

Investigating activity dependent dynamics of synaptic structures using biologically plausible models of post-deafferentation network repair



University of
Hertfordshire **UH**

Engineering and Computer Science Research Conference 2019

Ankur Sinha, UH Biocomputation Group

17/04/2019

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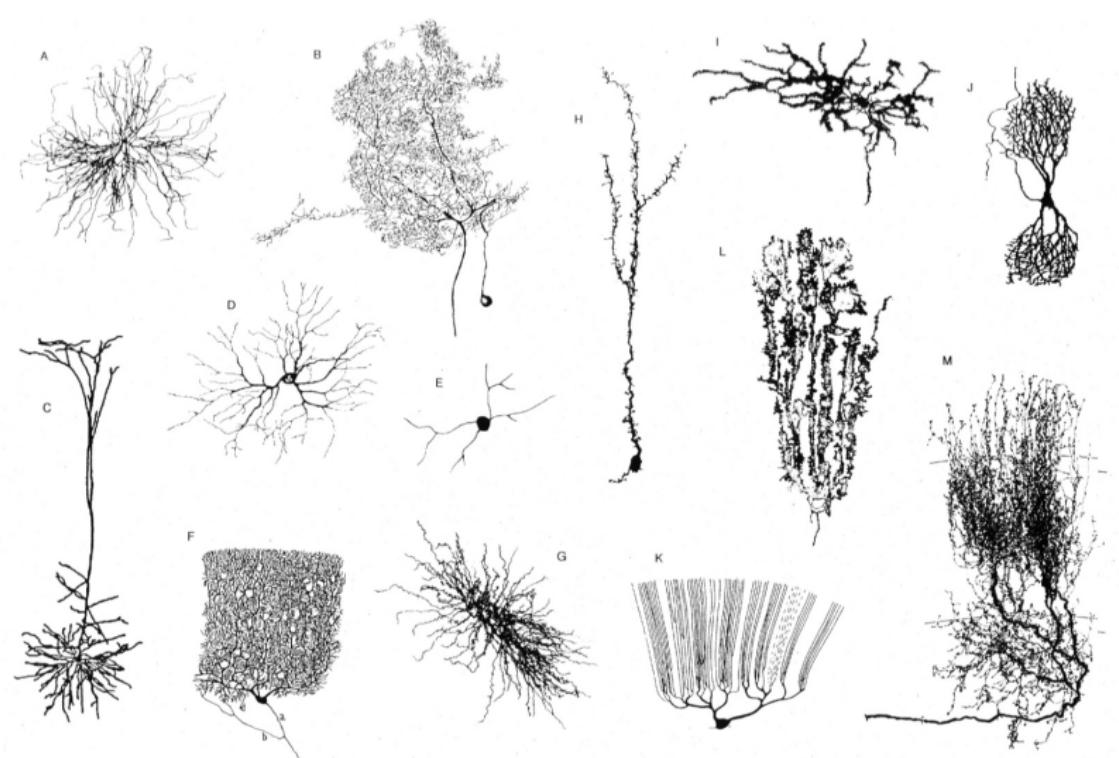
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The brain: learning, plasticity, stability

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The brain: neurons



Dendrites, Oxford University Press, 2015; Modified from Mel, B.W. Neural Computation, 1994.

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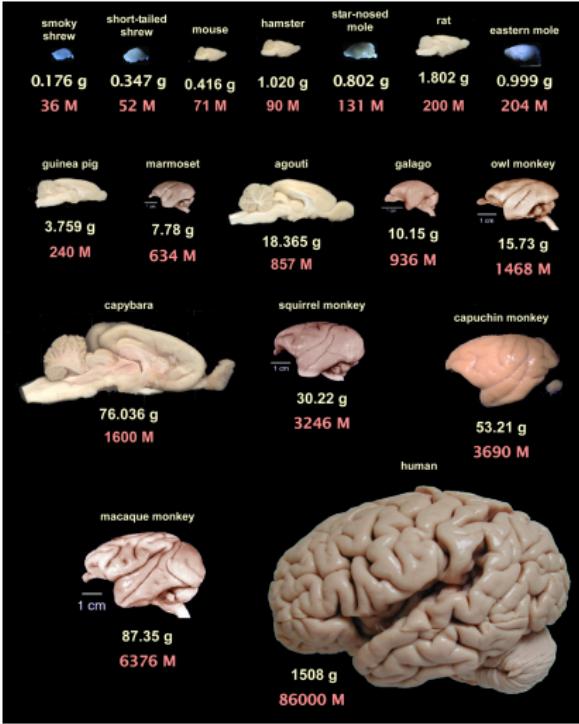
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1. The brain is composed of specialised cells that enable it to process information by the use of electrical impulses
2. As the figure shows, these cells, neurons, have specialised into many many types. They serve different functions, include different proteins and markers, and can be classified in many different ways.



