

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



University of
Hertfordshire **UH**

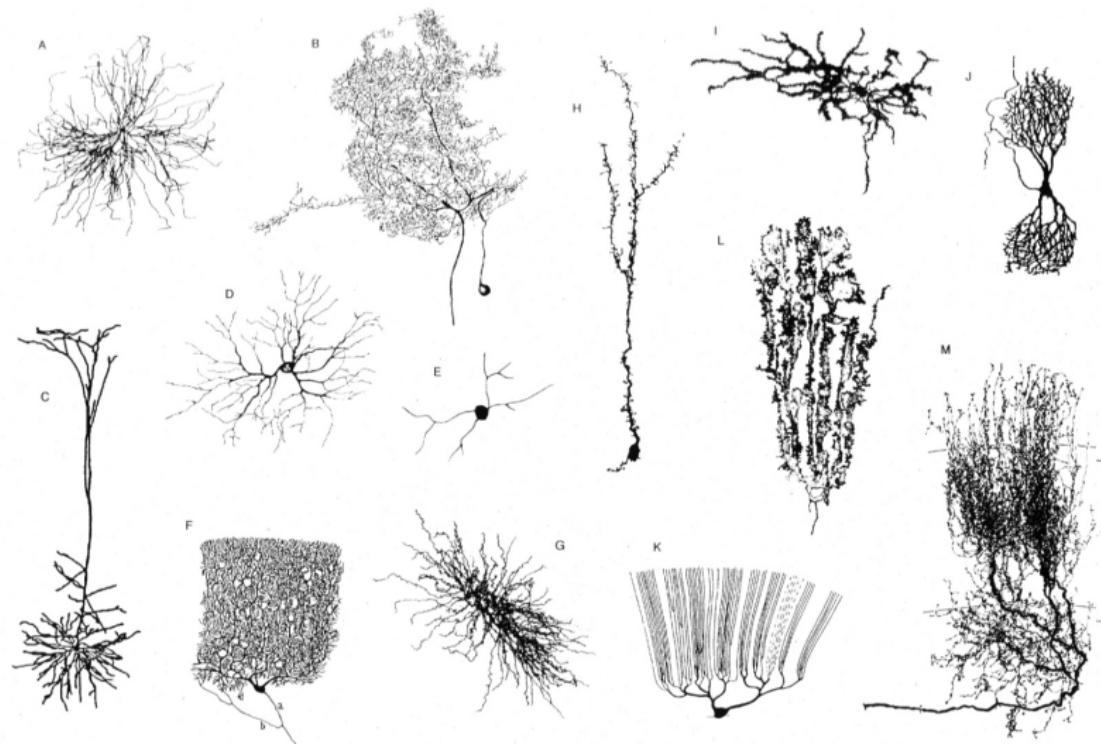
Engineering and Computer Science Research Conference 2019

Ankur Sinha, UH Biocomputation Group

17/04/2019

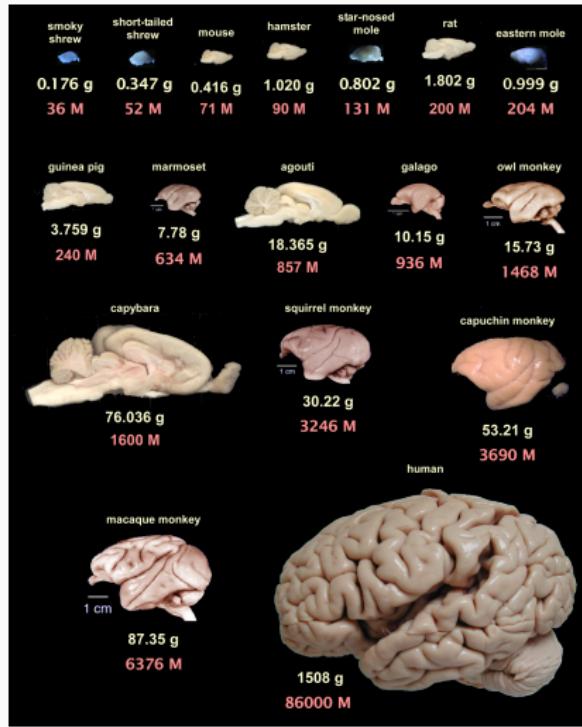
The brain: learning, plasticity, stability

