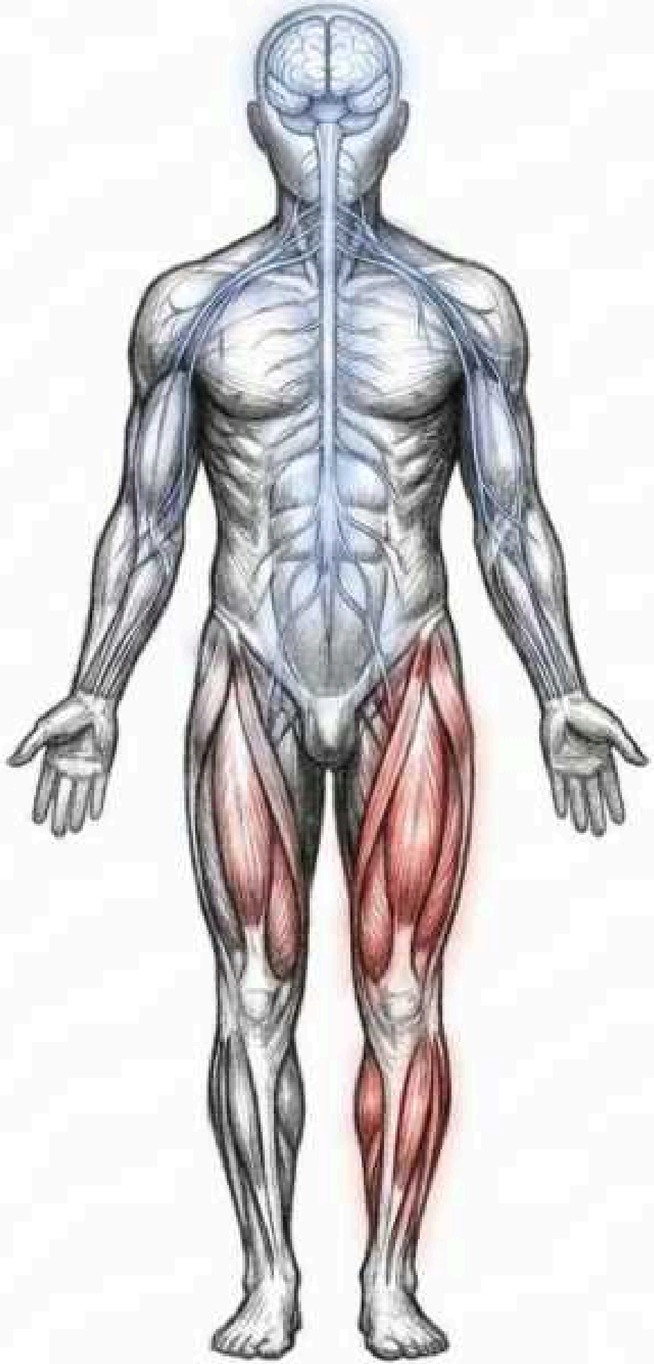
¶ 2.1

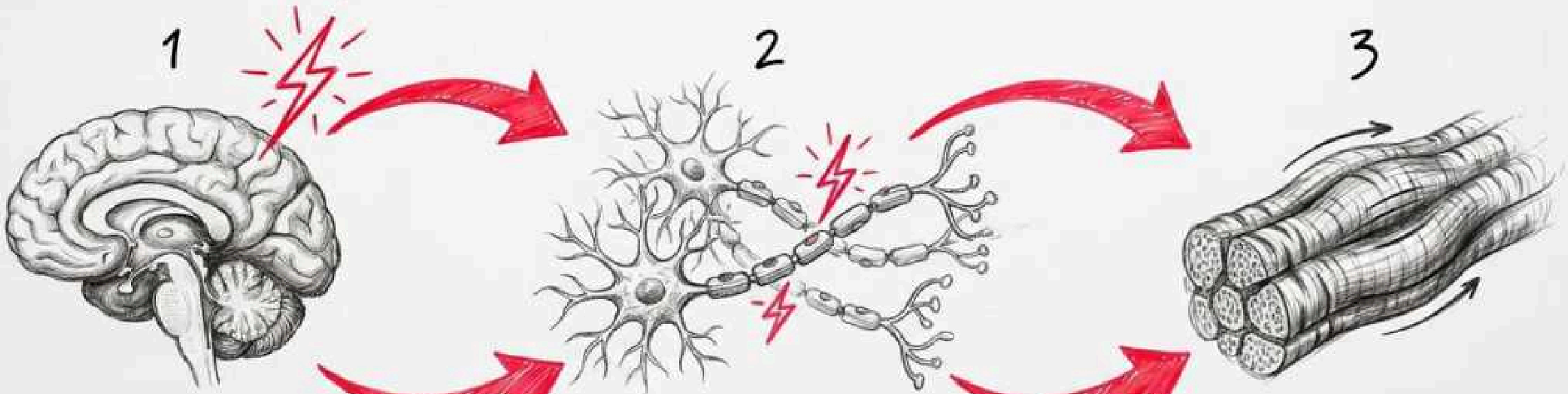
Lecture 2: Nerves and Muscles

Resting and action potentials, synapses, the neuromuscular junction, and the sliding filament model of muscle.



The Communication Loop

¶ 2.2

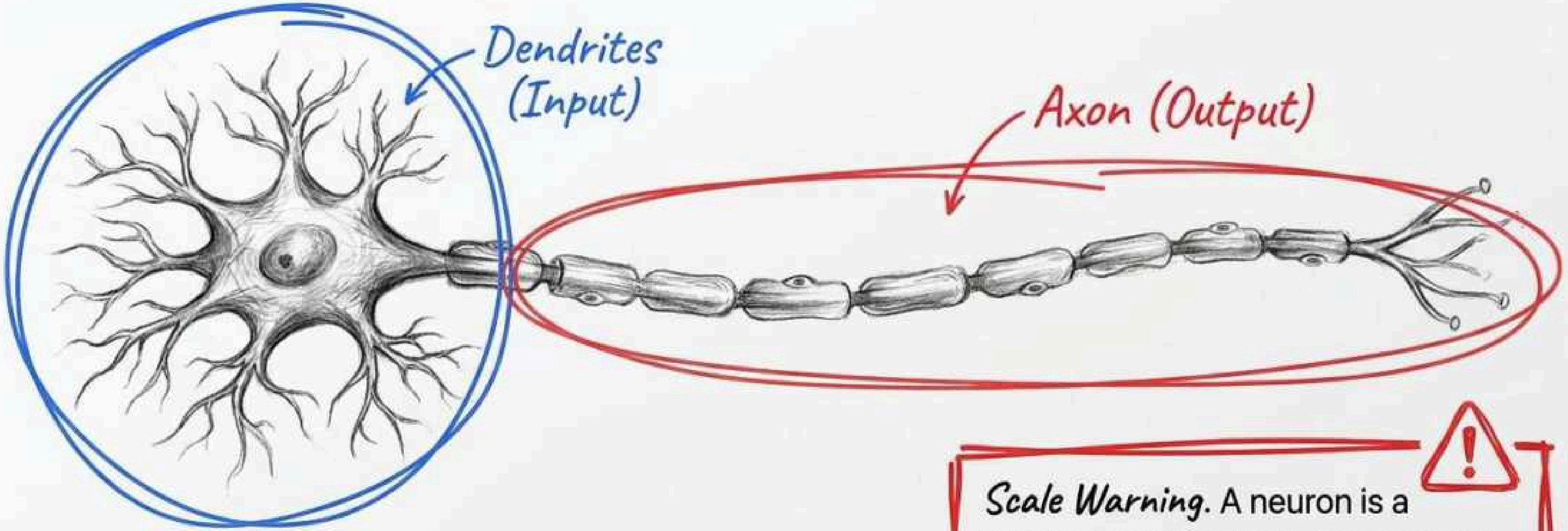


- Nerve cells send electrical signals
- Muscle cells turn signals into physical force

A single complex movement is built entirely from a symphony of tiny cellular events.

¶ 2.3

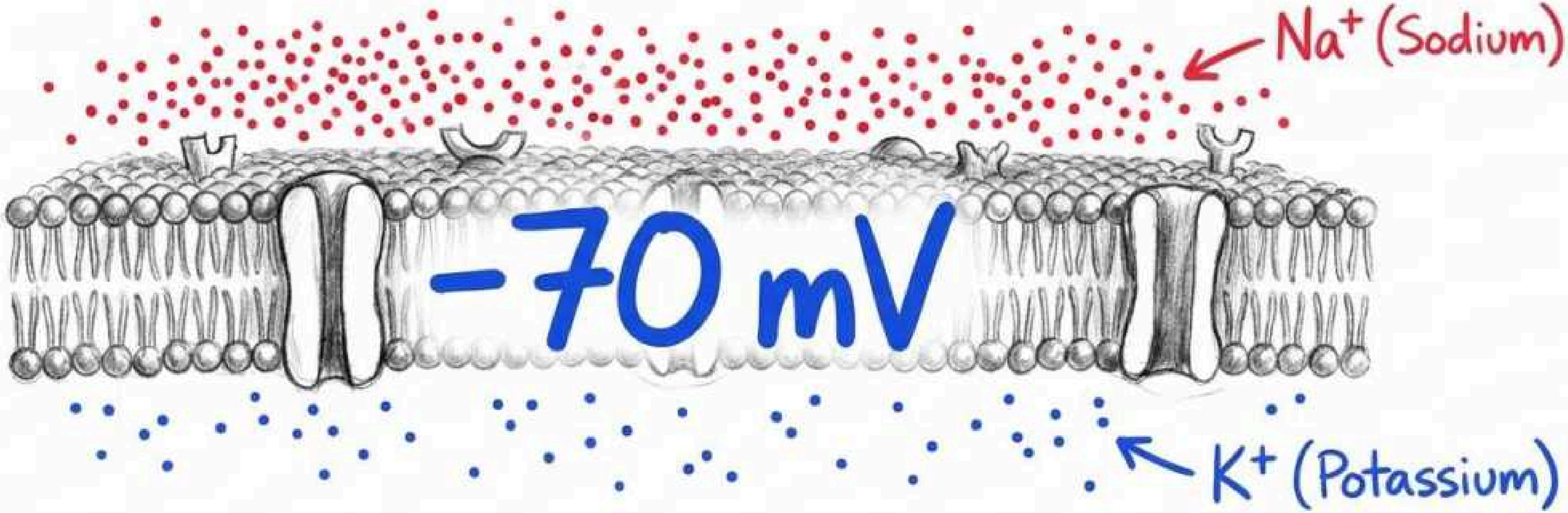
Anatomy of a Signal



Scale Warning. A neuron is a single specialized cell. Some axons stretch over a meter long—from the spinal cord all the way to the big toe.

