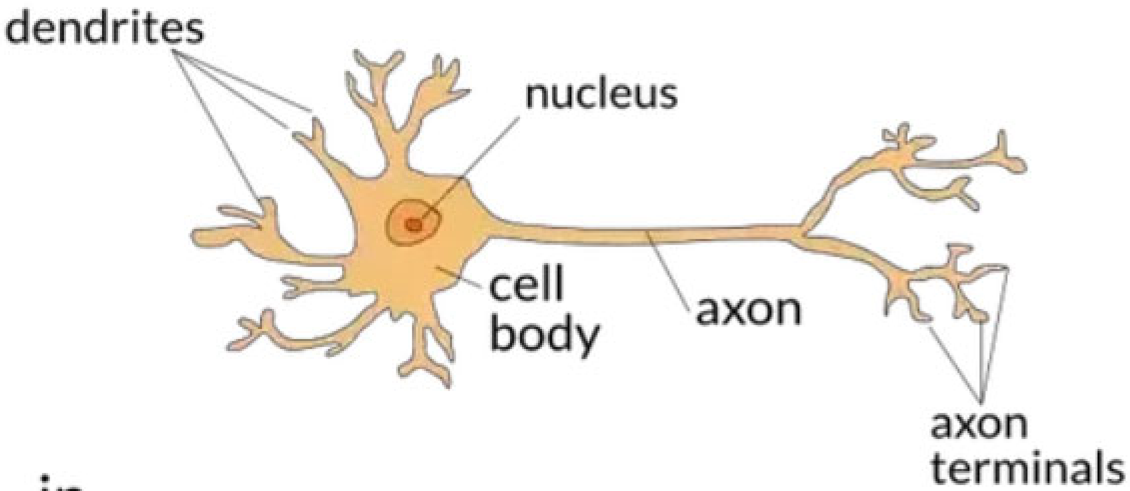
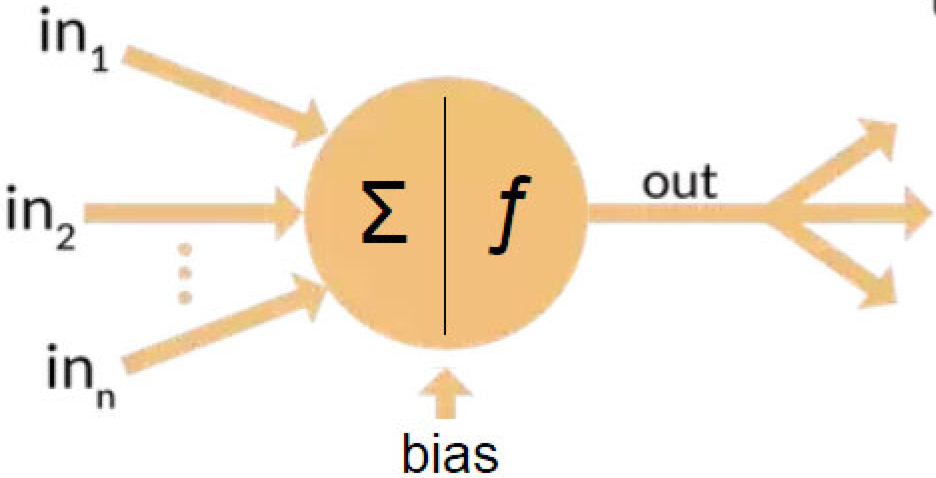
Machine Learning
Introduction to Neural Networks