The brain: neurons



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

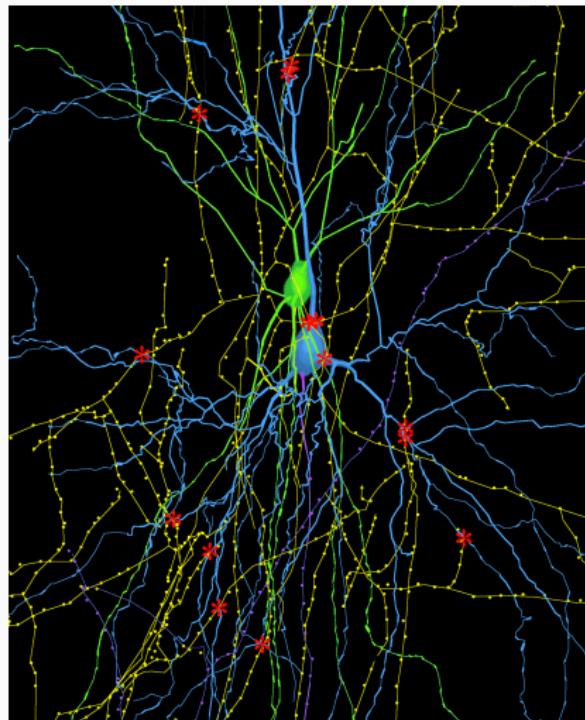
The brain: in numbers: neurons



- 86000M neurons¹.

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

The brain: in numbers: synapses

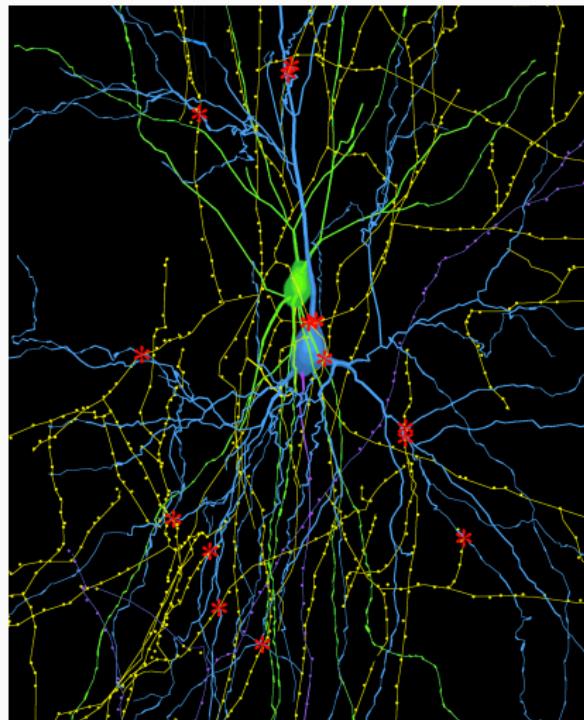


- Thousands of connections (synapses) between pairs².

²Image from The GAO lab

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

The brain: in numbers: synapses



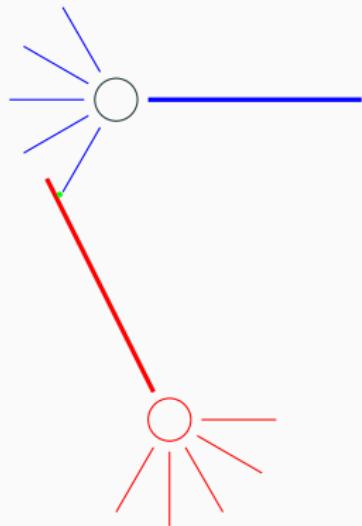
- Thousands of connections (synapses) between pairs².
- Synapses underlie learning³.

²Image from The GAO lab

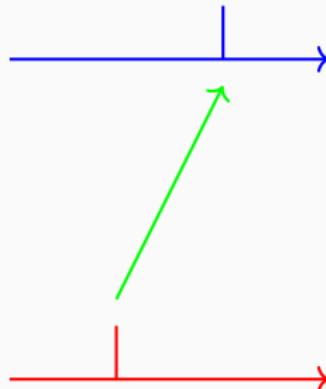
³Hebb, D. O. *The organization of behavior: A neuropsychological theory*. 1949

The brain: plasticity and learning

Food: curry!

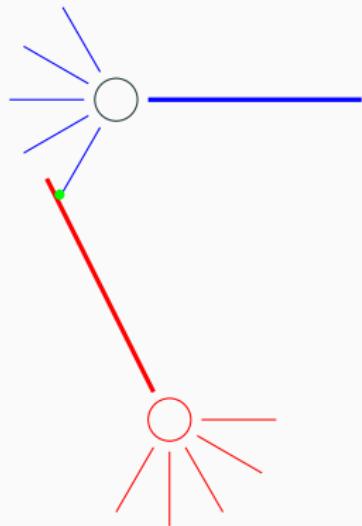


Smell A

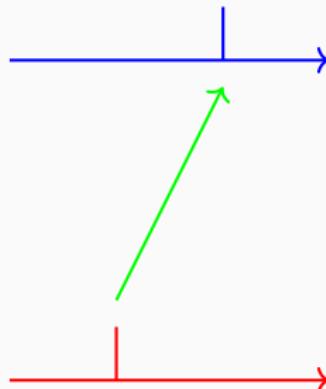


The brain: plasticity and learning

Food: curry!

