NEUROSCIENCE II PRINCIPLES!

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LAST TIME

* neurons

* action potentials (aka spikes)

  * threshold nonlinearities

* synapses

  * neurotransmitters

* neural circuits (Jeffress model)

TODAY

* synaptic plasticity

* homeostasis

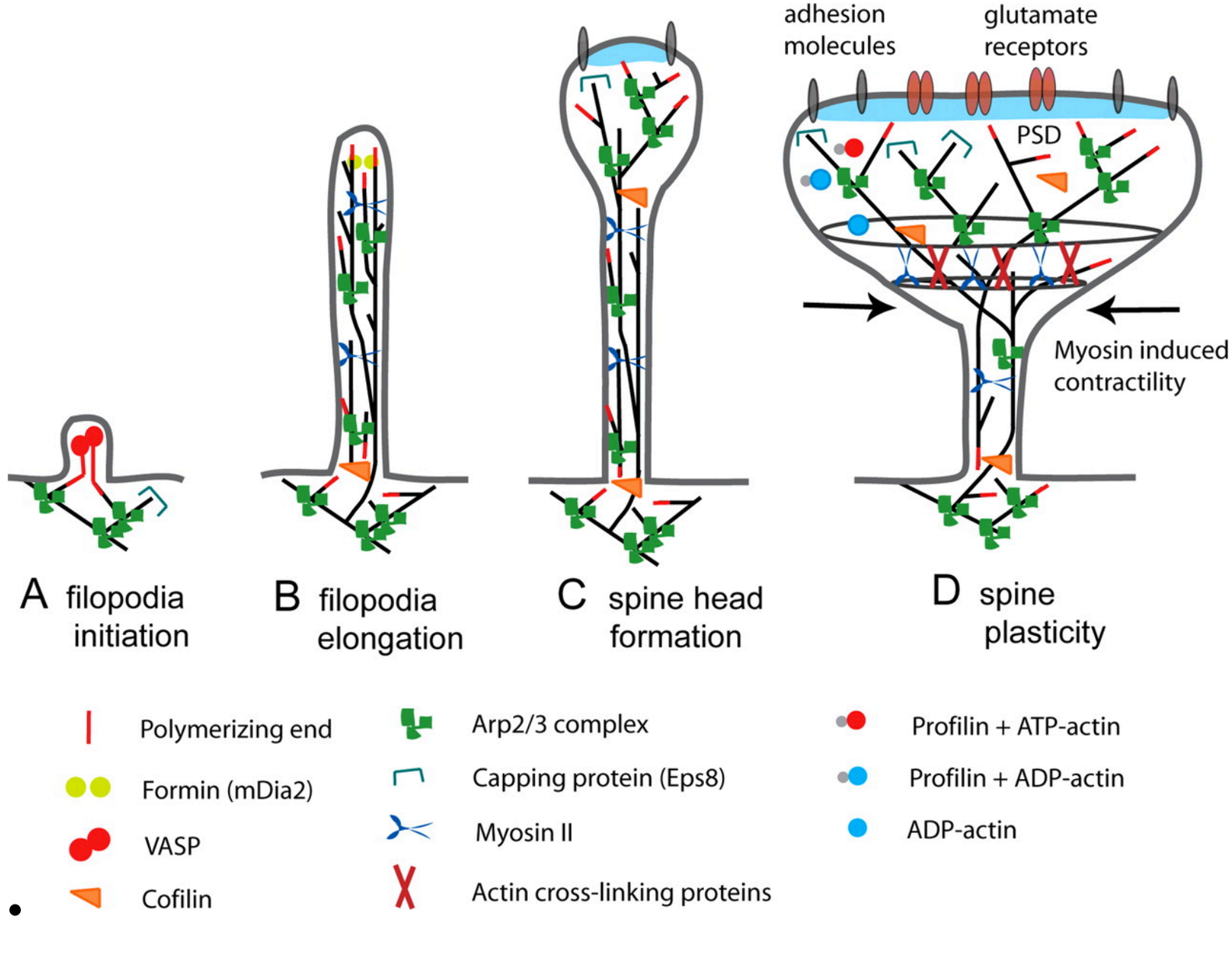
* hebbian learning & how to fix it

* human brain anatomy?

Recall: SYNAPSES

* Synapses vary in **strength** (the effect of an incoming spike)

* *MANY* factors influence synaptic strength, stability, etc.