Jian Liu

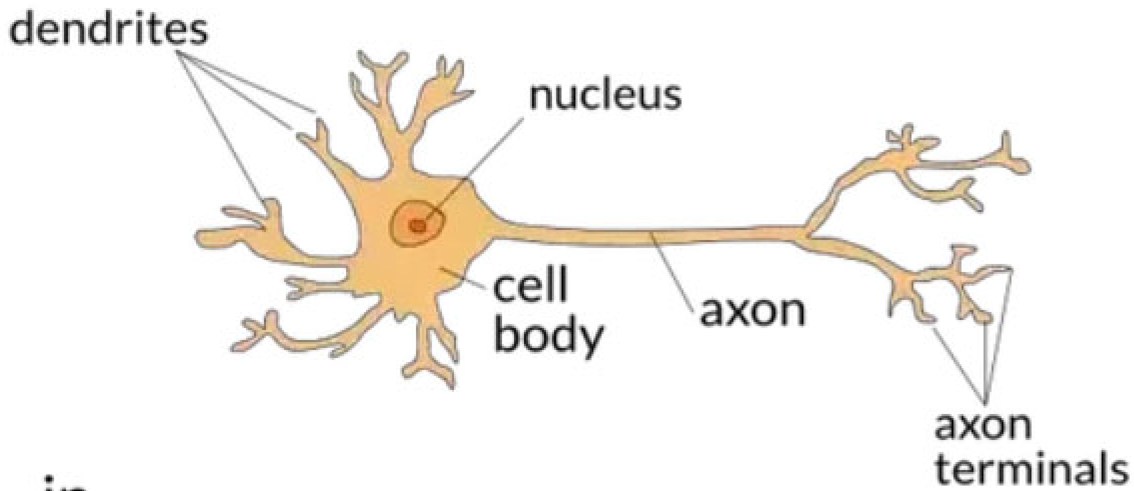




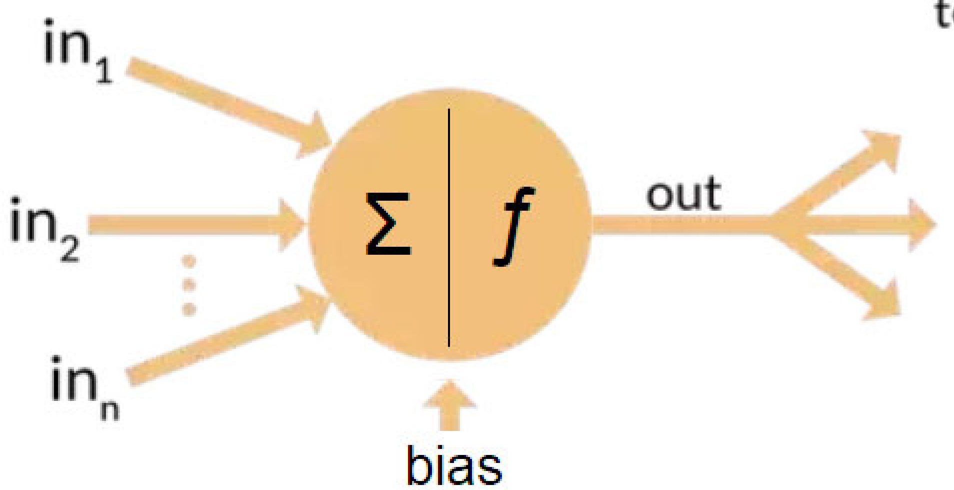
from towardsdatascience

Motivation for artificial neurons

Part 1:
Biological neurons

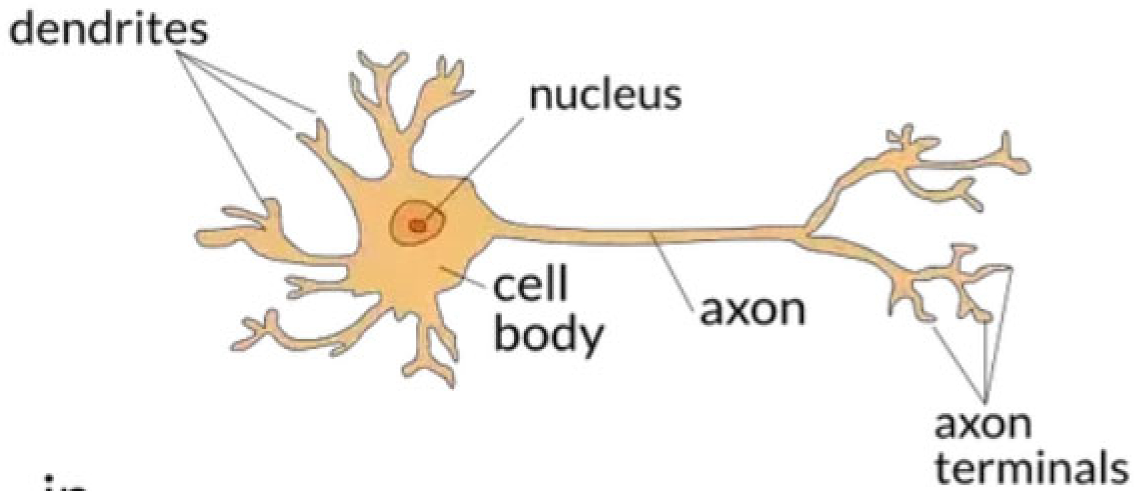


Part 2:
Artificial neurons

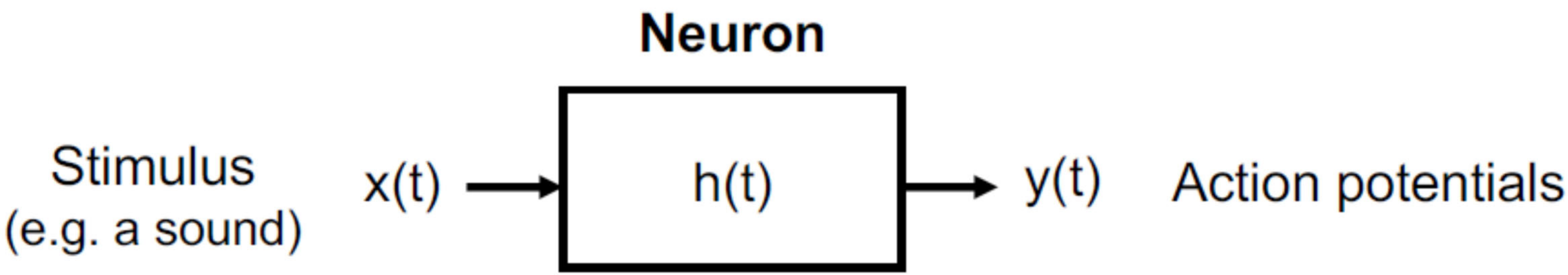


Motivation for artificial neurons

Part 1:
Biological neurons



Neuron as an information processor

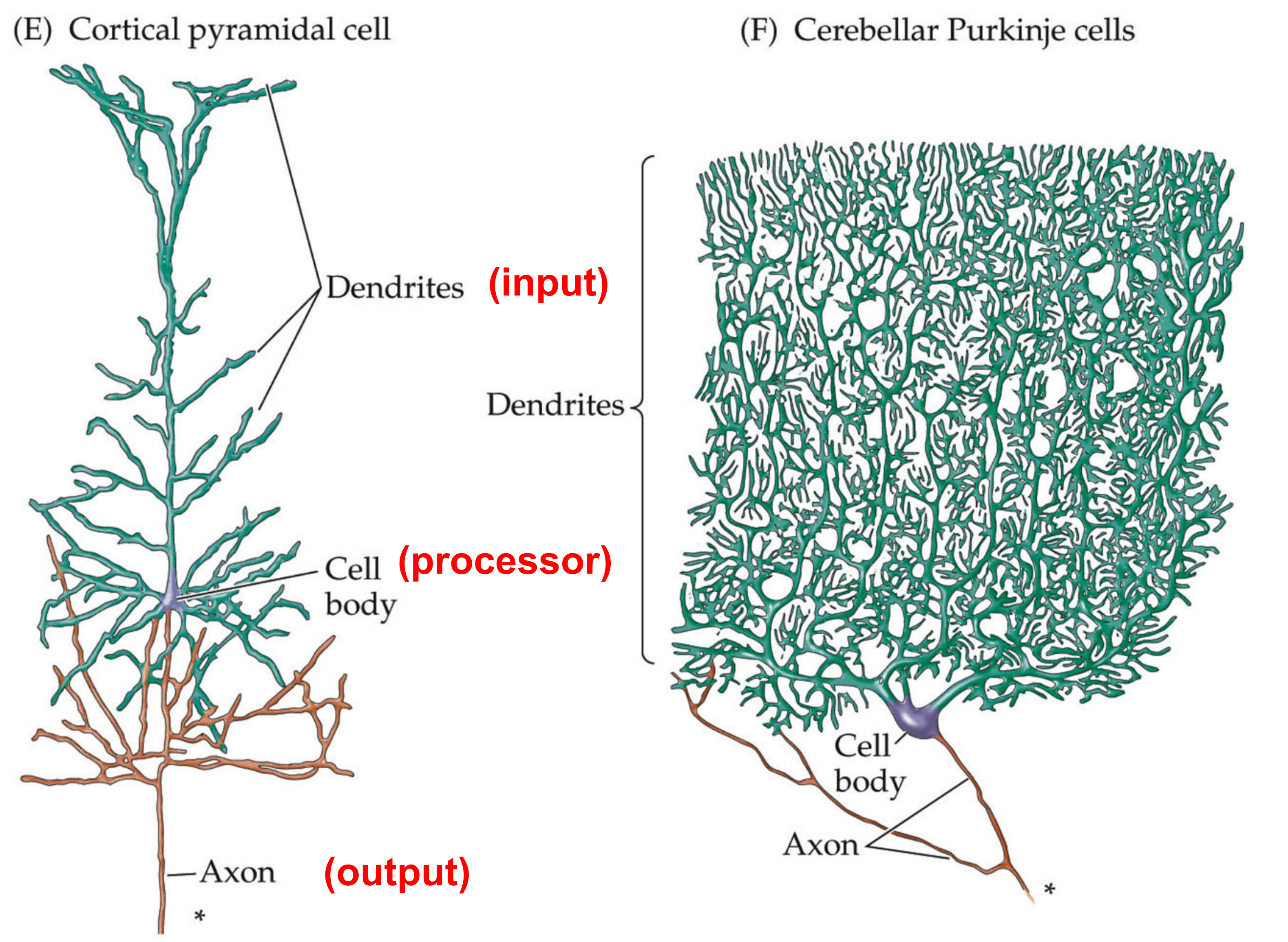


Neuron:

Structure: building block of the brain

Function: basic computational unit

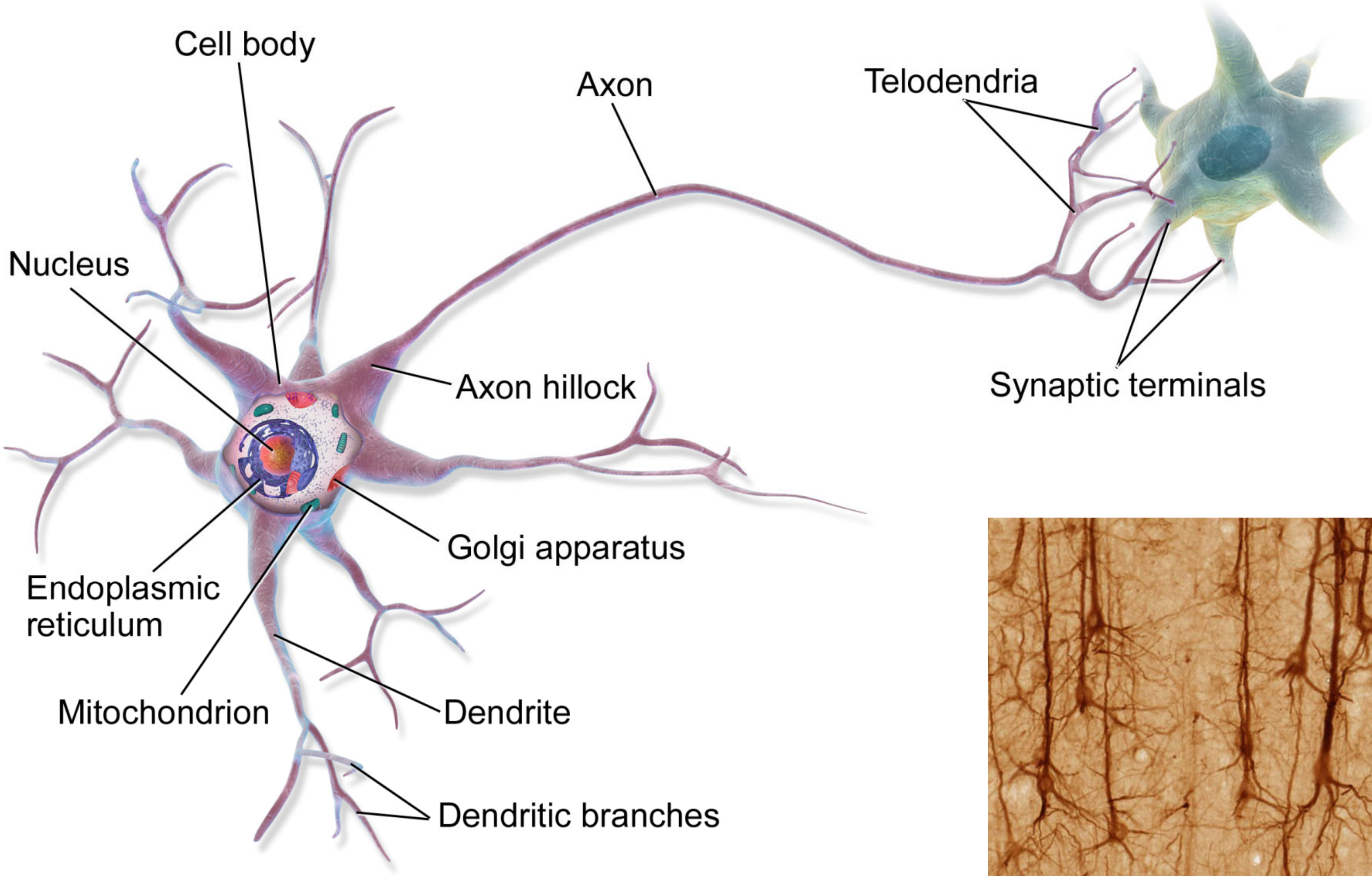
Neurons are building blocks of the brain



