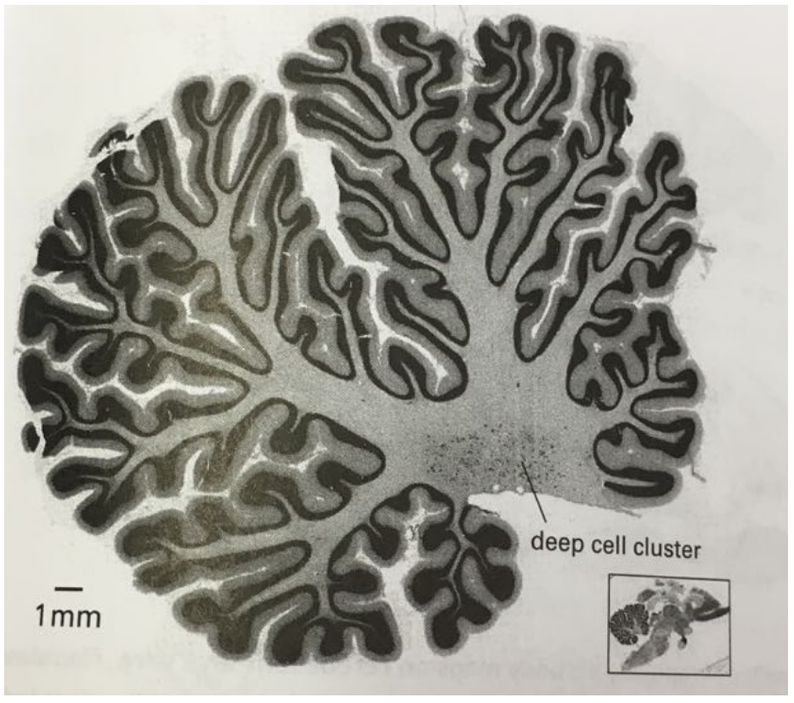
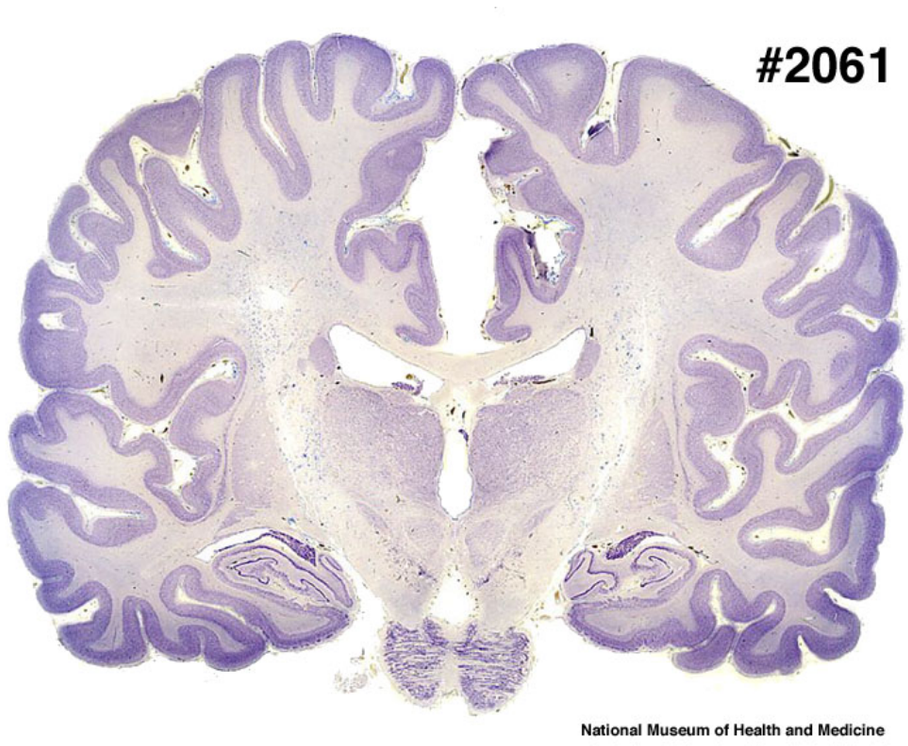
Recap

The synaptic organization of cerebral cortex vs. cerebellar cortex

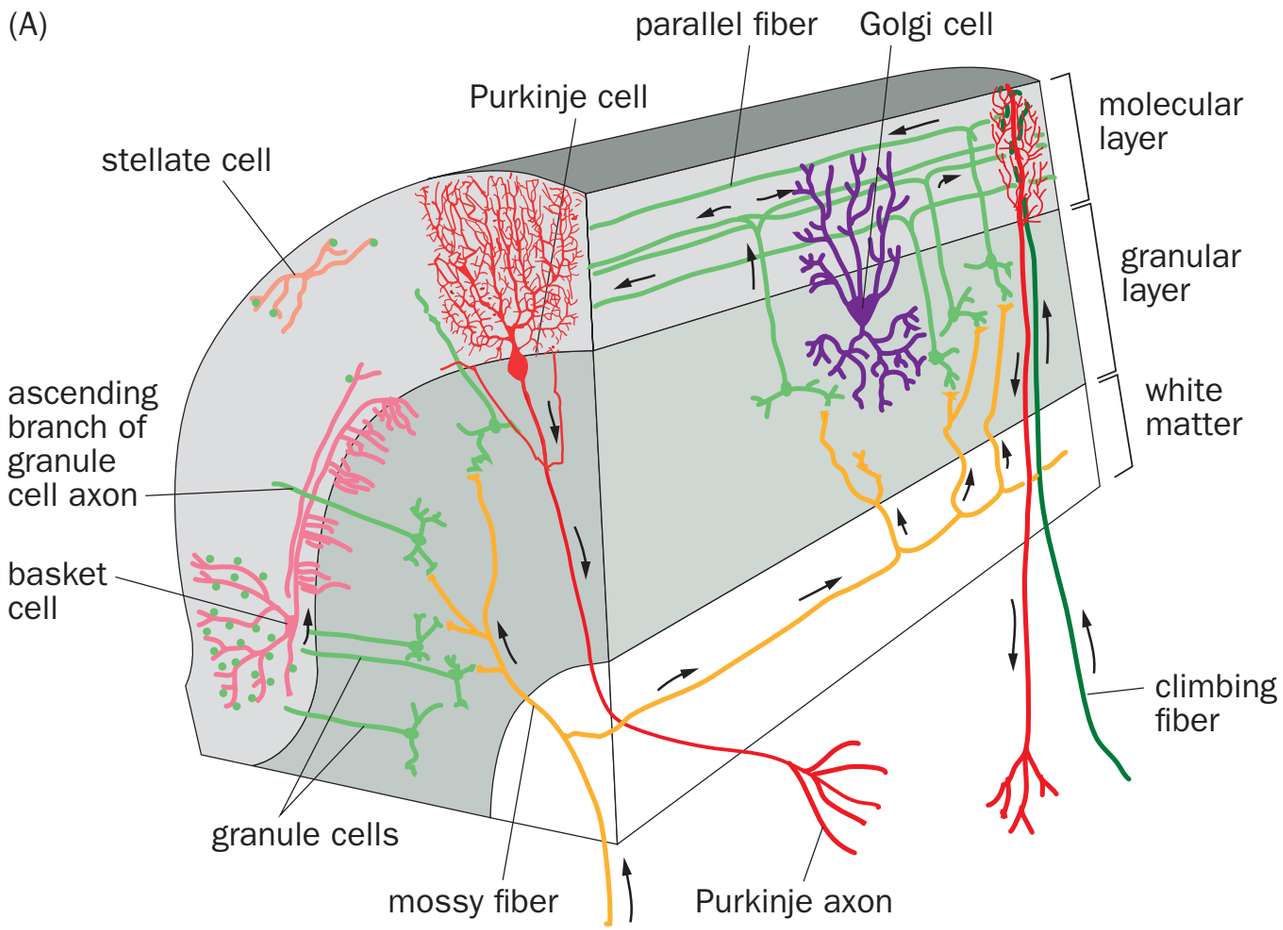


cerebellum

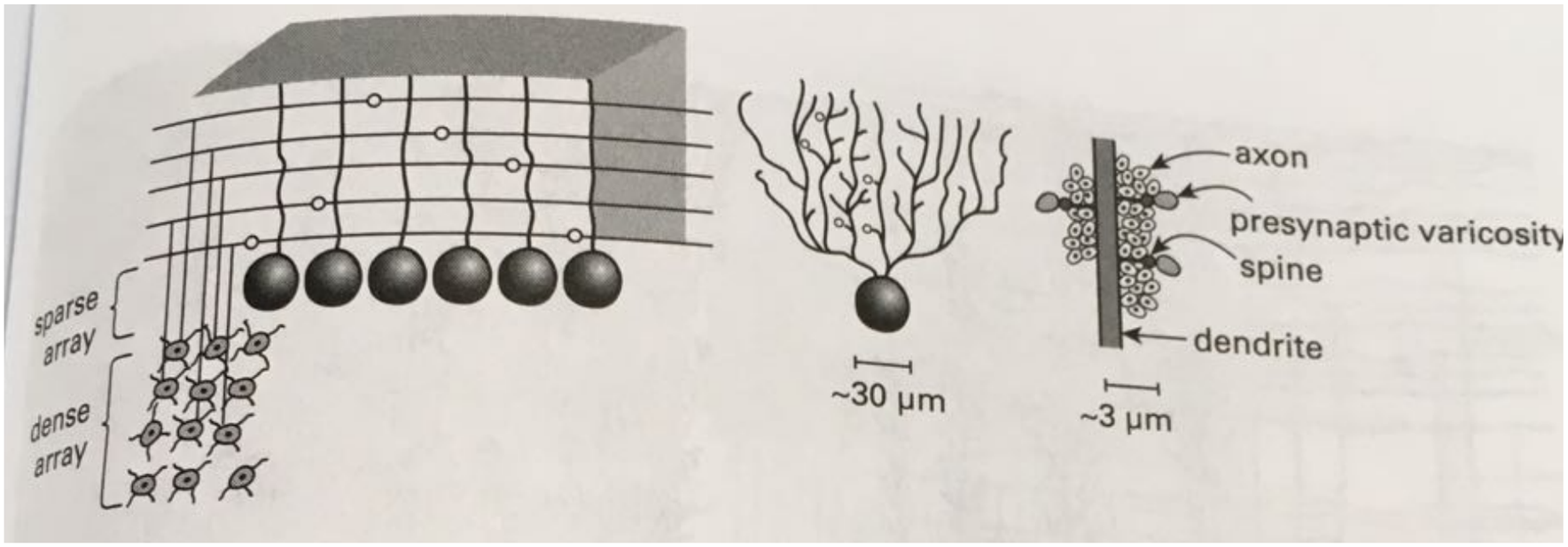


cerebral cortex

The organization cerebellar cortex



Cerebellar cortex: connecting dense array to sparse array with extreme convergence and divergence



$$N_g D = N_p C$$

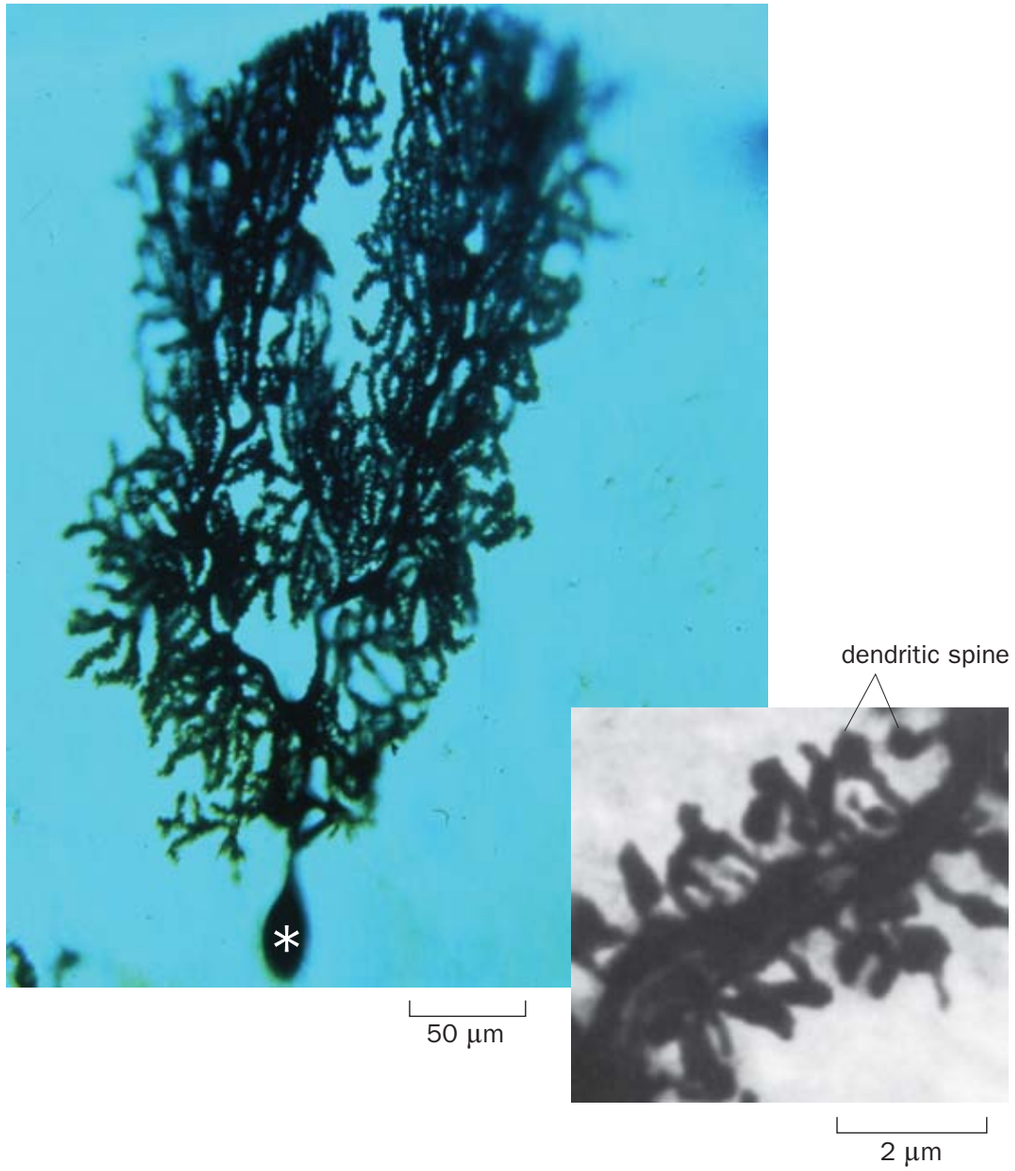
$$N_g \gg N_p$$

N_g : **number of granule cells**

N_p : **number of Purkinje cells**

D : **divergence**

C : **convergence**



Purkinjie cell in the cerebellum has the highest spine density in the brain

The organization of the functional column in the cerebral cortex

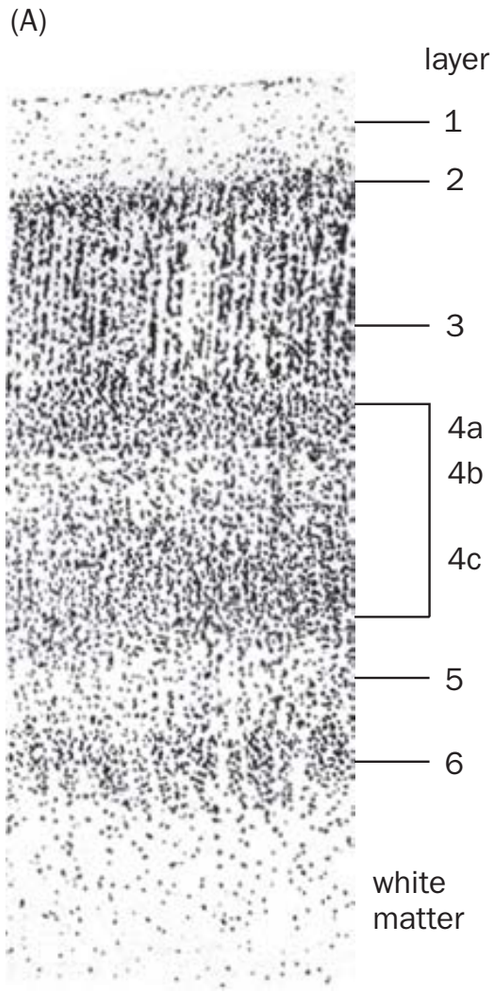
85% excitatory cells

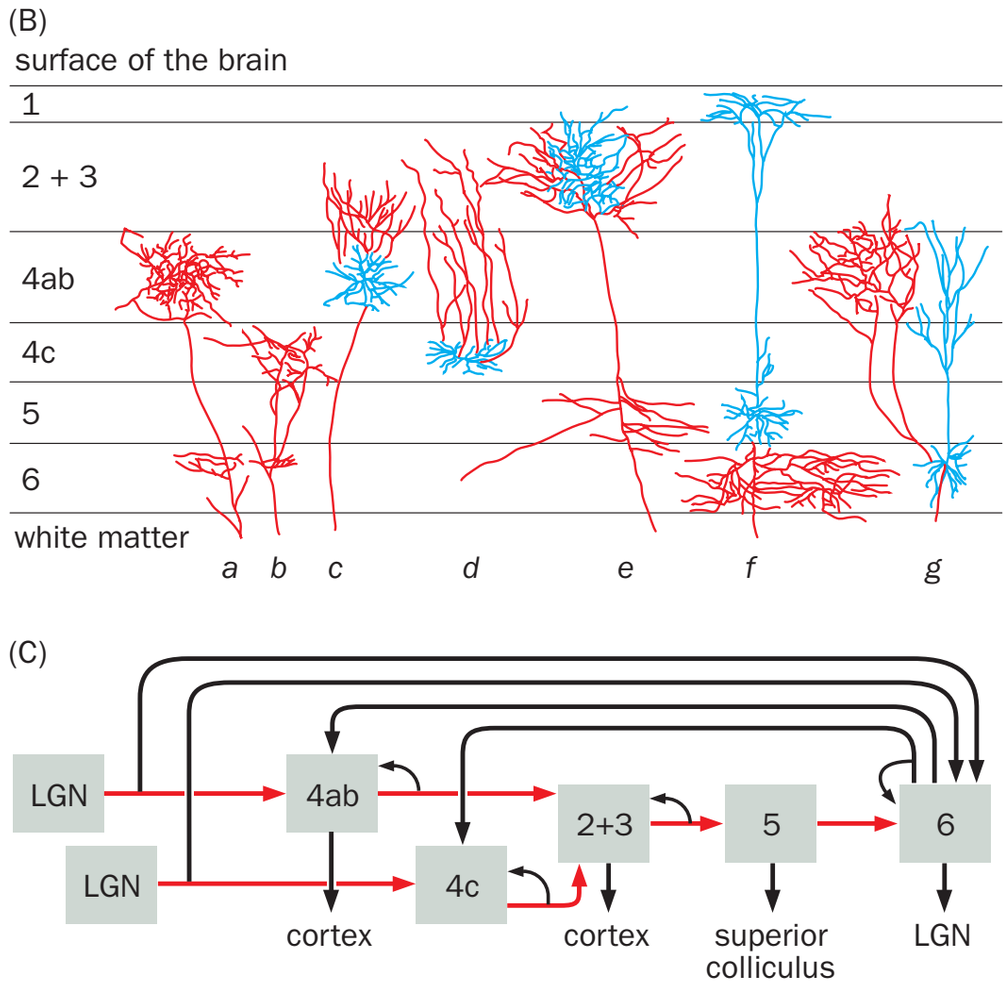
15% inhibitory cells

10^5 neurons

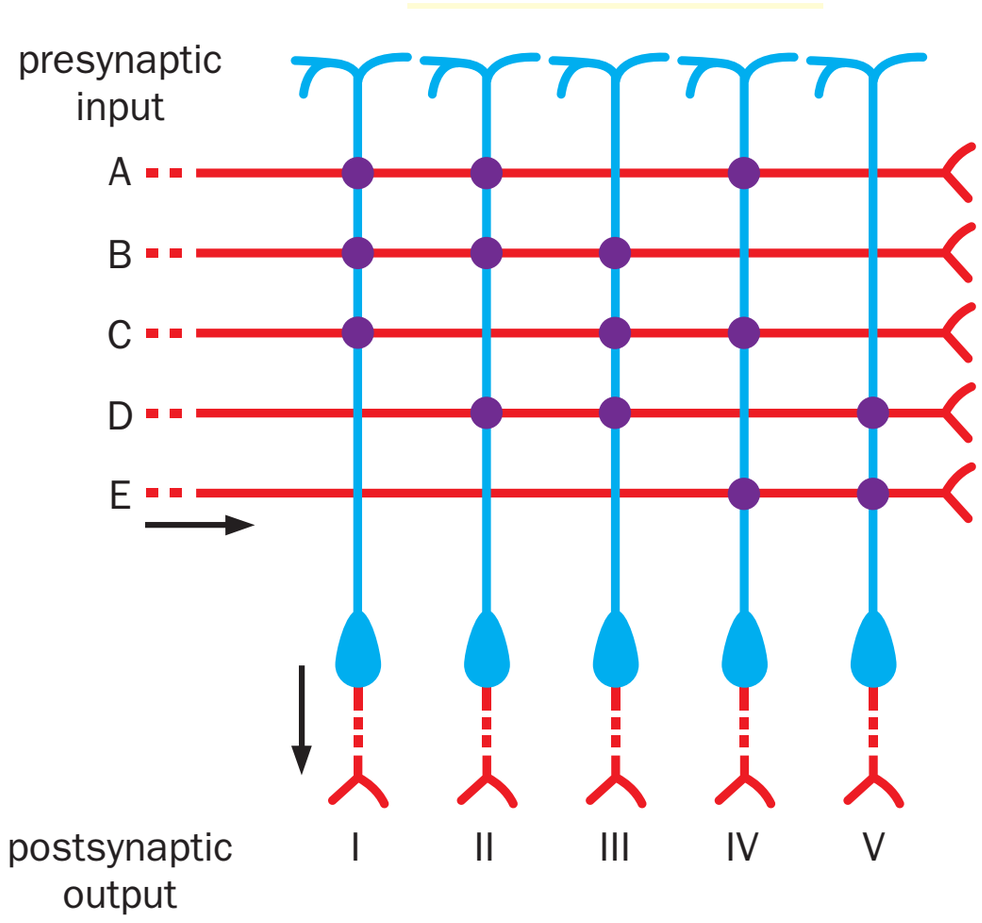
10^9 synapses

5000 m wires





Cerebral cortex: connecting many dense arrays to many other dense arrays with moderate convergence and divergence



N **presynaptic neurons**

N **postsynaptic neurons**

Why do we need axons and dendrites?

Occam's Razor

entities should not be multiplied without necessity.

奥卡姆剃刀定律

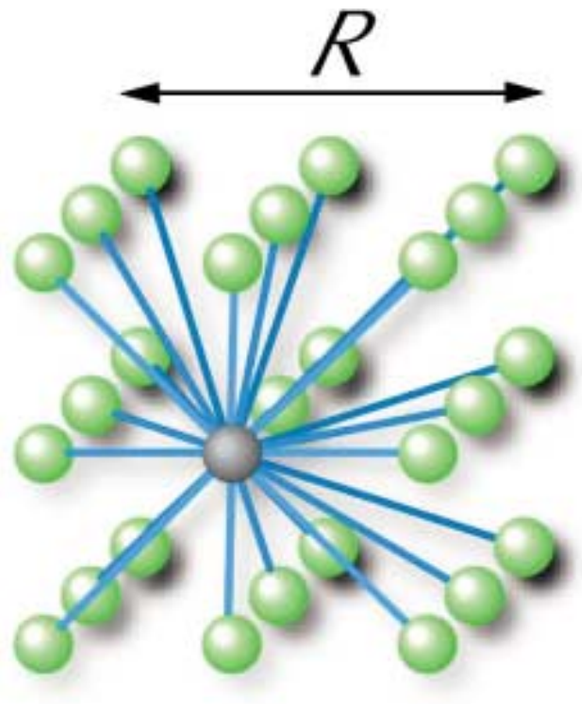
如无必要，勿增实体。简单有效原理。《箴言书注》：切勿浪费较多东西去做，用较少的东西，同样可以做好的事情。

Wiring Optimization of Neural Circuit

"After the many shapes assumed by neurons, we are now in a position to ask whether this diversity ... has been left to chance and is insignificant, or whether it is tightly regulated and provides an advantage to the organism. ... we realized that all of the various conformations of the neuron and its various components are simply morphological adaptations governed by laws of conservation for time, space, and material."

Ramon y Cajal

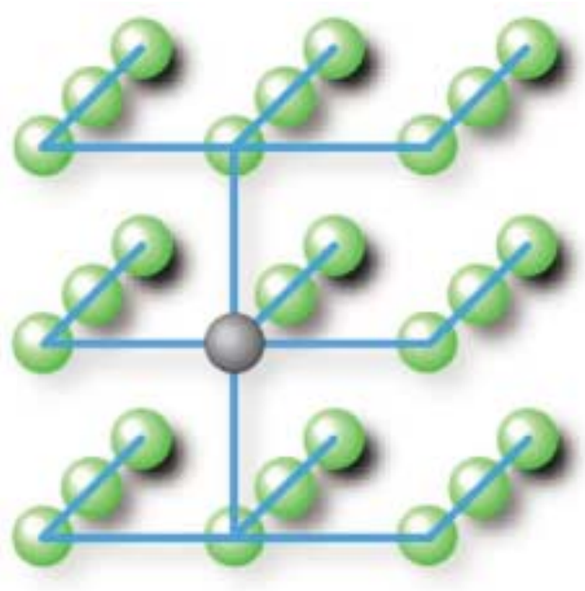
Why do we need axons and dendrites?



N: number of neurons
d: process diameter
R: network linear size

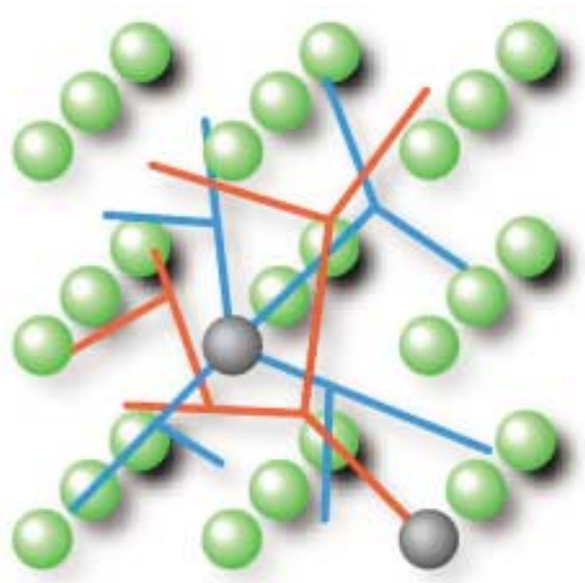
Design I

Why do we need axons and dendrites?



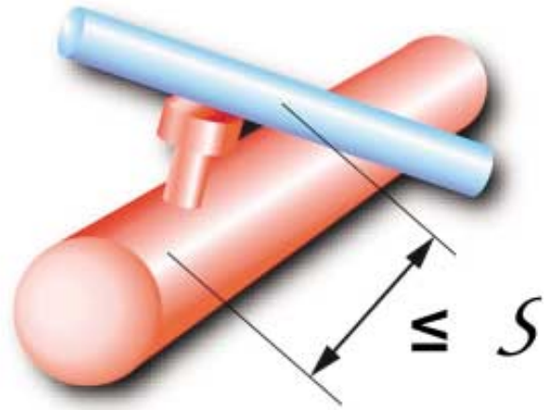
Design II

Why do we need axons and dendrites?



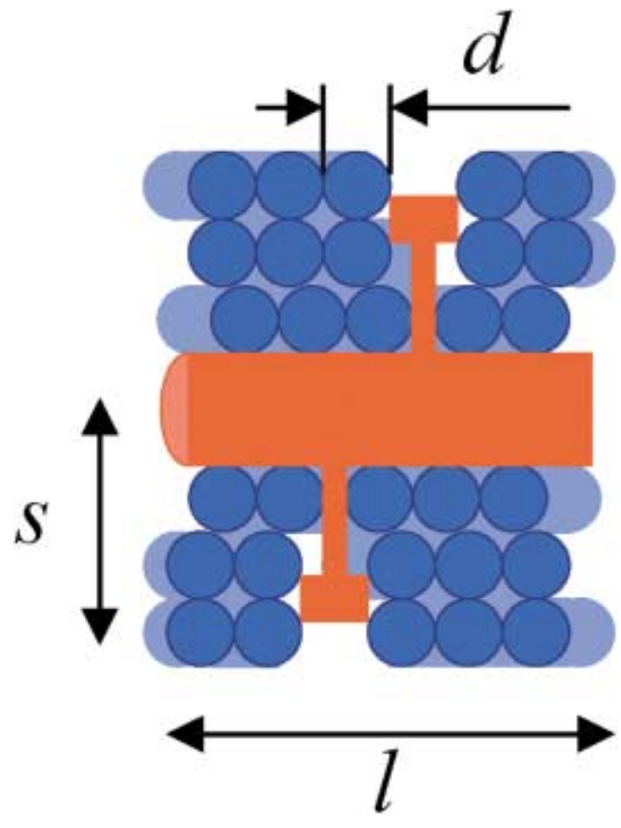
Design III

Why do we need axons and dendrites?