The Resting Potential

¶ 2.4



The inside of a resting neuron is 70 millivolts more negative than the outside. This membrane potential exists due to the uneven spread of concentrated ions.

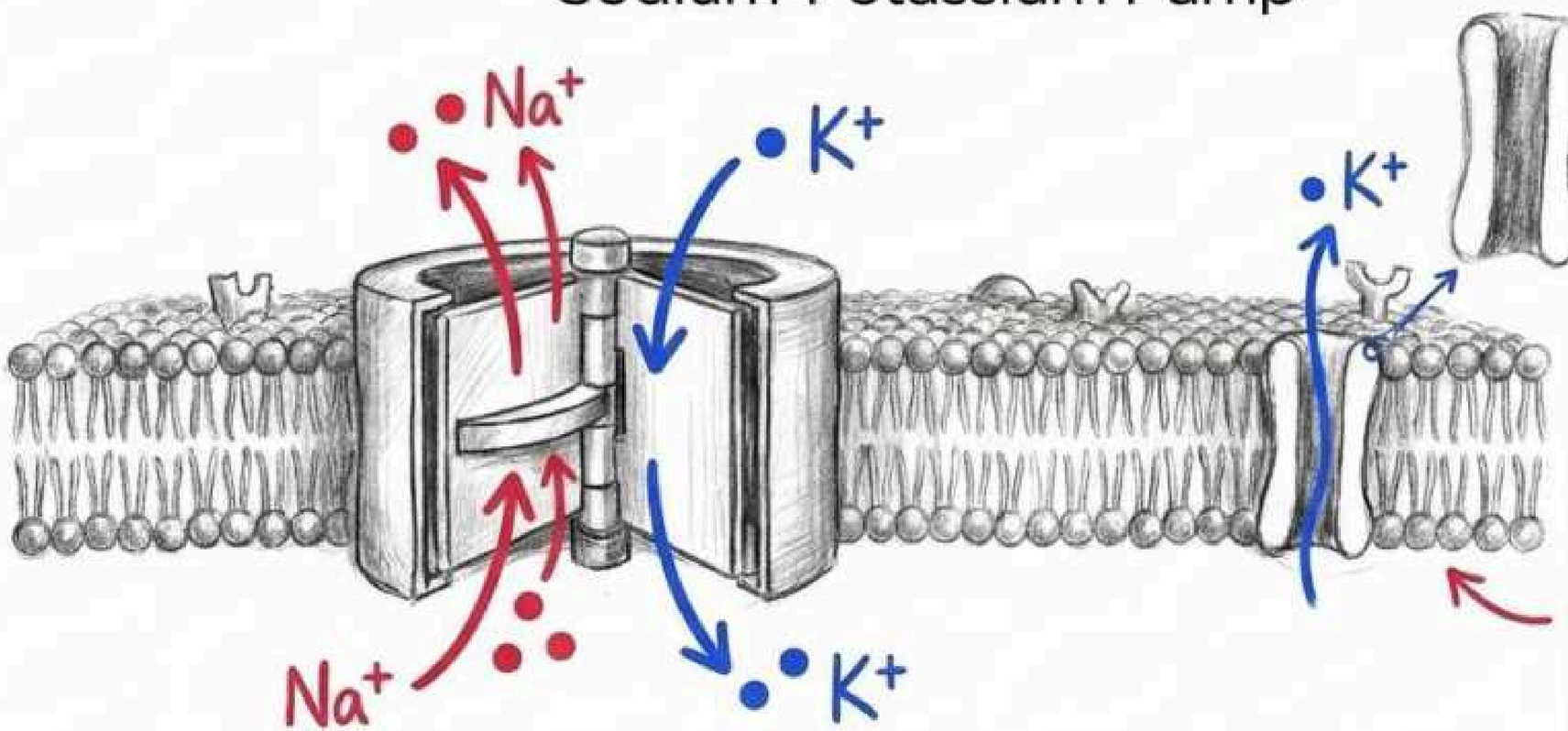
The Energy Pump

¶ 2.5

1 ATP → 3 Na^+ OUT & 2 K^+ IN

The pump burns cellular energy (ATP) to build the chemical imbalance.

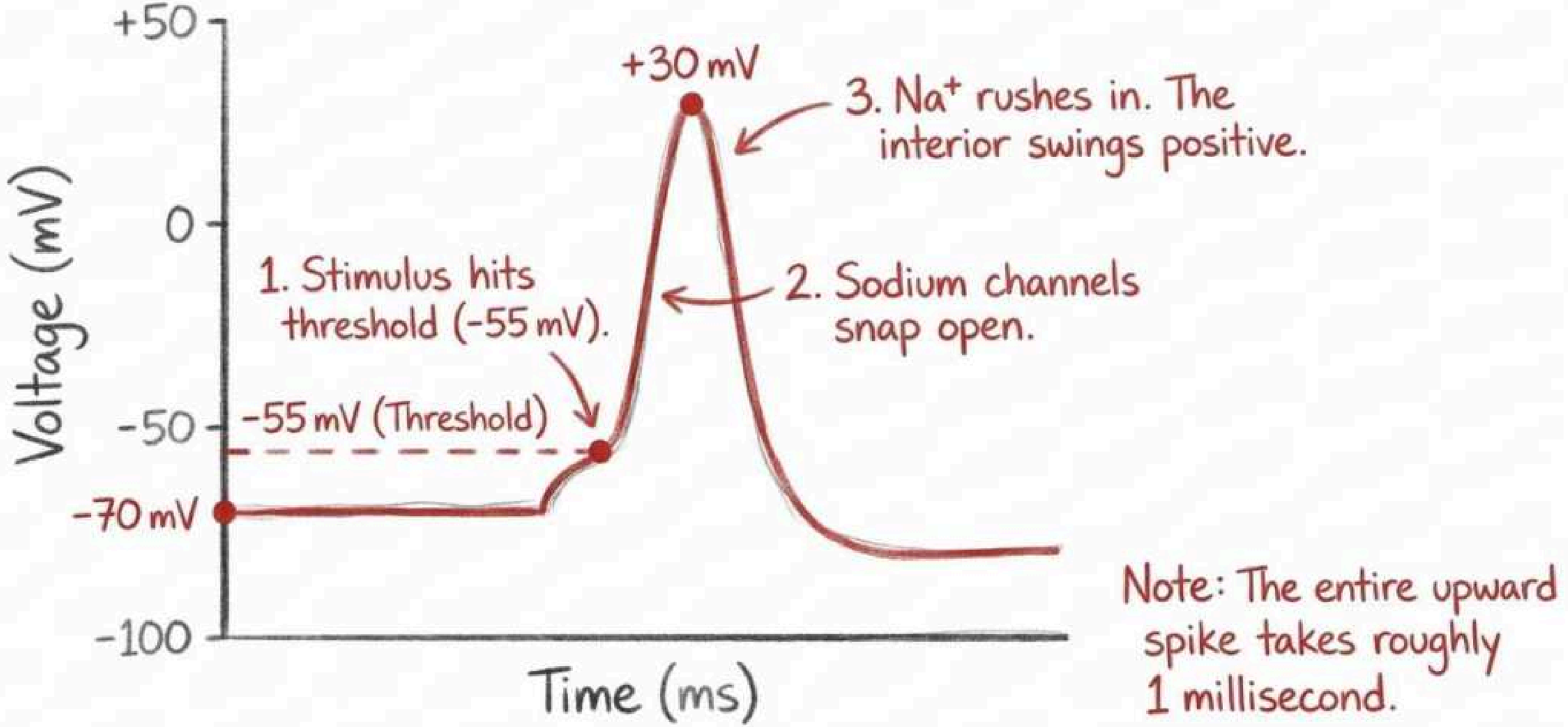
Sodium-Potassium Pump



The Leak:
Potassium channels rest slightly open. K^+ leaks out, leaving a negative charge behind. This sets the baseline −70 mV.