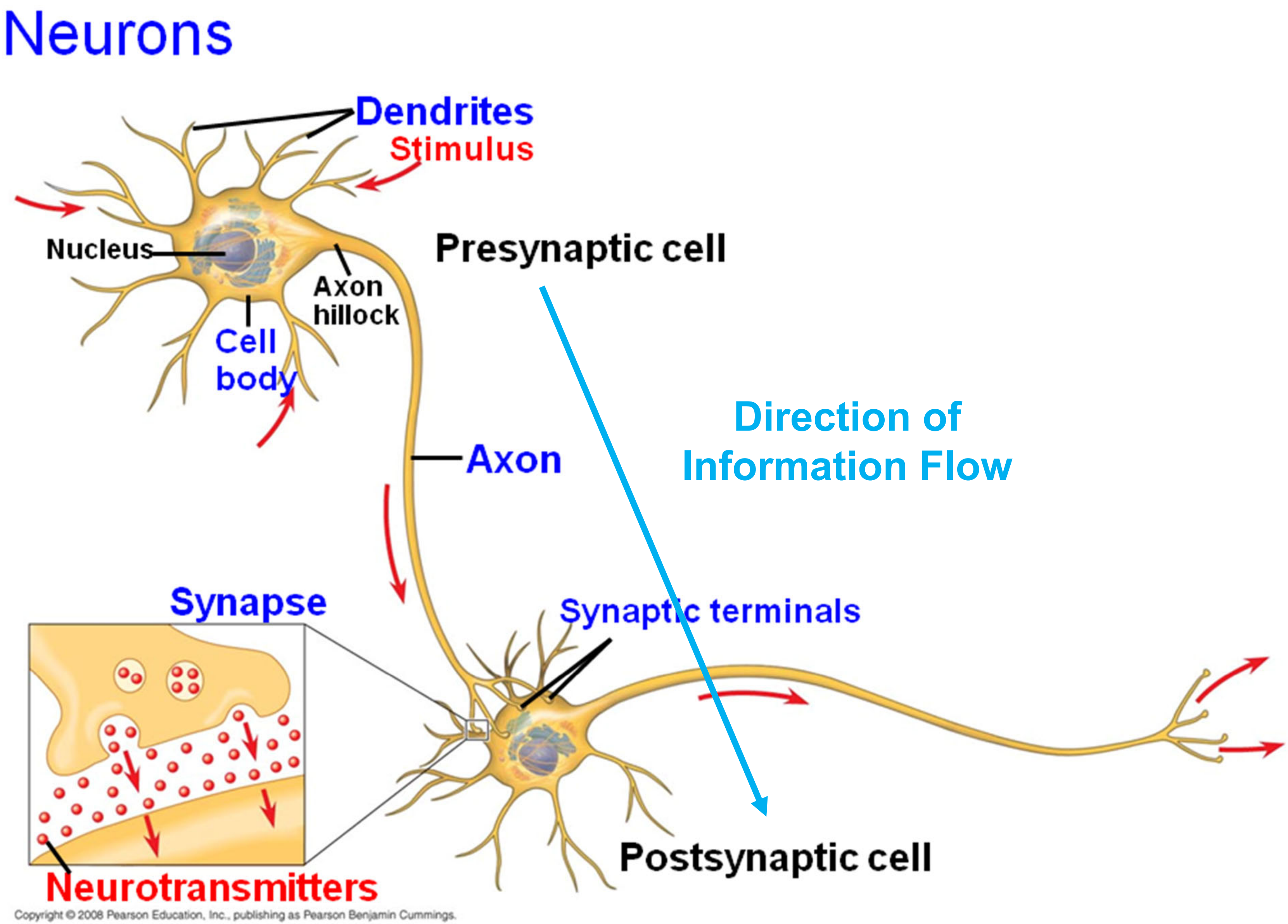
***NEUROSCIENCE*, *Fourth Edition*, Figure 1.2 (Part 2)**