HEBBIAN LEARNING

Donald Hebb
(1904-1985)

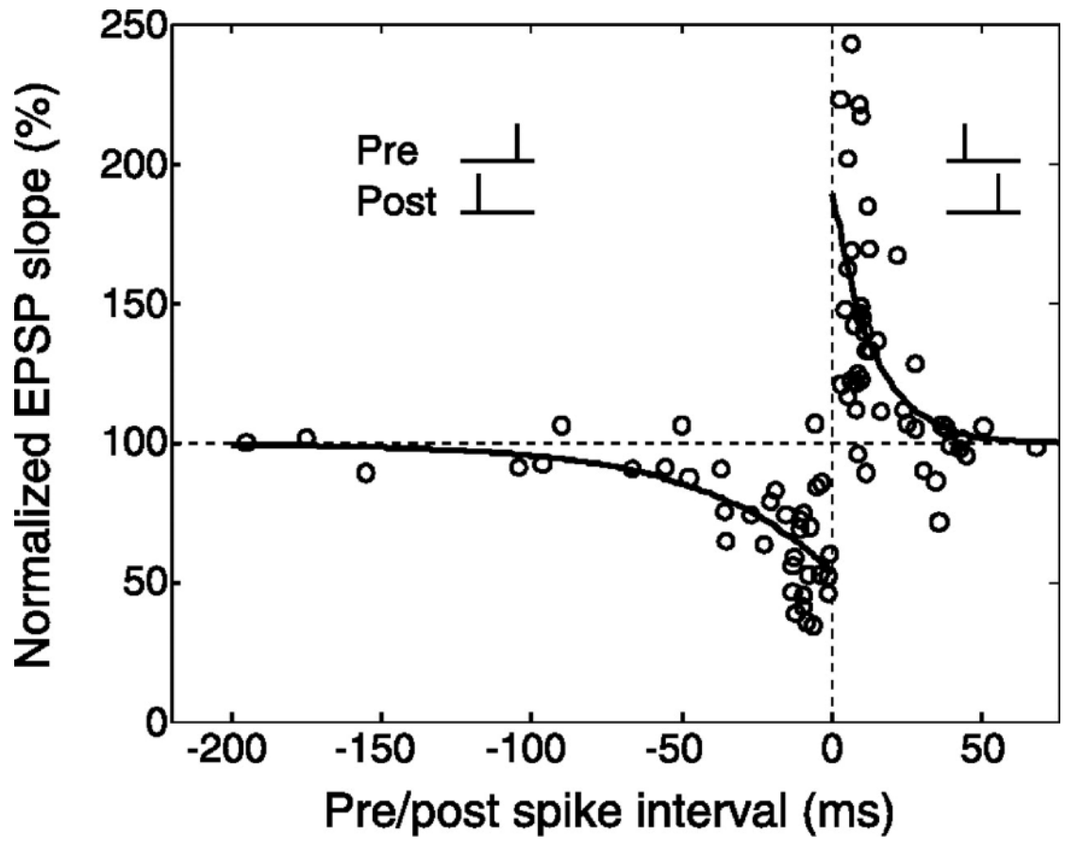
* Synaptic weights are **plastic**
* **Hebb's rule:**
  * *Neurons that fire together, wire together*

HEBBIAN LEARNING

* Spike-timing dependent plasticity (STDP)

* Long-term potentiation (LTP)

* Long-term depression (LTD)



HEBBIAN LEARNING

* Suppose we have a linear neuron with inputs *x*, weights *w*, and output *y*:

$$y = \sum_j w_j x_j$$

* Hebb's insight implies a learning rule:

$$\Delta w_j = \eta x_j y$$

HEBBIAN LEARNING

* BUT Hebb’s rule is **unstable** (notebook example)

    * Synaptic weights always diverge to infinity!

    * This would be bad if it happened in the brain!!

INSTABILITY

* Unless carefully tuned, activity in recurrent neural networks (e.g. brains) can also be **unstable**

* Unstable networks tend to either become **quiescent** (converge to zero activity),

* or **diverge**

INSTABILITY

* Example: seizure / epilepsy

HOMEOSTASIS

* Thankfully, many mechanisms in biological neural networks maintain **homeostasis**