Design IV

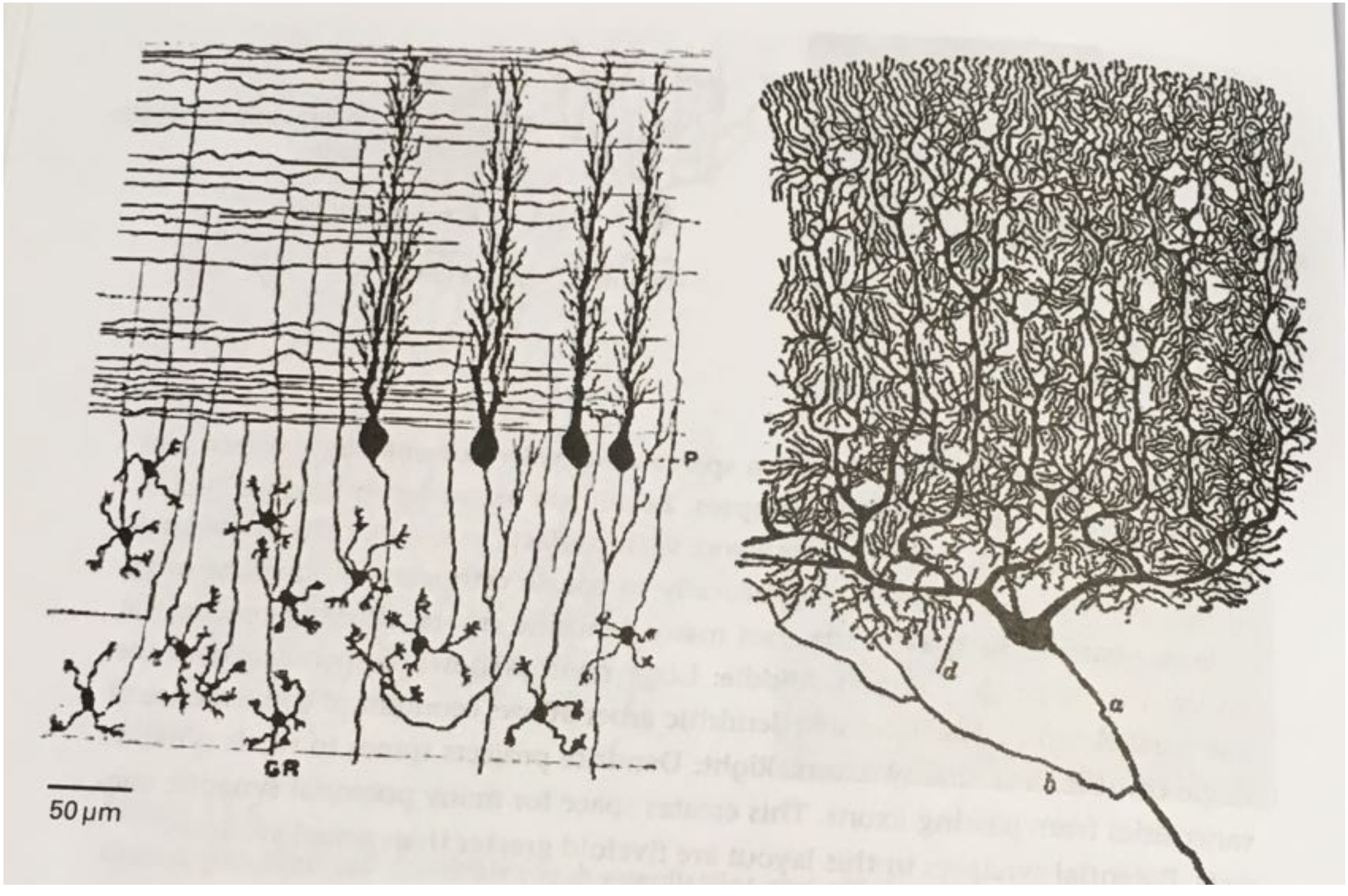
Why do we need axons and dendrites?



The Optimality of the design

Chklovskii *Neuron* 2004

The cerebellar cortex



Single Cortical Neurons as Deep Artificial Neural Networks

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Can Single Neurons Solve MNIST? The Computational Power of Biological Dendritic Trees