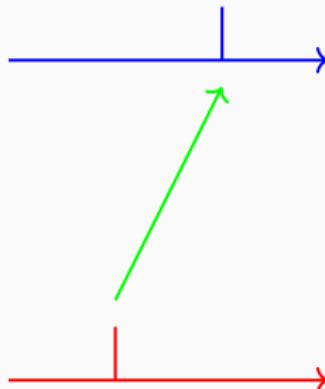
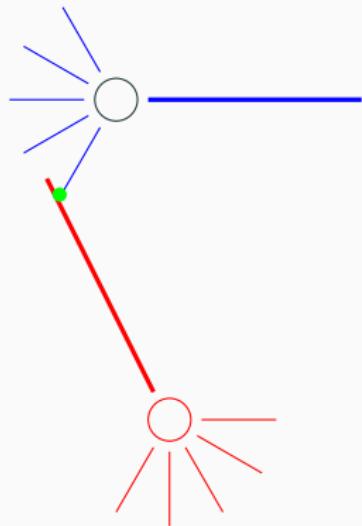


Smell A



The brain: plasticity and learning

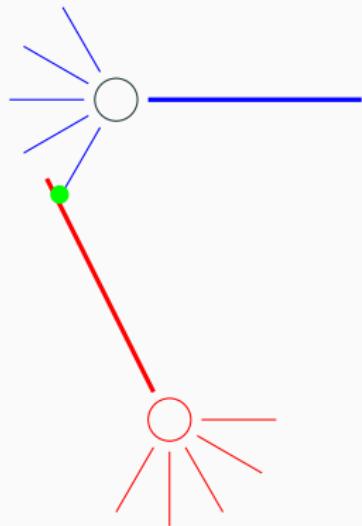
Food: curry!



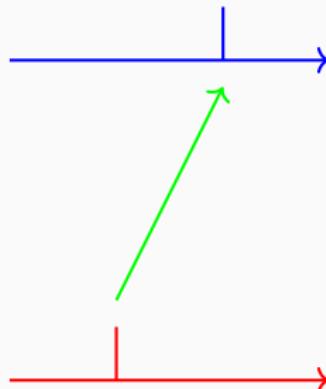
Smell A

The brain: plasticity and learning

Food: curry!

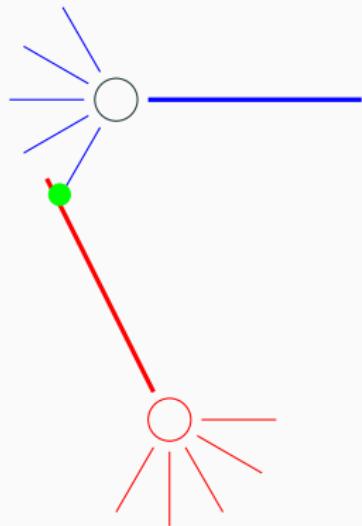


Smell A

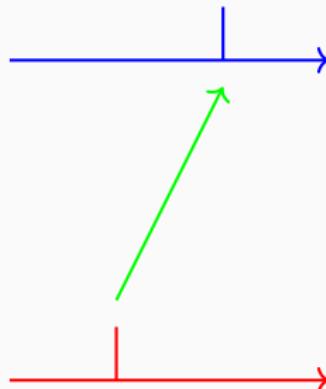


The brain: plasticity and learning

Food: curry!



Smell A



The brain: plasticity and stability?

- Learning occurs **all the time**.

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

⁵ Turrigiano, G. G. Homeostatic plasticity in neuronal networks: the more things change, the more they stay the same. *Trends in neurosciences* **22**, 221–227 (1999)

The brain: plasticity and stability?

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

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

⁵ Turrigiano, G. G. Homeostatic plasticity in neuronal networks: the more things change, the more they stay the same. *Trends in neurosciences* **22**, 221–227 (1999)

The brain: plasticity and stability?

- Learning occurs **all the time**.
- In fact, **whole synapses are formed and removed** all the time⁴: **structural plasticity**.
- Unregulated brain activity causes disorders: **epilepsy**.
- So, how does the brain remain **stable** despite changing all the time?

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

⁵ Turrigiano, G. G. Homeostatic plasticity in neuronal networks: the more things change, the more they stay the same. *Trends in neurosciences* **22**, 221–227 (1999)

The brain: plasticity and stability?

- Learning occurs **all the time**.
- In fact, **whole synapses are formed and removed** all the time⁴: **structural plasticity**.
- Unregulated brain activity causes disorders: **epilepsy**.
- So, how does the brain remain **stable** despite changing all the time?
- Stabilising (**homeostatic**) processes⁵?

