## Synaptic plasticity and learning

James Humble

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#### Learning outcomes

- Identify different types of plasticity.
- Describe current biological knowledge on short and long term plasticity.

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 Demonstrate how plasticity can be implemented computationally. Outline

#### Short term plasticity

Synaptic depression Synaptic facilitation Synaptic failure

#### Long term plasticity

LTP and LTD Voltage and calcium dependency What happens at the synapse?. Late LTP STDP Heterosynaptic plasticity Homeostasis

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#### Computational modelling

Dynamic synapses model Hebbian learning STDP learning

Summary

# Section 1

## Short term plasticity

## Synaptic depression





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# Synaptic depression





- Depletion of the readily releasable pool
- Inactivation of release sites
- Reducation in calcium influx

## Synaptic facilitation



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# Synaptic facilitation



- Residual calcium may increase release probability
- Saturation of calcium buffers
- Increase of calcium currents

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## Synaptic failure

- Release of transmitter vesicles is stochastic
- Typical synapses release 4 to 15 vesicles
- Complete transmission failure is possible
- Some synapses are indeed very unreliable



## Section 2

# Long term plasticity

#### LTP



Bliss&Lomo, 1973

#### LTP continued



Paradiso et al, 2007

LTD



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## Voltage and calcium dependency



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# Voltage and calcium dependency



- LTP and LTD seem to be dependent on:
  - calcium levels
  - membrane voltage
- Calcium levels are usualy high when membrane potential is also high.
- High levels are associated with LTP.

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## What happens at the synapse?



A magnesium block is removed from NMDA receptors at high voltages. Sodium, potassium and calcium can then then flow.

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#### What happens at the synapse? cntd.



#### AMPA receptors



# Late LTP



**STDP** 



## Heterosynaptic plasticity

 LTP/LTD on one pathway can be associated with a reversal, respectively, on another.

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- Previous LTP can lead to easier LTD
- Can be both pre- and postsyanptic.
- Might be linked to calcium diffusion.

#### Homeostasis



## Section 3

## Computational modelling

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#### Dynamic synapses model



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## Hebbian learning



- Donald Hebb Founder of Neuropsychology.
- Book: "The Organization of Behavior" (1946).

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## Hebbian learning



- Donald Hebb Founder of Neuropsychology.
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- Synapses should strengthen if connected neurons often fire together; A "causes" B to fire.
- Extend this to include the opposite (LTD).

## STDP learning

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# STDP learning

- Weight dependence: hard or soft bounds.
- Additive exponential STDP rule.  $w(t) = w(t \Delta) + A_{\pm}f(w)$

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Multiplicative exponential STDP rule. w(t) = (w<sup>max</sup> − w(t − Δ))A<sub>±</sub>f(w)

# STDP learning

- Weight dependence: hard or soft bounds.
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- Multiplicative exponential STDP rule. w(t) = (w<sup>max</sup> − w(t − Δ))A<sub>±</sub>f(w)
- ► Temporal all-to-all versus nearest-neighbour spike-interaction.



► Homeostasis?

# Summary

There are different types of short- and long-term plasticity including:

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- Depression
- Facilitation
- Failure
- LTP & LTD
- STDP
- Heterosynaptic plasticity and homeostasis

# Summary

- There are different types of short- and long-term plasticity including:
  - Depression
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  - Heterosynaptic plasticity and homeostasis
- Different plasticity types use difference mechanisms:
  - Pre-synaptic: vesicle use, nature of synapse and calcium
  - Post-synaptic: increase/decrease in number of receptors, signalling cascades and neuron/dendritic wide homeostatic changes.

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## Summary

- There are different types of short- and long-term plasticity including:
  - Depression
  - Facilitation
  - Failure
  - LTP & LTD
  - STDP
  - Heterosynaptic plasticity and homeostasis
- Different plasticity types use difference mechanisms:
  - Pre-synaptic: vesicle use, nature of synapse and calcium
  - Post-synaptic: increase/decrease in number of receptors, signalling cascades and neuron/dendritic wide homeostatic changes.
- These biological phenomena can be described/modelled to a certain extent computationally.

#### Learning outcomes

- Identify different types of plasticity.
- Describe current biological knowledge on short and long term plasticity.

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