The brain: neurons

The brain: in numbers: neurons

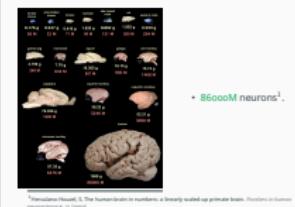


- 86000M neurons¹.

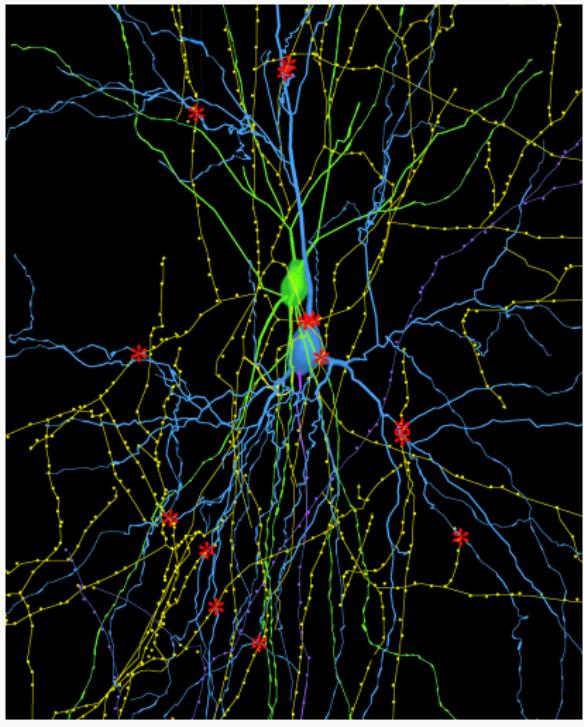
¹ Herculano-Houzel, S. The human brain in numbers: a linearly scaled-up primate brain. *Frontiers in human neuroscience* 3, 31 (2009)

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The brain: in numbers: synapses



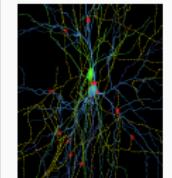
- Thousands of connections (synapses) between pairs².

²Image from The Gao lab, College of Medicine, Drexel University.

³Hebb, D. O. *The organization of behavior: A neuropsychological theory*. 1949

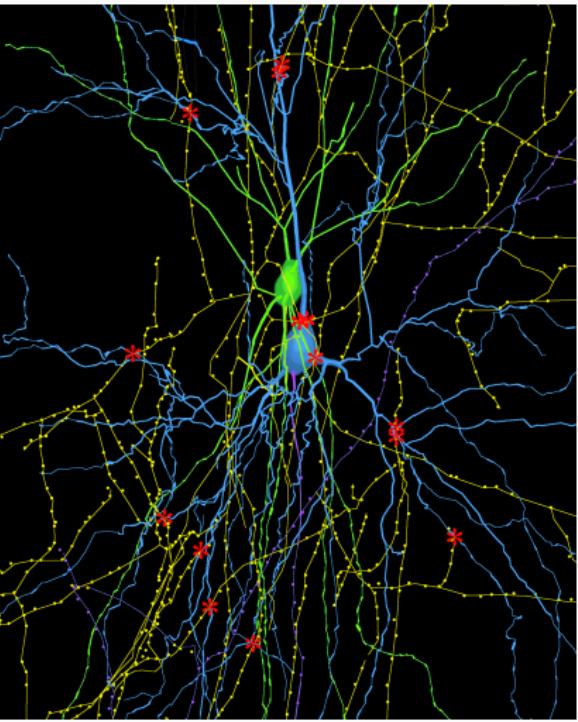
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The brain: in numbers: synapses



- Thousands of connections (synapses) between pairs².
- Synapses underlie learning³.

