Topological explorations in neuroscience

Public Lecture
8th European Congress of Mathematicians
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What is the Blue Brain Project??
Neuronal distribution in the rat somatosensory neocortex

Circuit: cxt1_v5:r0
Size: 31546 neurons
Target: mc2_Column
Visualisation: 1000 neurons
Coloring: per layer 1 to 6 and per synaptic class

Exhibitory samples
-80% of neural cells are excitatory

Inhibitory samples
-20% of neural cells are inhibitory

Vis. eng. & design: Nicolas Artille
Scientific owners: Henry et al Cell, 2015
Workflow: anatomy

A Morphological diversity of neurons: (a) m-types, (b) cloning

B Microcircuit anatomy: (a) Microcircuit dimensions, (b) m-type distribution, and morphology selection

C Reconstructing microcircuit connectivity

H. Markram et al., Cell, 2015
Workflow: physiology

D Electrical diversity of neurons: e-types

E Synaptic diversity: s-types

F Reconstructing virtual tissue volumes for in silico experimentation

H. Markram et al., Cell, 2015
Why?
Why?

Study the emergent structural and functional properties of the microcircuit.
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Study the **emergent structural and functional properties** of the microcircuit.

Study neurological disorders and neuroprostheses *in silico*. 
Why?

Study the **emergent structural and functional properties** of the microcircuit.

Study neurological disorders and neuroprotheses *in silico*.

Reduce the need for animal testing in laboratory experiments.
Topological analysis of the microcircuit

Topology is...

- the mathematics of shape;
Topology is...

- the mathematics of shape;
- the mathematics of connectivity;
Topology is...

• the mathematics of shape;
• the mathematics of connectivity;
• the mathematics of emergence of global structure from local constraints.

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From networks to topology
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• Analyze the huge network of directed connections among neurons in terms of much smaller significant subnetworks.
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• The numbers of different types of significant subnetworks provide important local information about the whole network.
From networks to topology

• Analyze the huge network of directed connections among neurons in terms of much smaller significant subnetworks.

• The numbers of different types of significant subnetworks provide important local information about the whole network.

• Quantify how the significant subnetworks overlap in the larger network to obtain important global information.
Measuring structure
The functional importance of simplices
The idea of a cavity

1 simplex

3 simplices...

a cavity made of 4 simplices
Higher dimensions for a cavity

1 simplex

3 simplices...

A cavity made of 8 simplices
Topology faithfully reflects biology
Classification of neuron morphologies

Y. Deitcher et al, Cerebral Cortex, 2017.
L. Kanari et al, Cerebral Cortex, 2019.
Collaborators

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• Rodrigo Perin (Laboratory of Neural Microcircuitry, EPFL)
Thank you!