Neurons generally have similar “input-processor-output” structures

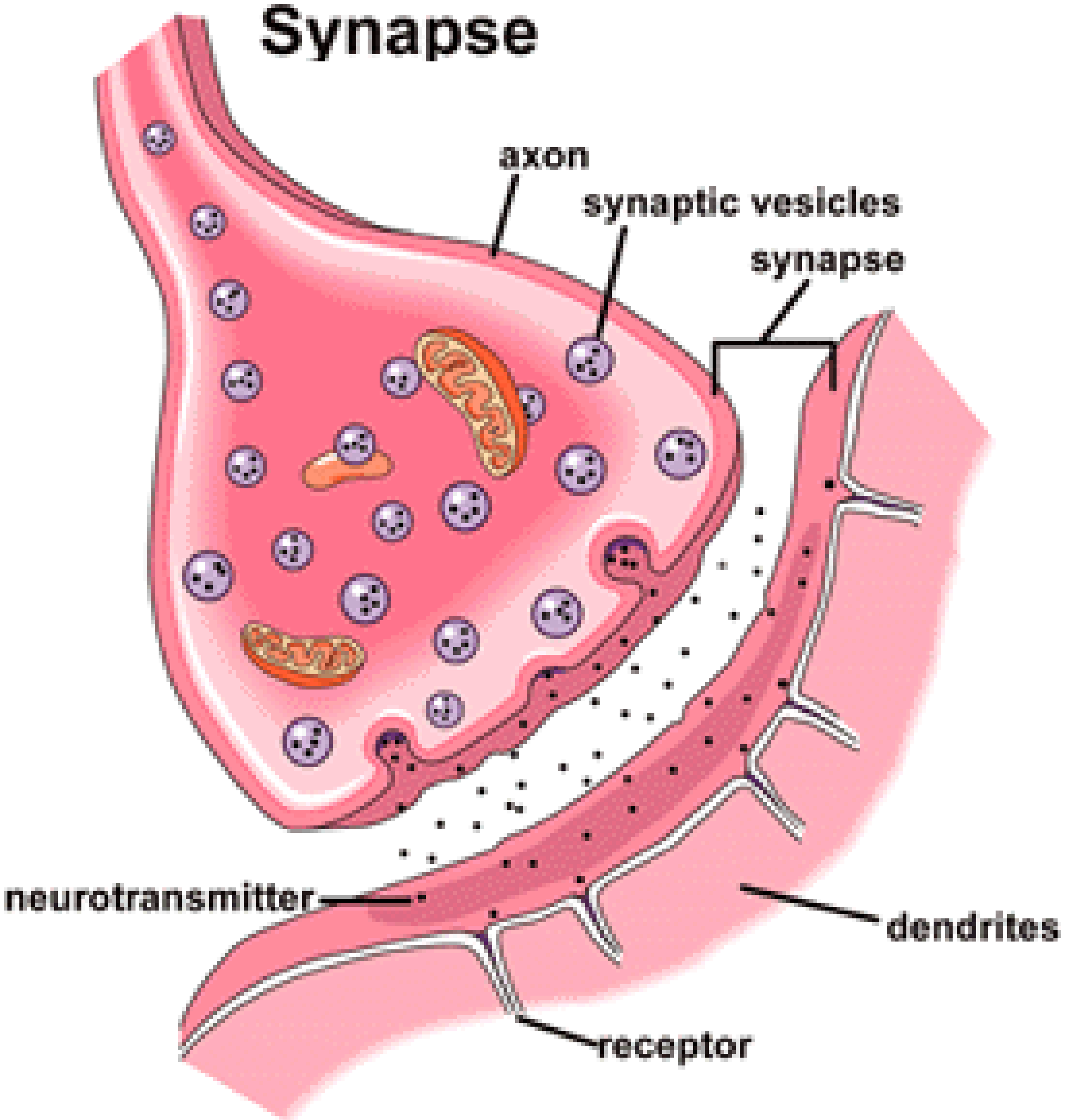
Structure of a typical neuron



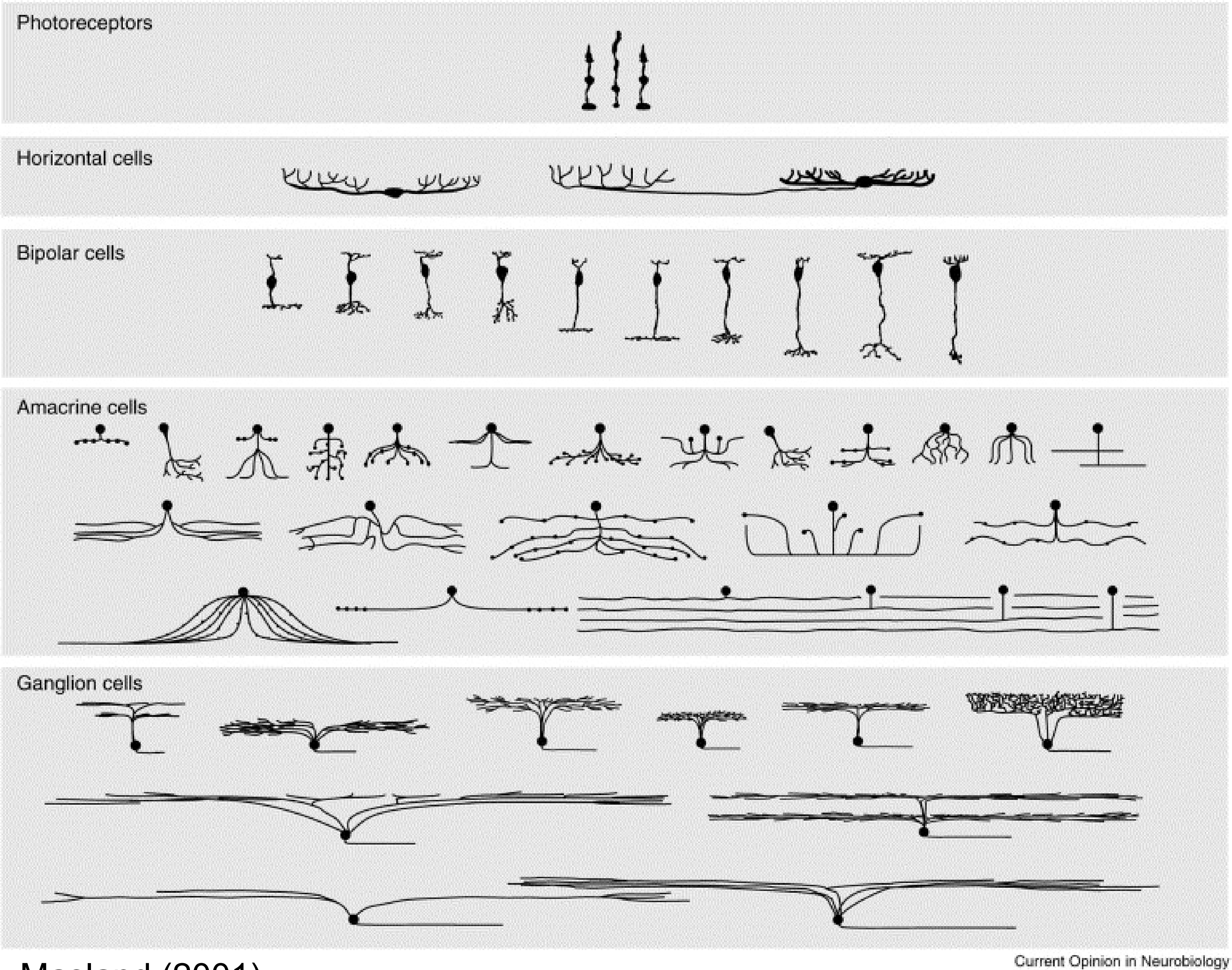
Neuronal information flow



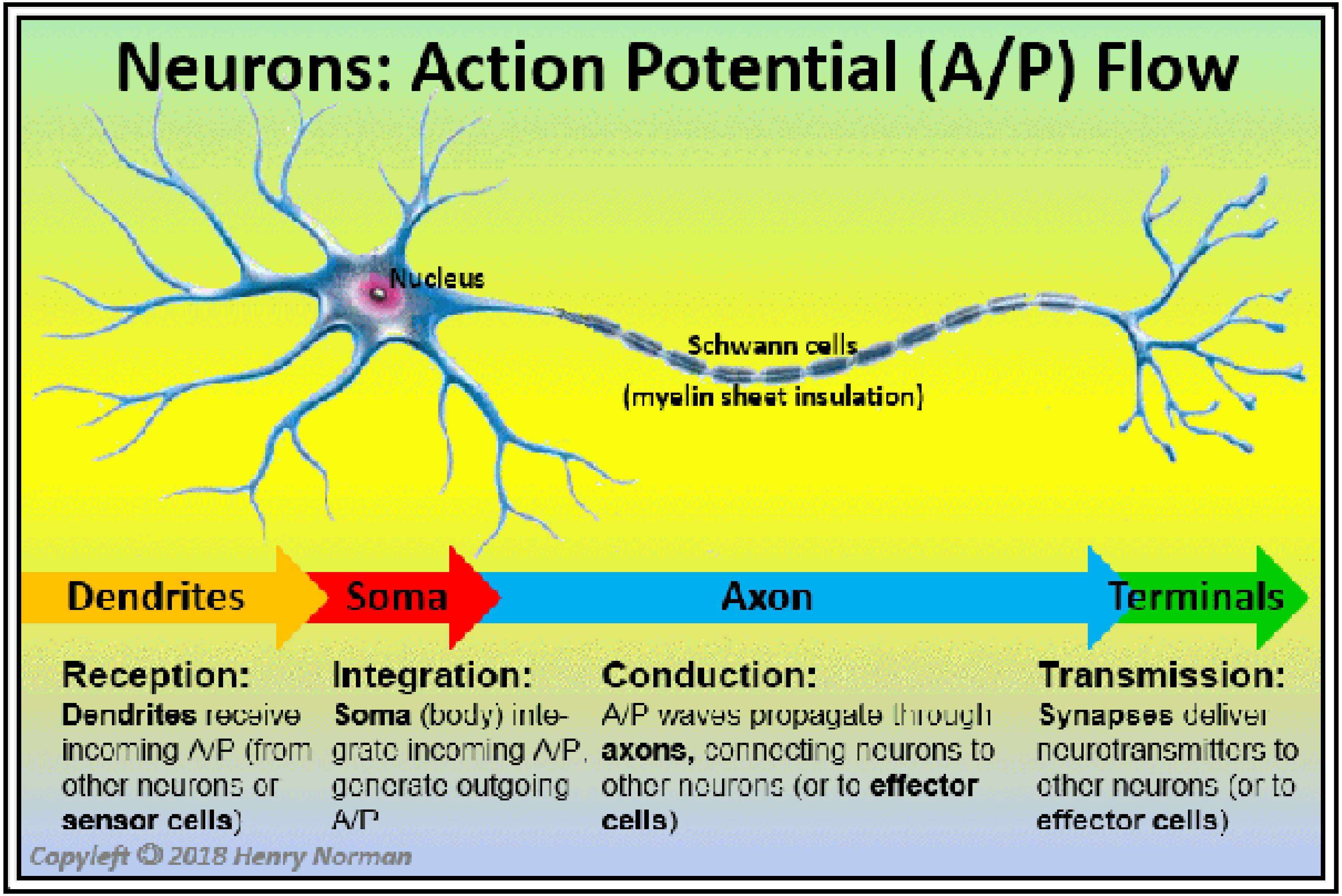
Synaptic weights



Retinal neurons

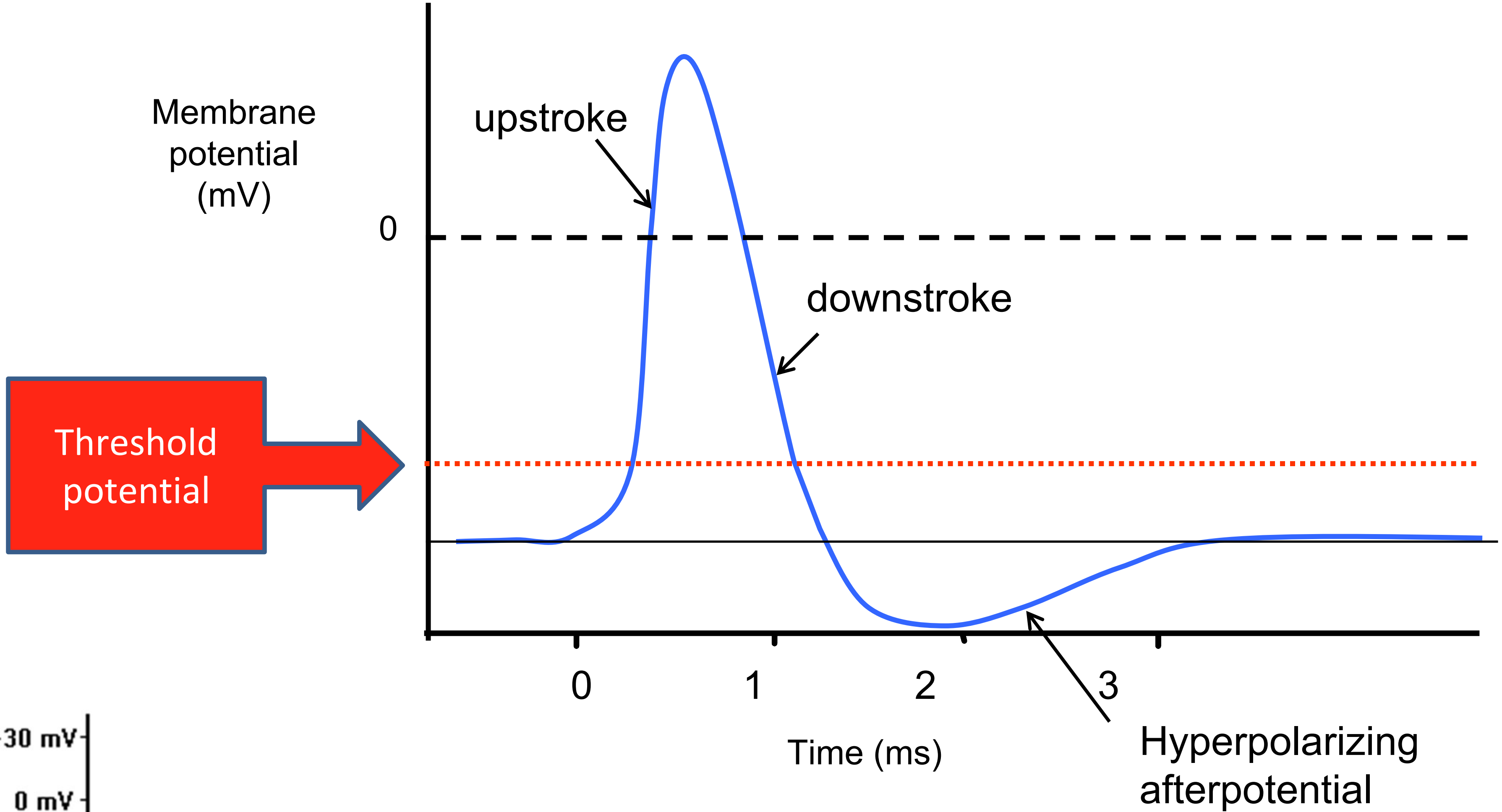


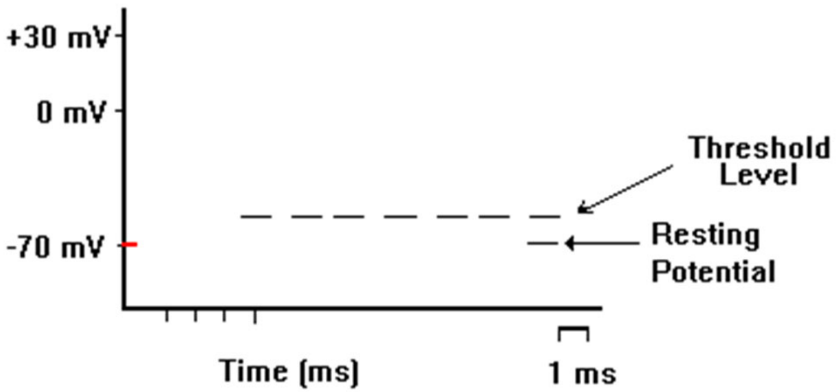
Masland (2001)