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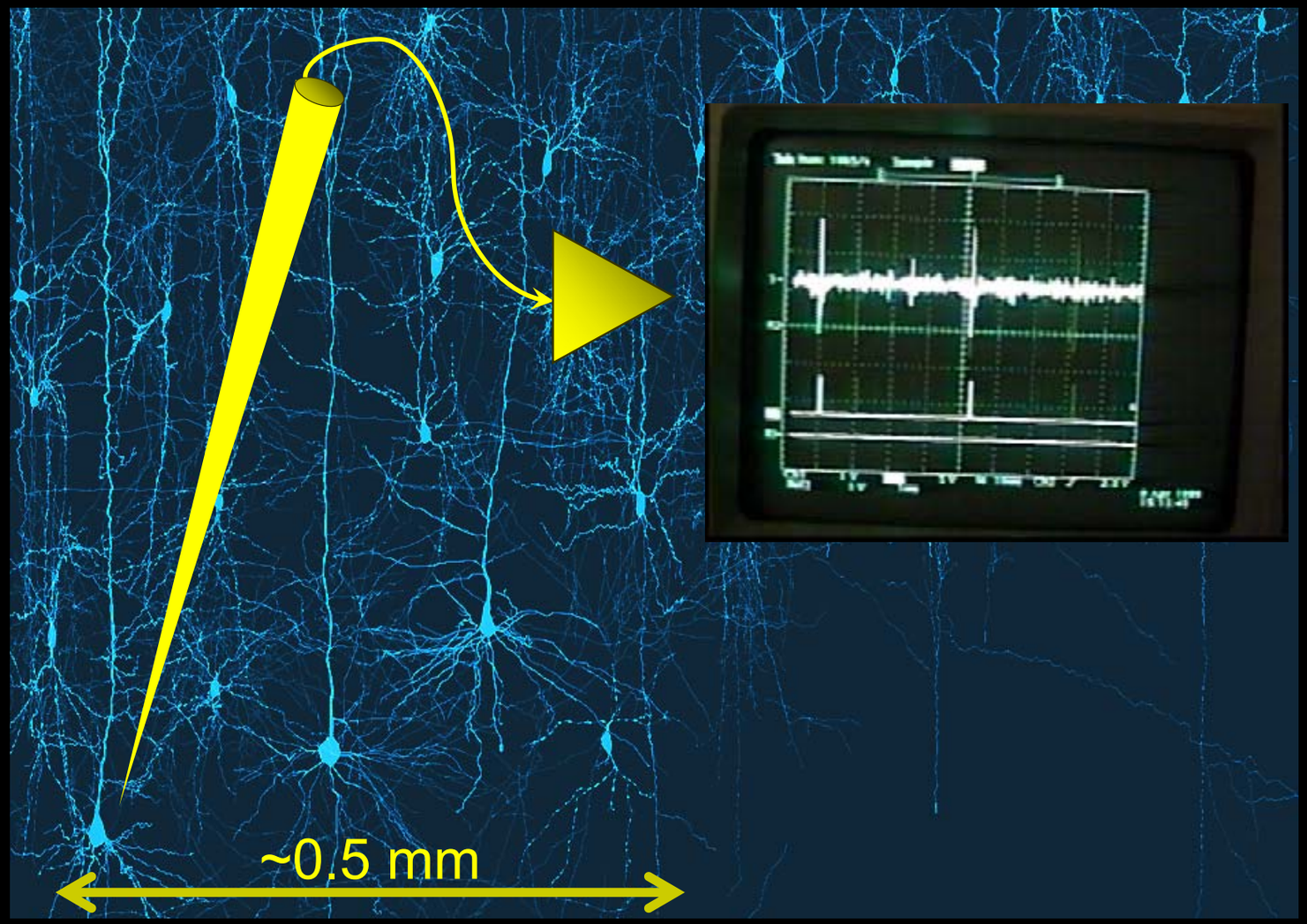
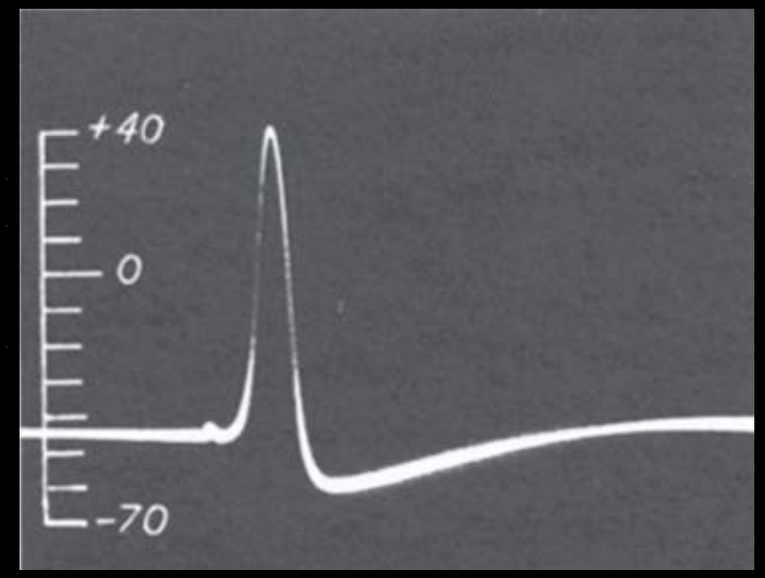
[1]Department of Neuroscience, University of Pennsylvania
[2]Departments of Neuroscience and Bioengineering, University of Pennsylvania

