Computational Neuroscience 03 hippocampus

Conor

coms30127.github.io

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Modelling

This is an example of a model that explains what might be happening without giving a detailed simulation of the individual components involved.

Recap - McCulloch-Pitts neurons

$$x_i = \phi\left(\sum_j w_{ij} x_j\right)$$

where in classic applications

$$x_i = \begin{cases} +1 & \sum_j w_{ij} x_j > \theta \\ -1 & \text{otherwise} \end{cases}$$

and here we simplify further by setting $\theta = 0$.

Modelling

Here we look at the hippocampus and introduce a more top down style of modelling.

The hippocampus

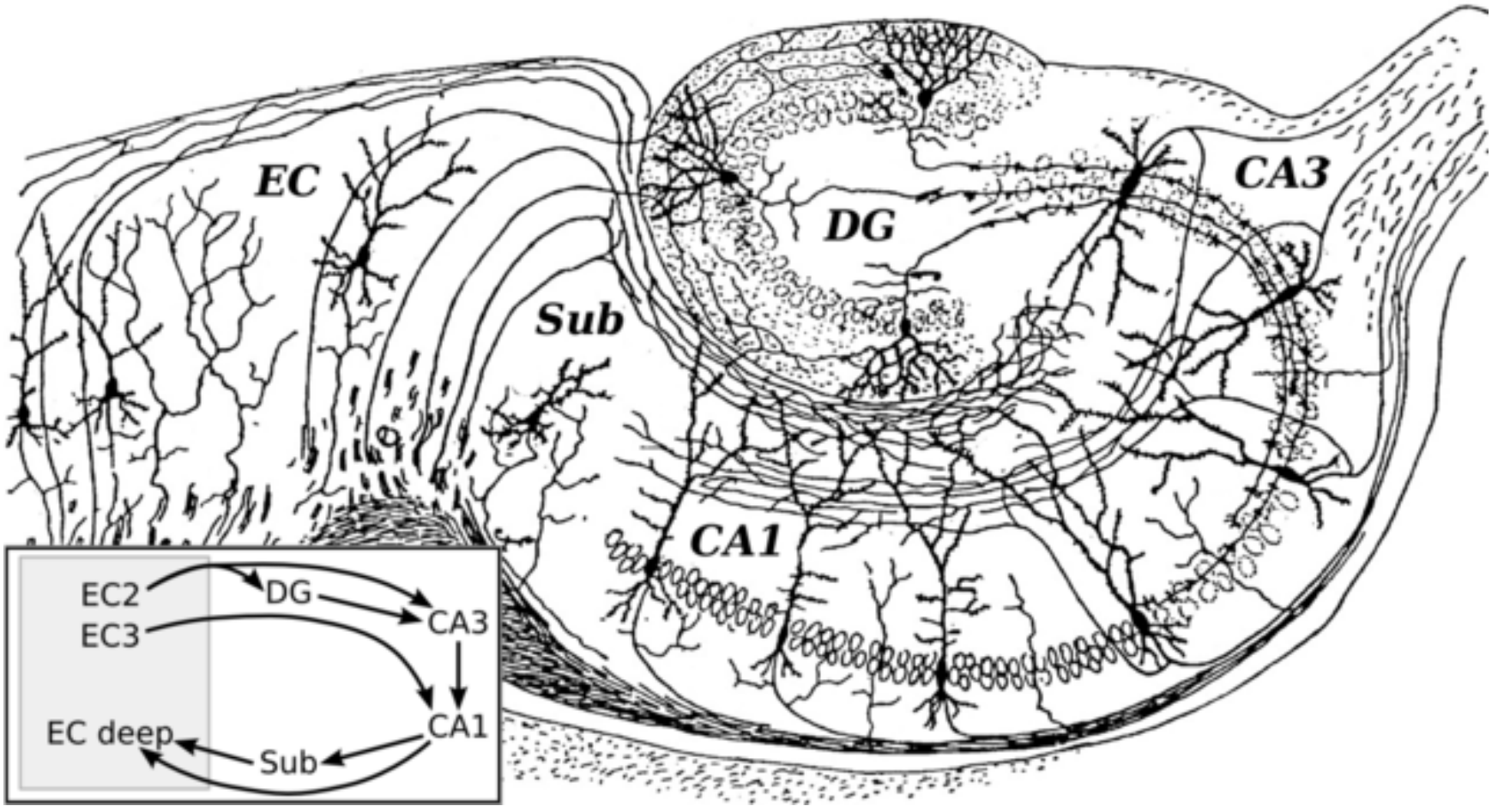