¶ 2.6

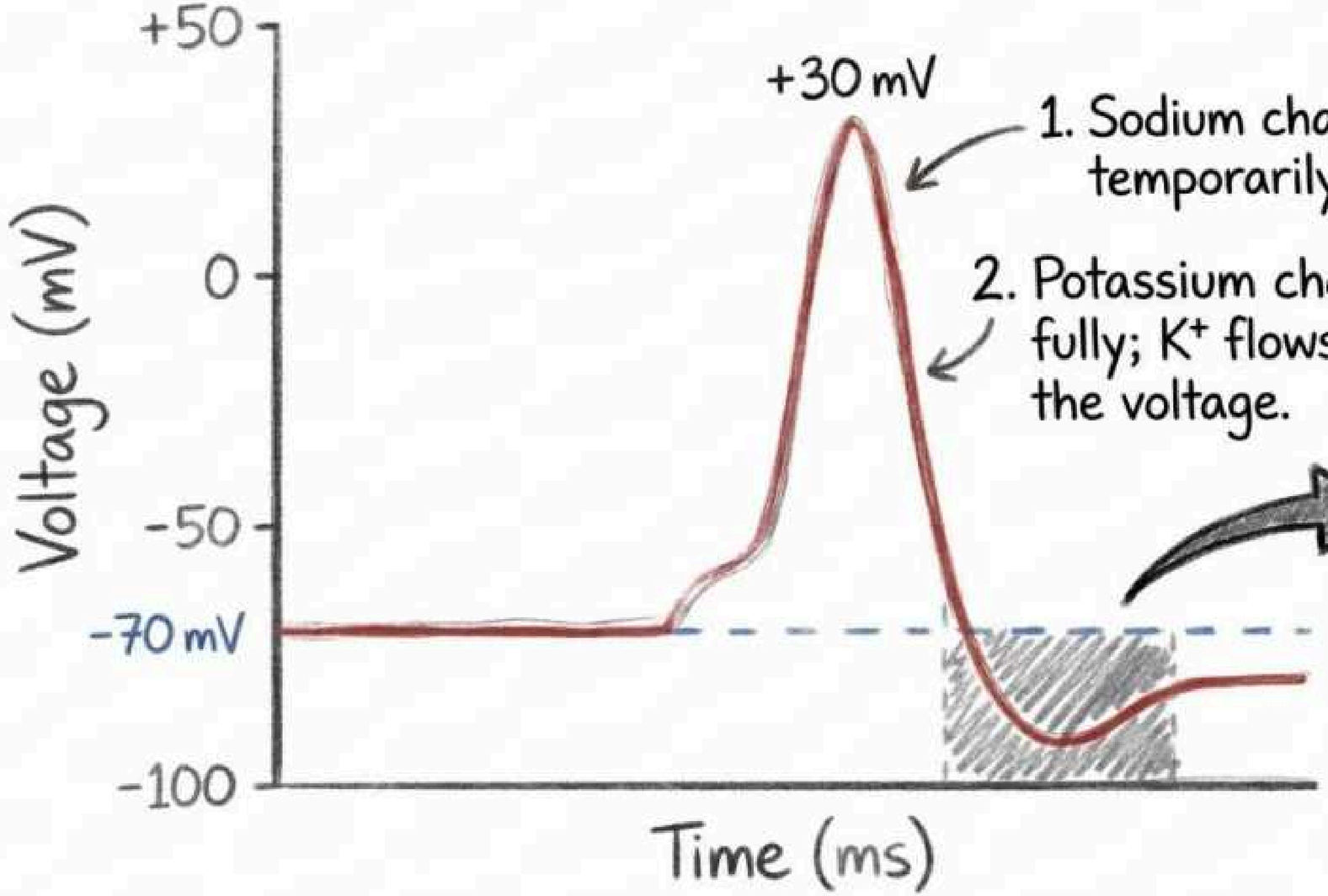
The Action Potential (Spike)



Note: The entire upward spike takes roughly 1 millisecond.

¶ 2.7

The Reset & Refractory Period



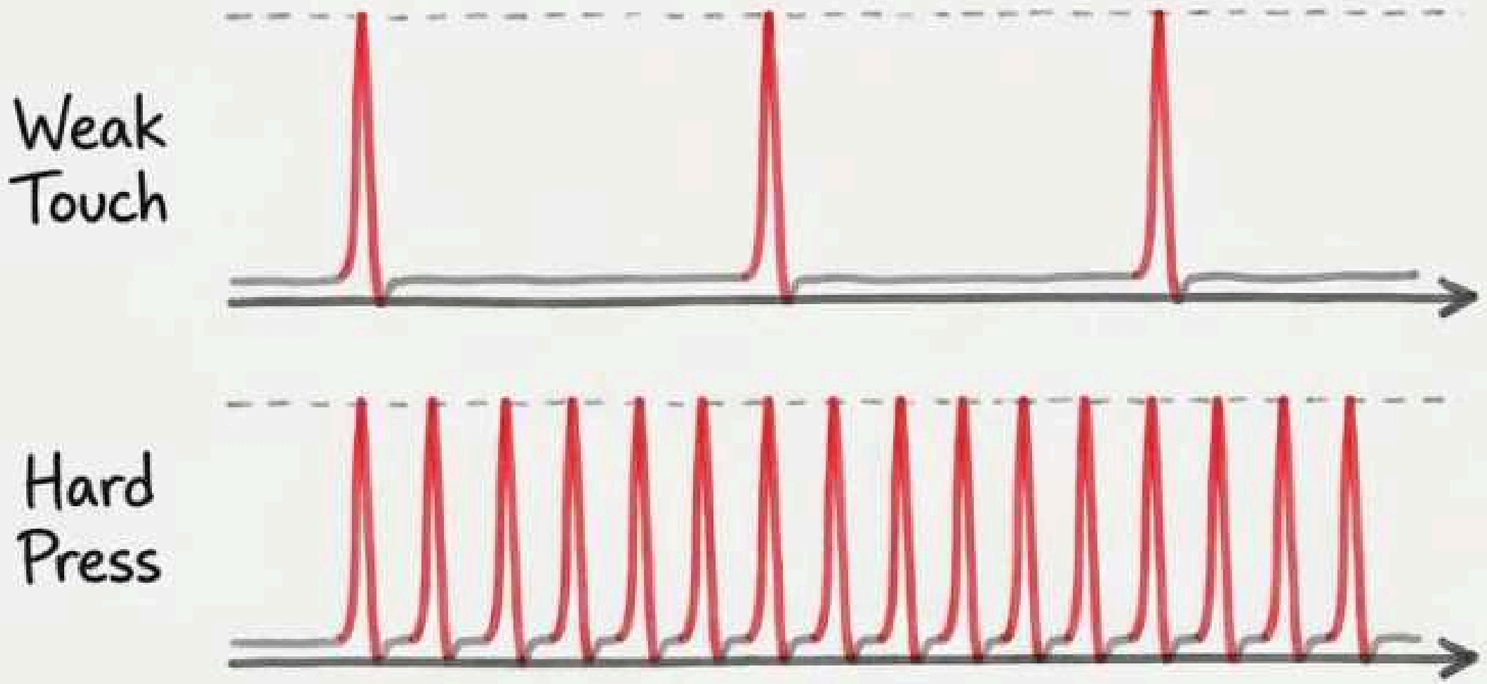
1. Sodium channels close and temporarily deactivate.

2. Potassium channels open fully; K^+ flows out, dropping the voltage.

Refractory Period: The neuron cannot fire again immediately. This forces the signal to travel in only one direction and places a hard speed limit on firing.

¶ 2.8

The All-or-None Law



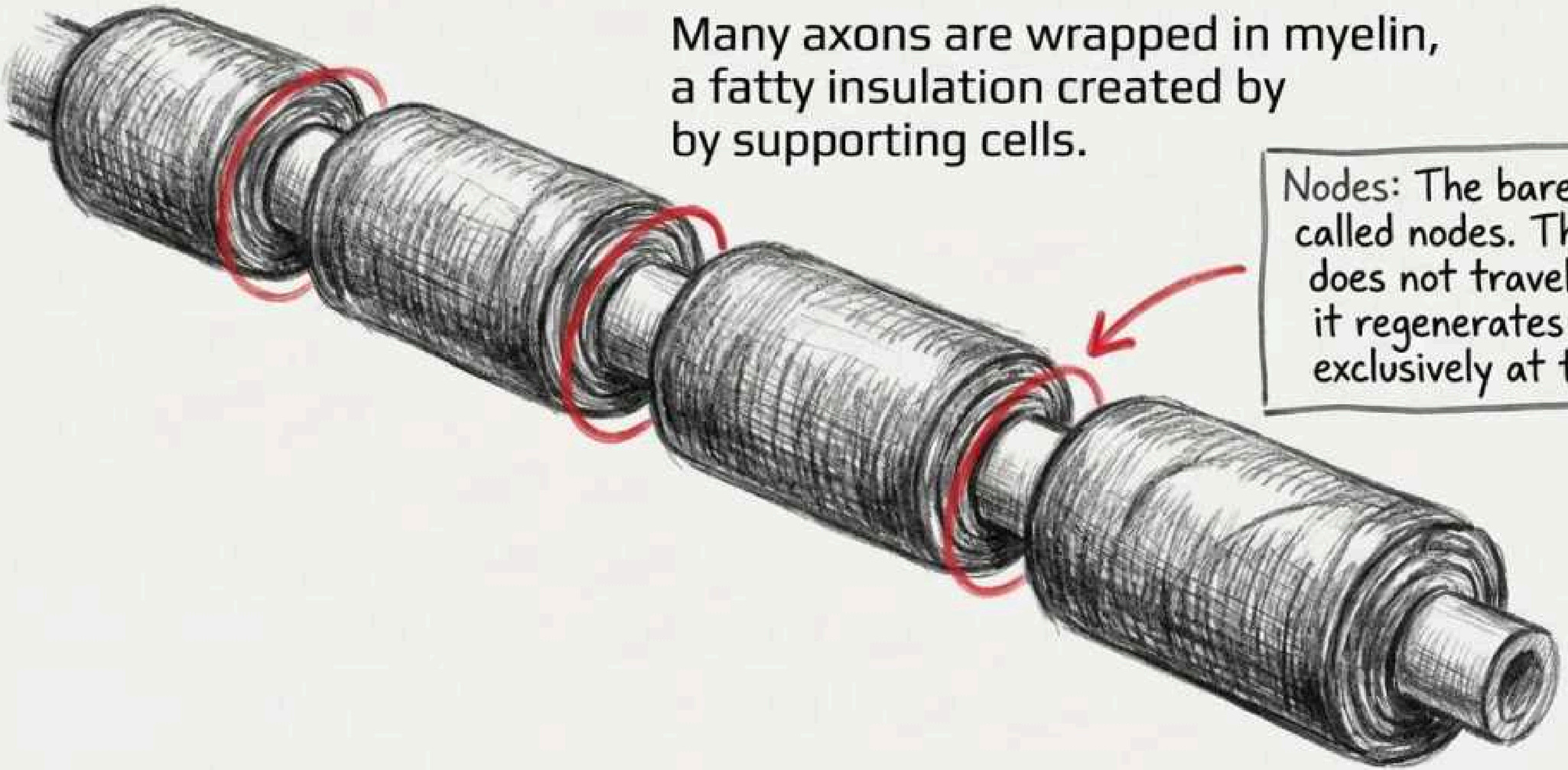
- A stimulus below threshold produces nothing.
- A stimulus above threshold produces a full spike, always the exact same size.