September 4, 2020

Action potential



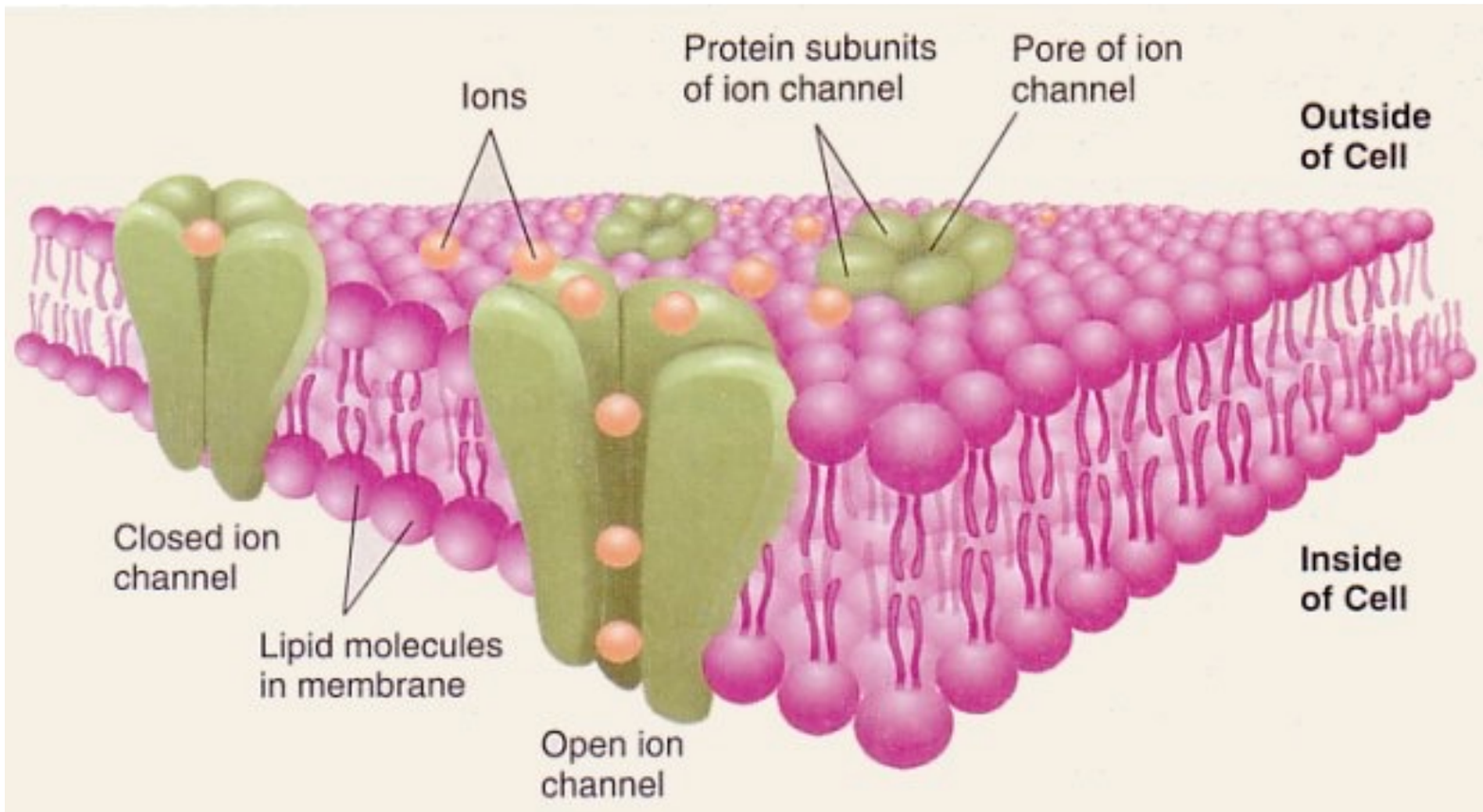


2 ms

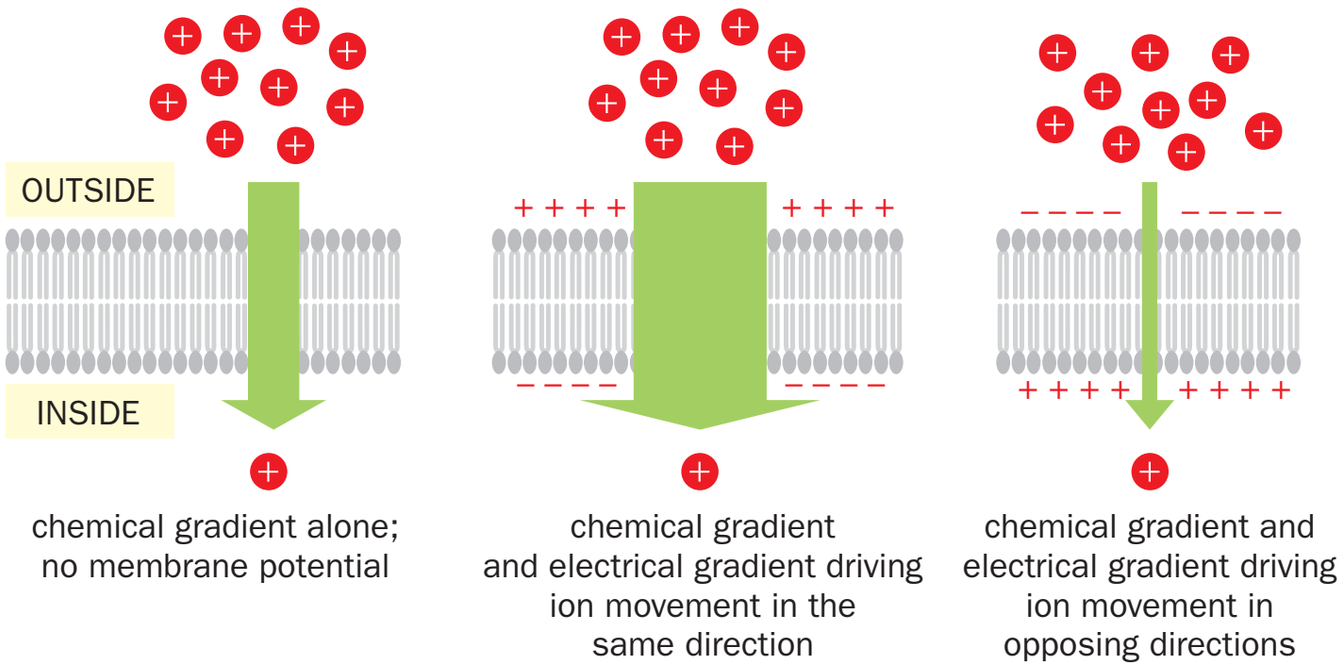
How does a neuron generate an action potential?

Single Neuron Dynamics

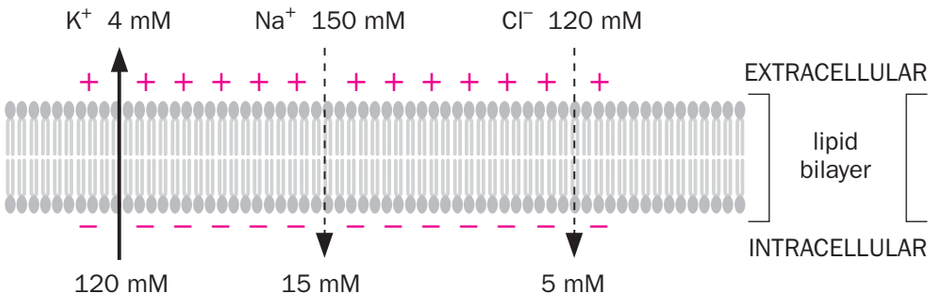
— point neuron model


Ions
Protein subunits of ion channel
Pore of ion channel
Outside of Cell
Closed ion channel
Lipid molecules in membrane
Open ion channel
Inside of Cell

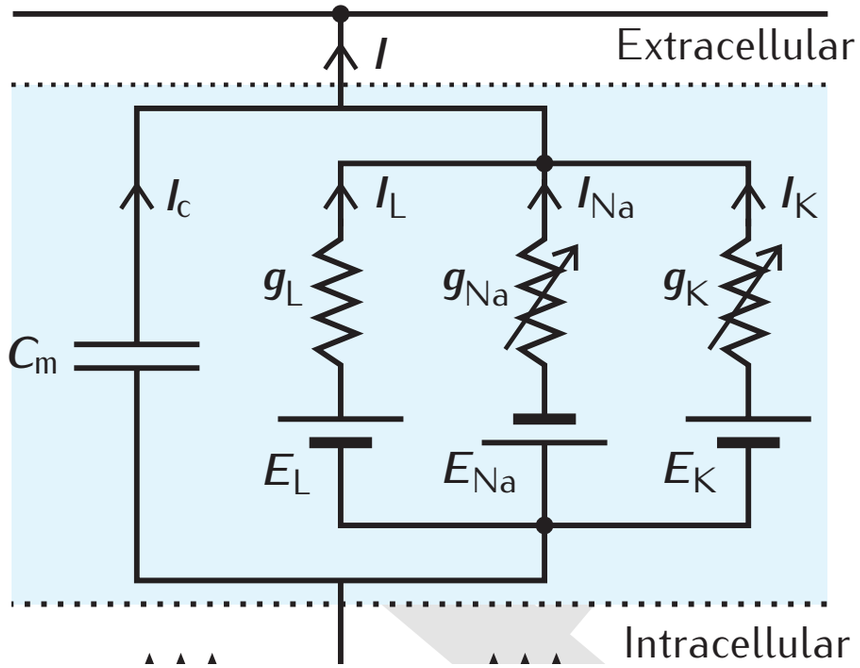
What determines the resting potential of a neuron?



(A)

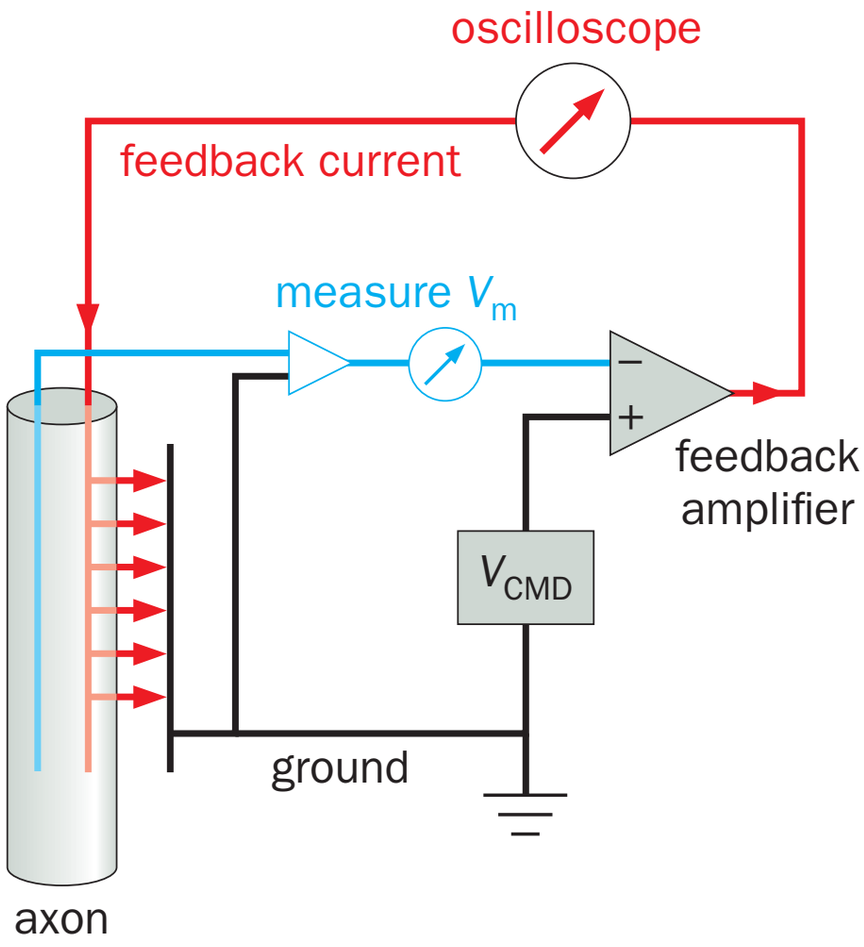

K+ 4 mM
Na+ 150 mM
Cl− 120 mM
EXTRACELLULAR
lipid bilayer
INTRACELLULAR
120 mM
15 mM
5 mM

