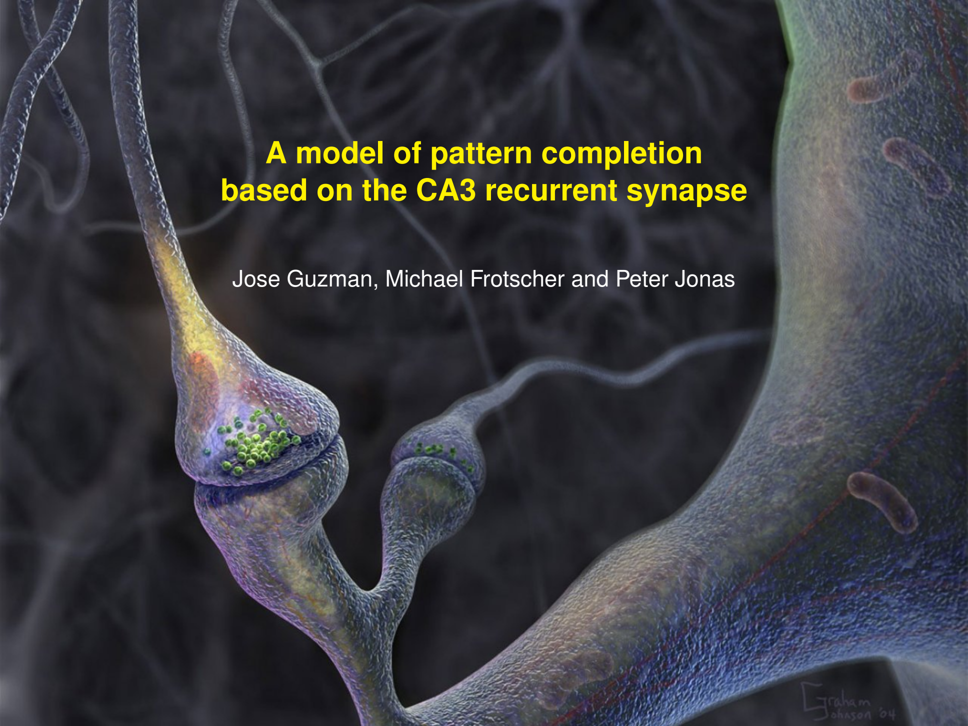
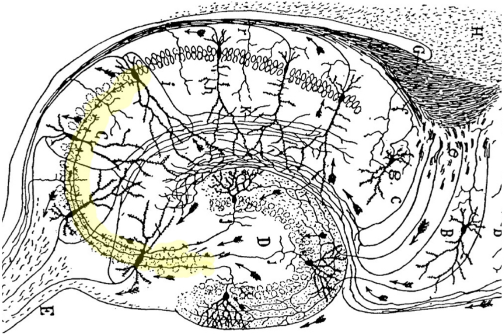
A model of pattern completion based on the CA3 recurrent synapse

Jose Guzman, Michael Frotscher and Peter Jonas

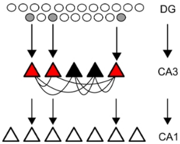


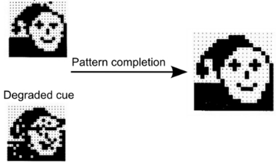
The neural structure for pattern completion

Histologie du Systeme Nerveus de l'Homme et des Vertebres,
Vols. 1 & 2. A. Maloine. Paris. 1911. Ramón y Cajal.

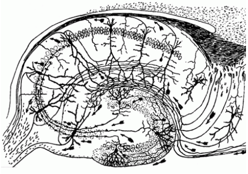


Trisynaptic pathway

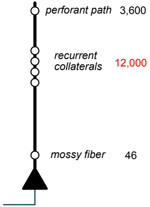




Synaptic basics of pattern completion



Ramón y Cajal, 1911

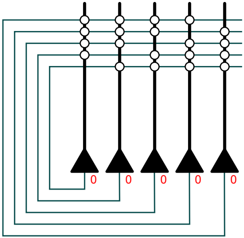


adapted from Amaral *et al.*, 1990

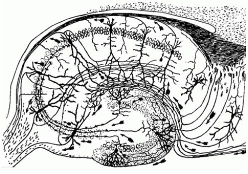
Auto-associative network

An autoassociative network can perform *pattern completion* when it associates the input to the principal cells with their own output (Marr, 1971)