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

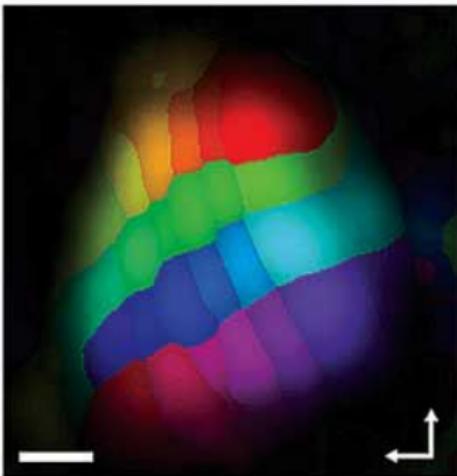
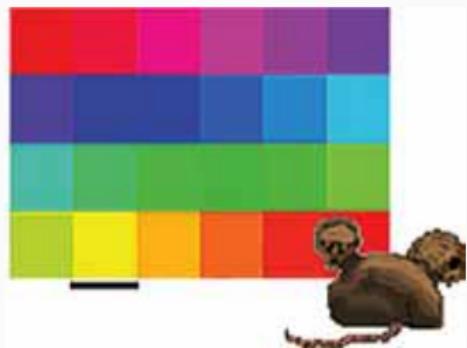
⁵ Turrigiano, G. G. Homeostatic plasticity in neuronal networks: the more things change, the more they stay the same. *Trends in neurosciences* **22**, 221–227 (1999)

Our research focus

- We study homeostatic structural plasticity.

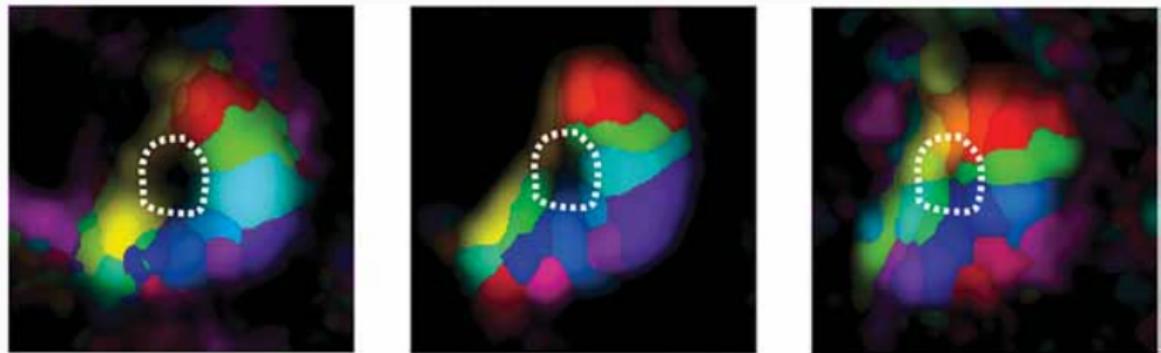
Homeostatic structural plasticity

Studying homeostatic structural plasticity: biologists



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 ...



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

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.

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.
- Modelling gives us **flexibility**:
 - we can change whatever we want, record whatever we want.
 - analyse data, test different hypotheses.

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.
- Modelling gives us **flexibility**:
 - we can change whatever we want, record whatever we want.
 - analyse data, test different hypotheses.
- We then **send our ideas back to biologists** for validation.

Our model: replicates biological observations

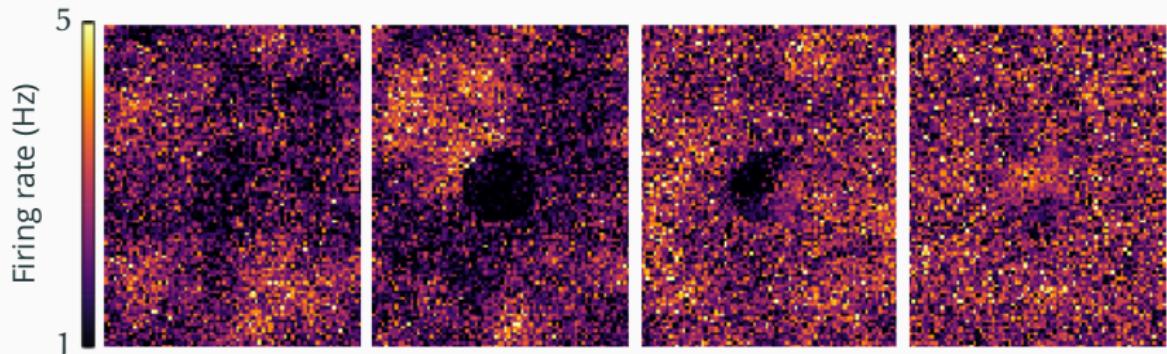


Figure 1: Our model: 1000 neurons. Simulation duration: 7 days on the cluster with 128 CPU nodes.

It suggests: