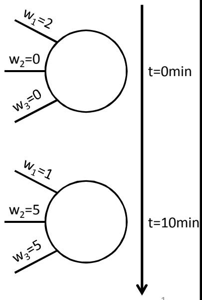
CISC 3250
Systems Neuroscience

Neuroplasticity: Learning in Neurons

Professor Daniel Leeds
dleeds@fordham.edu
JMH 328A

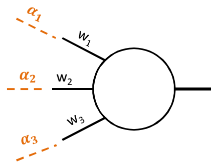


Review of weights

RI(t)=$\sum_j w_j \alpha_j(t)$

Weights indicate

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



Association

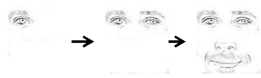
- We recall information through associations with other information
- Pneumonics:
  - Roy G. Biv
  - Please Excuse My Dear Aunt Sally () ^{Exp} x / + -
- Memories of experiences:
  - Lake -> Summer vacation 2012 
  - Dealy -> Final exam Fall 2014 
- Complex objects


::Bark:: -> Dog, fur, happy/fear

Features of associators

- Pattern completion/ generalization

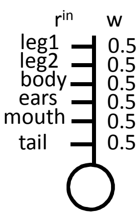
- Fault tolerance
  - Selected dendrites miss input, post-synaptic neuron still fires
- Learning prototypes



  - Neuron firing for common combinations

Pattern completion

Activation requires only a subset of desired inputs

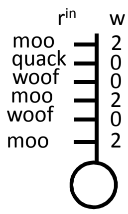


How many inputs needed to fire?

Define input $h = \sum_i w_i r_i^{in}$
Neuron fires at rate r^{out}=1 when $h > 1.5$
Assume r^{in}=1 when active, r^{in}=0 when inactive

Fault tolerance

Activation requires only a subset of desired inputs

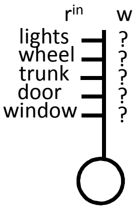


How many inputs needed to fire?

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

Prototypes

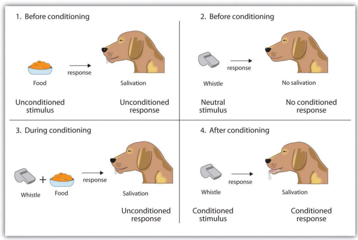
Activation requires all desired inputs



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

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

Learning to associate: Conditioning



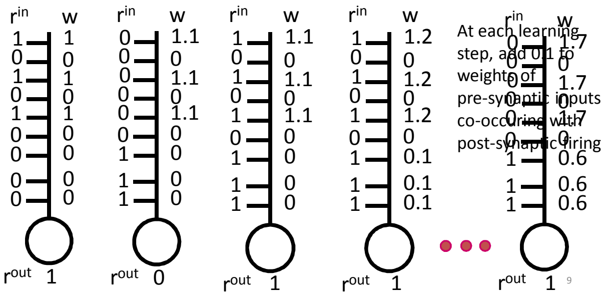
Associating both smell and whistle with food

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

Computing level: Associator network

Define input $h = \sum_j w_j r_j^{in}$

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

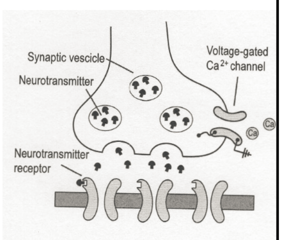
Increase weight by improving NT detection

Post-synaptic:

- Insert more receptors into dendrite membrane
- Improve performance of receptors

Pre-synaptic:

- Increase amount of NT released



Marr's levels of analysis

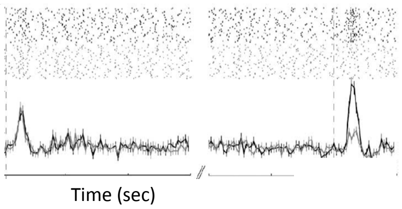
- **Computational theory:** Learn associations among sensations
- **Representation and algorithm:** Associate each sense with set of neural outputs, adjust weights on these outputs into another neuron
- **Hardware implementation:** Insert/remove NT receptors from dendrites

Math of Hebbian rate learning

"Cells that fire together, wire together"

r_i --- r^{out}
r_j --- r^{in}
ϵ learning speed

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



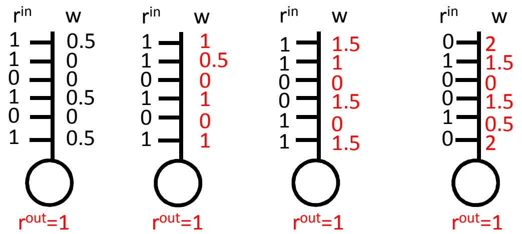
13

Using the learning rule

Define input $h = \sum_j w_j r_j^{in}$
Neuron fires at rate r^{out}=1 when $h > 1$

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

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



14

Weight control and decay

- Synaptic weights are finite
- Propose learning rules that keep weights bounded

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

- Or, preserve total synaptic weight across network: **"normalization"**

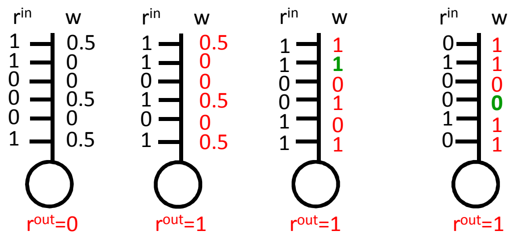
$$w_{ij} \leftarrow \frac{w_{ij}}{\sum_j w_{ij}}$$

15

Using weight control and decay

Define input $h = \sum_j w_j r_j^{in}$
Neuron fires at rate r^{out}=1 when $h > 1$

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



16

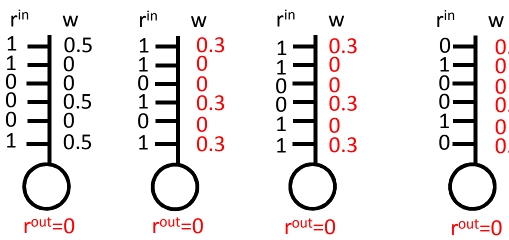
Using weight control and decay

Define input $h = \sum_j w_j r_j^{in}$
Neuron fires at rate r^{out}=1 when $h > 1$

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

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

$$\boldsymbol{w_{ij} \leftarrow \frac{w_{ij}}{\sum_j w_{ij}}}$$



17