Key Insight: Intensity is not signaled by the size of the spike, but by the speed of the firing (e.g., a few spikes per second vs. hundreds).

¶ 2.9

Myelin and Insulation

Many axons are wrapped in myelin, a fatty insulation created by by supporting cells.



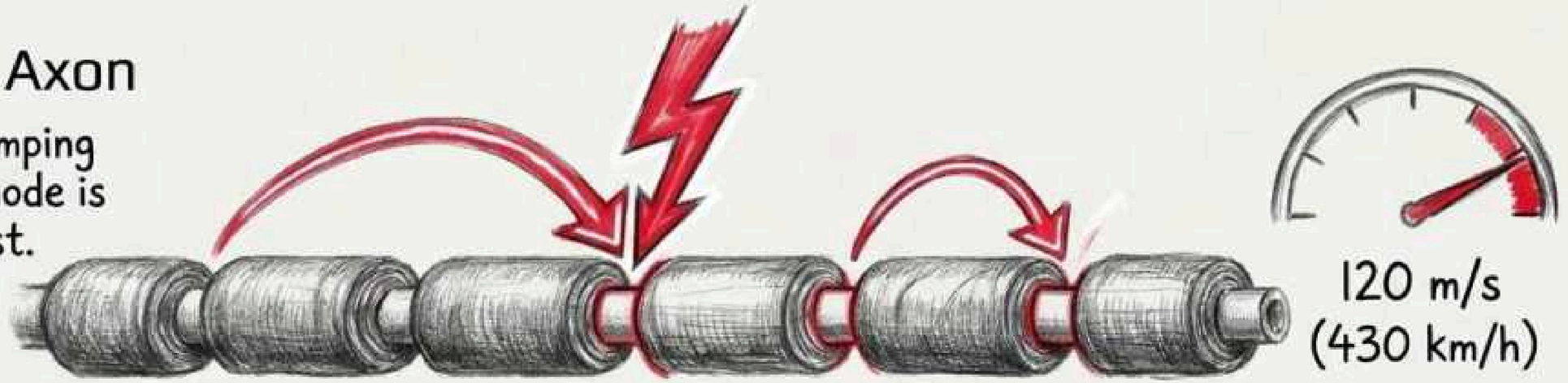
Nodes: The bare gaps are called nodes. The signal does not travel smoothly; it regenerates itself exclusively at these gaps.

¶ 2.10

Saltatory Conduction (Speed)

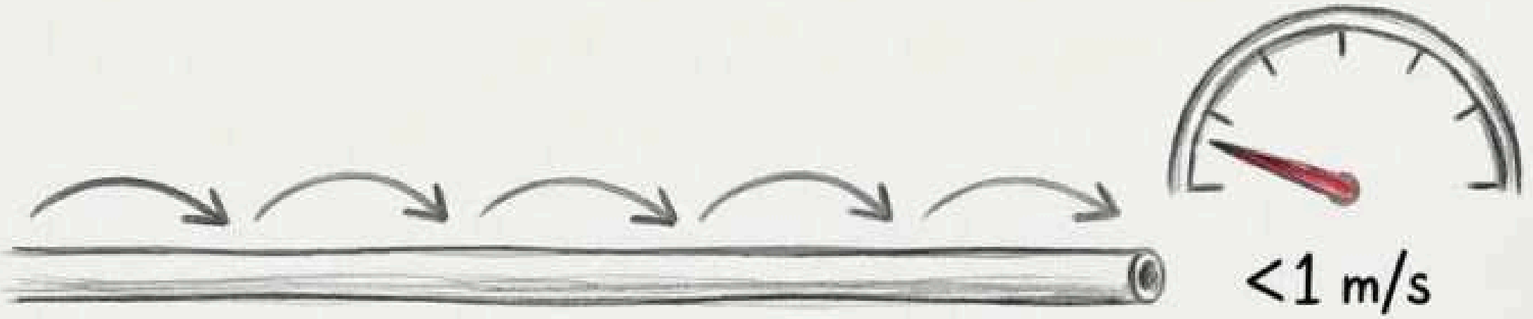
Myelinated Axon

The impulse jumping from node to node is blisteringly fast.

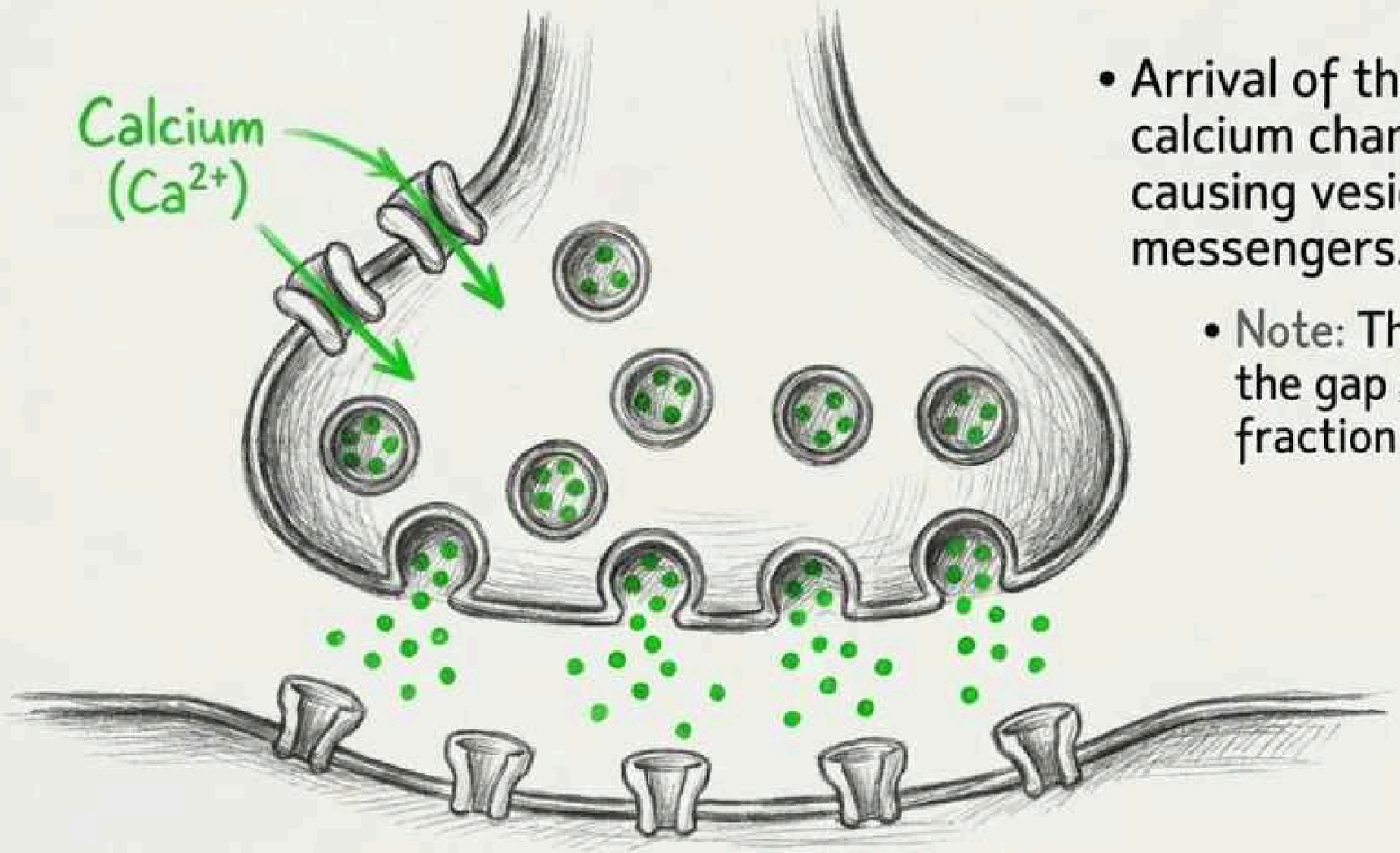


Unmyelinated Pain Fiber

Clinical Note: Multiple Sclerosis. The immune system damages the myelin, causing signal conduction to drastically slow down or fail completely.

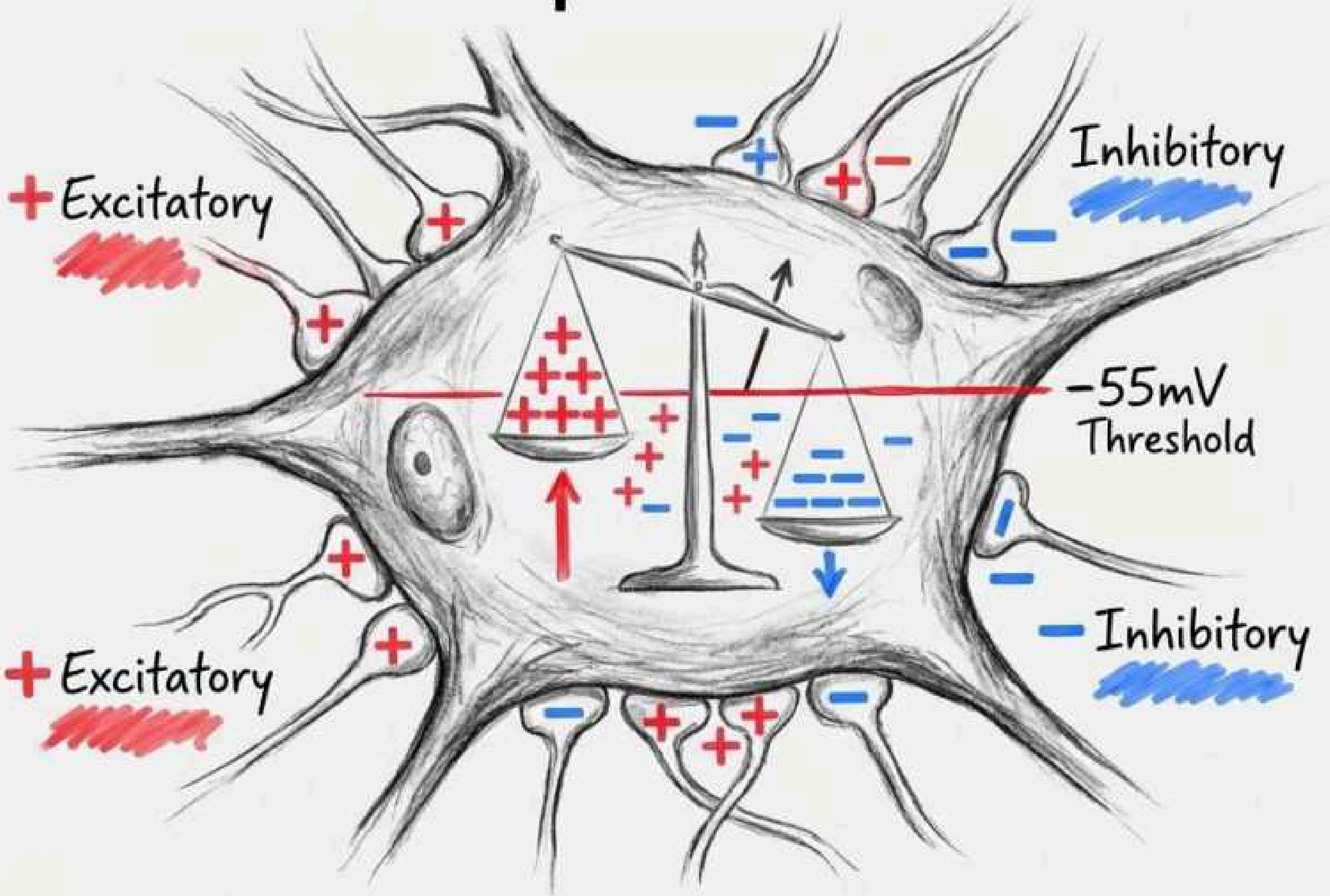


The Synapse



- Arrival of the action potential opens calcium channels. Ca^{2+} floods in, causing vesicles to release chemical messengers.
    - Note: The neurotransmitters cross the gap and bind to receptors in a fraction of a millisecond.

Neural Computation



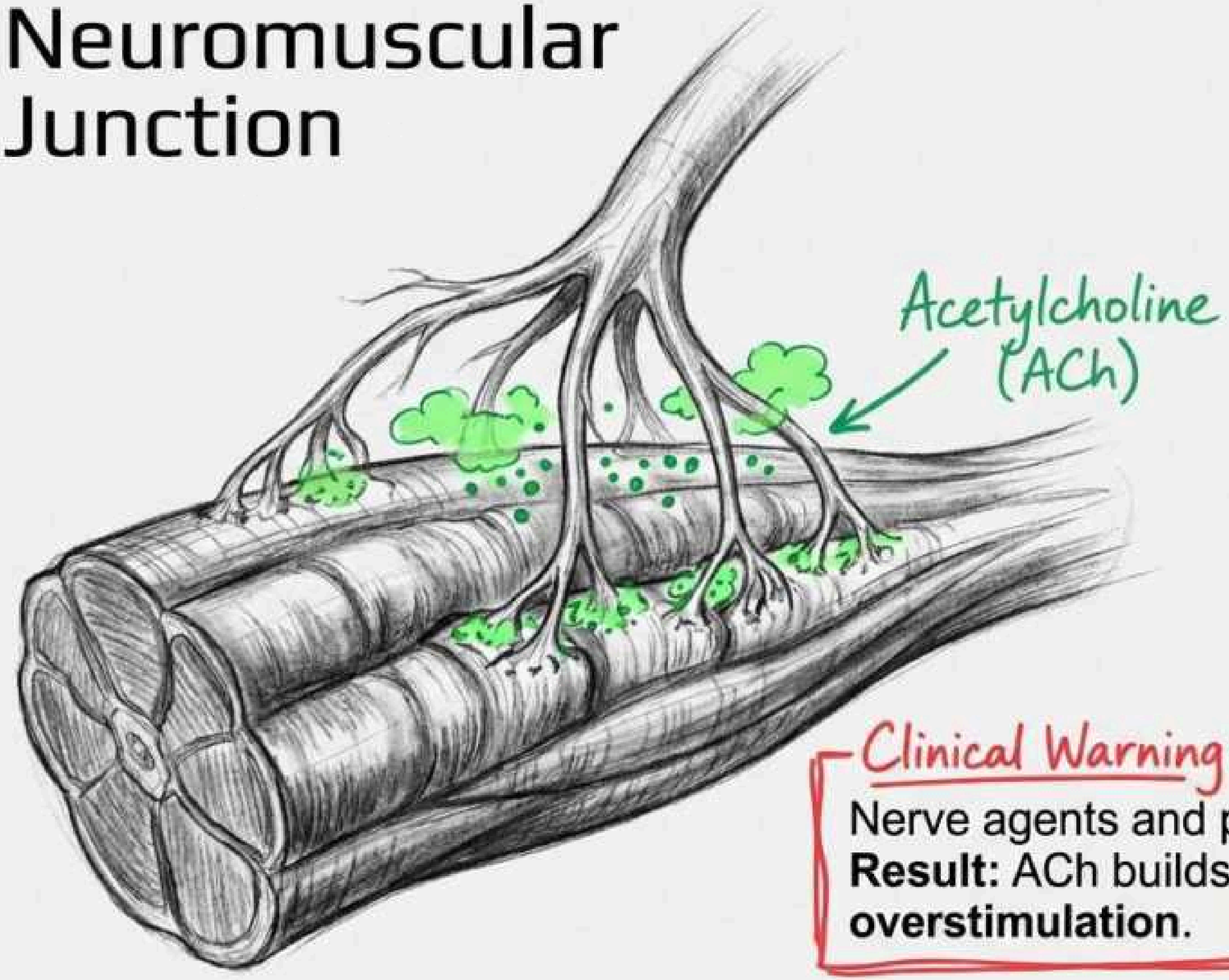
- Excitatory inputs push voltage toward threshold.
- Inhibitory inputs push it away.

The Math of the Mind

A single neuron sums up inputs from up to 10,000 other cells. It fires only if the grand total breaches the threshold.

Neuromuscular Junction

¶ 2.13



Key Player:
Acetylcholine (ACh) triggers the muscle action potential.