* Neurons seem to have a **target level** of activity

  * If activity is too low, it is raised

  * If activity is too high, it is lowered

HOMEOSTASIS

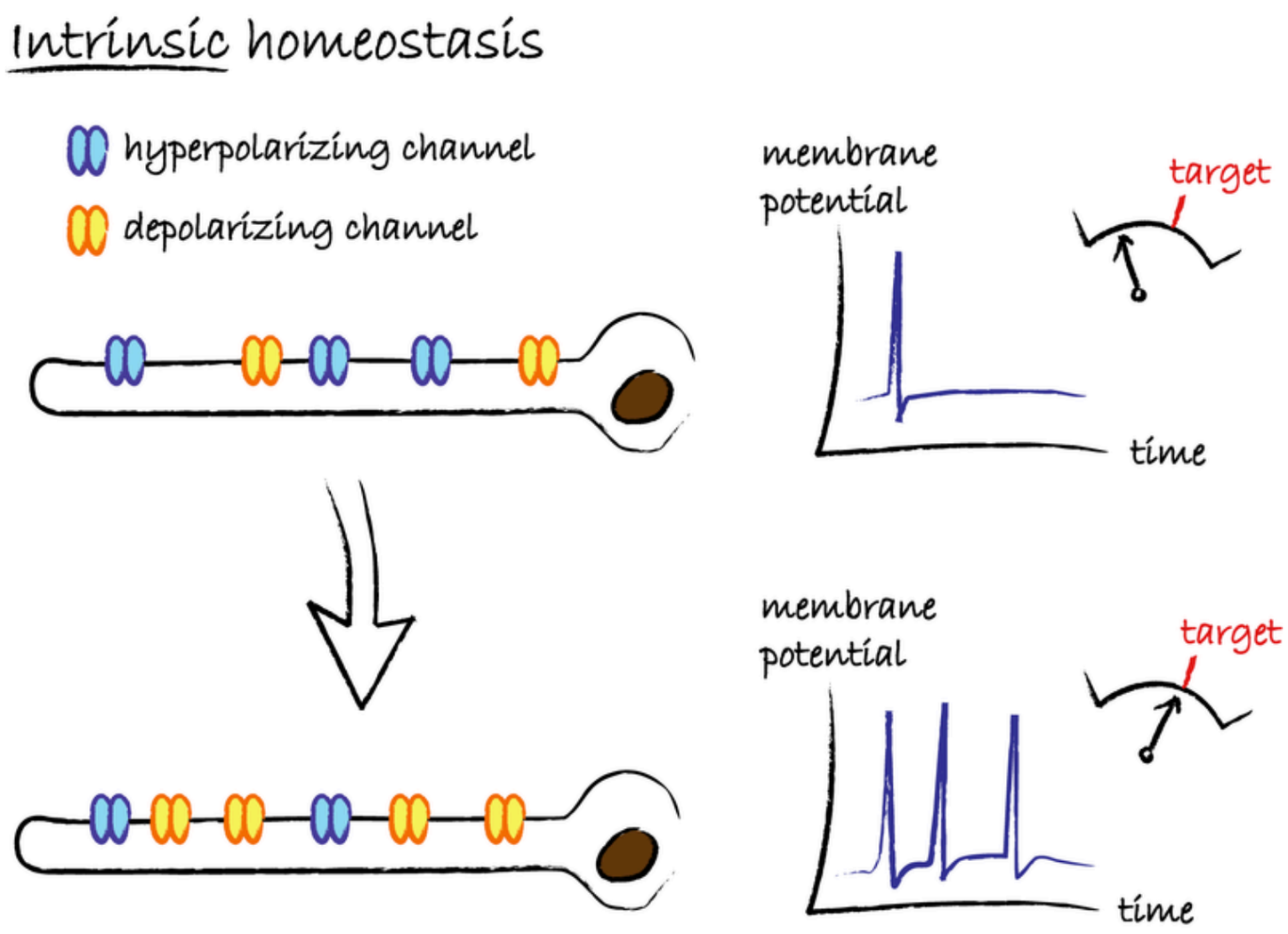
* **Homeostatic plasticity** seems to come in two flavors:

* Intrinsic homeostasis

* Synaptic homeostasis

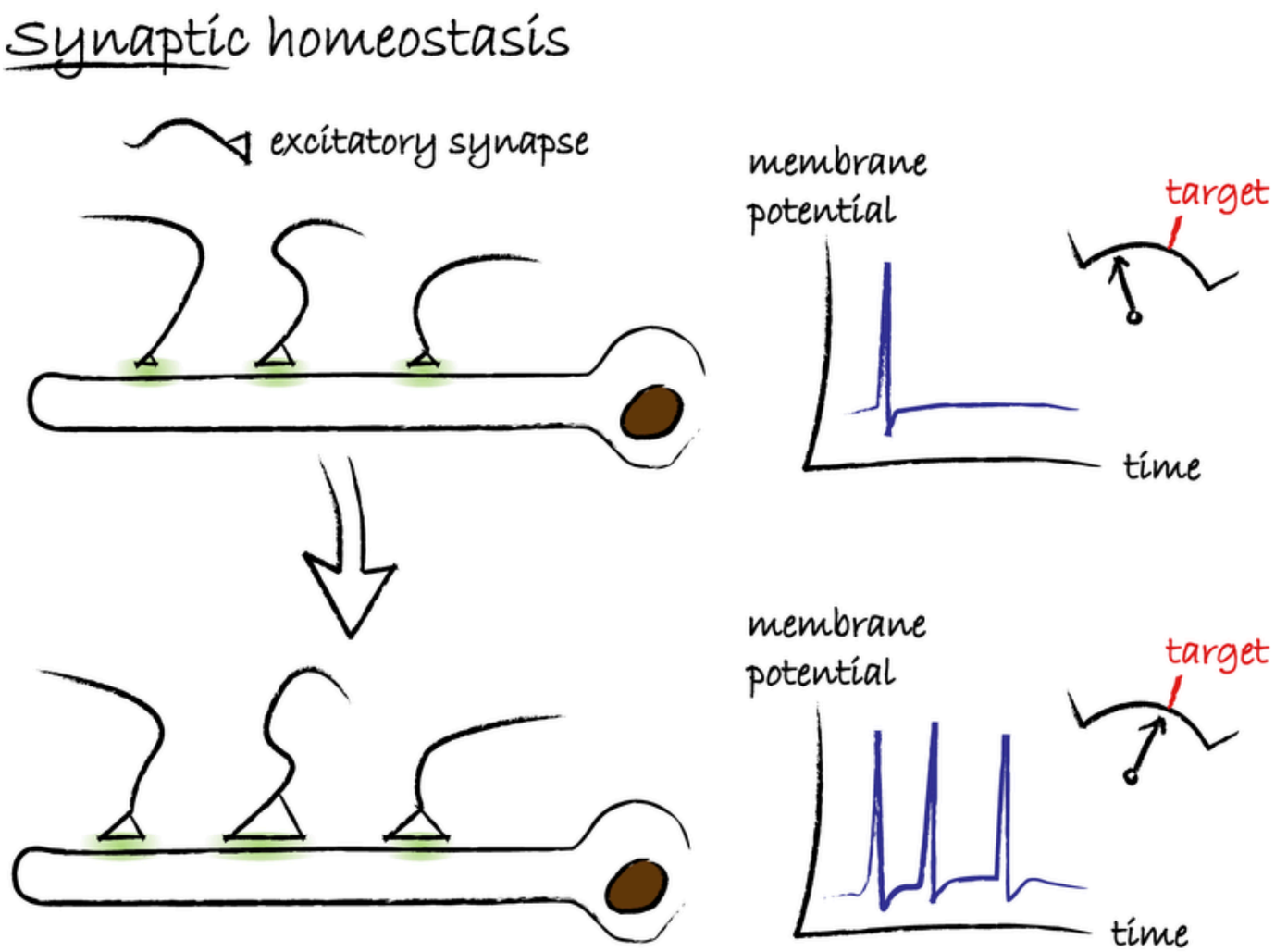
HOMEOSTASIS

* In **intrinsic homeostasis**, electrical properties of neurons are changed



HOMEOSTASIS

* In **synaptic homeostasis**, synapses are modified



HOMEOSTASIS

* Homeostasis can also be **harmful**:
    * Tinnitus
    * Phantom limb
    * *Delirium tremens*

FIXING HEBB

* How do we fix Hebb’s learning rule so that it doesn’t explode?

OJA’S RULE

Erkki Oja (1948-)

* Scale weight changes by output & current weights (Oja’s rule):

