Neurons

Cellular components of the brain's circuitry

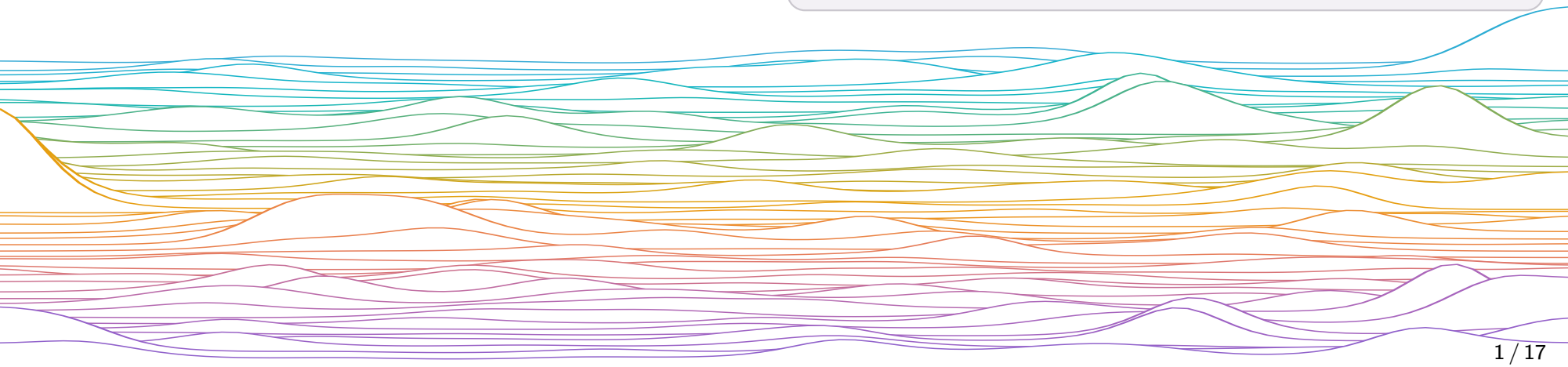
Computational Neuroscience

University of Bristol

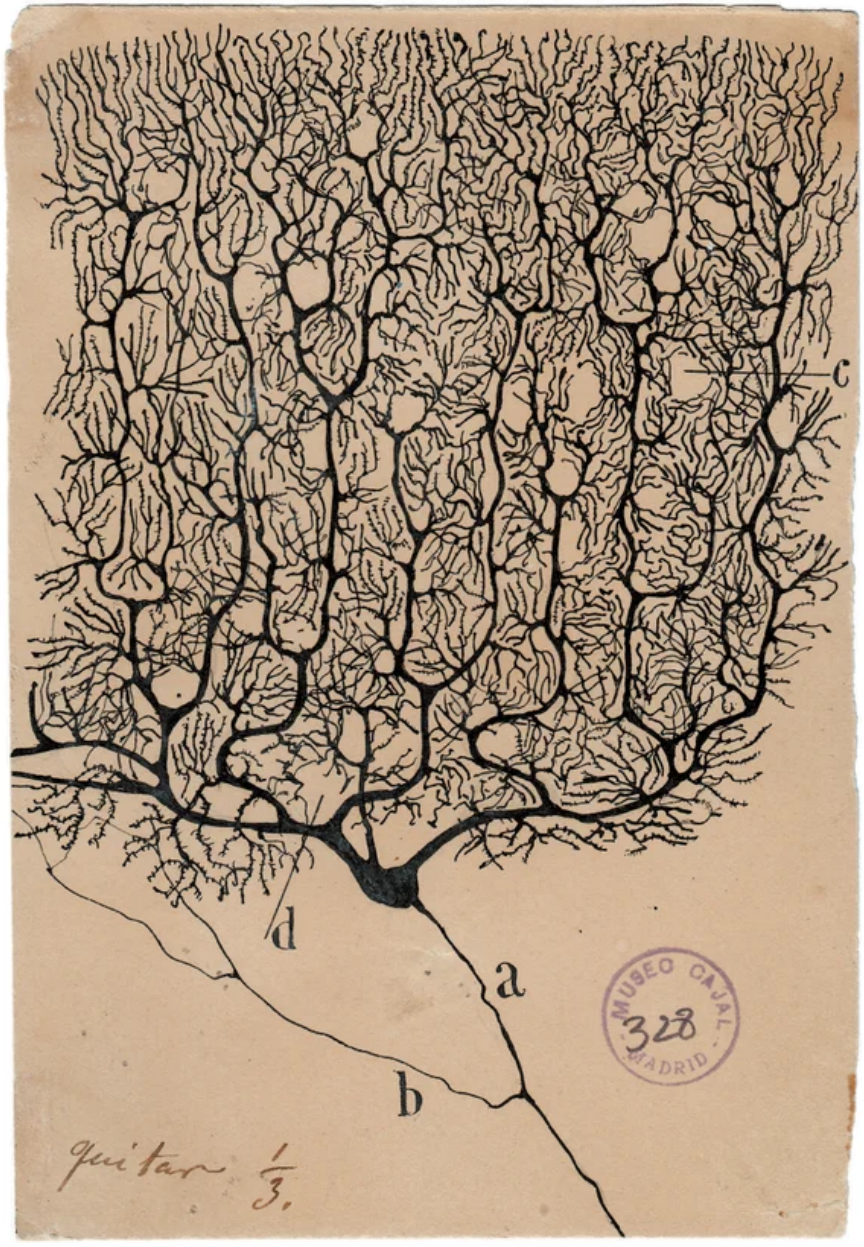
M Rule

Learning outcomes:

- Understand the structure of neurons at a basic level
- Recognize, draw, label soma/axons/dendrites/synapse
- Describe how neurons communicate with each other
- Detail the role of Na^+, K^+, Cl^- ions in the membrane voltage