1. Storage
2. Activation
3. Recall



Synaptic bases of pattern completion



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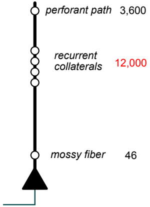

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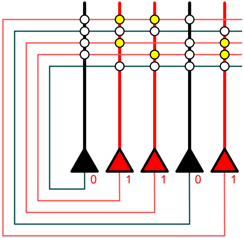

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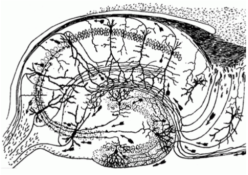

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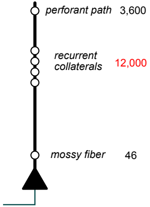

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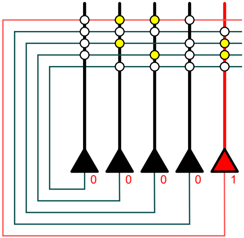
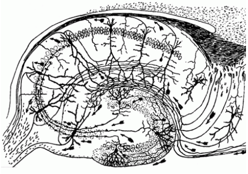


Synaptic bases of pattern completion



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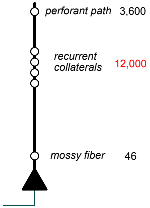

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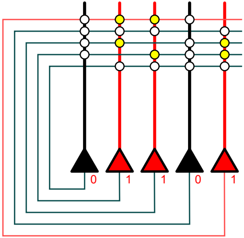

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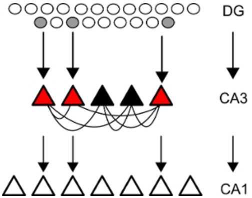
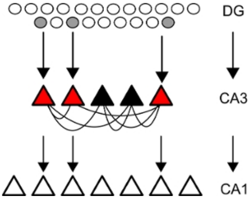


1 $\boxed{\text{Macro-connectomics}}$ CA3–CA3 connectivity?

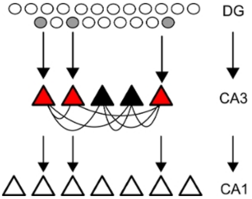
Synaptic bases of pattern completion



1 Macro-connectomics CA3–CA3 connectivity?

2 Micro-connectomics properties of recurrent synapses

Synaptic bases of pattern completion



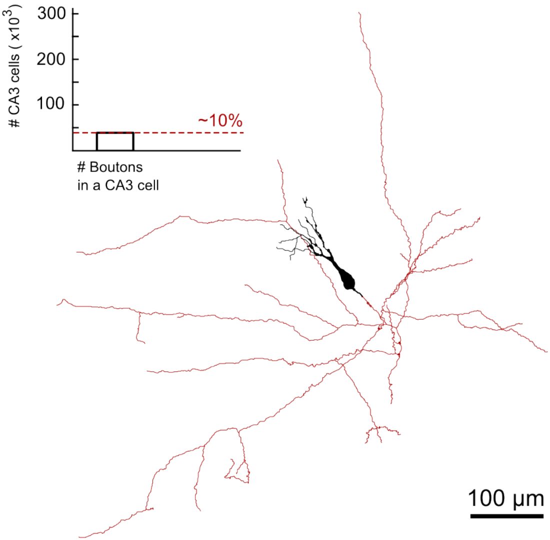
1. $\boxed{\text{Macro-connectomics}}$ CA3–CA3 connectivity?
2. $\boxed{\text{Micro-connectomics}}$ properties of recurrent synapses
3. how are memories stored? (i.e. plasticity rules)

Macro-connectomics

what is the connectivity between CA3 cells?

