signal and the postsynaptic action potential as well as their temporal order determine respectively the amplitude and the sign of the synaptic modification.

Generalized Hebbian Algorithms

✓ The Covariance Hypothesis

✓ Spike-Timing-Dependent Plasticity

Markram et al., 1997, Science
Feldman, 2000, Neuron

Zhang and Poo, 1998, Nature
Hebb’s synapse and R.S.E

Hebbian Pairing results in:
- Reconfiguration of synaptic dynamics
- Reinforcement in transient changes (temporal contrast)
- Improvement of synchrony and of synfire propagation
- Phase sequence learning

Functional Validation of Hebb’s Hypothesis

- Visual Cortical Epigenesis
- Cellular analogs of visual epigenesis
- Rewiring the brain
- Adult Plasticity
**DOMINANCE OCULAIRE**

La plupart des cellules de l’aire 17 sont binoculaires (classes 2-6 de la classification de Hubel et Wiesel).

**PERIODE CRITIQUE**

La dominance oculaire corticale est affectée par l’expérience visuelle pendant une période critique postnatale (Hubel and Wiesel, 1961; Wiesel and Hubel, 1963).

**OCULAR DOMINANCE PLASTICITY**

**Test of the Covariance Hypothesis**

Reiter and Stryker, 1988
SELECTIVITE A L’ORIENTATION
Plasticité de la distribution corticale des orientations préférées par l’expérience visuelle précoce
(Blakemore and Cooper, 1970; Hirsch and Spinelli, 1970).

Etat initial

Exposition à un environnement vertical

Période critique

Représentation anisotropique suite à un élevage restreint à une orientation.

Functional Validation of Hebb’s Hypothesis

- Visual Cortical Epigenesis
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Cellular analogs of visual cortical epigenesis

I. Plasticity of orientation selectivity

II. Plasticity of Binocular Integration
Activity-dependent regulation of “ON” and “OFF” responses


Control Pairing
+20 mn  +40 mn  +60 mn

ON OFF ON OFF

S+ S-

ON OFF

Visual Cortical Epigenesis
Cellular analogs of visual epigenesis
Rewiring the brain
Adult Plasticity

Functional Validation of Hebb’s Hypothesis

Topographic reorganization of the hand representation following repeated stimulation of finger tips during behavior control (Jenkins et al, 1990)

Scotome Bilatéral
Dynamic properties of adult visual cortex. Effect of making retinal lesion on cortical topography.
(Gilbert and Wiesel, 1990, 1992; Heinen and Skavenski, 1991)

Reorganisation de la projection rétino-corticale
Changement des champs récepteurs vers les bords du scotome
Invariance of the orientation network following bilateral scotoma of homologous retinal sites (Das and Gilbert, 1995)

Visual Cortical Epigenesis
Cellular analogs of visual epigenesis
Rewiring the brain
Adult Plasticity

Building a new cortical architecture: «Seeing the thunder»
Building a new cortical architecture: « Seeing the thunder »

A1 recablé  V1 normal

Building a new cortical architecture: « Seeing the thunder »

Connectivité horizontale

Building a new cortical architecture: « Seeing the thunder »

Adaptation comportementale

Algorithmes théoriques de Plasticité
et examples d’application

Règles de Plasticité
observées
modélisées
in vito

Applications

Re-câblage: entendre l’éclair
voir le tonnerre
Sharma, Angelucci and Sur M
CONCLUSION....

**McCarthy et al., 1956**

We propose that a 2 month, 10 man study of artificial intelligence be carried out during the summer of 1956 at Dartmouth College in Hanover, New Hampshire.

The study is to proceed on the basis of the conjecture that every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it. An attempt will be made to find how to make machines use language, form abstractions and concepts, solve kinds of problems now reserved for humans, and improve themselves.

We think that a significant advance can be made in one or more of these problems if a carefully selected group of scientists work on it together for a summer.

- Machine ?
- Learning and Intelligence ?
**FACETS : Basic idea, methodological approach and goals**

**Neurobiology :** Structural and Functional Investigation of the Neocortical Microcircuit and the Circuit Elements in-vivo and in-vitro

**Modelling :** Virtual Microcircuits on State-of-the-art Hardware: Emulation in analog and mixed-signal VLSI systems

**Methodology :** Tool Development (Computing, VLSI) Reduction of Biological Detail / Complexity

**Common Goal :** Study non-classical universal computing solutions Verification (Biology vs. Modelling vs. Hardware with visual tasks in VI)

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**Status and Future of Neuromorphic Computing**

- **Supercomputers vs. Dedicated Hardware**
  - Neocortex (10^8 neurons)
  - V1 (10^7 neurons)
  - 1 mm^3 = 10^5 neurons and 10^8 synapses

- **FACETS VLSI Approach**
  - 16 node PIV
  - 40 node PIV
  - 12,000 node BlueGene
  - 16 node Pill

- **Speed w.r.t. biological real-time**
  - 10^3 to 10^6

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**We are here today :** Machine complexity of neuromorphic devices still exceeds the one of von Neumann machines. Current problems tackled with neuromorphic devices are still simple. New computational paradigms are expected pay off with more complex input data and larger networks.