Layer V Pyramidal Cells, Santiago Ramón y Cajal



Purkinje Cell, Santiago Ramón y Cajal

Pyramidal cell soma typically 15–50 µm in diameter

Neurons are cells specialised for computation and communication

Soma cell body

- Nucleus, DNA → mRNA
- Convergence of electrical signals

Dendrites detect inputs

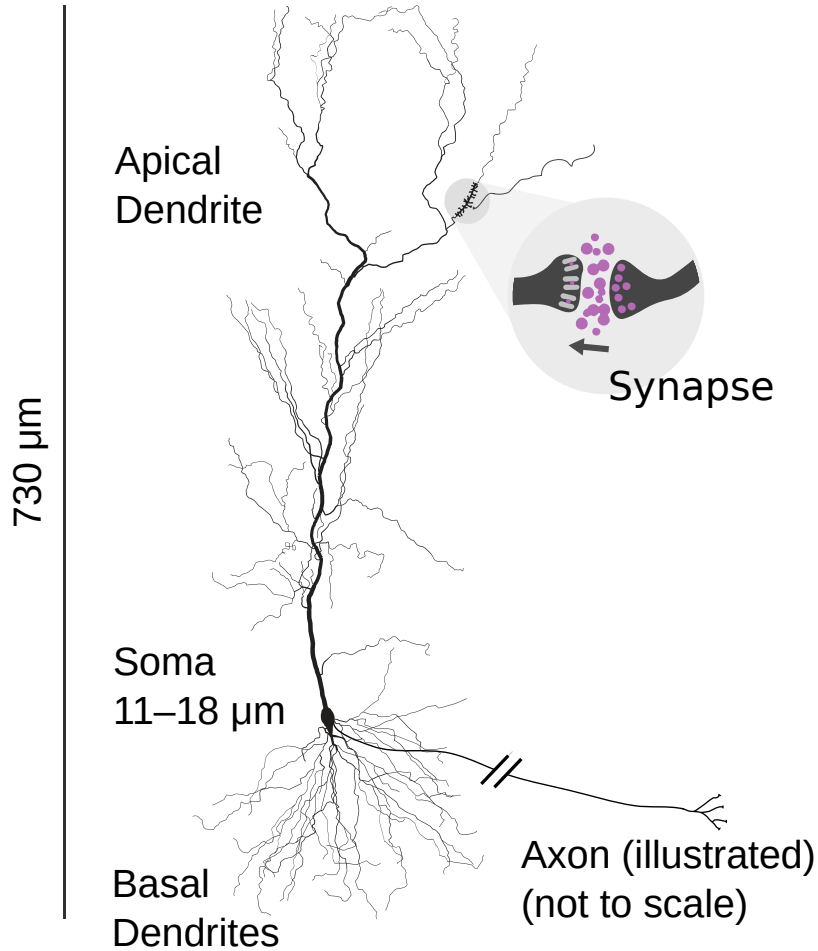
- Tree-shaped, $\sim 5 - 1000$ branches
- Short-range, local
- Collect, integrate inputs
- Analog computation

Axons send output

- Usually 1 per cell
- Transmit many targets
- Local ≤ 1 mm or long-range (~ 1 m in humans)

Synapses **connect neurons**

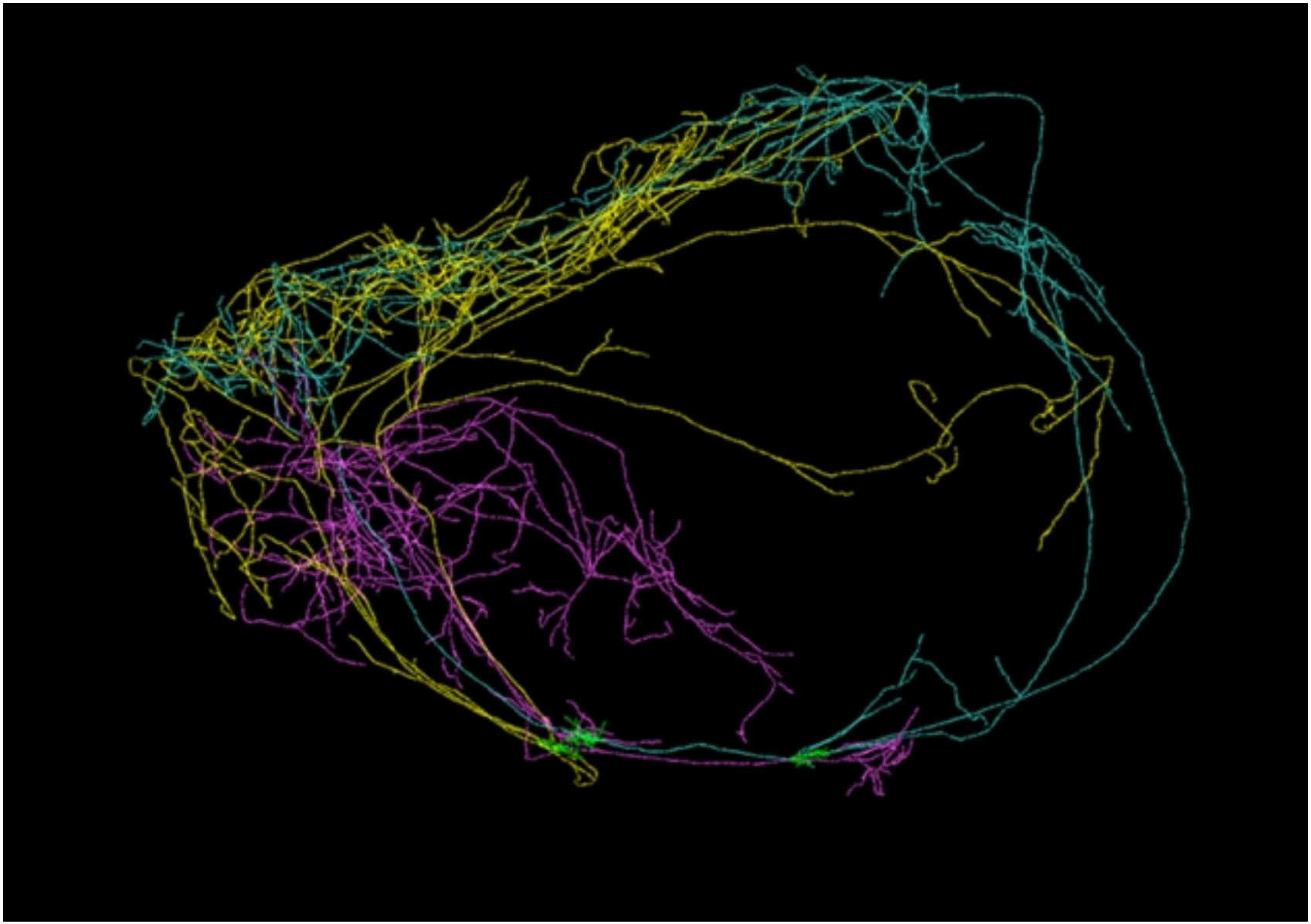
- $\sim 10^{14}$ in our brains ($\sim 10^{11}$ neurons)
- Each neuron has "a few" up to $\sim 10^5$



Golding et al. (2005) CA1 Pyramidal Neuron

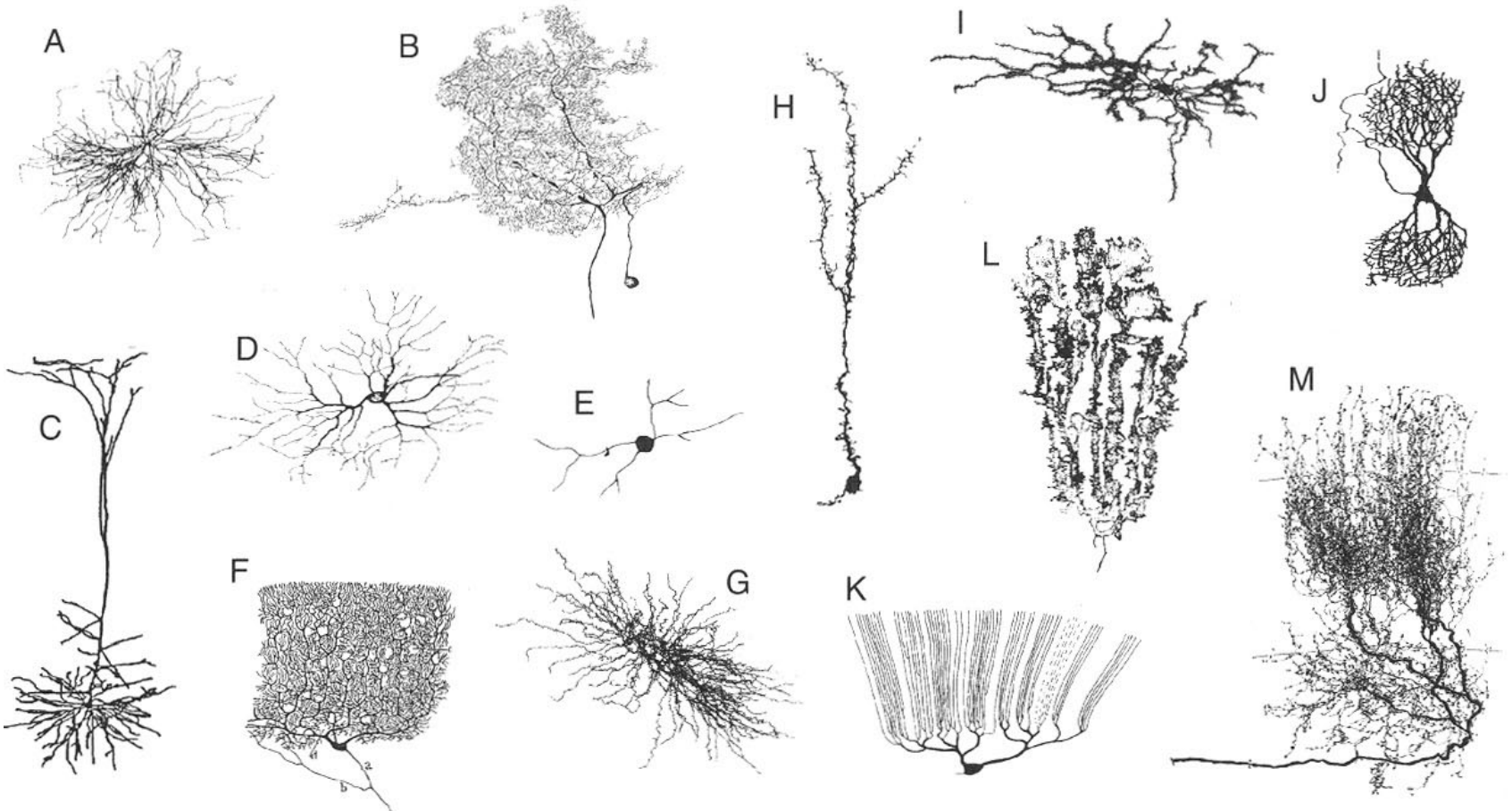
axons may be branched; don't confuse the axon and apical dendrite

Axons



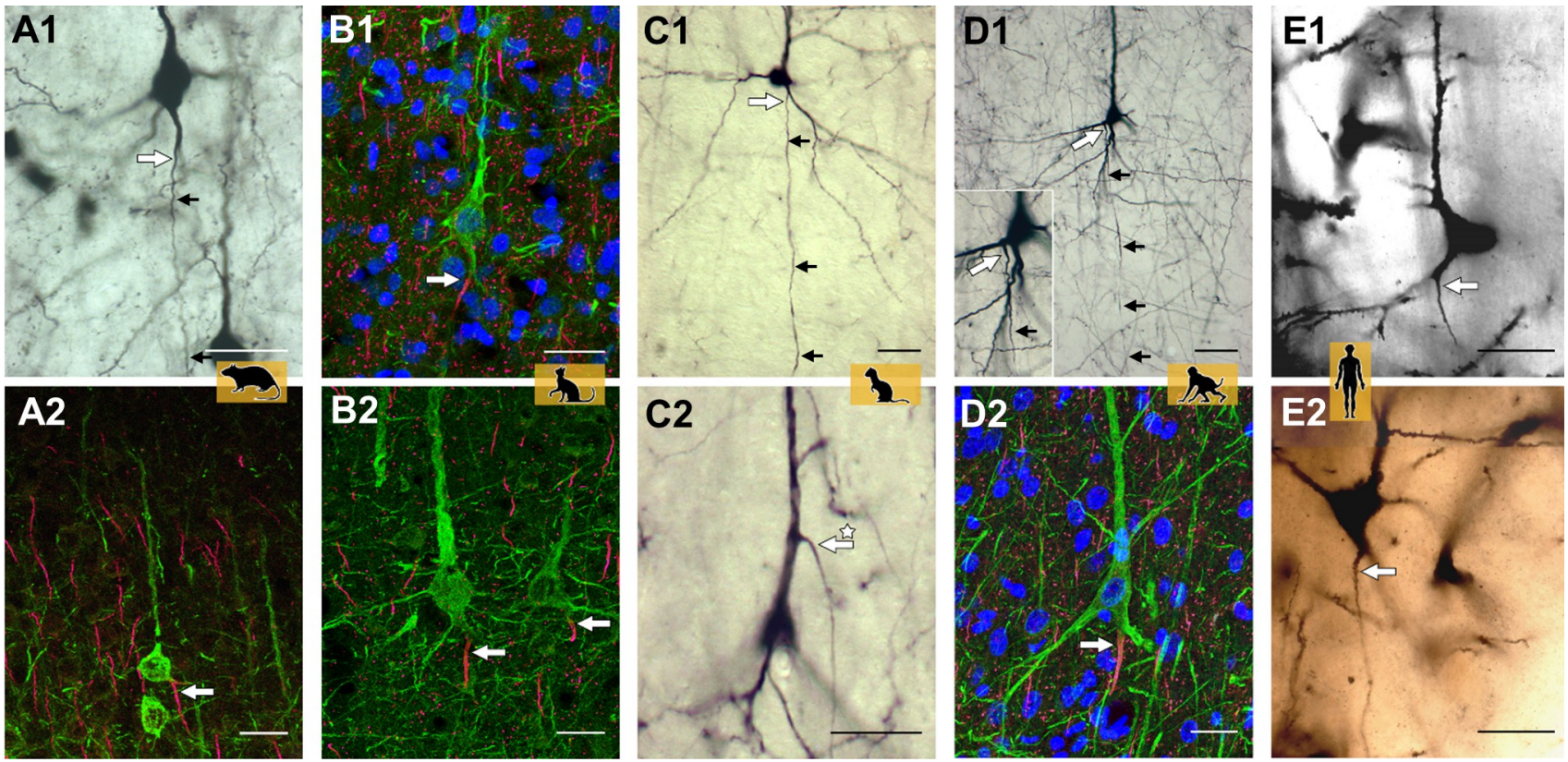
A digital reconstruction of a neuron that encircles the mouse brain.