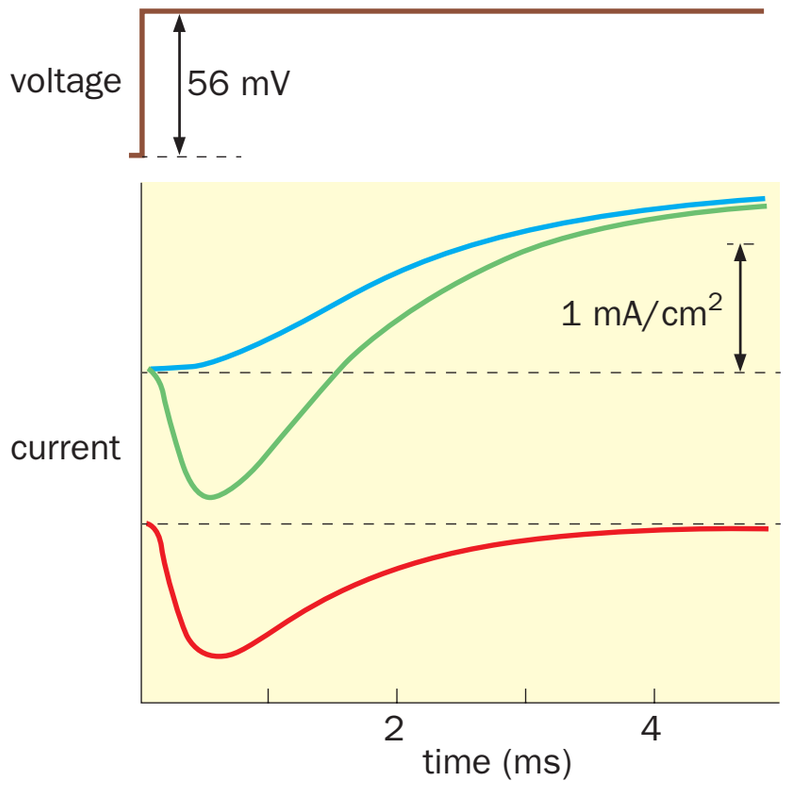
The Equivalent Electronic Circuit of a Neuron



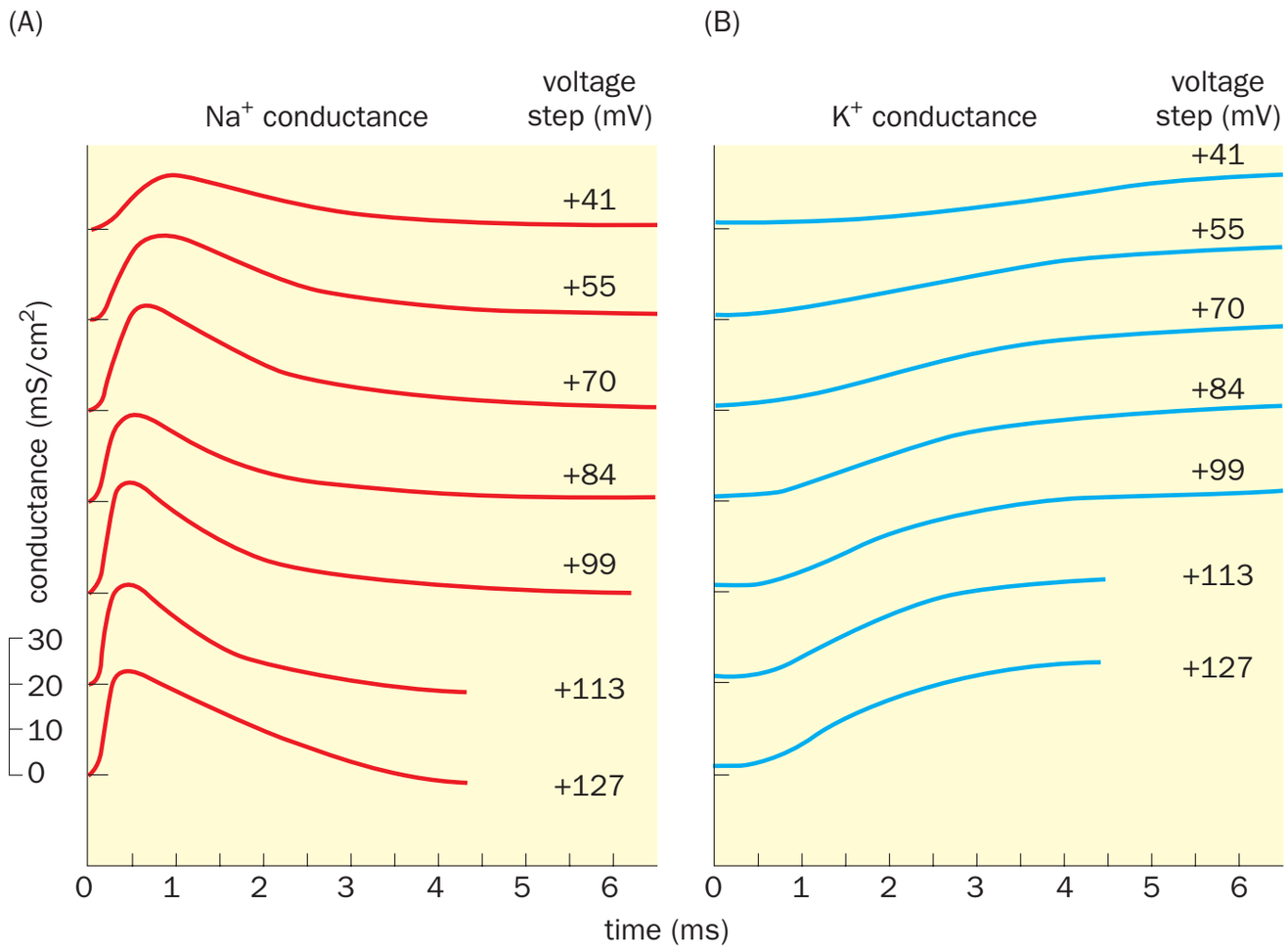
$$C_m \frac{dV}{dt} = -\sum_i g_i(V)(V - E_i) - \bar{g}_L(V - E_L) + I_e$$

Voltage Clamp Recording





Voltage-gated Conductance



Qualitative explanation of action potential generation