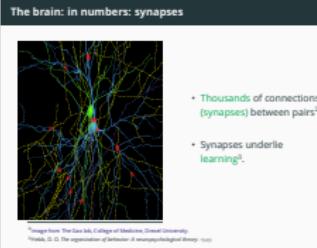
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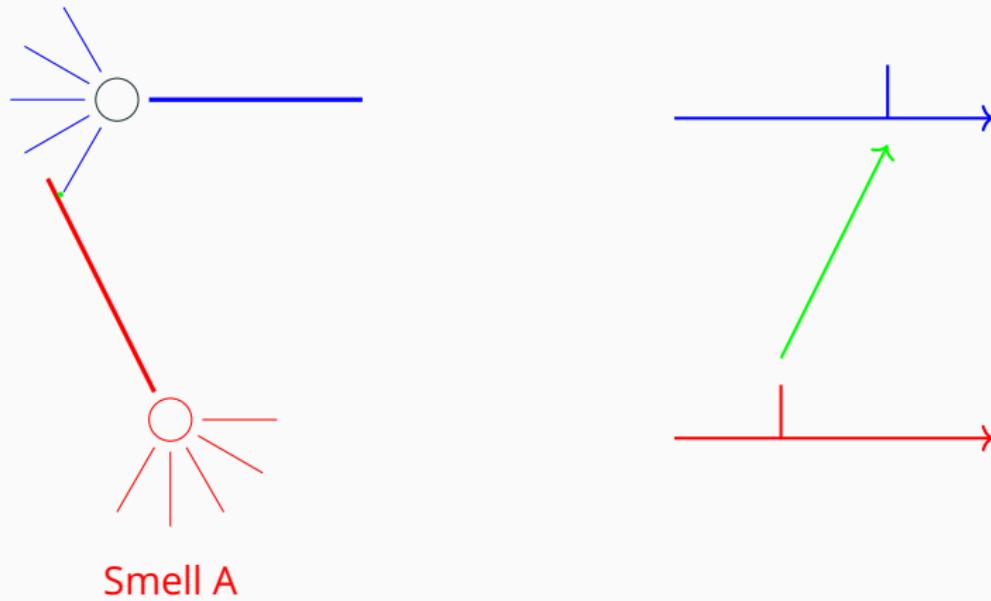
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The brain: plasticity and learning

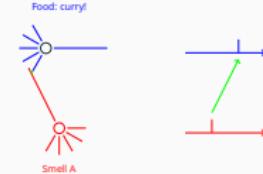
Food: curry!



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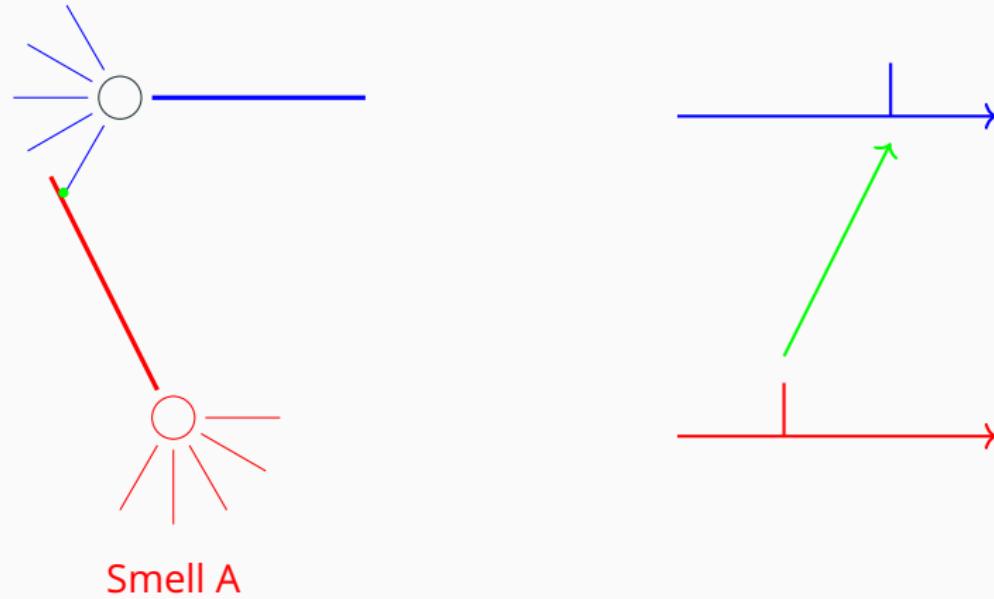
Investigating activity dependent dynamics of synaptic structures using biologically plausible models of post-deafferentation network repair

1. We learn when synapses change in the brain
2. As an example, let's say we have a neuron that was activated by a smell.
3. Later, we found out that that was the smell of some food, say curry.
4. Because these neurons fired one after the other here, this synapse is strengthened.
5. When this happens repeatedly, the synapse is strengthened again and again.
6. Until, the faintest whiff of the smell reminds you of the food!