Dendrites



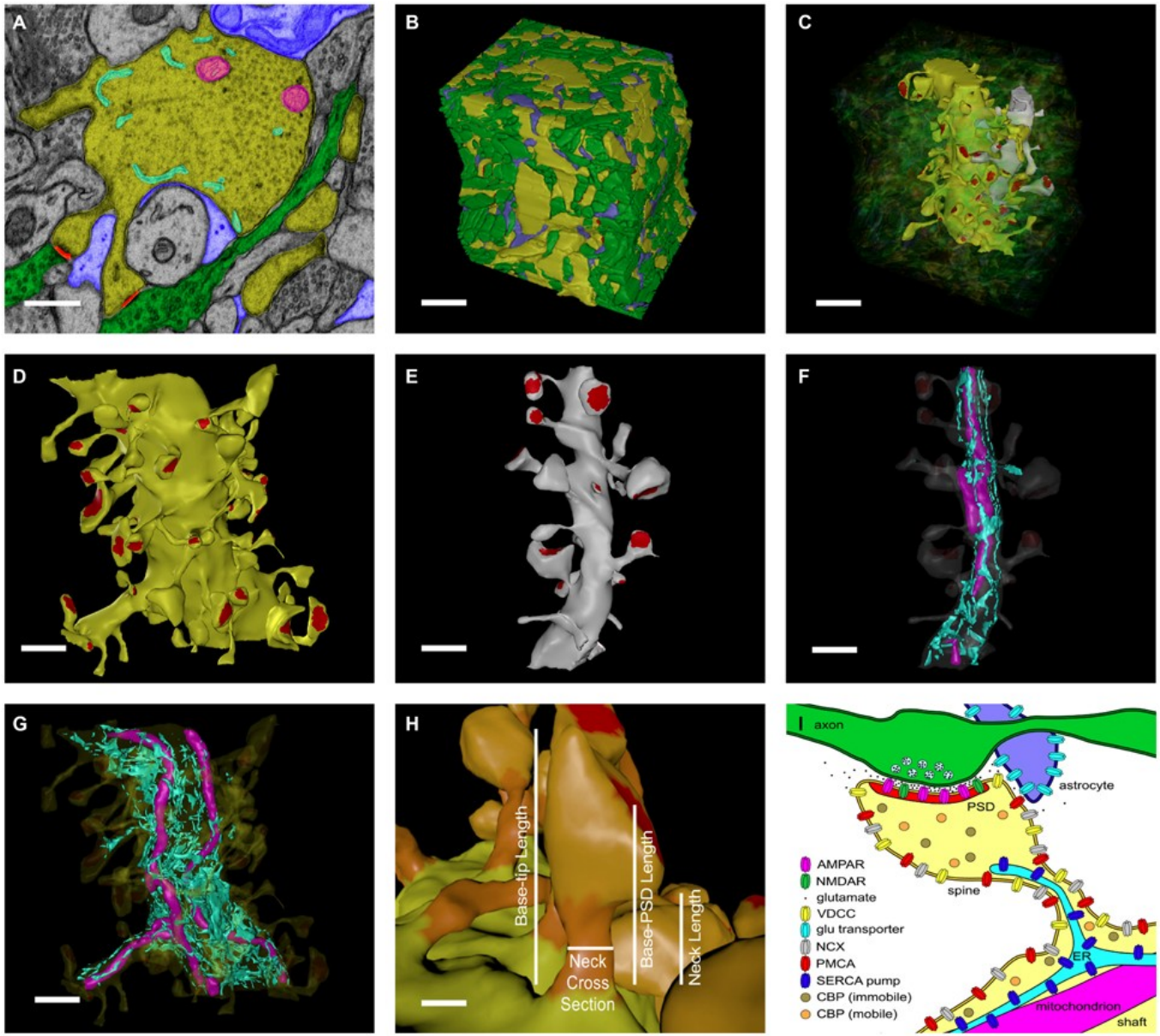
Koch, Biophyiscs of Computation (1999)

Axons that emerge from dendrites ?!



Wahle & al. Neocortical pyramidal neurons with axons emerging from dendrites are frequent in non-primates, but rare in monkey and human (2022)

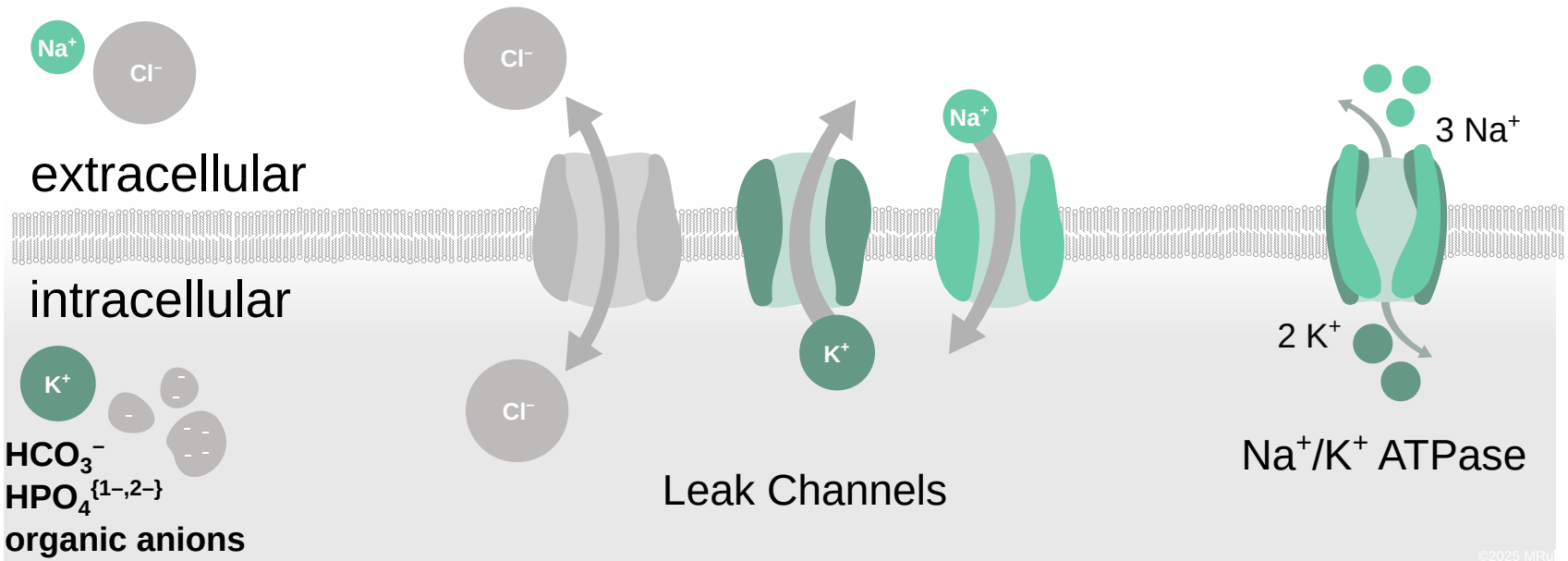
Synapses



Bartol et al(2015) Figure 1. Reconstruction of hippocampal neuropil.