image from wikipedia, originally due to Cajal

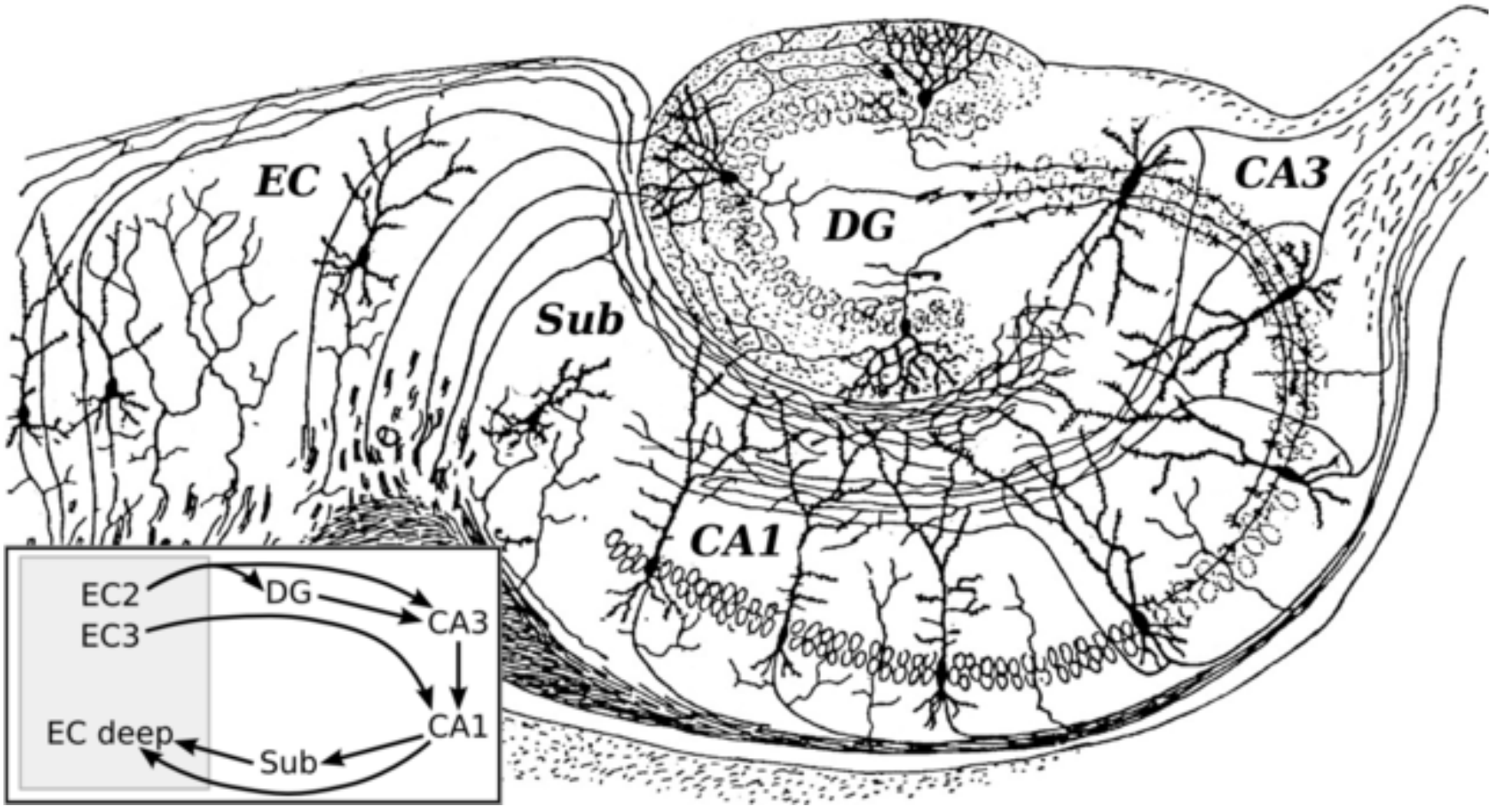
The role of the hippocampus

www.wikihow.life/Find-Things-You-Lost

The role of the hippocampus

image of Rodin's *The Thinker* from wikipedia

The hippocampus



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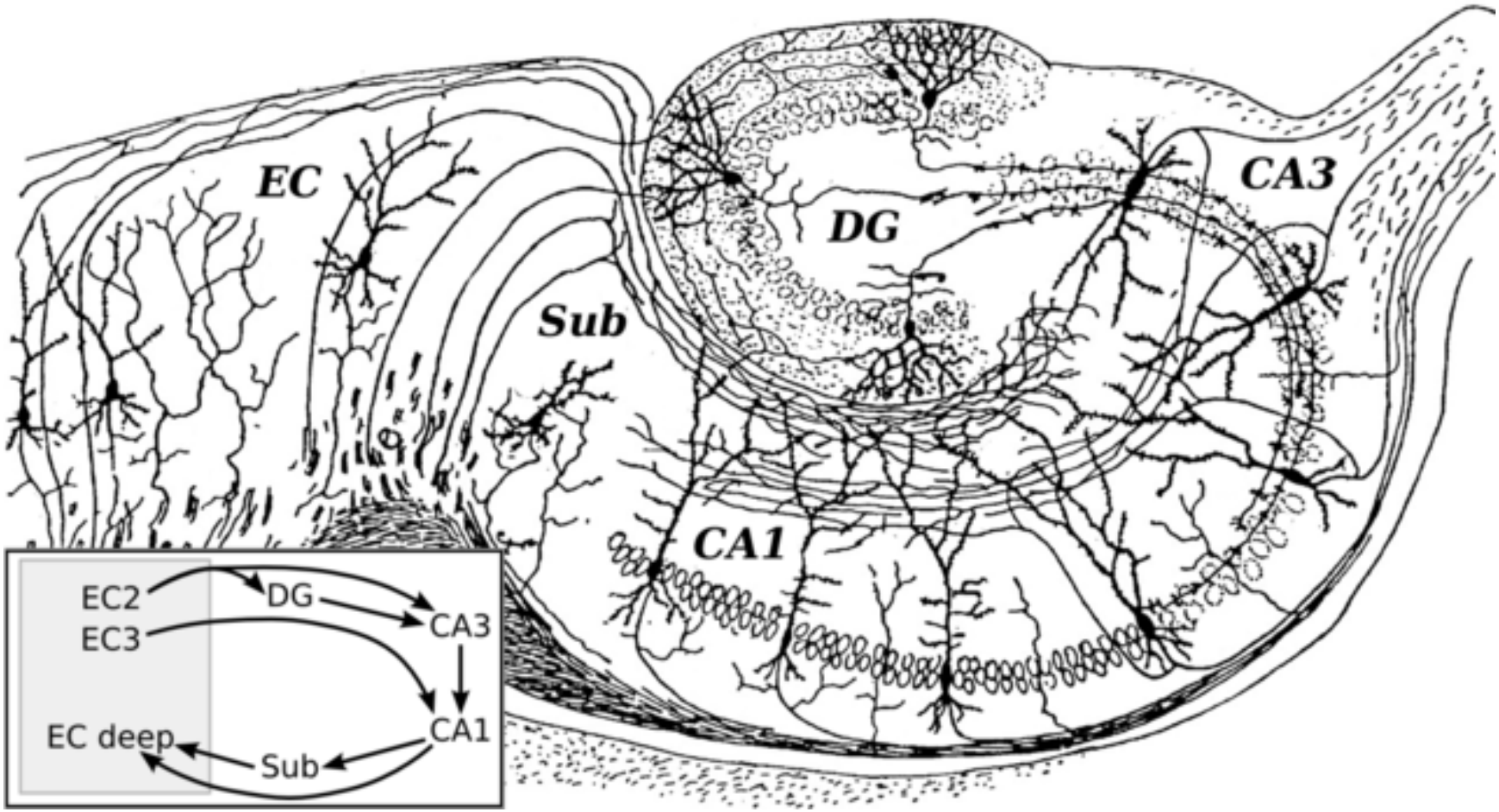
The hippocampus

Cornu Ammonis (CA) - meaning the *horn of Ammon*. The CA is usually divided into four regions, labelled CA1 through to CA4.



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The hippocampus

Cornu Ammonis (CA) - meaning the *horn of Ammon*. The CA is usually divided into four regions, labelled CA1 through to CA4 - sort of.

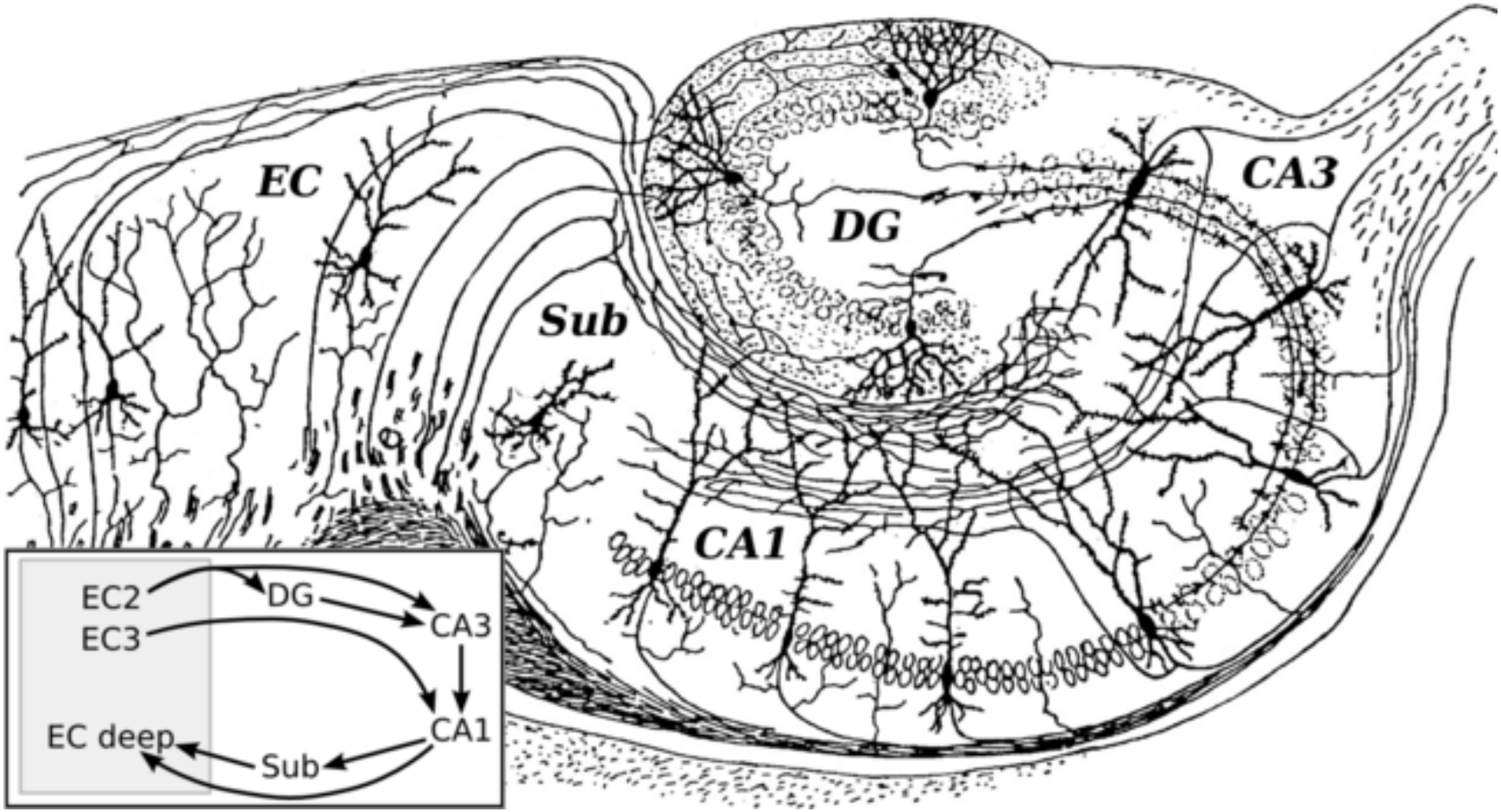


image from wikipedia, originally due to Cajal

The hippocampus

Dentate Gyrus (DG)- gyrus is the name given to the ridges in the cortex, dentate means *with teeth*.

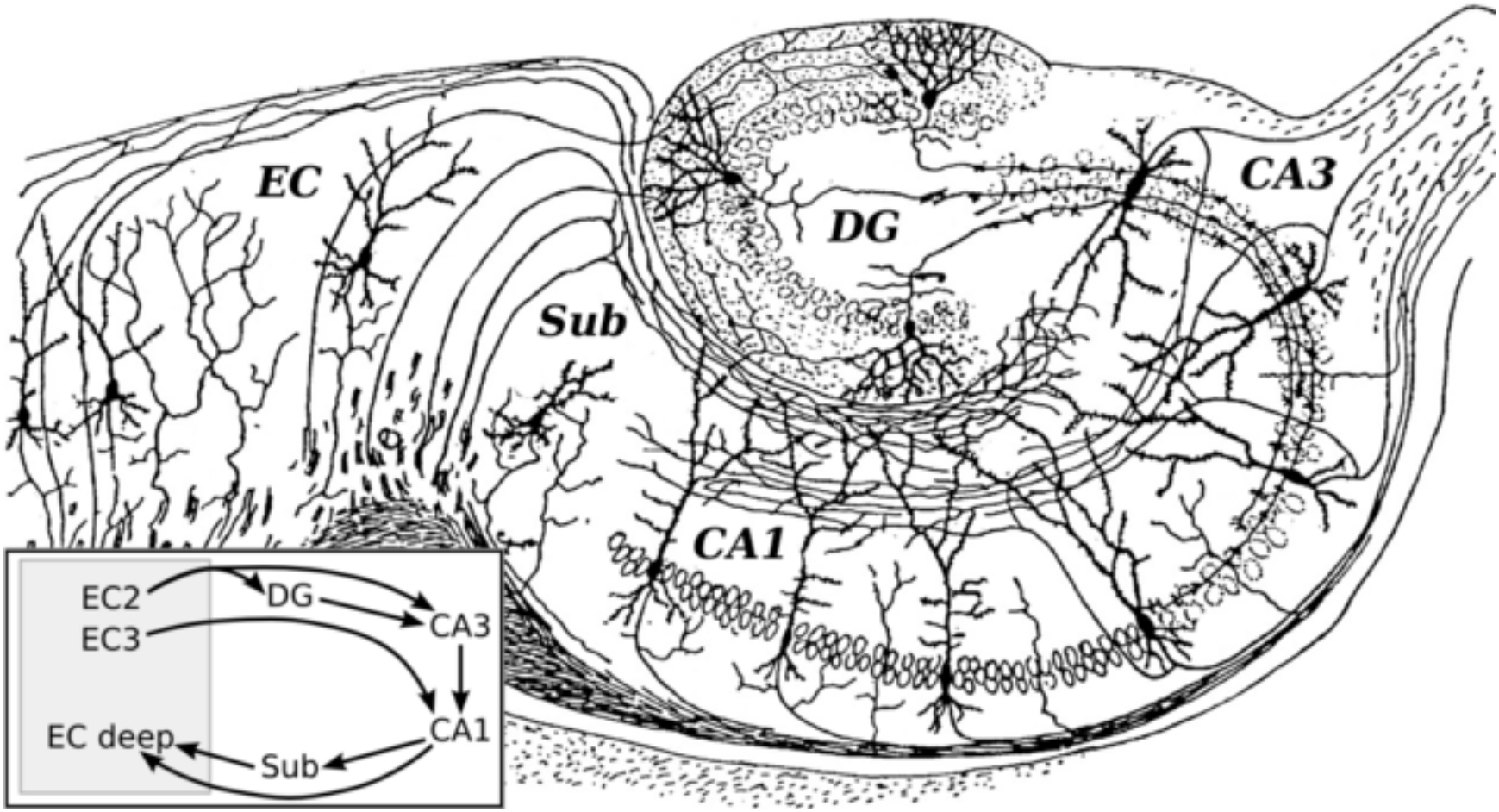


image from wikipedia, originally due to Cajal

The hippocampus

Entorhinal Cortex (EC) - entorhinal means *near the smell processing area* - an honorary part of the hippocampus.

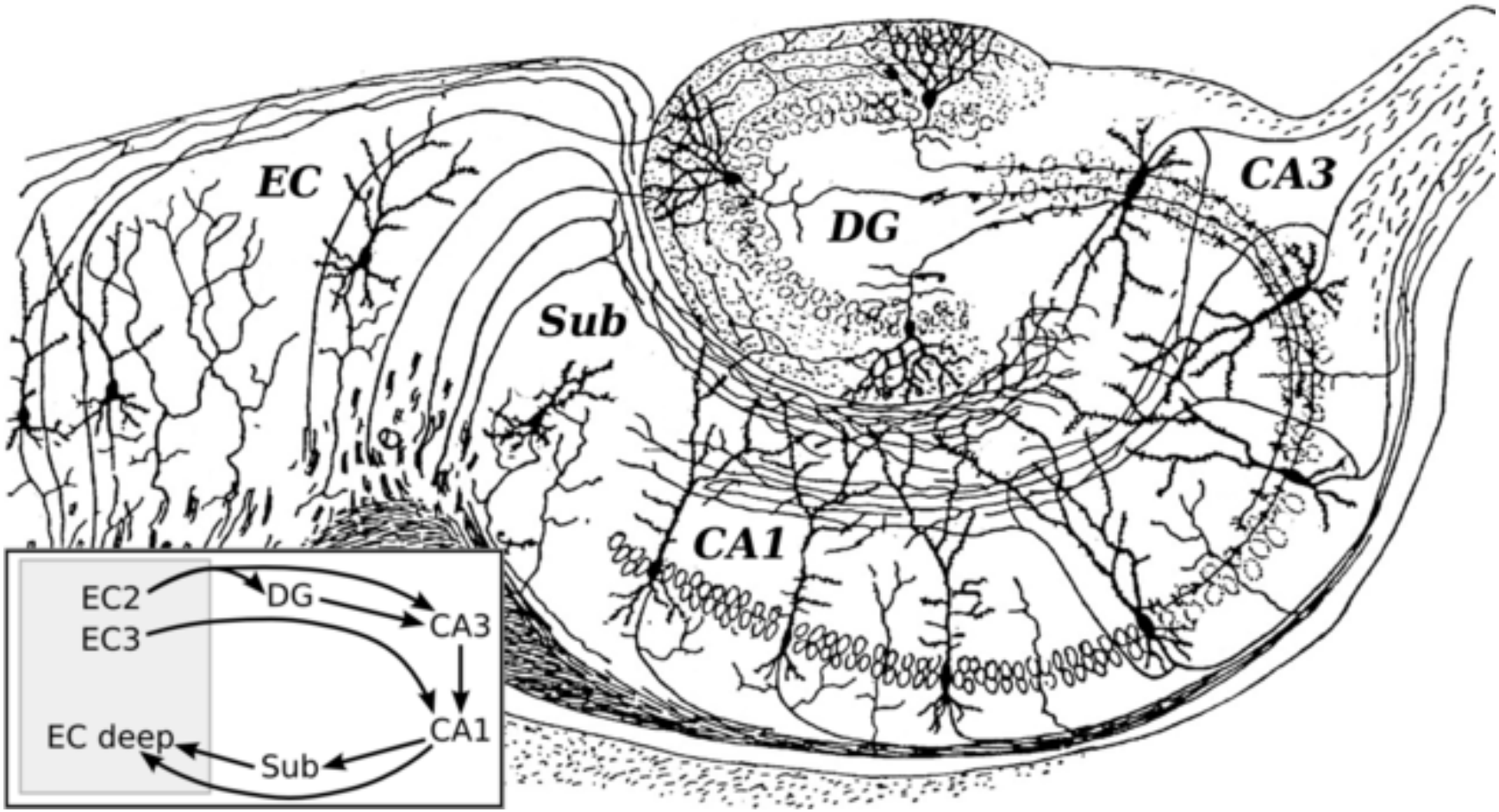
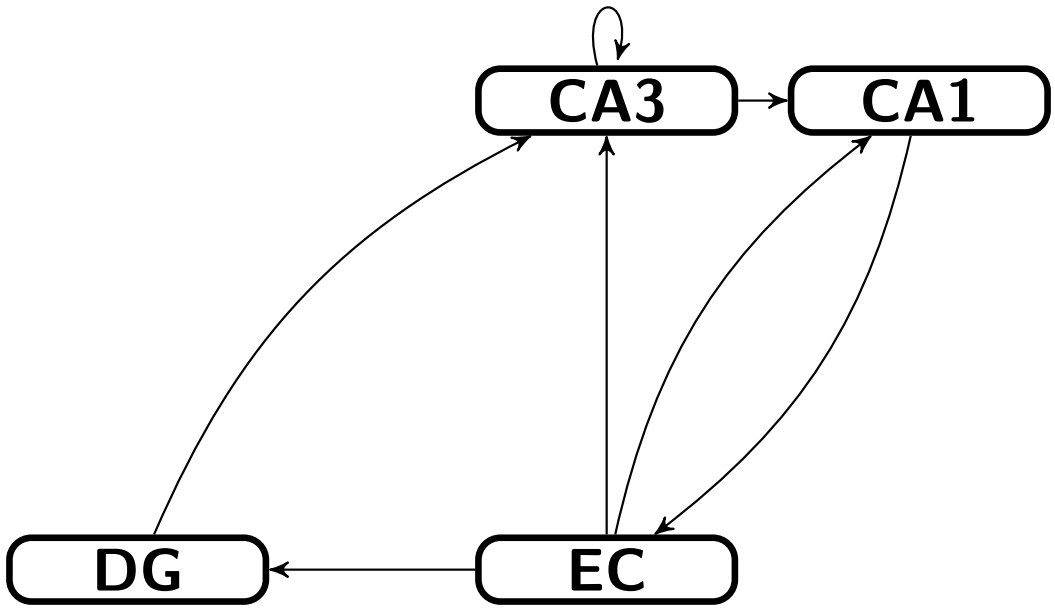


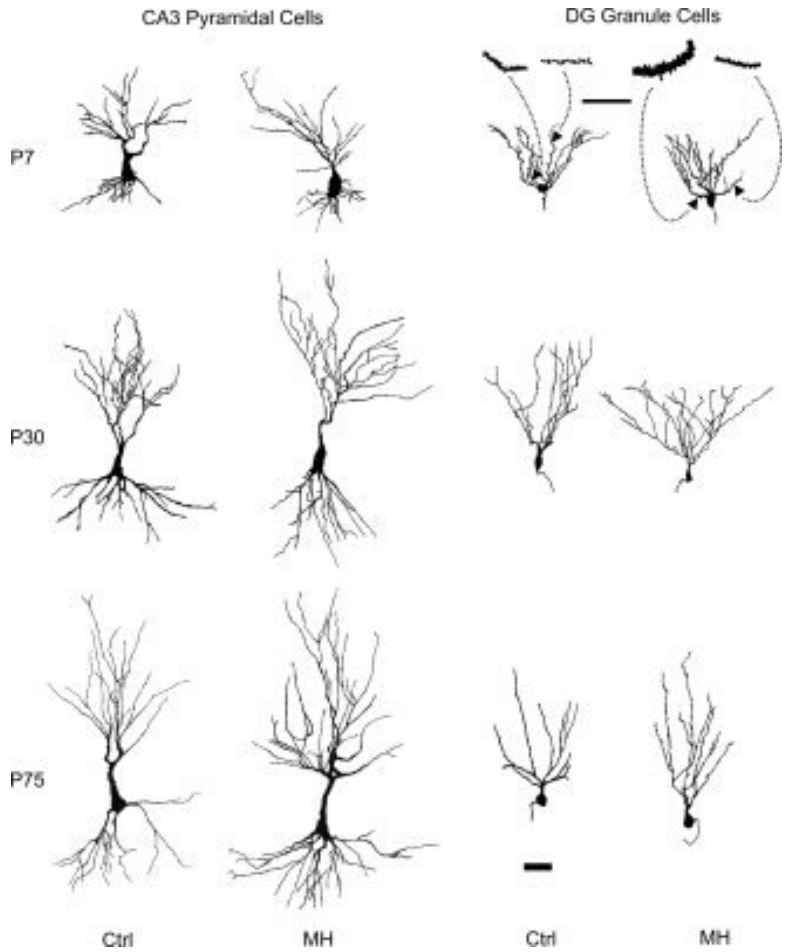
image from wikipedia, originally due to Cajal

How the hippocampus is connected



Cells

The dentate gyrus is composed of granule cells, CA3 of pyramidal cells. DG is thought of a *feed-forward* whereas CA3 is highly *recurrent*.



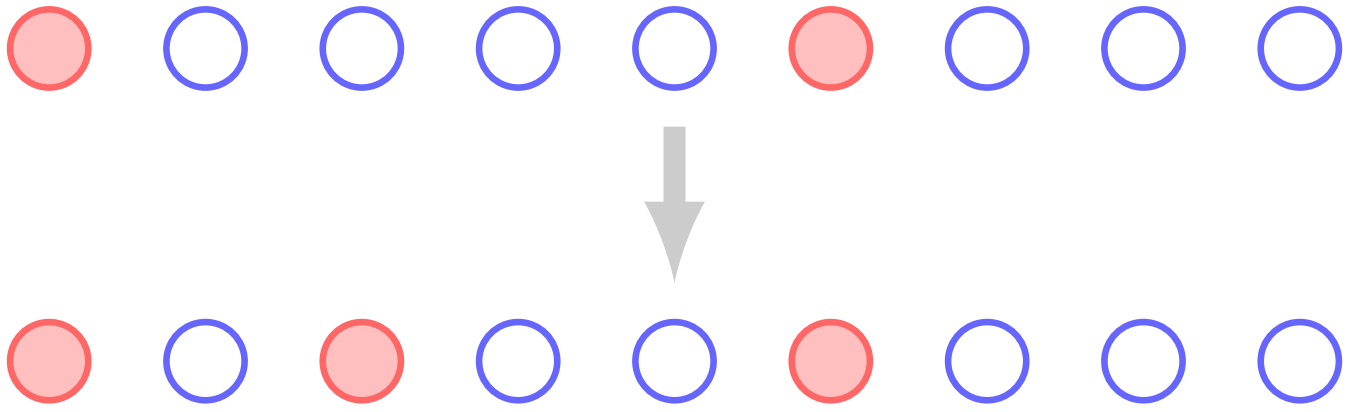
from 10.1002/jnr.21580

Auto-associative memory

A memory is a pattern of active neurons!

Auto-associative memory

The dynamics of the network complete partial patterns.



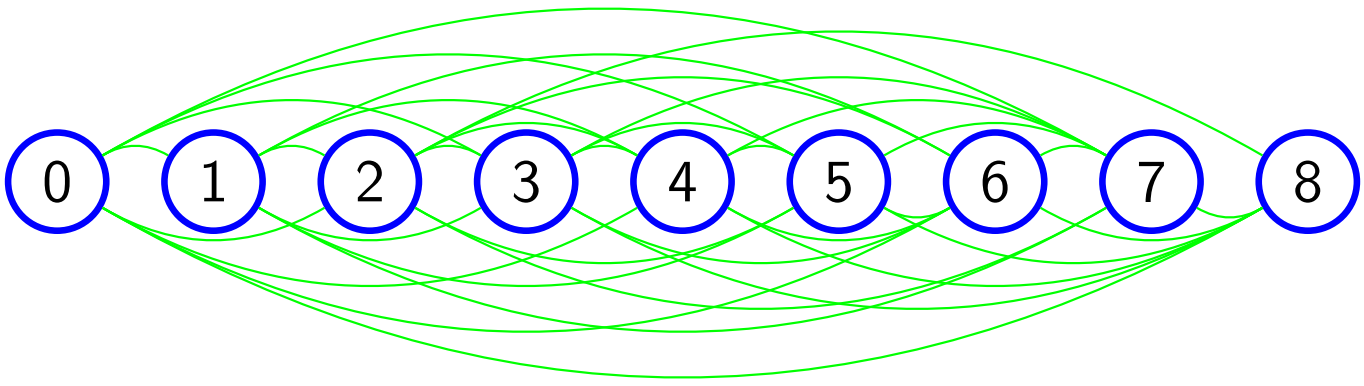
McCulloch-Pitts neurons

ON!

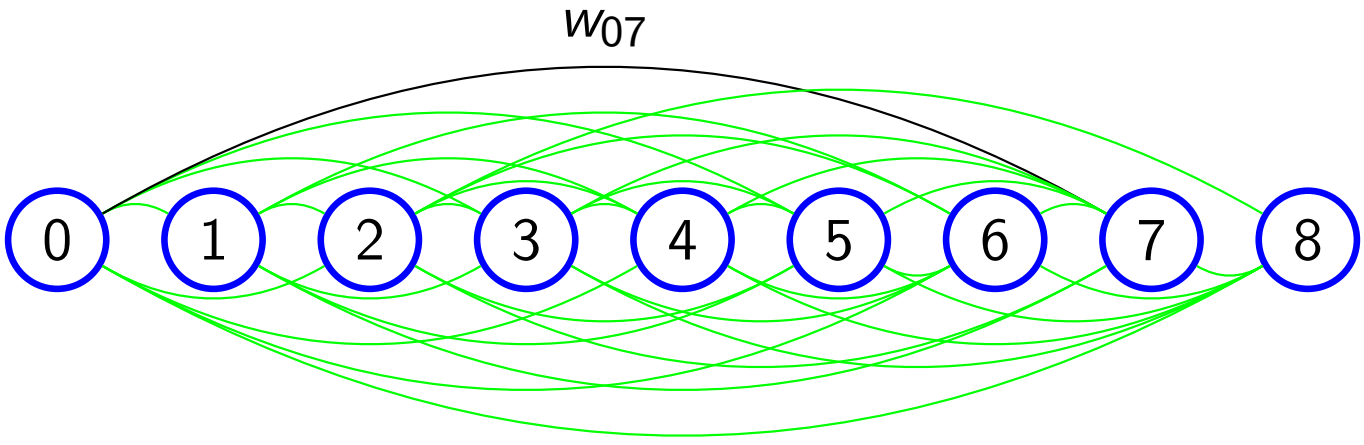
McCulloch-Pitts neurons

OFF!

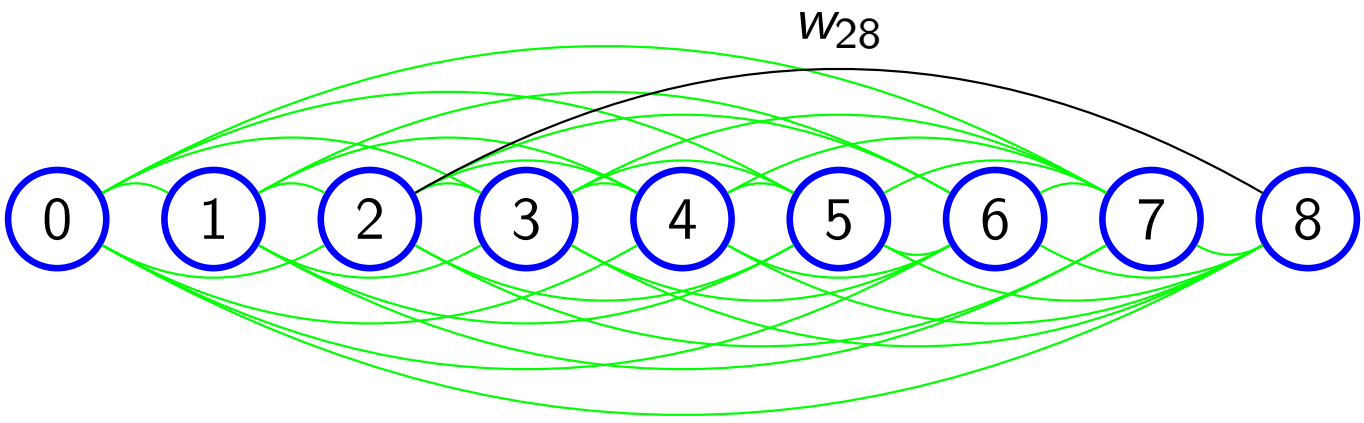
All-to-all network



All-to-all network



All-to-all network



Hebbian learning

$$\Delta w_{ij} = \eta(x_i - a)(x_j - a)$$

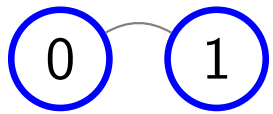
where a is the average number of ON nodes.

Hebbian learning

$$\Delta w_{ij} = \eta(x_i - a)(x_j - a)$$

OFF-OFF causes a small increase

$$\Delta w_{01} = \eta a^2$$

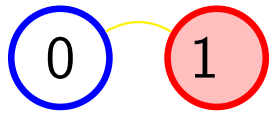


Hebbian learning

$$\Delta w_{ij} = \eta(x_i - a)(x_j - a)$$

OFF-ON causes a medium decrease

$$\Delta w_{01} = -\eta a(1 - a)$$

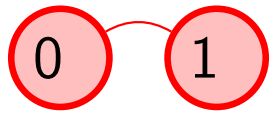


Hebbian learning

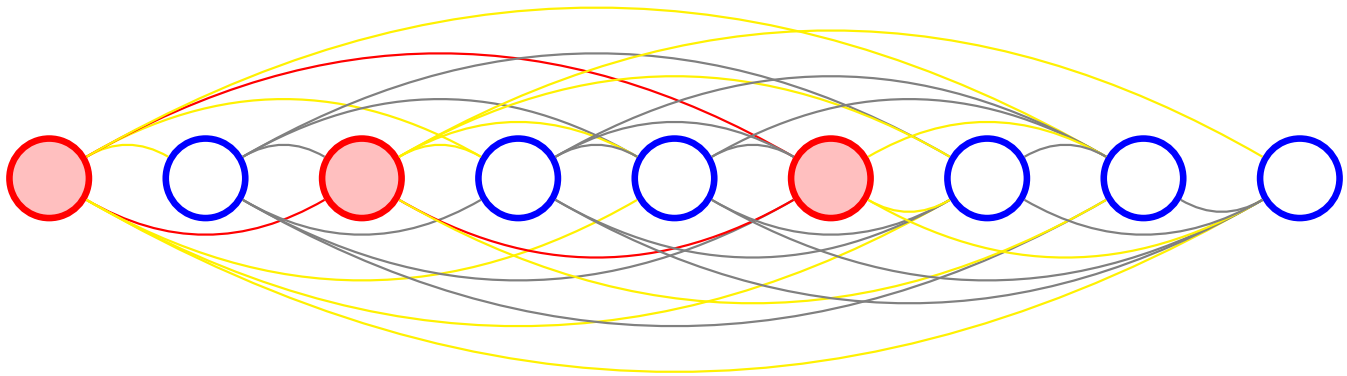
$$\Delta w_{ij} = \eta(x_i - a)(x_j - a)$$