Macro-connectomics: on CA3–CA3 connectivity

On CA3 numbers



$\sim$ **40,000 boutons**

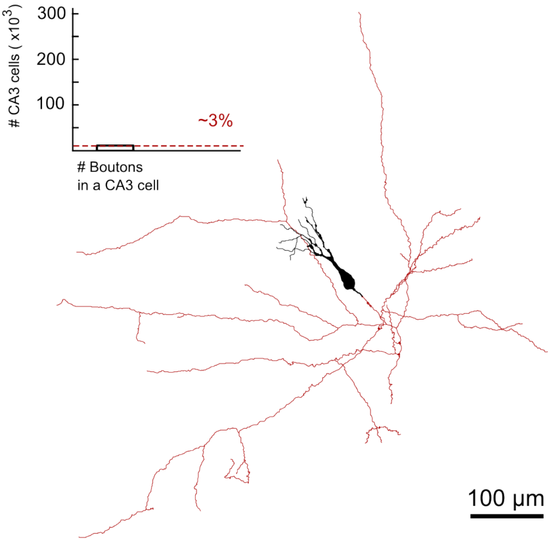
- Witter *et al.*, 2007
- Li *et al.*, 1994
- Ishizuka *et al.*, 1990

$\sim$ **330,000 CA3 cells**

- Boss *et al.*, 1987

Macro-connectomics: on CA3–CA3 connectivity

On CA3 numbers



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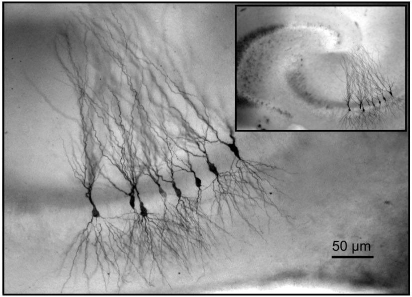
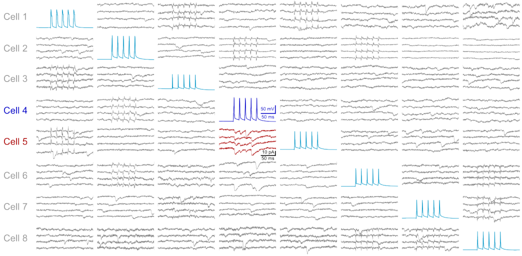
Octuple whole-cell recordings

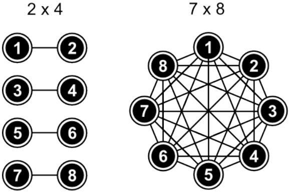
a) Simultaneous recordings

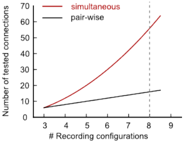


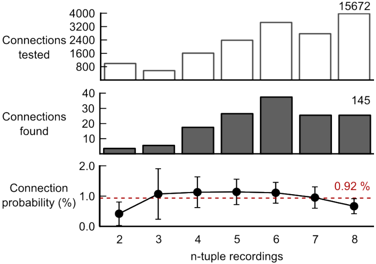
c) Connectivity matrix to test CA3–CA3 cells



b) Recording configurations







Octuple whole-cell recordings

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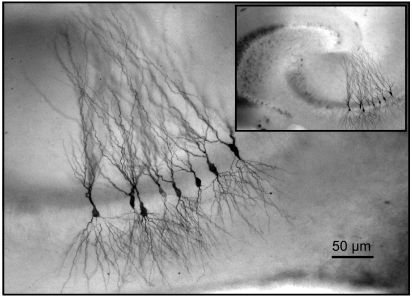

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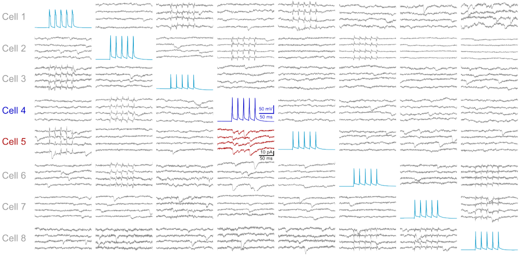

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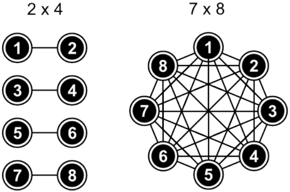
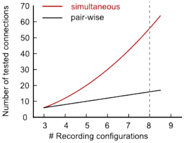
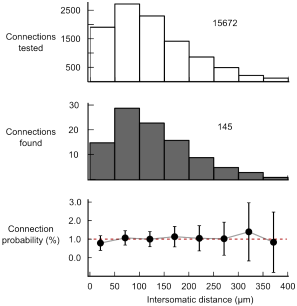
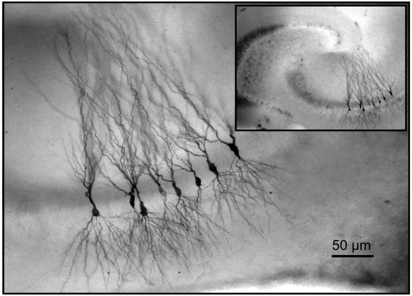