$$\Delta w_j = \eta(x_j y - y^2 w)$$

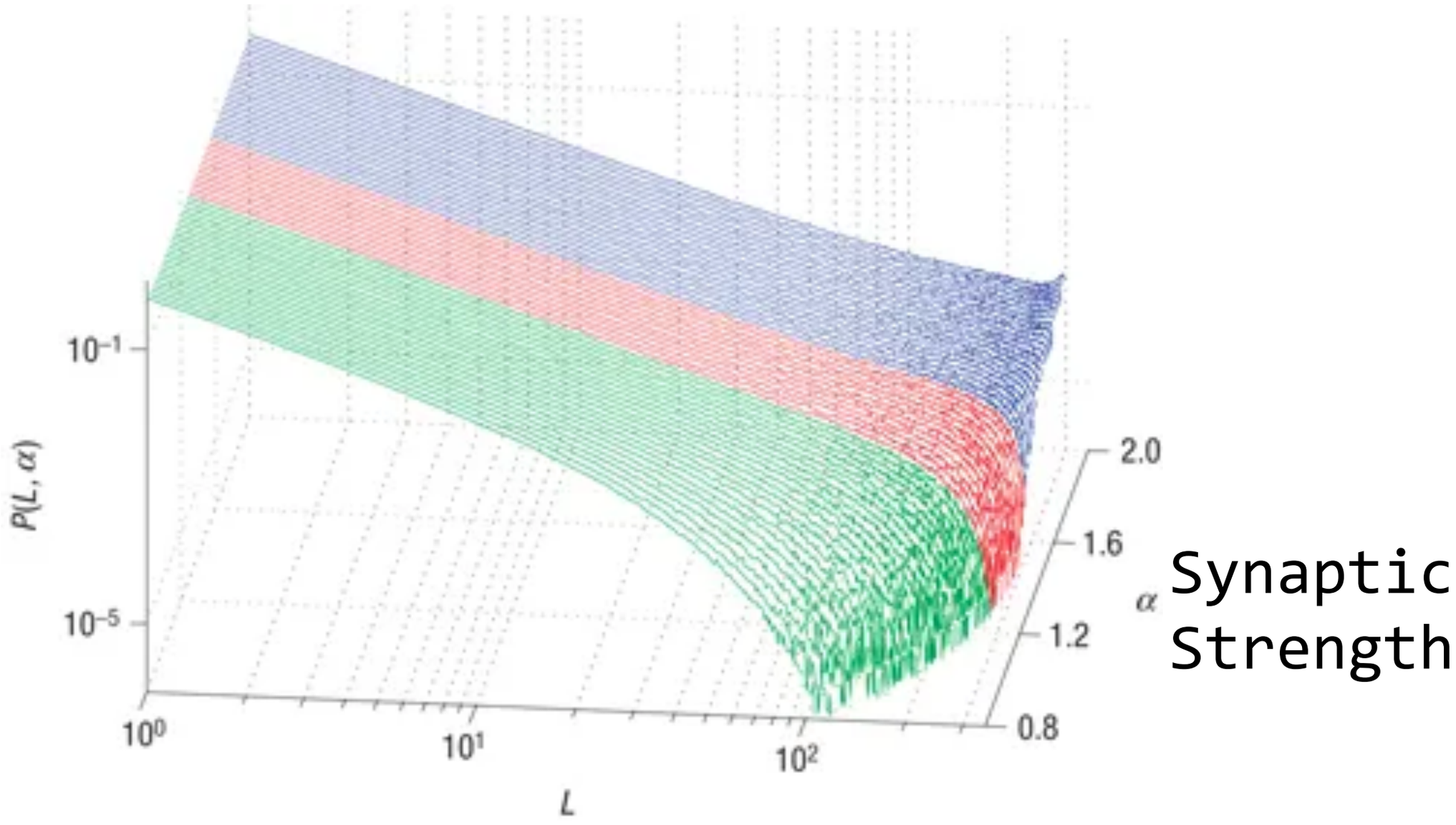
CRITICALITY

* Related physical concept: **criticality**

* Consider a recurrent neural network with average synaptic strength *alpha*

* If you trigger one spike, how many other neurons end up spiking? (**Avalanche** size)