ON-ON causes a big increase

$$\Delta w_{01} = \eta(1 - a)^2$$



Learning a pattern

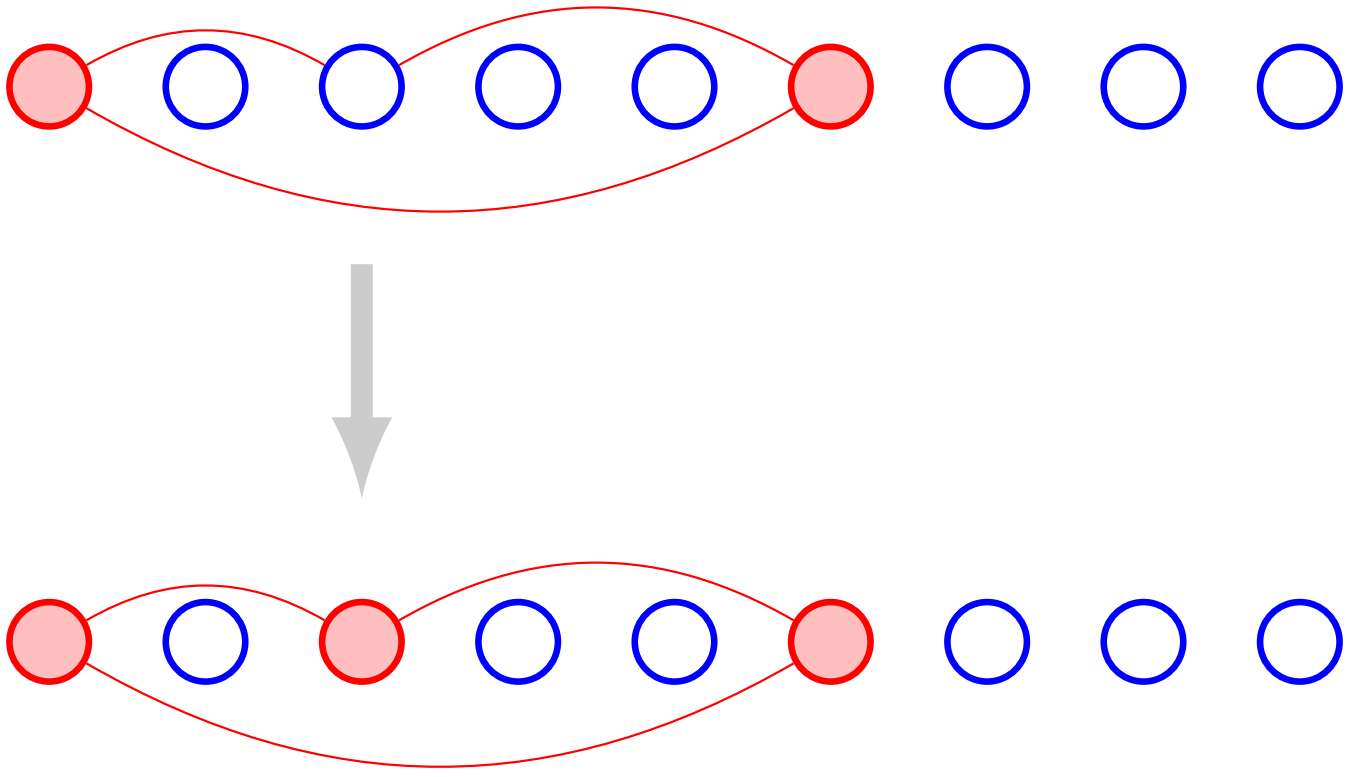


Activation

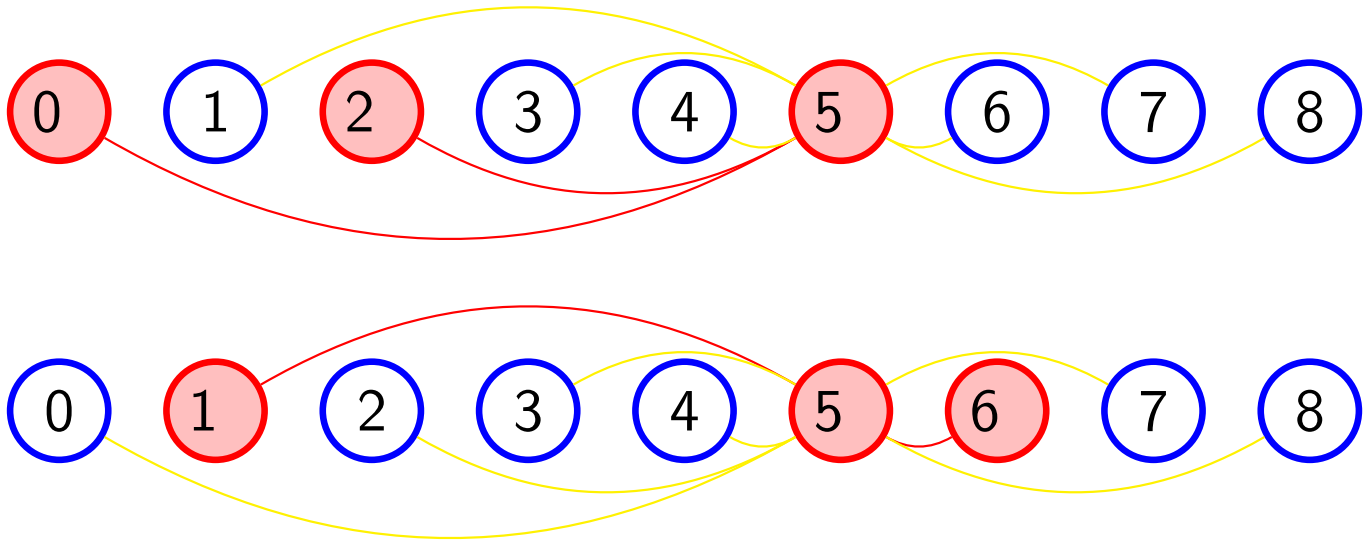
$$h_i = \sum w_{ij} x_j = w_{i0} x_0 + w_{i1} x_1 + w_{i2} x_2 + \ldots$$

and if $h_i > \theta$ set x_i to one, otherwise set it to zero.