Neurons are excitable

- They maintain a voltage difference across their cell membrane
- Charged ions with differing intracellular/extracelluar concentrations → chemical "batteries"
  - Effective voltage depends on ion's charge & concentration difference
  - Powers voltage dynamics for computation & communication
  - Active pumps set and maintain concentration differences



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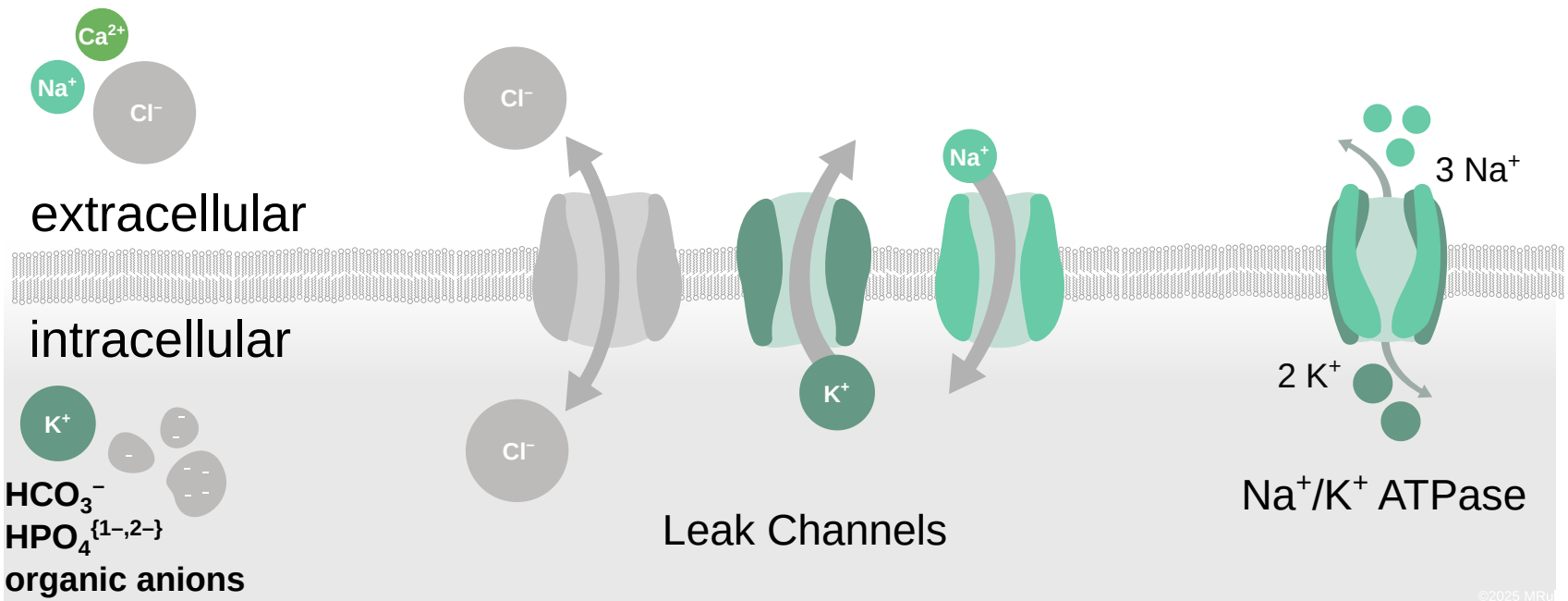
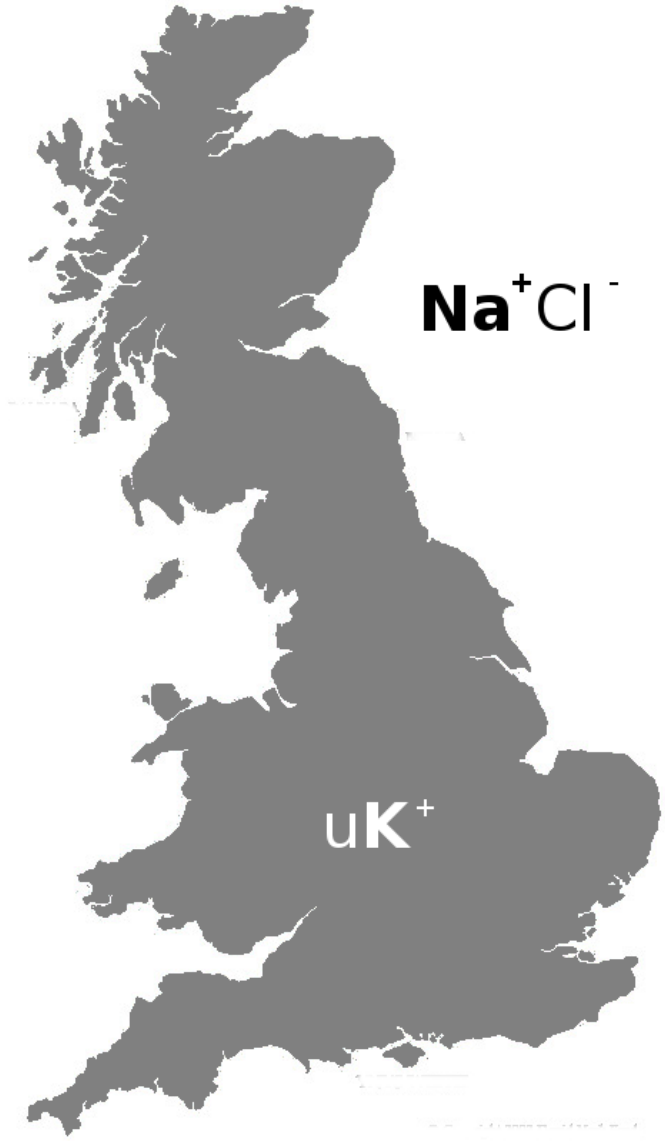
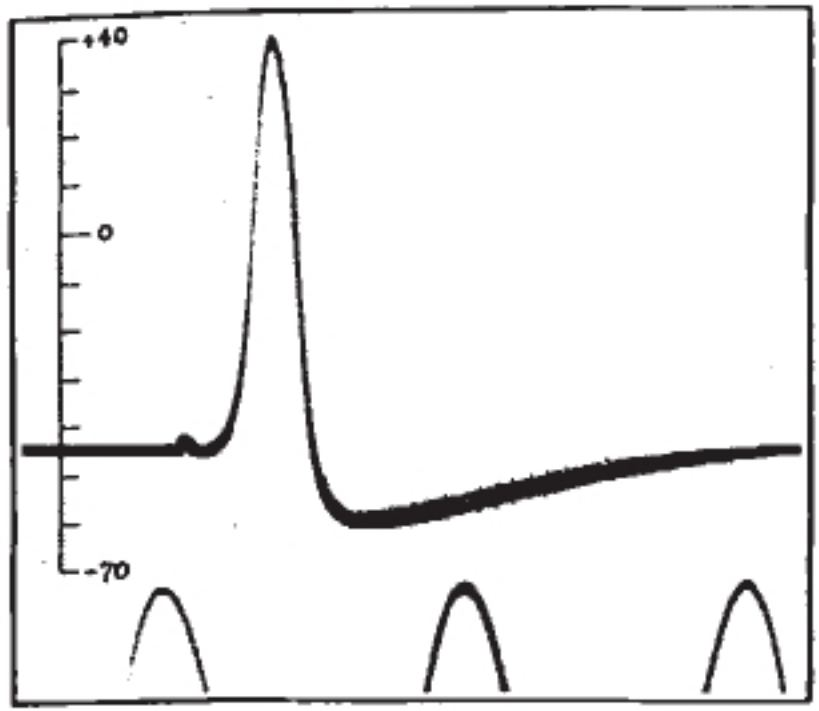




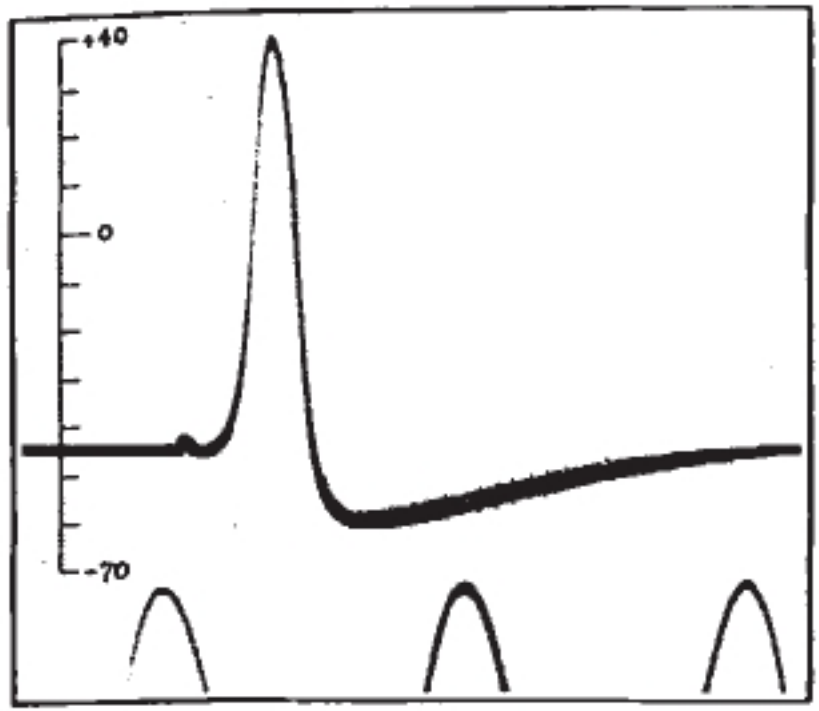
Conor Houghton

Neurons use spikes for reliable long-range communication



Oscilloscope trace from *Action Potentials Recorded from Inside a Nerve Fibre*, Hodgkin and Huxley (1939) ***"Action potential recorded between inside and outside of axon. Time marker 500 cycles/sec. The vertical scale indicates the potential of the internal electrode in millivolts, the sea water outside being taken at zero potential."***