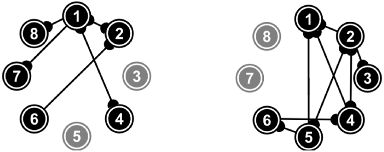


Motifs of connectivity

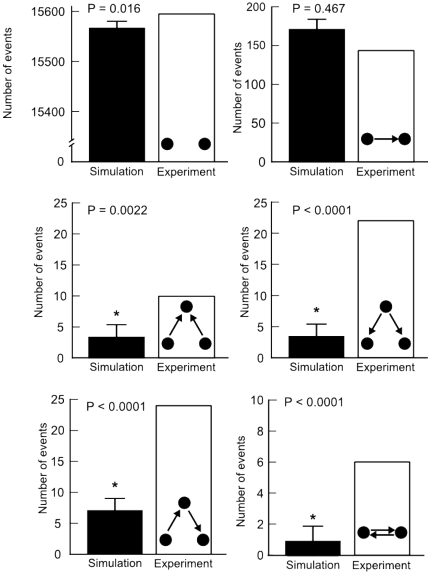
a) Simultaneous recordings



b) Motifs of hyperconnectivity



c) Connectivity motifs are representative



Macro-connectomics

what is the connectivity between CA3 cells?

CA3 neurons use motifs of hyperconnectivity embedded on a sparse network

$\boxed{\text{Micro-connectomics}}$

Properties of the CA3–CA3 synapses

Anatomical identification of synaptic contacts

A Biocytine labeling

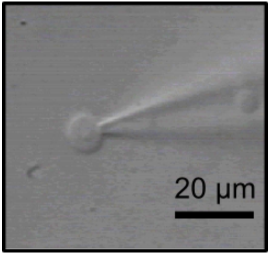
B Identification under light microscopy

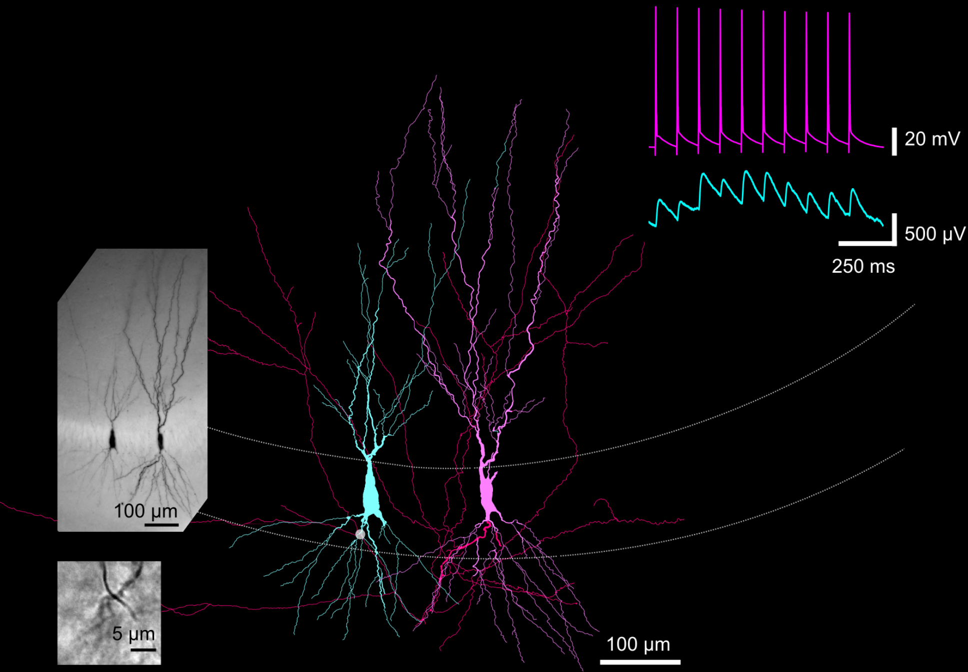
performed under 60X or 100X/1.4 oil-immersion objectives

- axon and dendrite belong to functionally connected pairs
- presence of enlargements at the axon/dendrite.
- appointments located at a single focal plane.