CRITICALITY



Synaptic Strength

Avalanche size

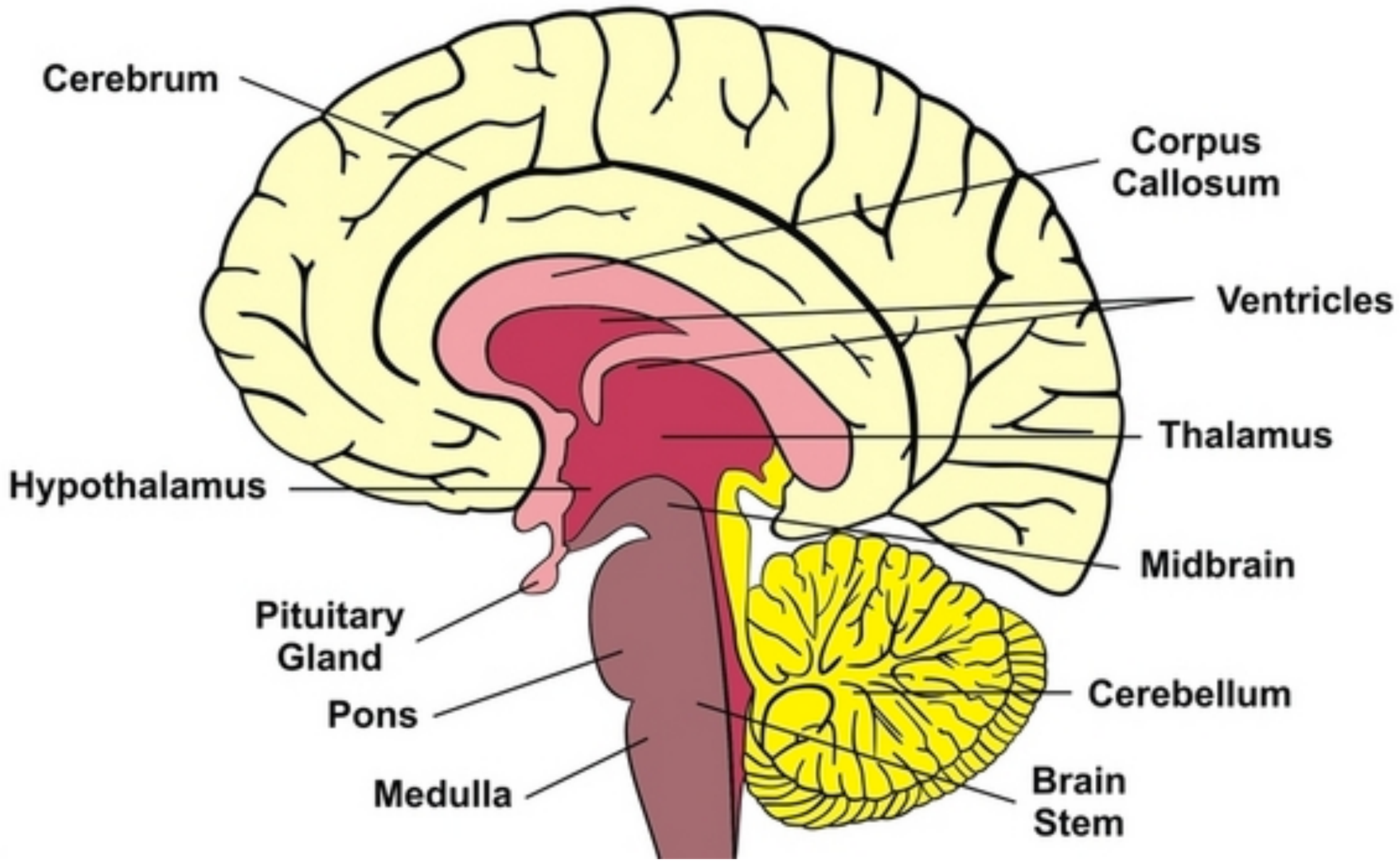
From Levina et al., 2007

CRITICALITY

* Criticality requires homeostasis

* Criticality is required for useful computation (perhaps)

* Is criticality the key quantity that the brain is optimizing?


Cerebrum
Corpus Callosum
Ventricles
Thalamus
Hypothalamus
Midbrain
Pituitary Gland
Cerebellum
Pons
Brain Stem
Medulla