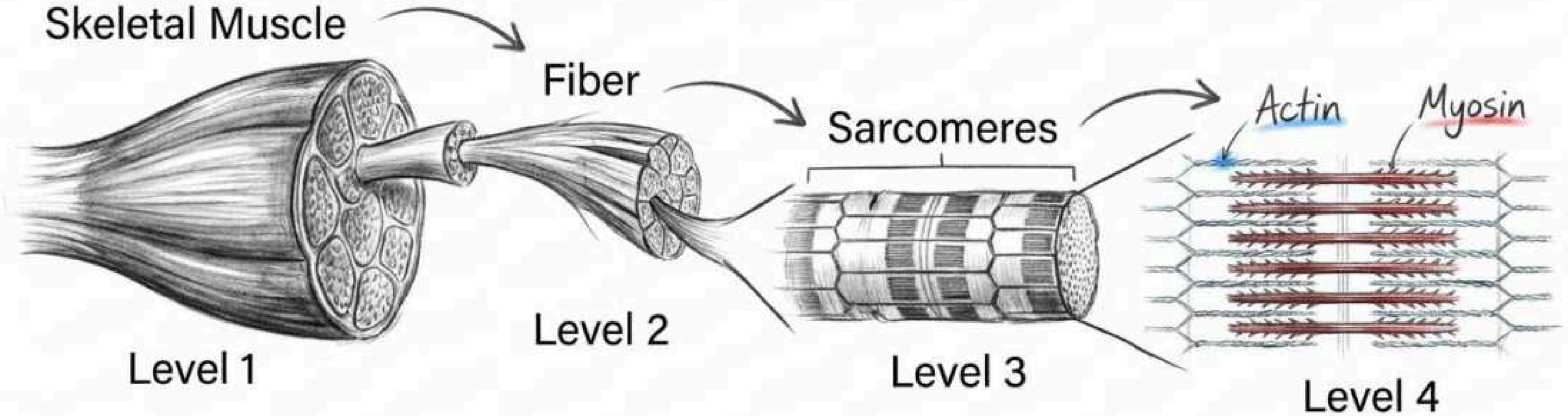
An enzyme, **Acetylcholinesterase**, instantly breaks ACh down to keep signals brief.

Clinical Warning:

Nerve agents and pesticides block the enzyme.
Result: ACh builds up, leading to fatal **muscle overstimulation**.

Muscle Architecture

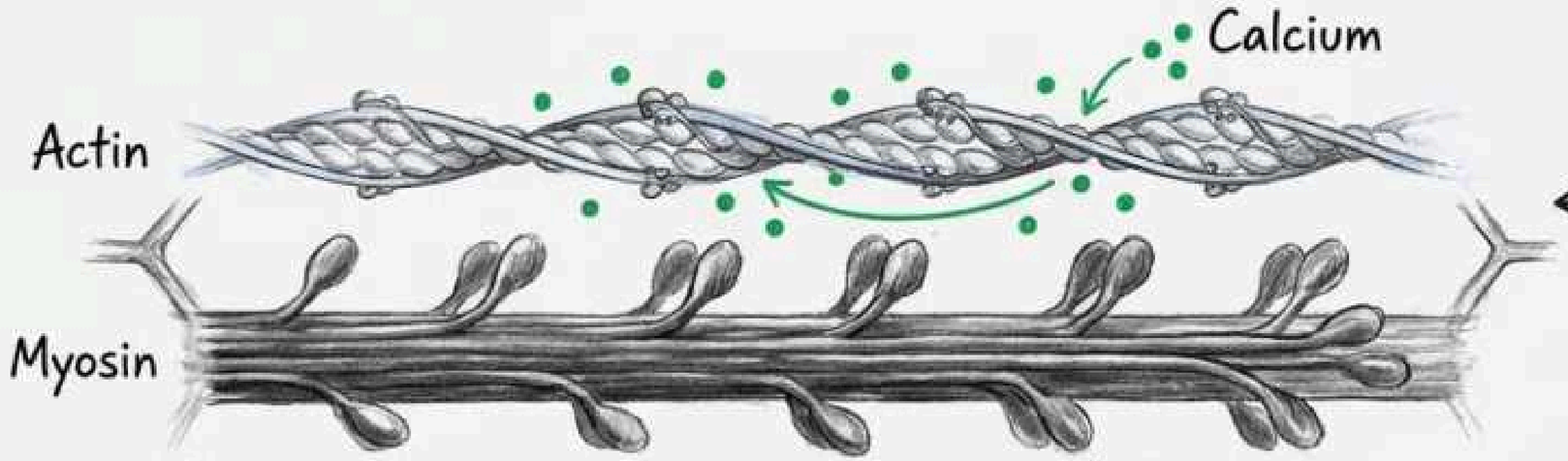
¶ 2.14



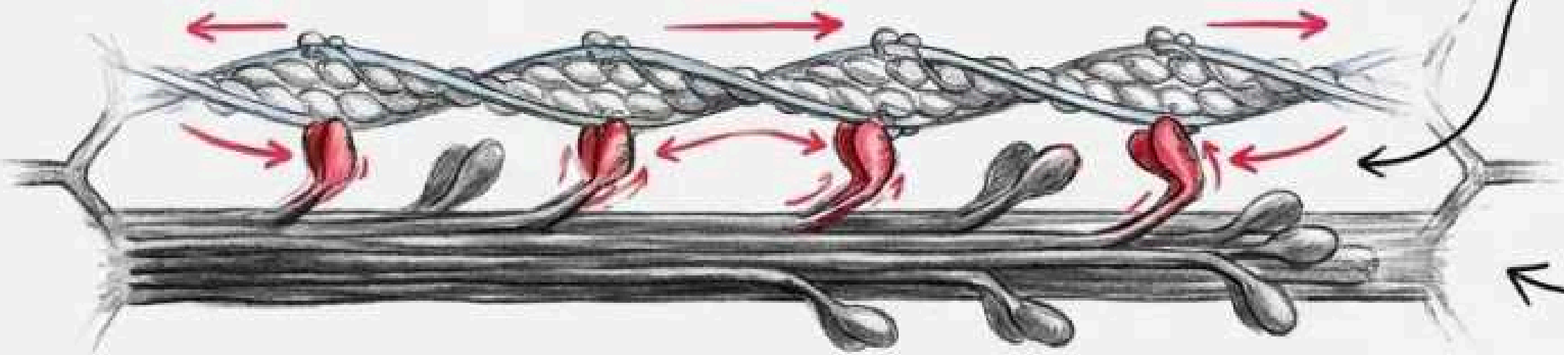
Skeletal muscle gets its distinct striped look under a microscope entirely from the precise, repeating arrangement of actin and myosin proteins.

The Sliding Filament Model

¶ 2.15



Step 1: Calcium unlocks the mechanism (binding to troponin to uncover actin).



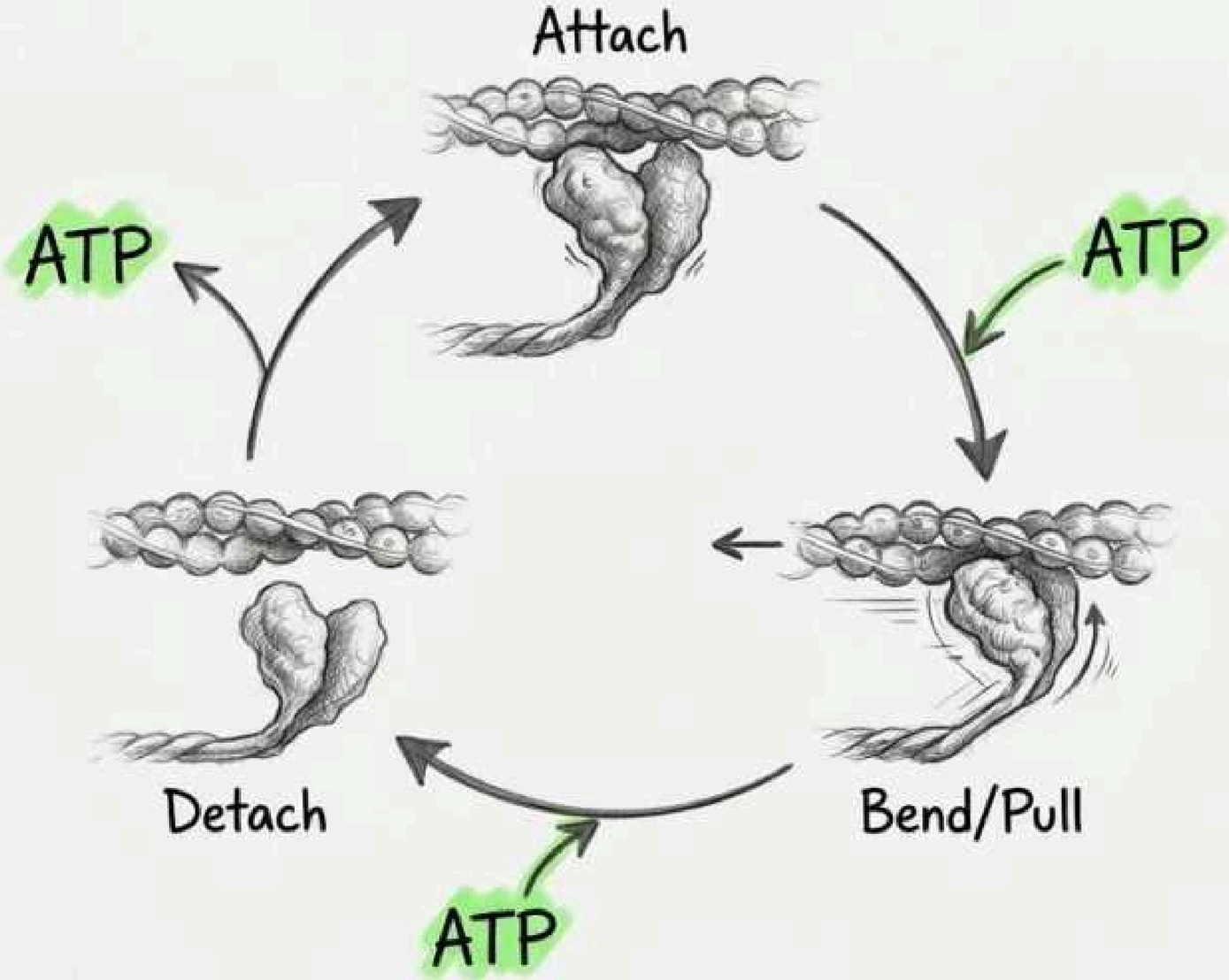
Step 2: Thick Myosin heads attach to the thin Actin strand, bend, and physically pull it inward. The sarcomere shortens.

Metaphor

The myosin heads detach and reattach repeatedly, pulling the actin inward like hands pulling a rope hand-over-hand.

The Role of ATP (and Death)

¶ 2.16



Cellular energy (ATP) is strictly required to power the bending of the head, AND to detach it afterward.

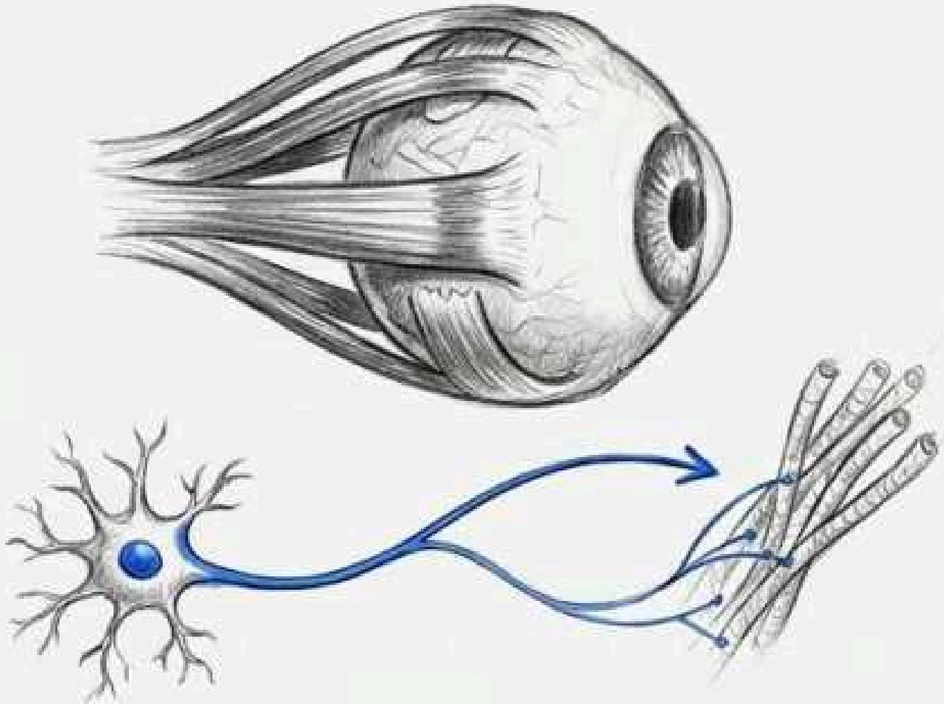
Rigor Mortis: After death, ATP runs out. Myosin stays locked permanently onto actin. Muscles stiffen until the proteins physically break down days later.

Motor Units & Control

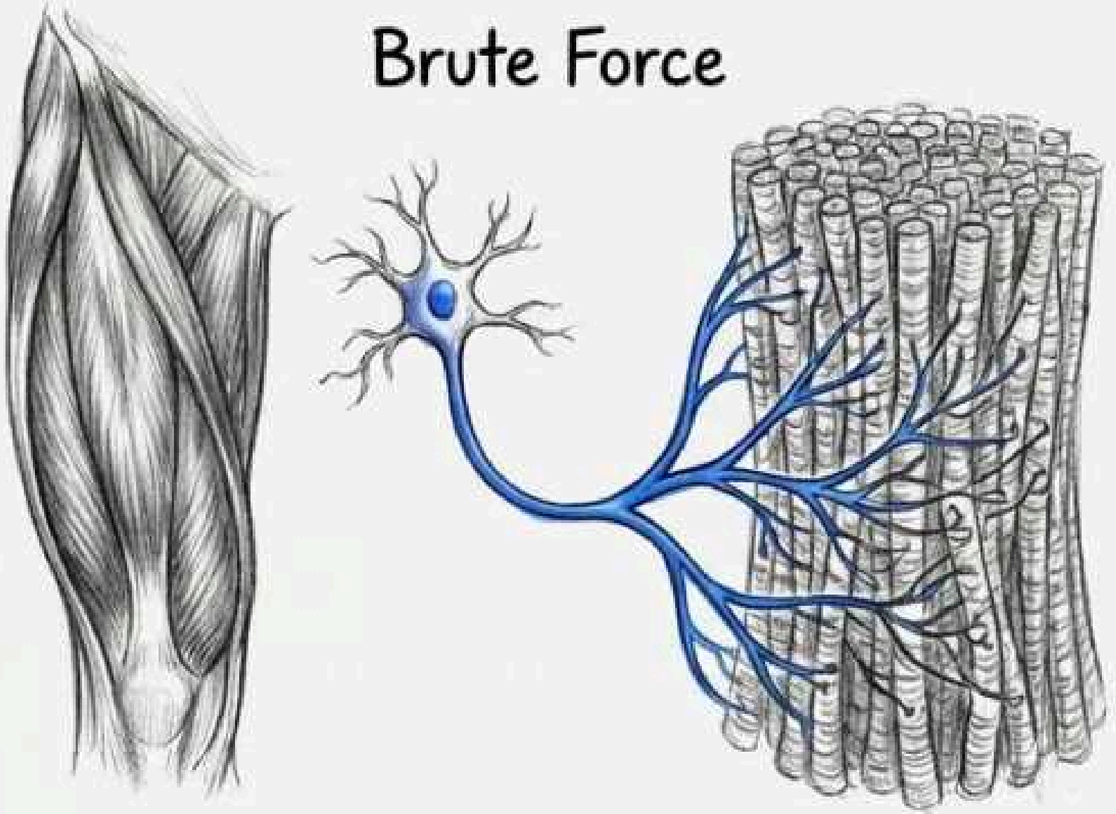
¶ 2.17

A motor unit = one motor neuron + the fibers it controls.

Precision



Brute Force



Precision: 1 neuron connects to <10 muscle fibers.

Tactics: To increase force, the brain recruits more units. To sustain force without fatigue, the brain **rotates** which units are active.

Brute Force: 1 neuron connects to 1,000+ muscle fibers.

Muscle Fiber Types

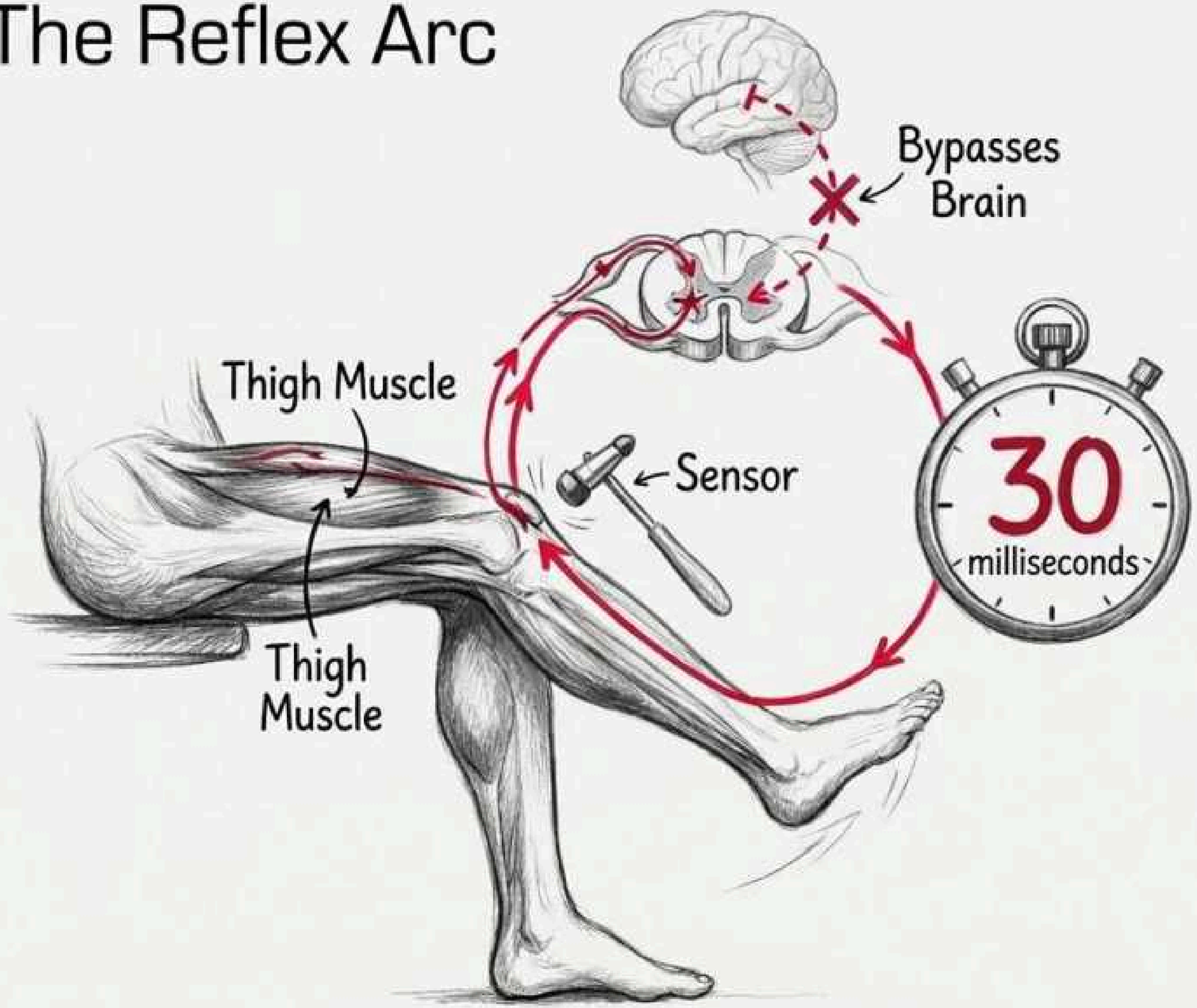
¶2.18

	Slow-Twitch Fibers	Fast-Twitch Fibers
Contraction Style	Gentle	Strong / Quick
Fatigue Resistance	High	Low
Oxygen Use	Efficient	Inefficient
Ideal Function	Posture / Marathons	Sprinting / Lifting