C Nucleated patches

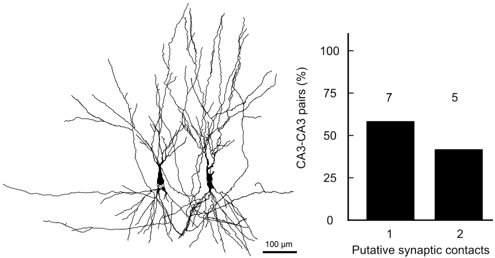
Sather *et al.*, 1992



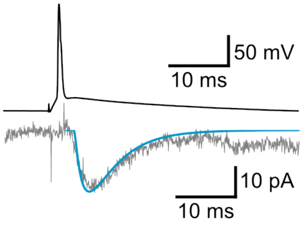

20 mV
500 µV
250 ms
100 µm
5 µm
100 µm

Micro-connectomics: 1–2 contacts per connection

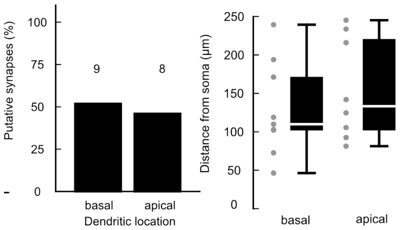
a) Digital reconstruction



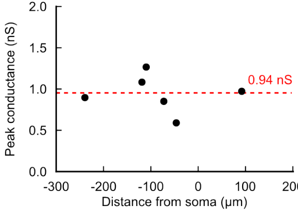
c) Cable modeling



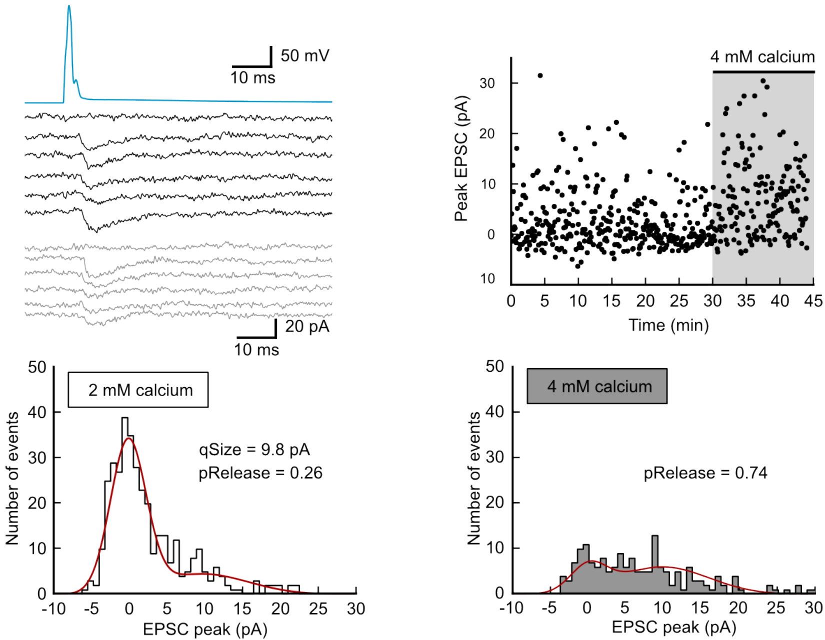
b) Putative synaptic contacts



d) Conductance estimation



Micro-connectomics: low number of functional sites



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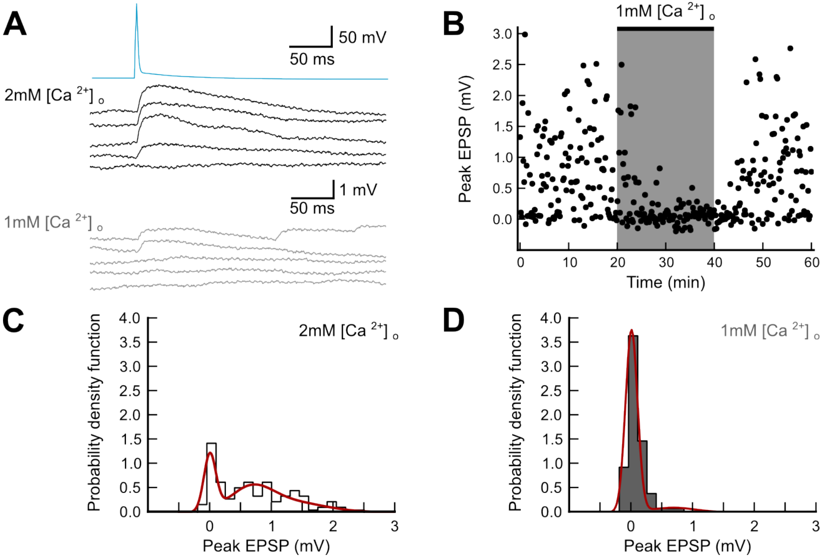

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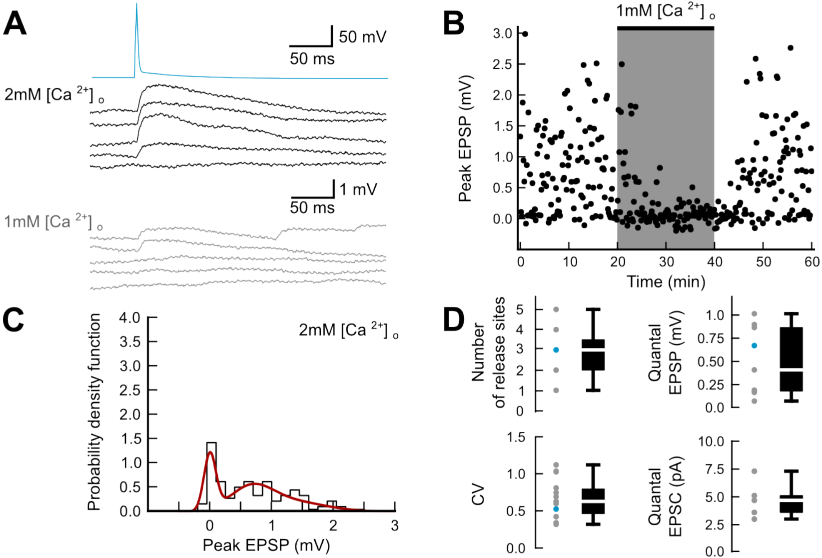