The brain: plasticity and learning

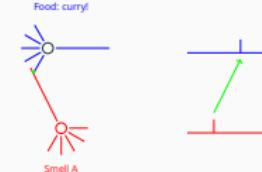
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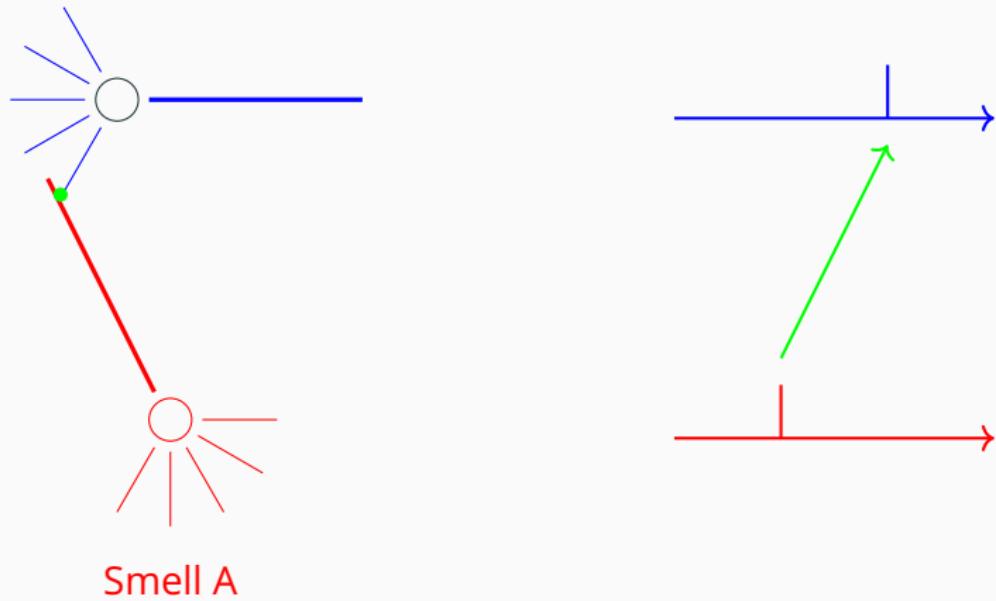
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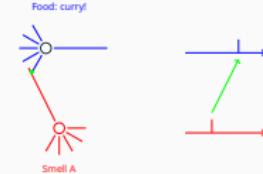
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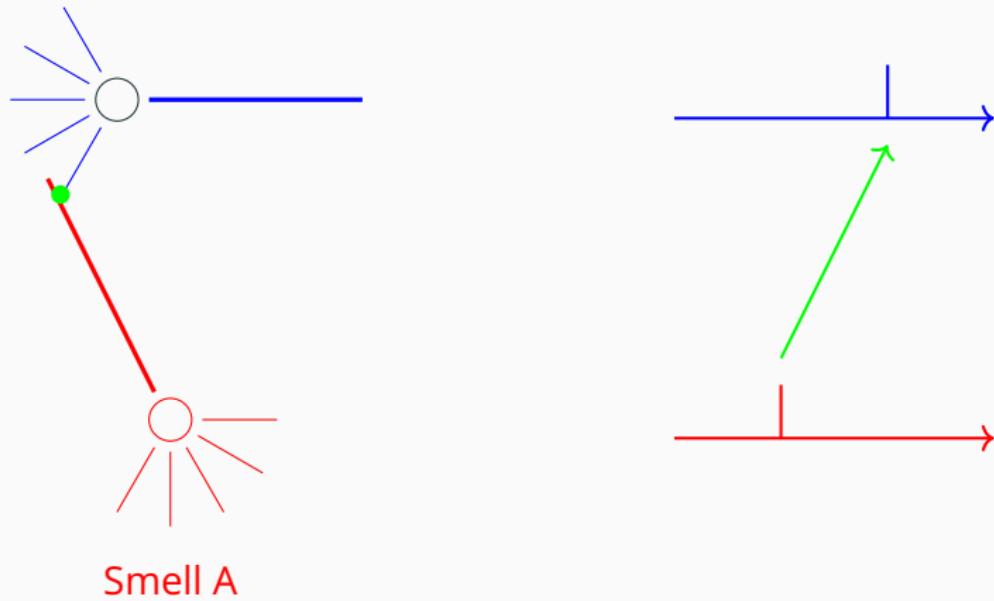
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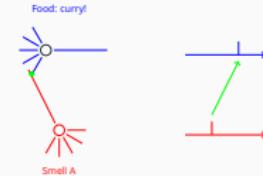
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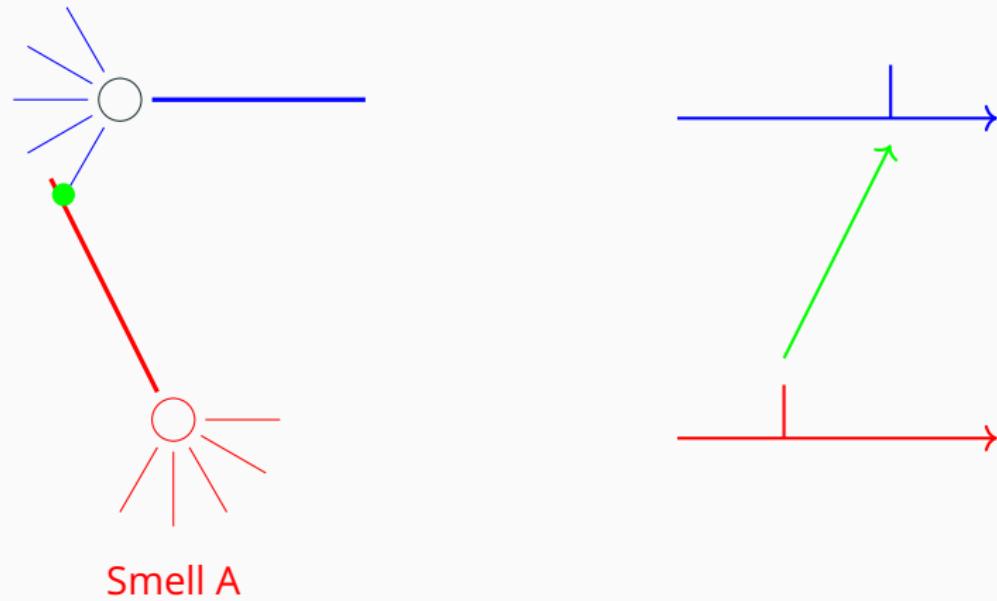
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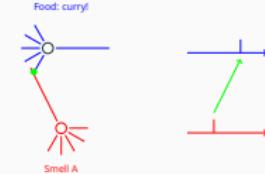
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The brain: plasticity and stability?

