Neuroplasticity: Learning in Neurons

- **Connection (0 or not)**
- **NT effect**
  - $w > 0$ excitatory
  - $w < 0$ inhibitory
- **Magnitude of impact of input**

**Review of weights**

$$R(t) = \sum_j w_j a_j(t)$$

**Association**

- We recall information through associations with other information
- Pneumonics:
  
  - Roy G. Biv
    - Please Excuse My Dear Aunt Sally (PEMDAS)
- Memories of experiences:
  - Lake -> Summer vacation 2012
  - Dealy -> Final exam Fall 2014
- Complex objects
  - Bark:: -> Dog, fur, happy/fear

**Features of associators**

- Pattern completion/generalization
- Fault tolerance
  - Selected dendrites miss input, post-synaptic neuron still fires
- Learning prototypes
  - Neuron firing for common combinations

**Pattern completion**

Activation requires only a subset of desired inputs

<table>
<thead>
<tr>
<th>Input</th>
<th>$w$</th>
</tr>
</thead>
<tbody>
<tr>
<td>leg1</td>
<td>0.5</td>
</tr>
<tr>
<td>leg2</td>
<td>0.5</td>
</tr>
<tr>
<td>body</td>
<td>0.5</td>
</tr>
<tr>
<td>ears</td>
<td>0.5</td>
</tr>
<tr>
<td>mouth</td>
<td>0.5</td>
</tr>
<tr>
<td>tail</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Define input $h = \sum_i w_i r_i^{in}$

Neuron fires at rate $r_i^{out} = 1$ when $h > 1.5$

Assume $r_i^{out} = 1$ when active, $r_i^{out} = 0$ when inactive

**Fault tolerance**

Activation requires only a subset of desired inputs

<table>
<thead>
<tr>
<th>Input</th>
<th>$w$</th>
</tr>
</thead>
<tbody>
<tr>
<td>moo</td>
<td>2</td>
</tr>
<tr>
<td>quack</td>
<td>2</td>
</tr>
<tr>
<td>woof</td>
<td>0</td>
</tr>
<tr>
<td>moo</td>
<td>0</td>
</tr>
<tr>
<td>moo</td>
<td>2</td>
</tr>
</tbody>
</table>

Define input $h = \sum_i w_i r_i^{in}$

Neuron fires at rate $r_i^{out} = 1$ when $h > 1.5$
Prototypes

Activation requires all desired inputs

\[ h = \sum_i w_i r_i^{in} \]
Neuron fires at rate \( r^{out} = 1 \) when \( h > 1.5 \)

Learning to associate: Conditioning

Associating both smell and whistle with food
- **Unconditioned stimulus**: smell – already associated with food
- **Conditioned stimulus**: whistle – indicates food coming

Computing level: Associator network

Define input \( h = \sum_i w_i r_i^{in} \)
Neuron fires at rate \( r^{out} = 1 \) when \( h > 1.5 \)

Two forms of plasticity

- **Structural plasticity**: generation of new connections between neurons
- **Functional plasticity**: changing strength of connections between neurons

Hebbian plasticity:
"cells that fire together, wire together"

Chemical level: NT receptors

Increase weight by improving NT detection
Post-synaptic:
- Insert more receptors into dendrite membrane
- Improve performance of receptors
Pre-synaptic:
- Increase amount of NT released

Marr’s levels of analysis

- **Computational theory**: Learn associations among sensations
- **Representation and algorithm**: Associate each sense with set of neural outputs, adjust weights on these outputs into another neuron
- **Hardware implementation**: Insert/remove NT receptors from dendrites
Math of Hebbian rate learning

“Cells that fire together, wire together”

$\Delta w_{ij} = \epsilon(w) r_i r_j$

Using the learning rule

Define input $h = \sum w_i r_i^{in}$
Neuron fires at rate $r^{out}=1$ when $h > 1$

$\epsilon(w) = \begin{cases} -0.5 & w < 0 \\ 0.5 & w \geq 0 \end{cases}$

$\Delta w_{ij} = \epsilon(w) r_i r_j$

Time (sec)

Weight control and decay

• Synaptic weights are finite
• Propose learning rules that keep weights bounded
  $\Delta w_{ij} = r_i r_j - c w_{ij}$
  $\Delta w_{ij} = r_i (r_j - w_{ij}) - \text{Willshaw}$

• Or, preserve total synaptic weight across network:
  $w_{ij} \leftarrow \frac{w_{ij}}{\sum_j w_{ij}}$

Using weight control and decay

Define input $h = \sum w_i r_i^{in}$
Neuron fires at rate $r^{out}=1$ when $h > 1$

$\Delta w_{ij} = r_i (r_j - w_{ij})$

Using weight control and decay

Define input $h = \sum w_i r_i^{in}$
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