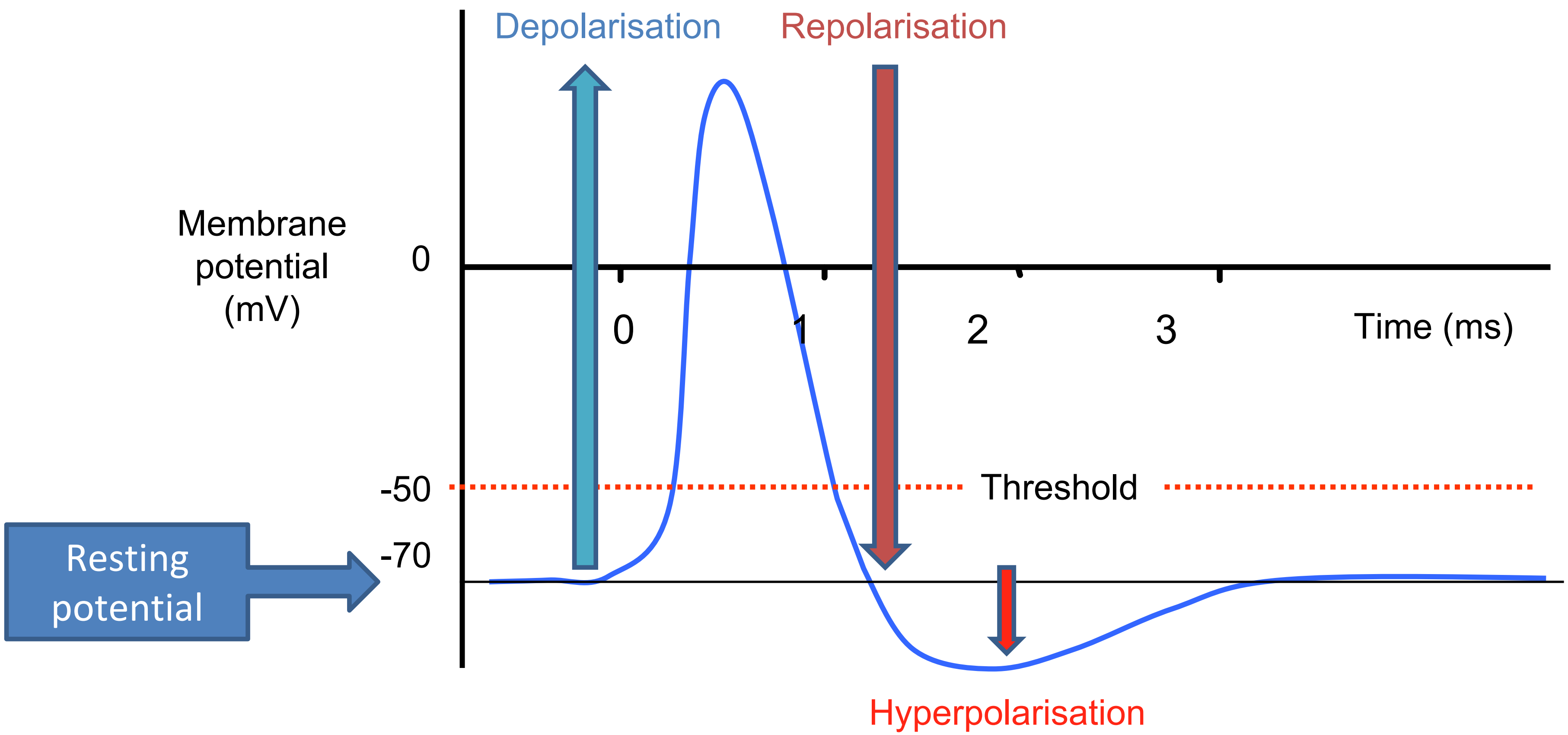
Structure → Function

The action potential



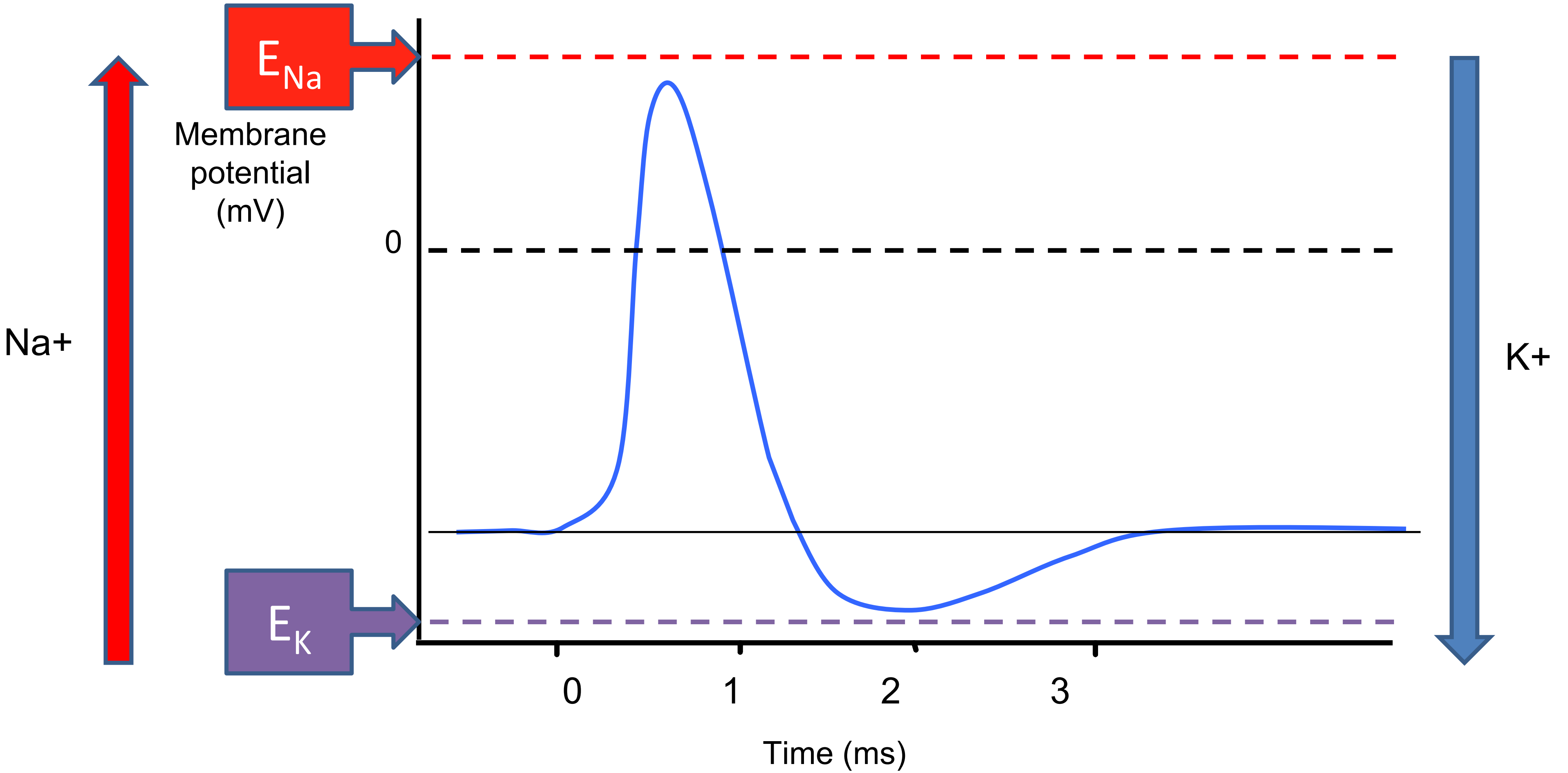


The action potential



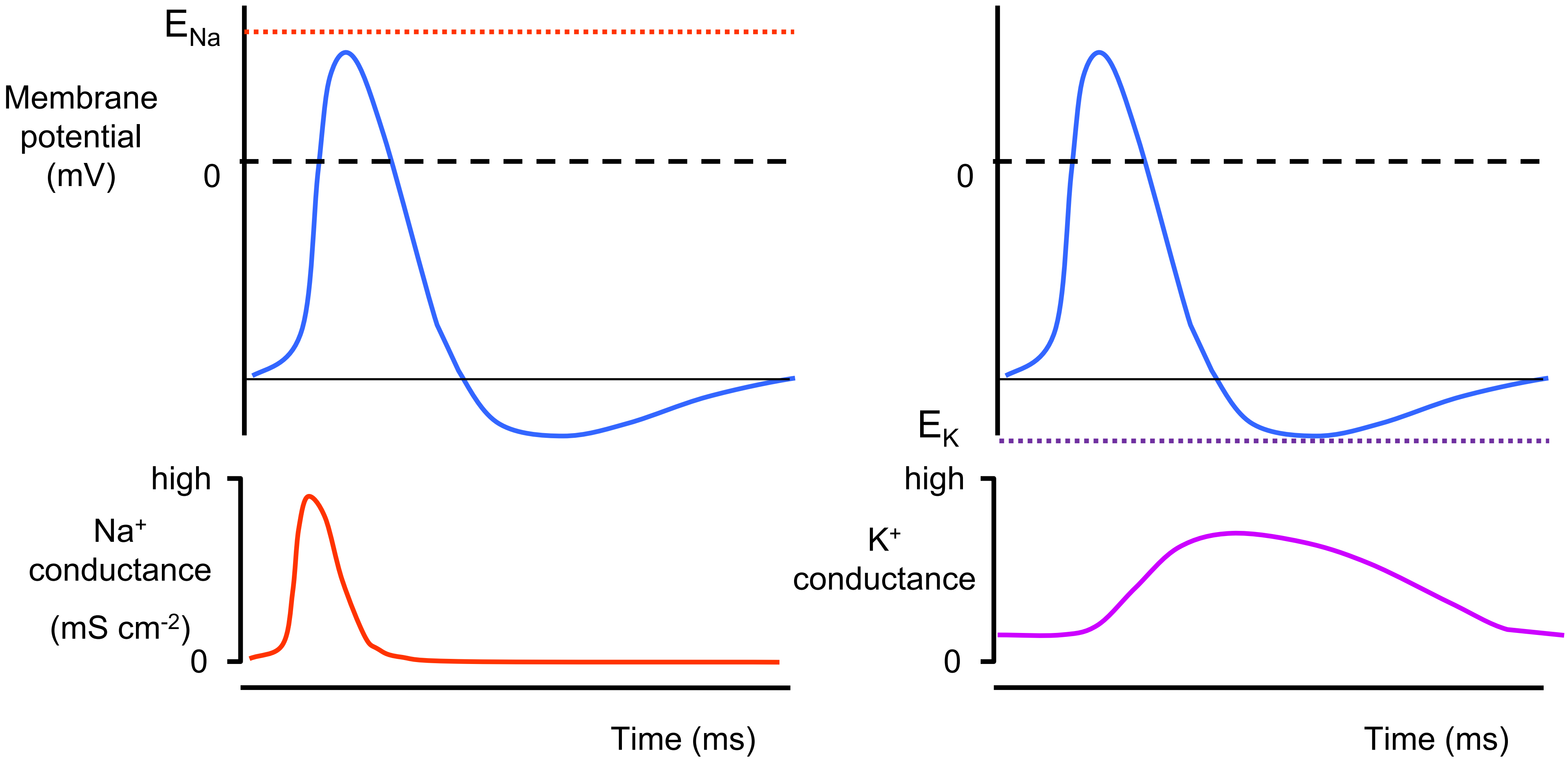
Synaptic inputs to neurons cause the membrane to depolarise and can lead to an action potential being triggered