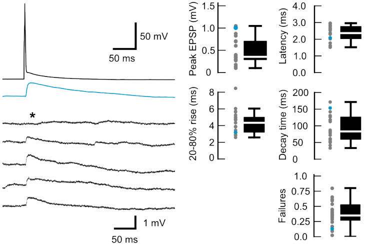
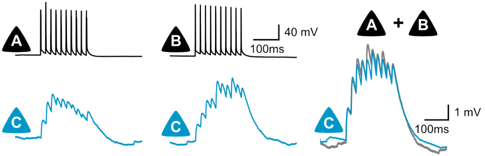


EPSPs are small but add efficiently

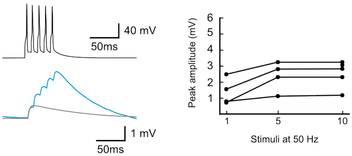
a) EPSP kinetics



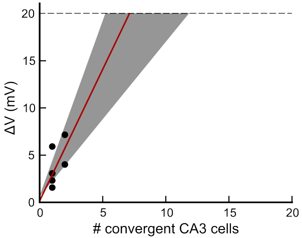
c) Spatial summation



b) Temporal summation



d) Low number of CA3 cells for spiking

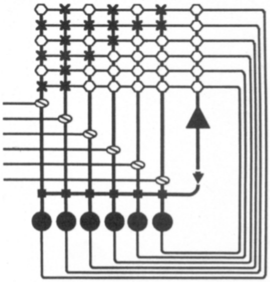


Micro-connectomics

Properties of the CA3–CA3 synapses

CA3 synapses exhibit a low number of sites and summation

Towards a quantitative model for pattern completion



Full size (330,000 neurons)
Neurons inactive (0) or active (1)
Excitatory synapses follow a clipped Hebbian rule
Inhibition proportional to global excitation level