Auto-associative memory



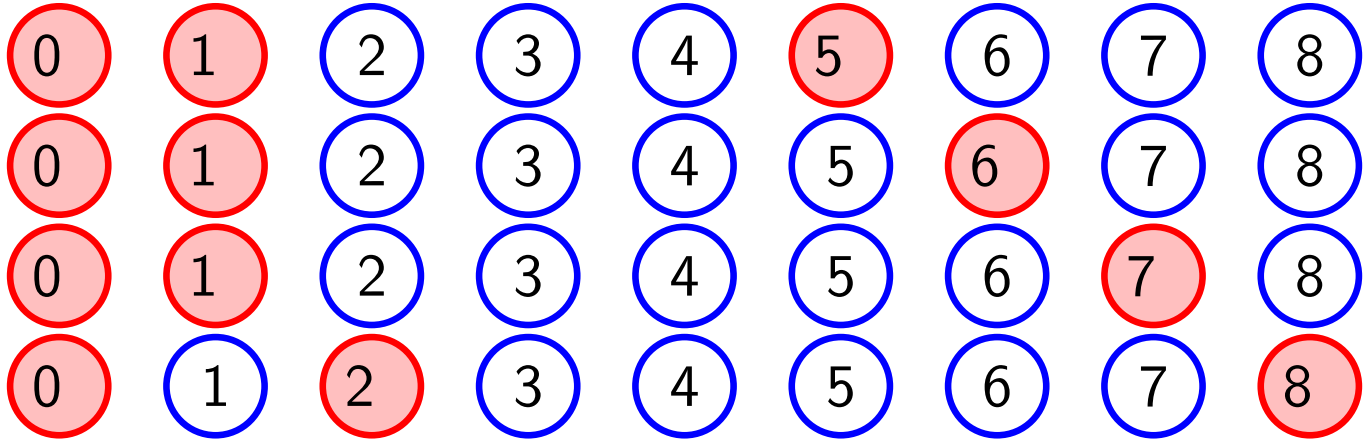
Capacity



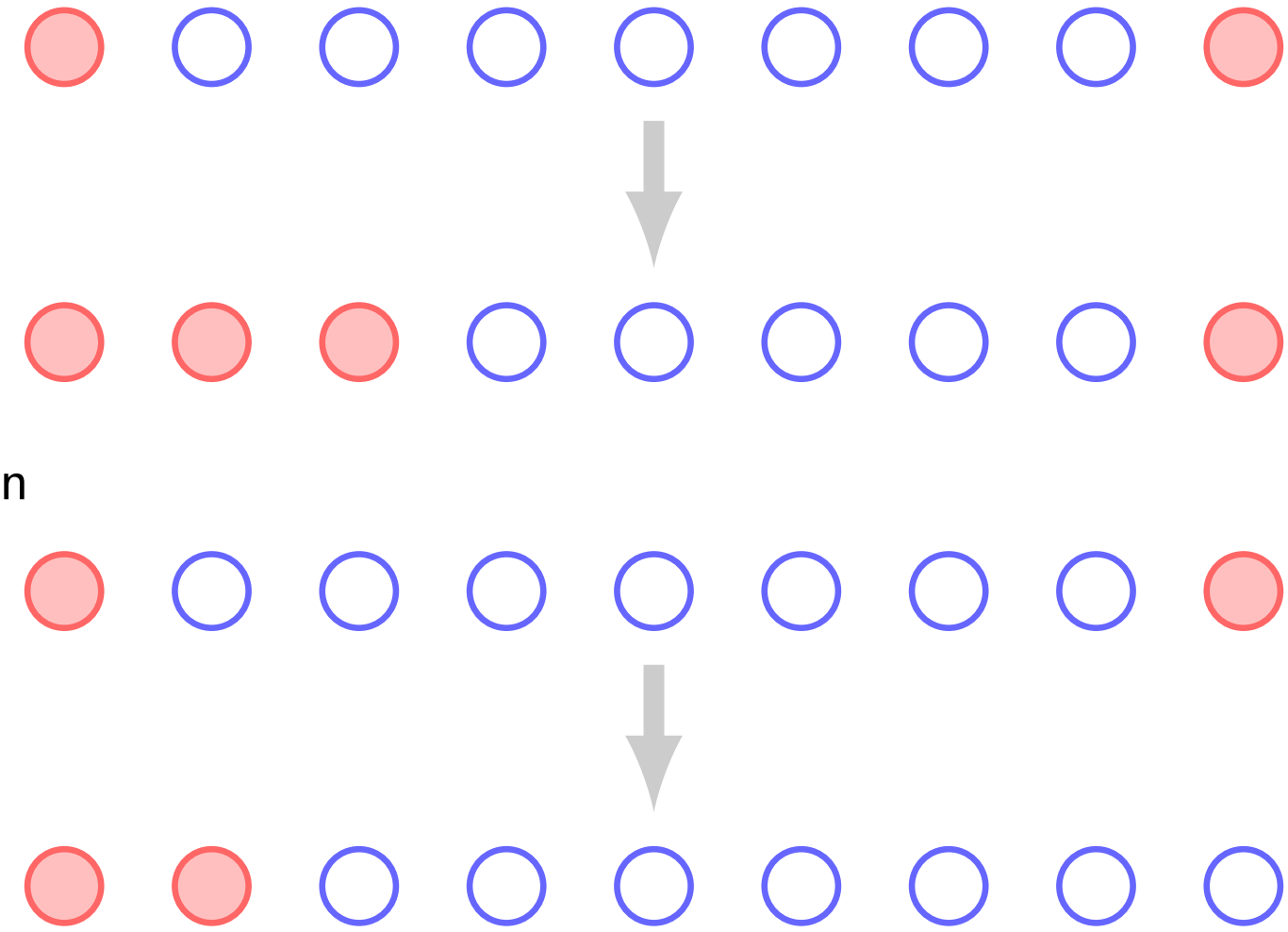
Capacity

- N^2 connections.
- N neurons in a pattern.
- Can store something proportional to $N^2/N = N$ patterns.

Correlated patterns



Erroneous completion



or even

Patterns seperation

Maybe the Dentate Gyrus fixes this problem!

Summary

1. CA3 - many recurrent connections, that is excitatory neurons connected to each other.
2. CA3 - an auto-associative memory store - patterns are completed.
3. CA3 - capacity proportional to N.
4. DG - feedforward, that is few, or even no, lateral connections between the excitatory neurons.
5. DG - seperates patterns ready for EC to store them by randomizing them.