The action potential



During action potential the selective permeability of membrane to ions changes due to activity of voltage-gated ion channels

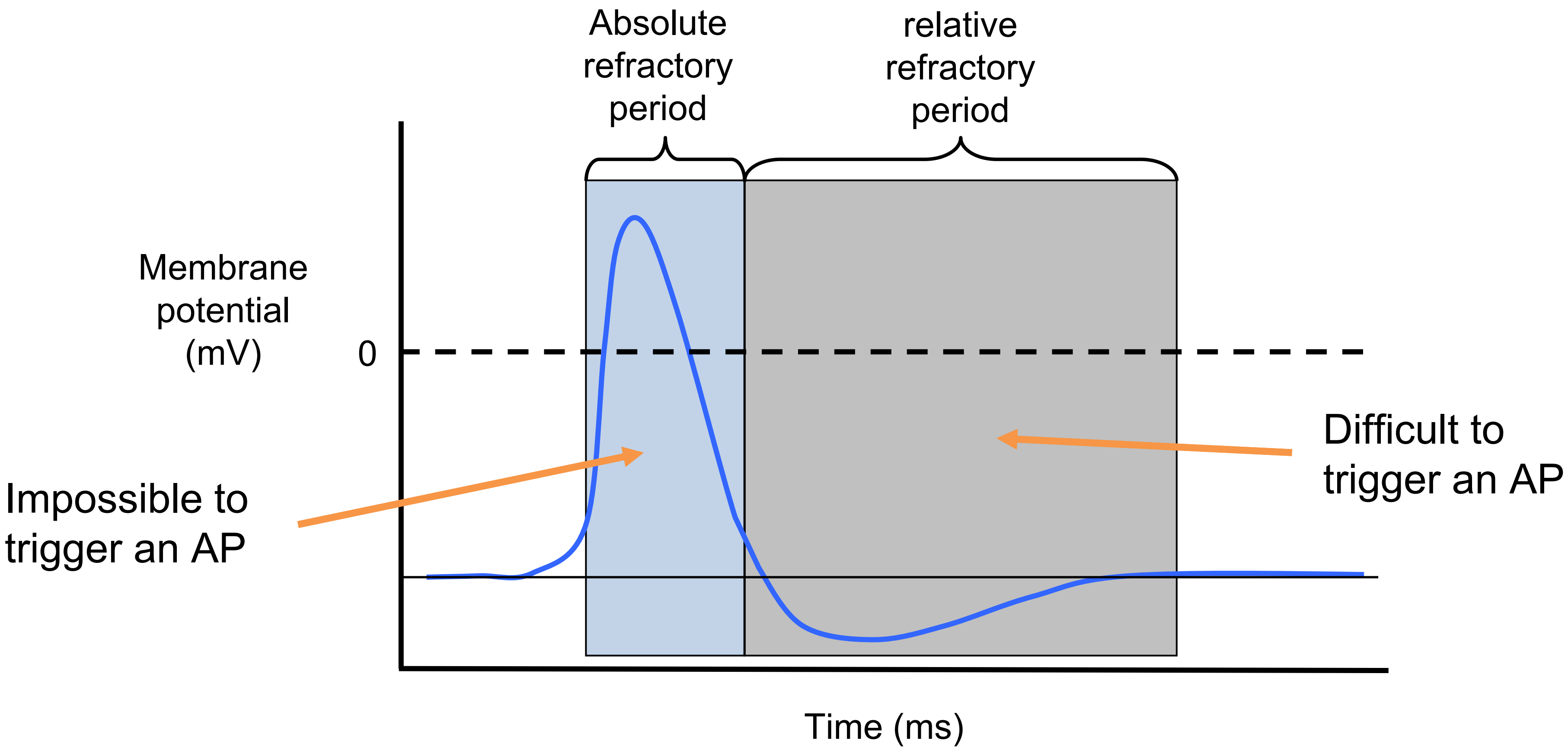
Changes of membrane permeability to sodium and potassium ions during the action potential



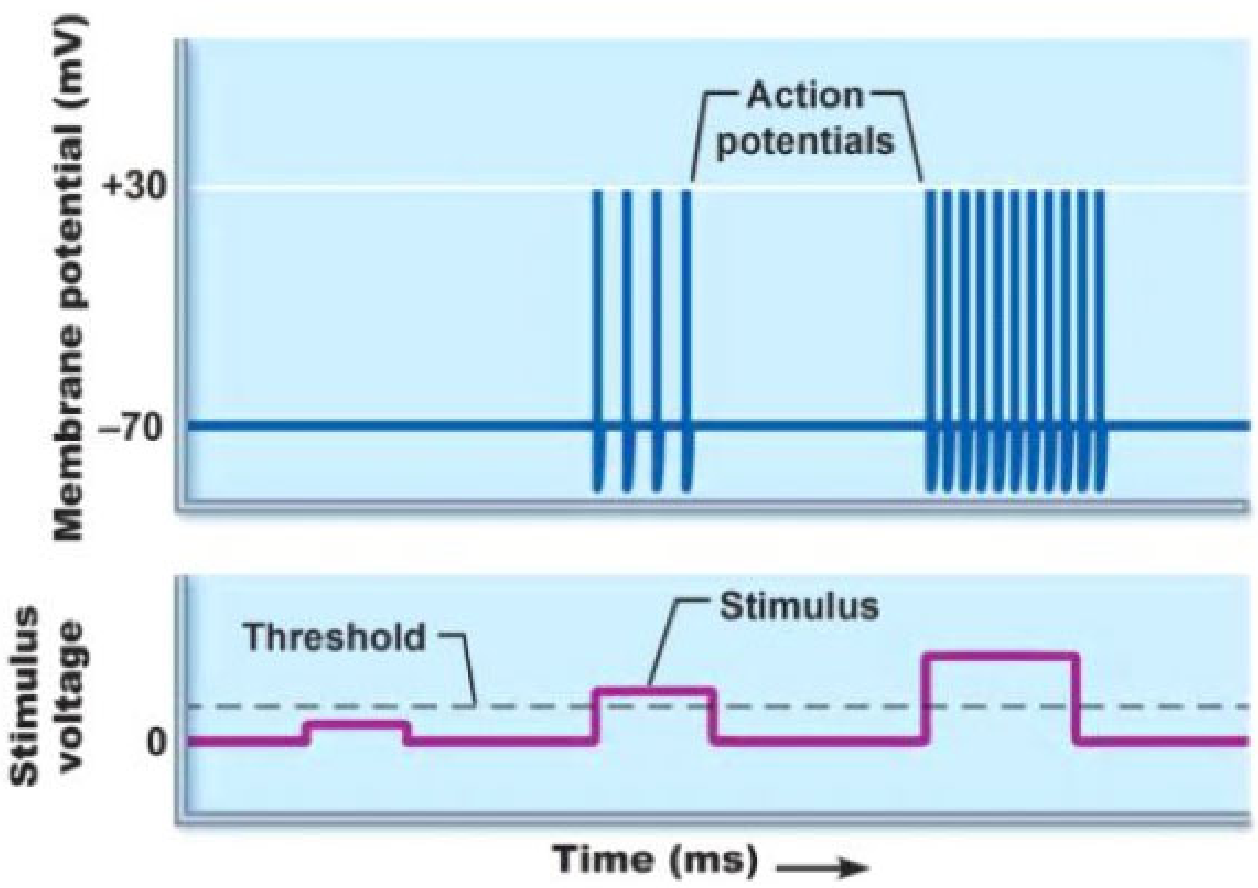
Voltage-gated ion channels permit the membrane to change its permeability