Neurons use spikes for reliable long-range communication

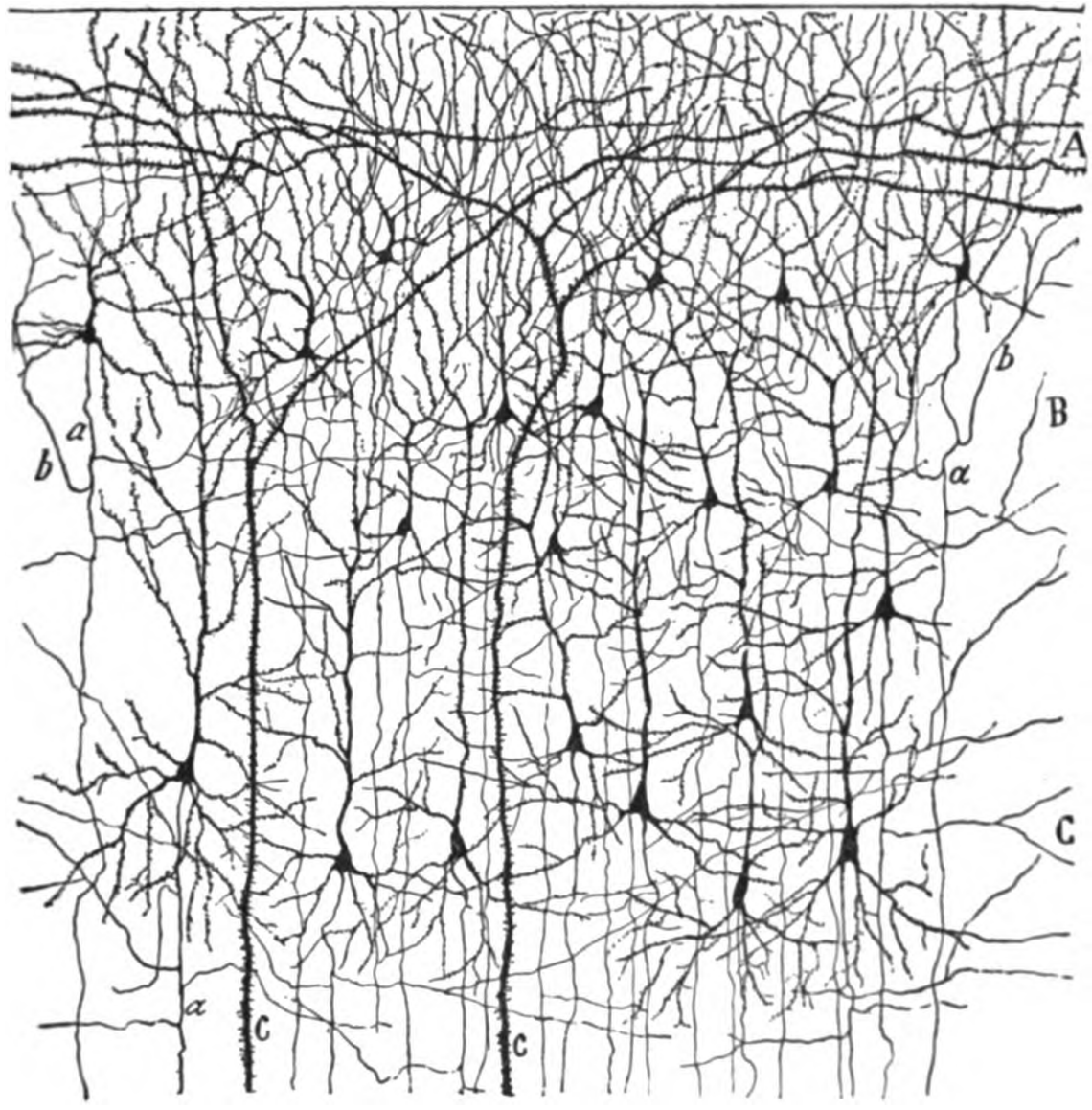


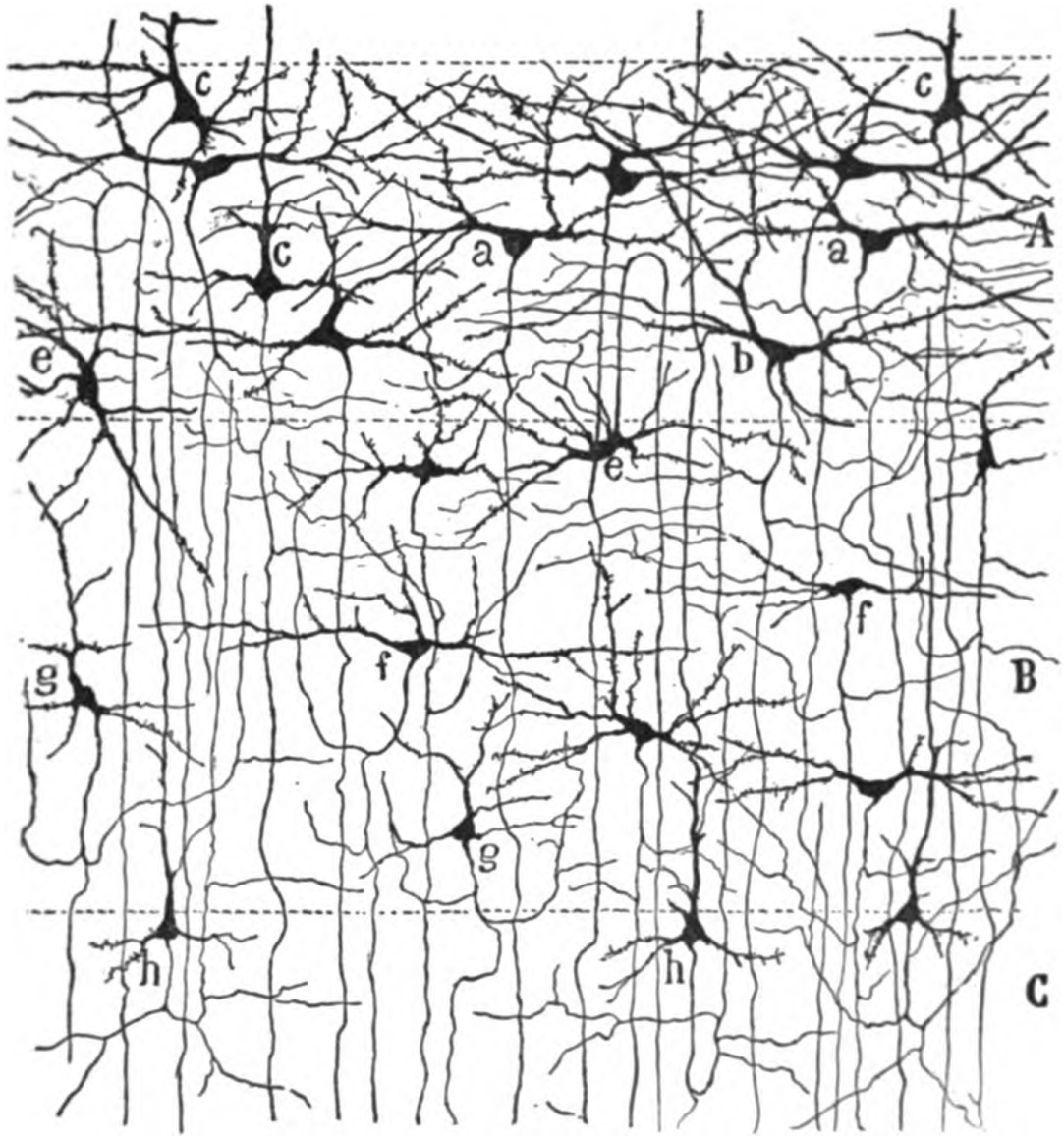
The action potential ("spike") is a sharp rise and fall in cell's membrane voltage