- Learning occurs all the time.

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Investigating activity dependent dynamics of synaptic structures using biologically plausible models of post-deafferentation network repair

- Changes in whole synapses change the structure of the networks of neurons, and is referred to as structural plasticity
- This led researchers to investigate stabilising processes which must work in parallel with learning

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⁴Holtmaat, A. J. G. D. et al. Transient and Persistent Dendritic Spines in the Neocortex In Vivo. *Neuron* **45**, 279–291. ISSN: 0896-6273 (2005)

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- In fact, **whole synapses are formed and removed** all the time⁴: **structural plasticity**.

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The brain: plasticity and stability?

- Learning occurs **all the time**.
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- Unregulated brain activity causes disorders: **epilepsy**.
- So, how does the brain remain **stable** despite changing all the time?

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Our research focus

- We study homeostatic structural plasticity.

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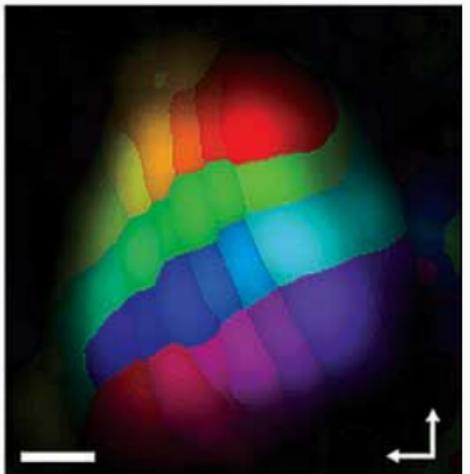
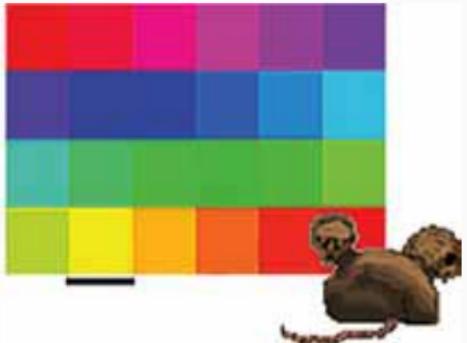
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Homeostatic structural plasticity