$$h_i(t) = \frac{1}{n} \sum_{j=1}^{n} (W_{ij} \circ J_{ij} \circ P_{ij}) X_j(t),$$

$$h_i(t) - \frac{1}{n} g_1 X(t) > g_0$$

Other assumptions: Connectivity 3%, synaptic CV 1

Storage phase

Apply original pattern

Repeat m times

Hebbian plasticity

Retrieval phase

Test degraded pattern

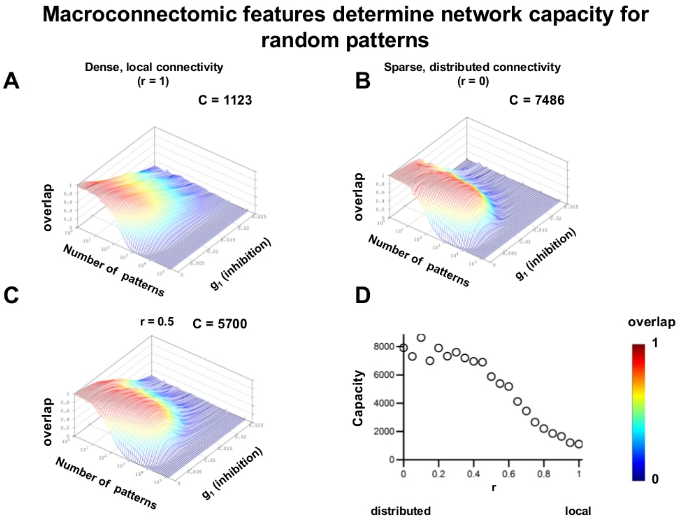
Repeat several times

Determine overlap between original patterns and final patterns

Determine capacity as number of patterns in which overlap is > 0.5

Marr, 1971; Hopfield, 1982; Bennett et al., 1994

Towards a quantitative model for pattern completion



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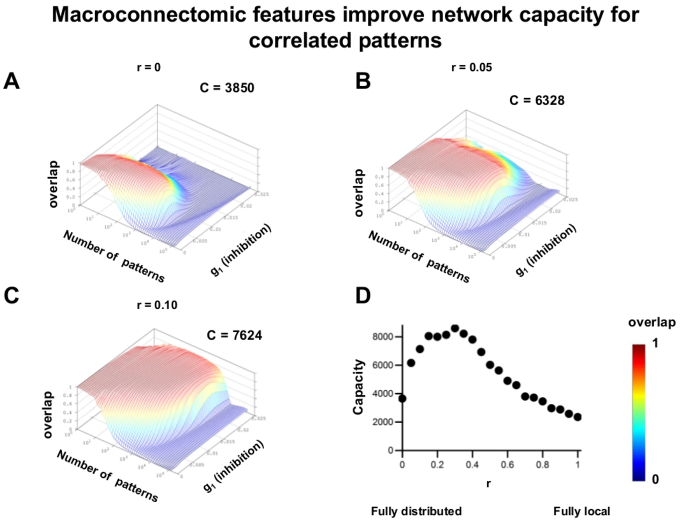
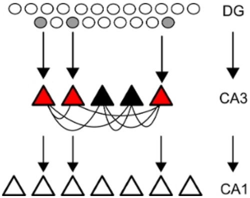
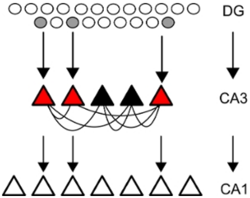


Summary



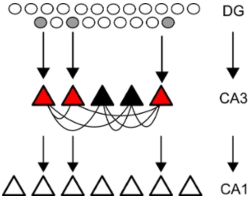
1 $\boxed{\text{Macro-connectomics}}$ combination of sparse and dense connectivity

Summary



1. $\boxed{\text{Macro-connectomics}}$ combination of sparse and dense connectivity
2. $\boxed{\text{Micro-connectomics}}$ small number of synapses, but very prone to summation

Summary



1 Macro-connectomics combination of sparse and dense connectivity

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Acknowledgments

1. Peter Jonas,
2. Alois Schlögl,
3. Jonas lab