THE HUMAN BRAIN

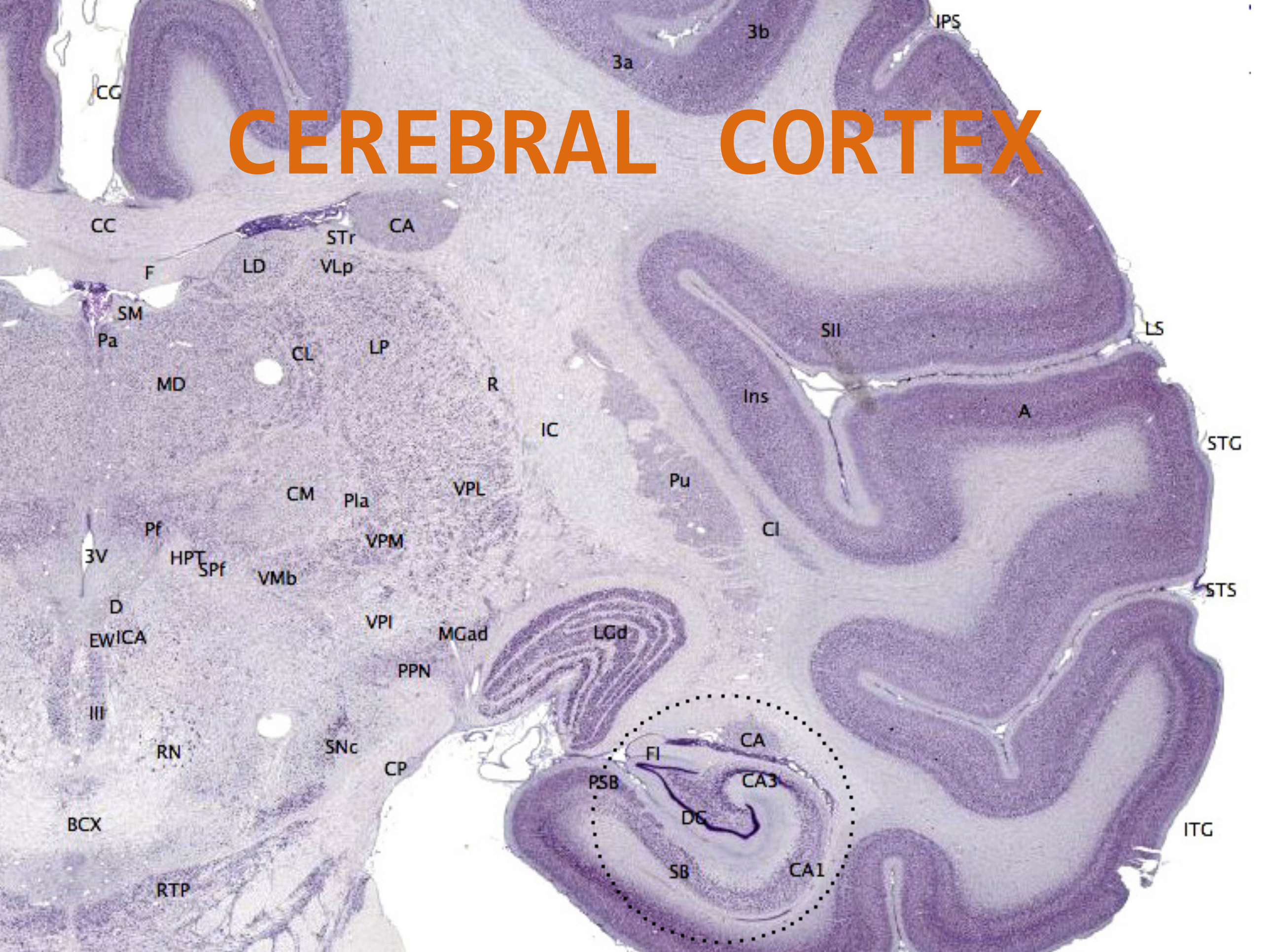
* ~85 billion neurons

* 12-15 billion in telencephalon

* ~70 billion in cerebellum

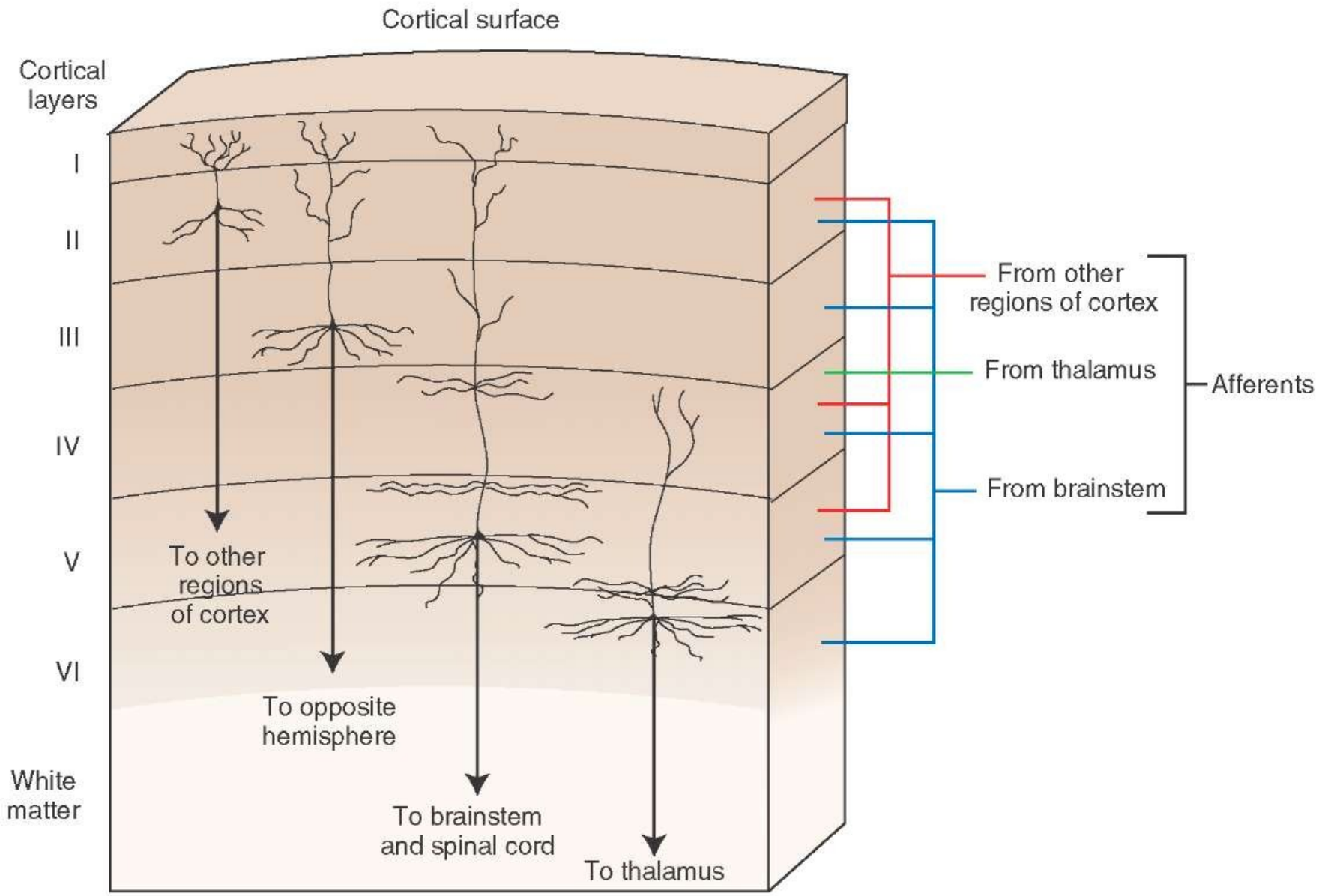
Herculano-Houzel, S. (2009)