Training shifts the balance slightly, but your baseline mix of fast-to-slow fibers is dictated by your genetics.

The Reflex Arc

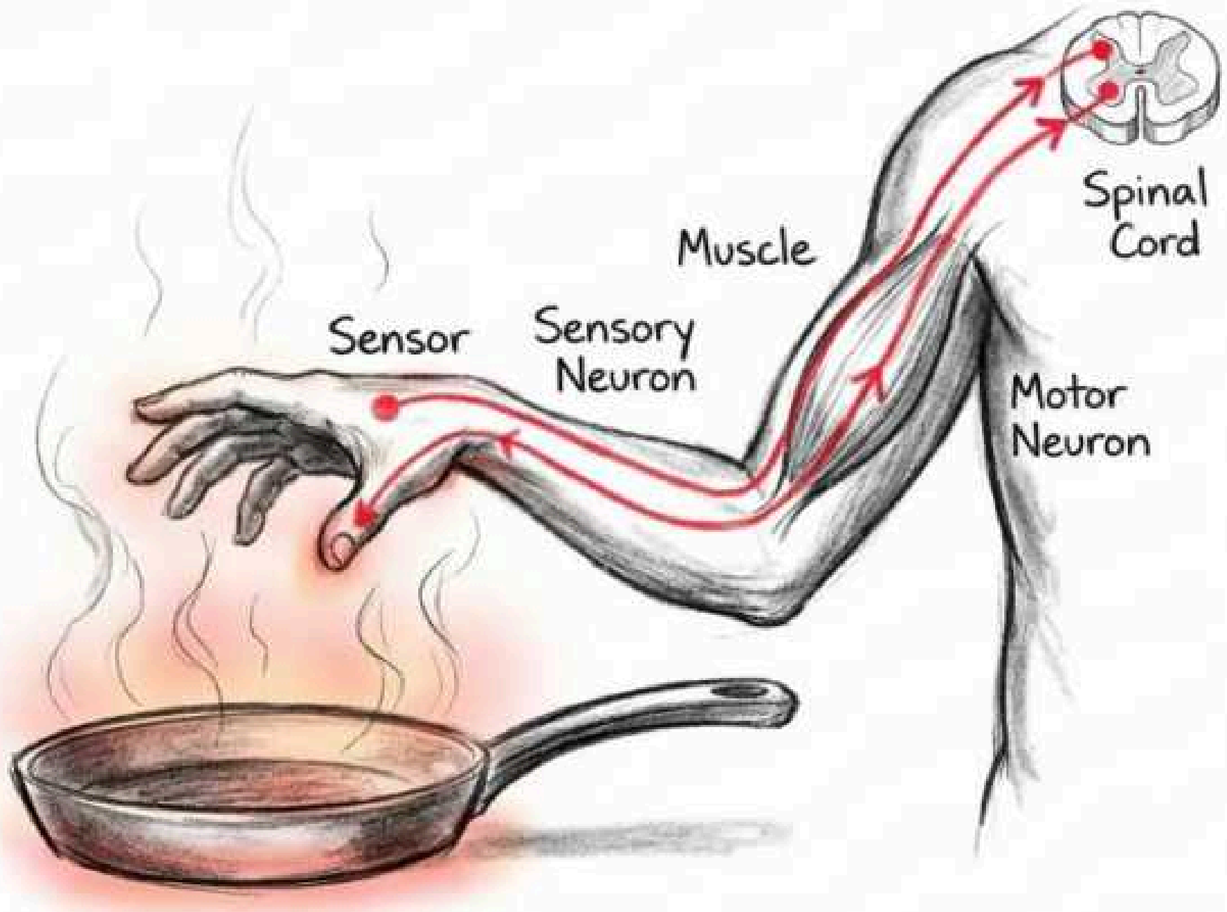
¶ 2.19



- Action without thought. A sensory neuron connects directly to a motor neuron in the spinal cord.
- The brain only learns about the kick after it has already happened.

Synthesis Challenge

¶2.20



Challenge

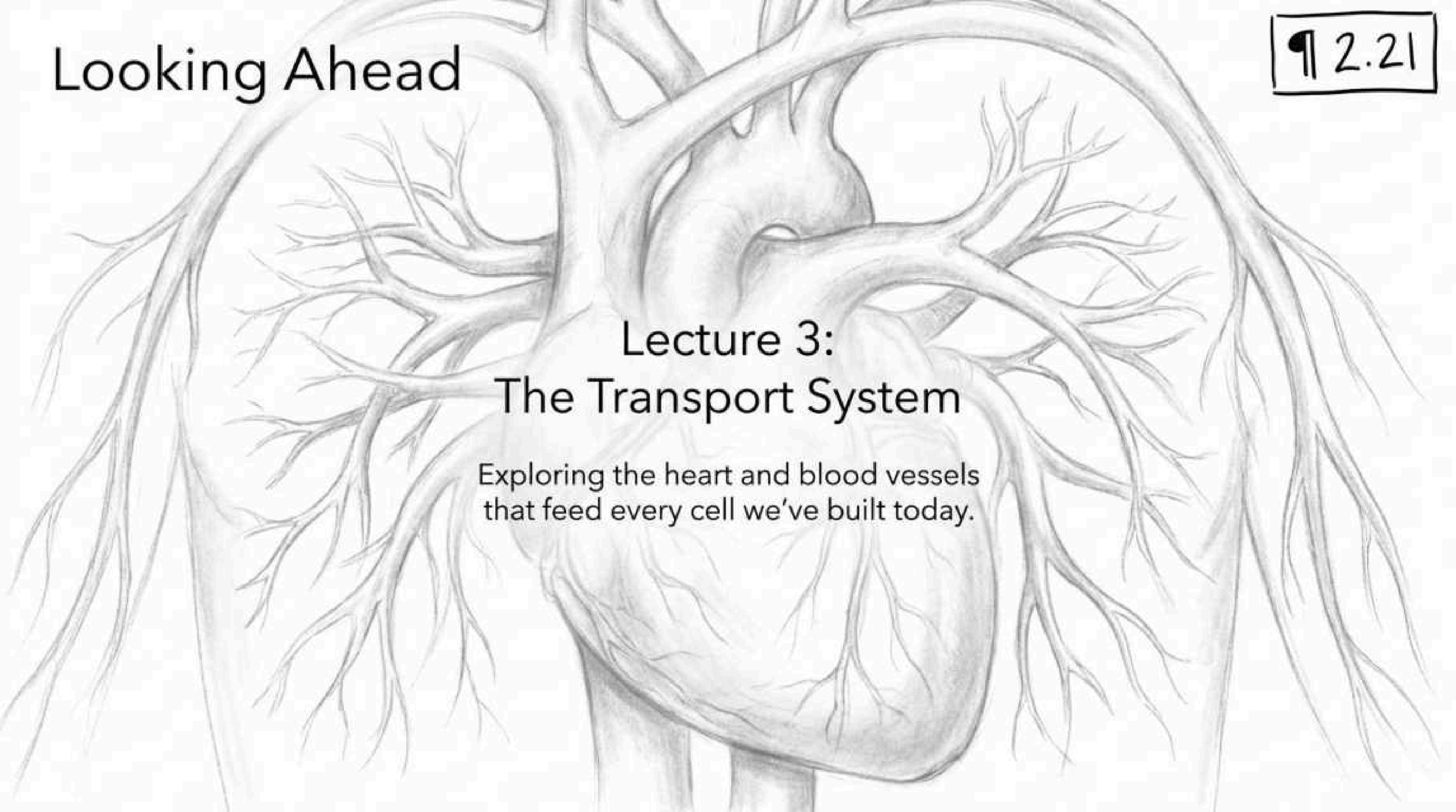
Trace the path of the signal from sensor to spinal cord to muscle.

1. Why is the reflex faster than conscious decision?
   Answer: It bypasses neural computation in the brain.

2. What feature of the axons makes it even faster?
   Answer: Heavy myelin insulation and large axon diameter for rapid saltatory conduction.

Looking Ahead

¶ 2.21



Lecture 3:
The Transport System

Exploring the heart and blood vessels
that feed every cell we've built today.