It is a regenerative wave & can travel along axons/dendrites without decay

$\sim$ All-or-nothing, binary $\{0, 1\}$

draw and label a prototypical (inter)neuron


A
B
C
C
C
a
b
a
b
a
b


c
c
c
a
a
A
e
b
e
f
f
g
B
g
h
h
C

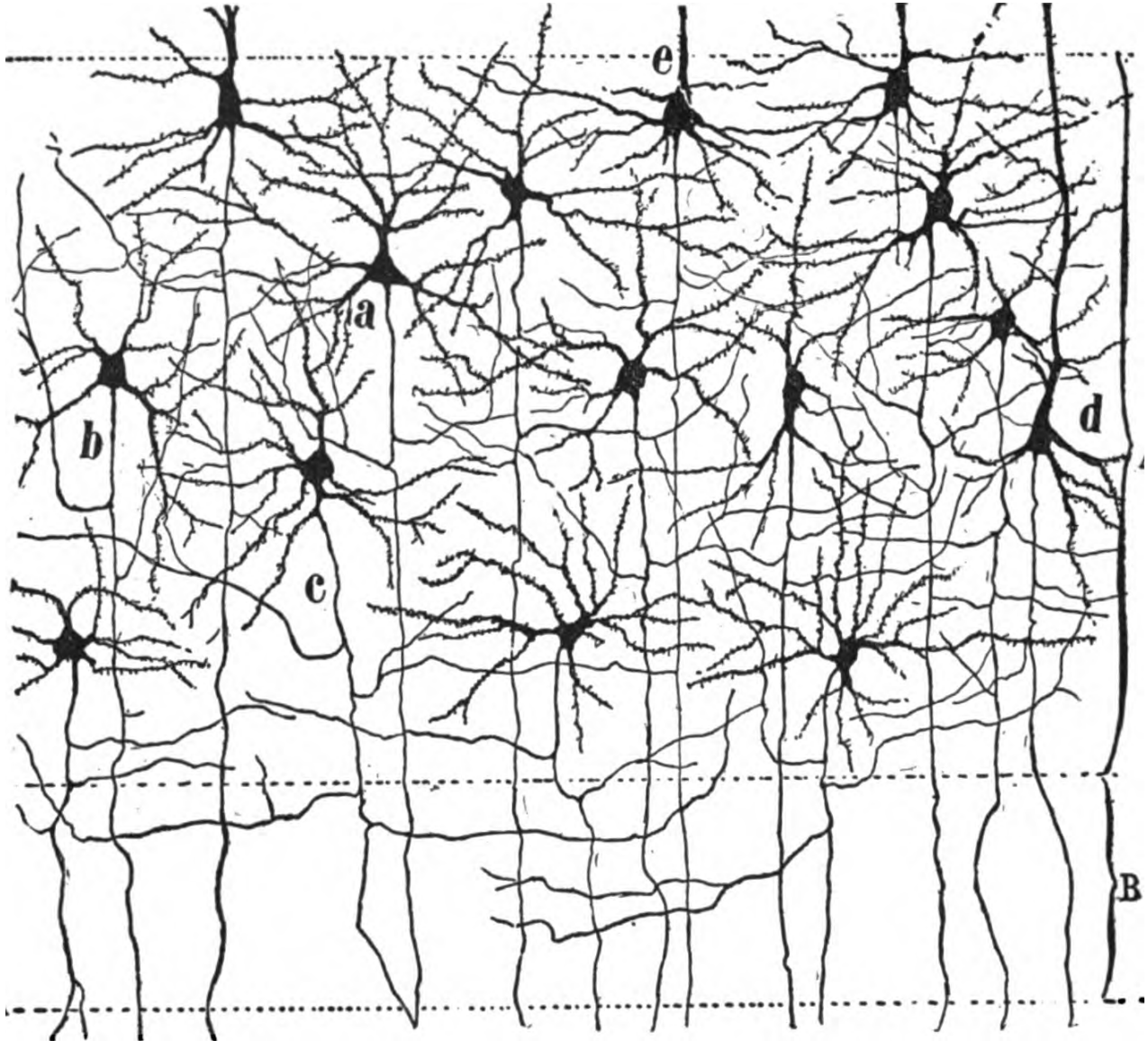
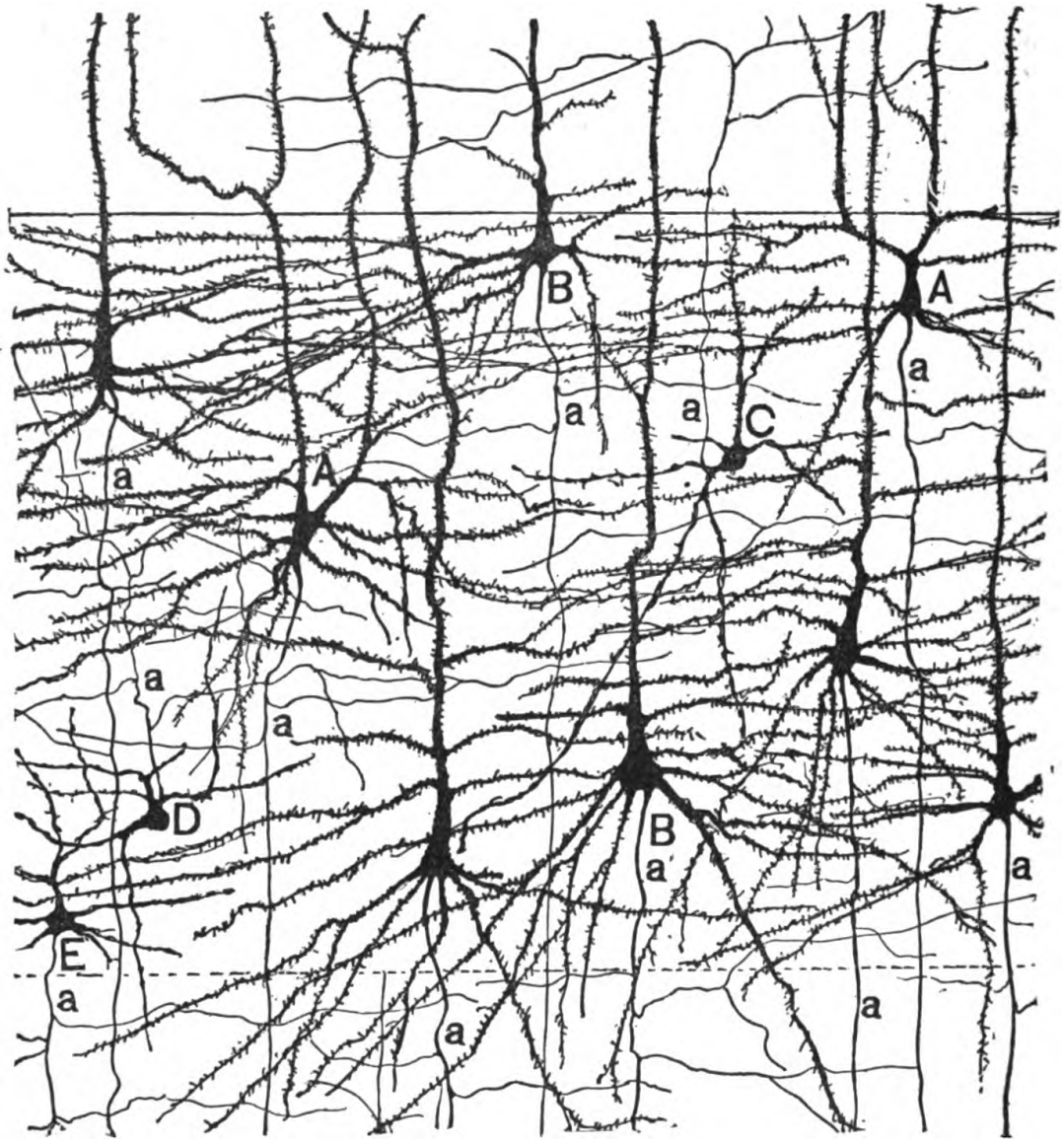

e
a
b
c
d
B

FIG. 20. — Cells of the 6th and 7th layers from the human visual cortex, infant 15 days old.


A
B
A
a
a
C
a
A
a
a
D
B
a
a
E
a
a
a

end