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Studying homeostatic structural plasticity: biologists



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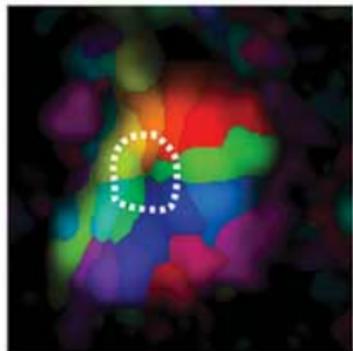
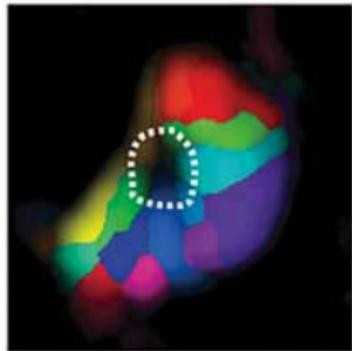
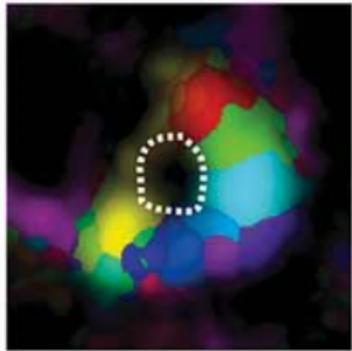
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1. The protocol is pretty standard. Here, for a study in the visual cortex, the retinal field of a rat or a mouse is mapped.



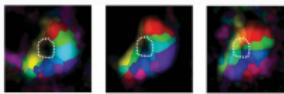
¹ Keck, T. et al. Massive restructuring of neuronal circuits during functional reorganization of adult visual cortex. *Nature neuroscience* **11**, 1162–1167 (2008)

after injury ...



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1. Then, a part of the retina is lesioned. This cuts off inputs to a part of the visual cortex, as shown in the first figure. This forms the Lesion Projection Zone (LPZ). By repeated imaging of the region over months, the reorganisation of the network is tracked.
2. Other lesion studies use similar methods: digit removal, whisker trimming, and so on—anything that cuts off projecting activity on to a set of neurons.

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Our investigations: computational modelling

- We make **models of small parts of the brain** on computers.
- We try to **replicate** what biologists observe in their laboratories.

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 - we can change whatever we want, record whatever we want.
 - analyse data, test different hypotheses.

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Our model: replicates biological observations

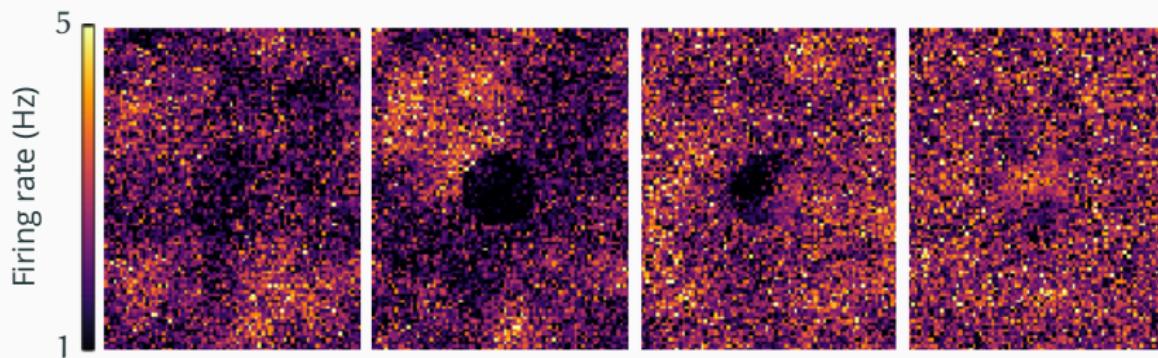
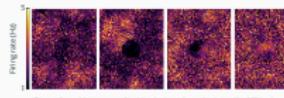


Figure 1: Our model: 1000 neurons. Simulation duration: 7 days on the cluster with 128 CPU nodes.

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It suggests:

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