CEREBRAL CORTEX



CEREBRAL CORTEX

* *Vaguely* stereotypical 6-layer structure

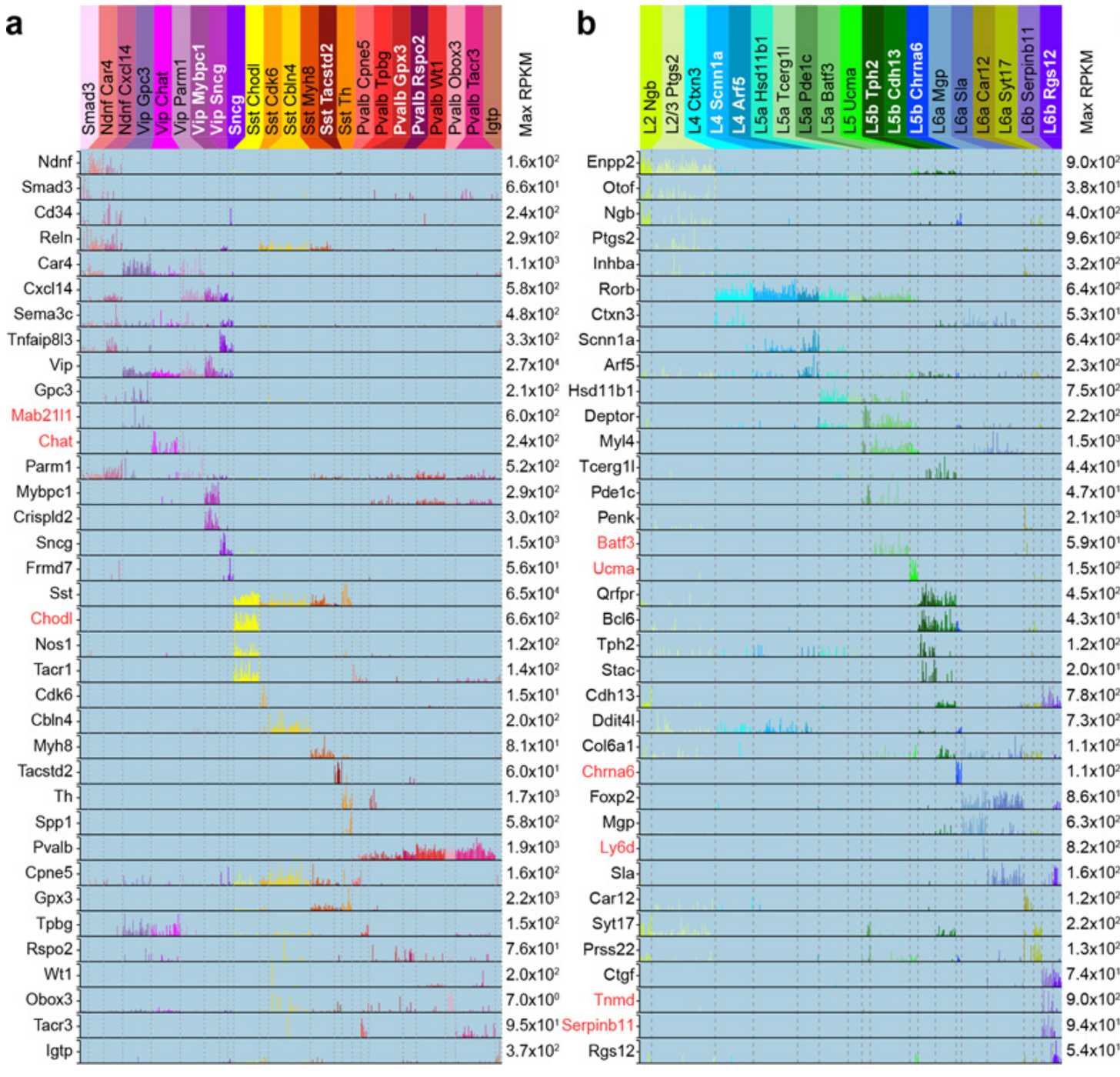


CEREBRAL CORTEX

* Traditional idea:
  * 1 type of excitatory cell (pyramidal), a few types of inhibitory cells (basket, chandelier, etc.)

CEREBRAL CORTEX

* Modern findings:
  * at least **23** excitatory types & **19** inhibitory types (in visual cortex alone!)



Tasic et al. (2016)

CEREBRAL CORTEX

* In short:

  * Cortex is complicated (much more so than neuroscientists thought a few years ago)

RECAP

* hebbian learning
  * spike-timing dependent plasticity
* homeostasis
* oja’s rule
* criticality
* the cortex

NEXT TIME

* neuroscience methods