Properties of action potentials

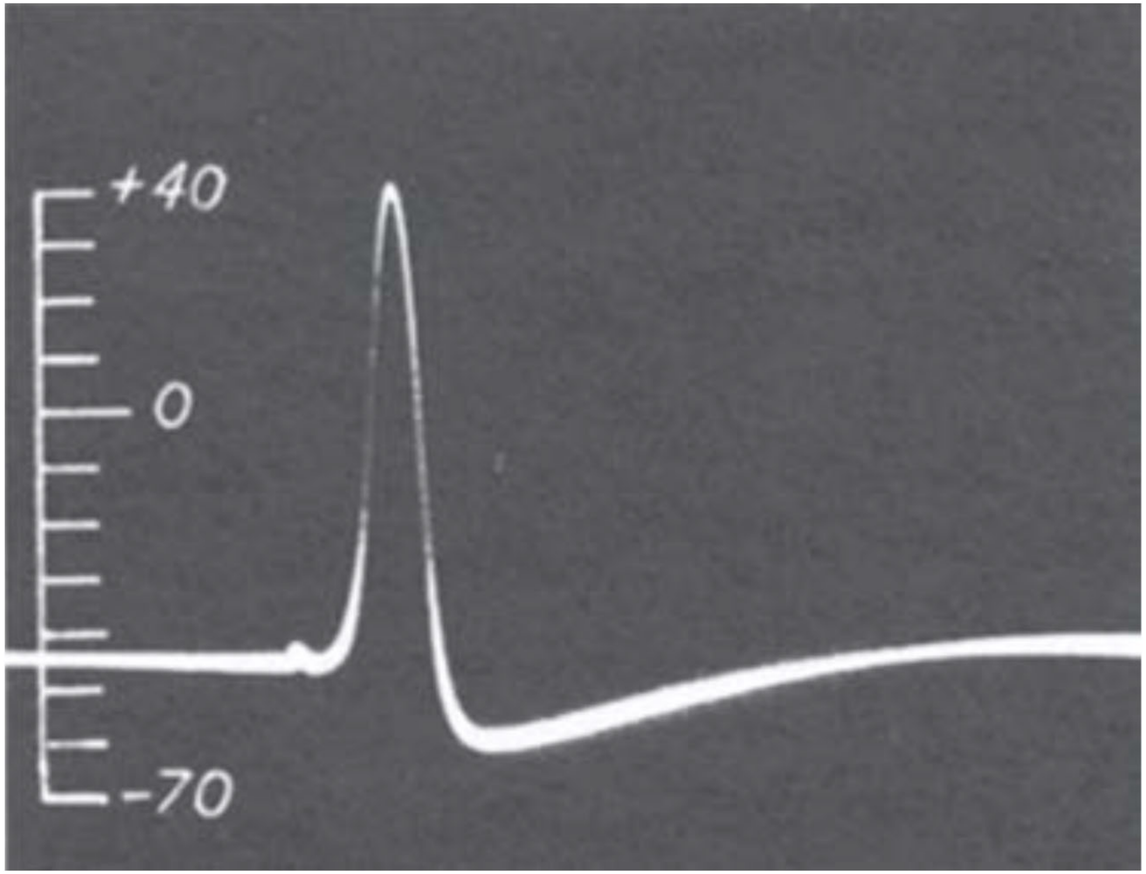
1) Threshold potential.
2) All or none – information coding is by frequency not amplitude.
3) Refractory periods – time during and after an AP when it is more difficult to fire a subsequent AP. Places an upper limit on AP firing frequency.



Increasing stimulus intensity increases frequency, not size of action potentials

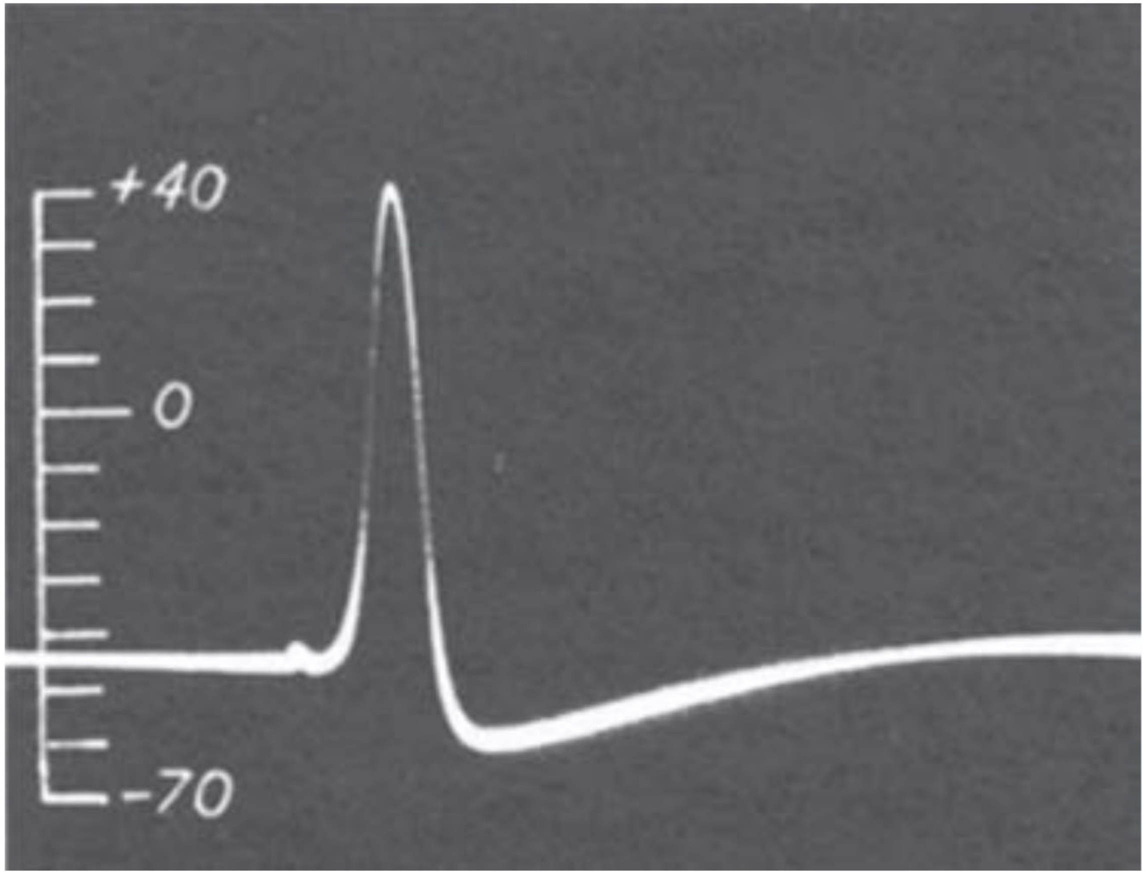


Hodgkin-Huxley model



$$C\frac{dV}{dt} = -\,g_K n^4(V - E_K) - g_{Na} m^3 h(V - E_{Na}) - g_L(V - E_L) - I_e$$

Hodgkin-Huxley model
action potential generation



$$C\frac{dV}{dt} = -\,g_K n^4(V - E_K) - g_{Na} m^3 h(V - E_{Na}) - g_L(V - E_L) - I_e$$

The action potential

The Action Potential

Differential equations

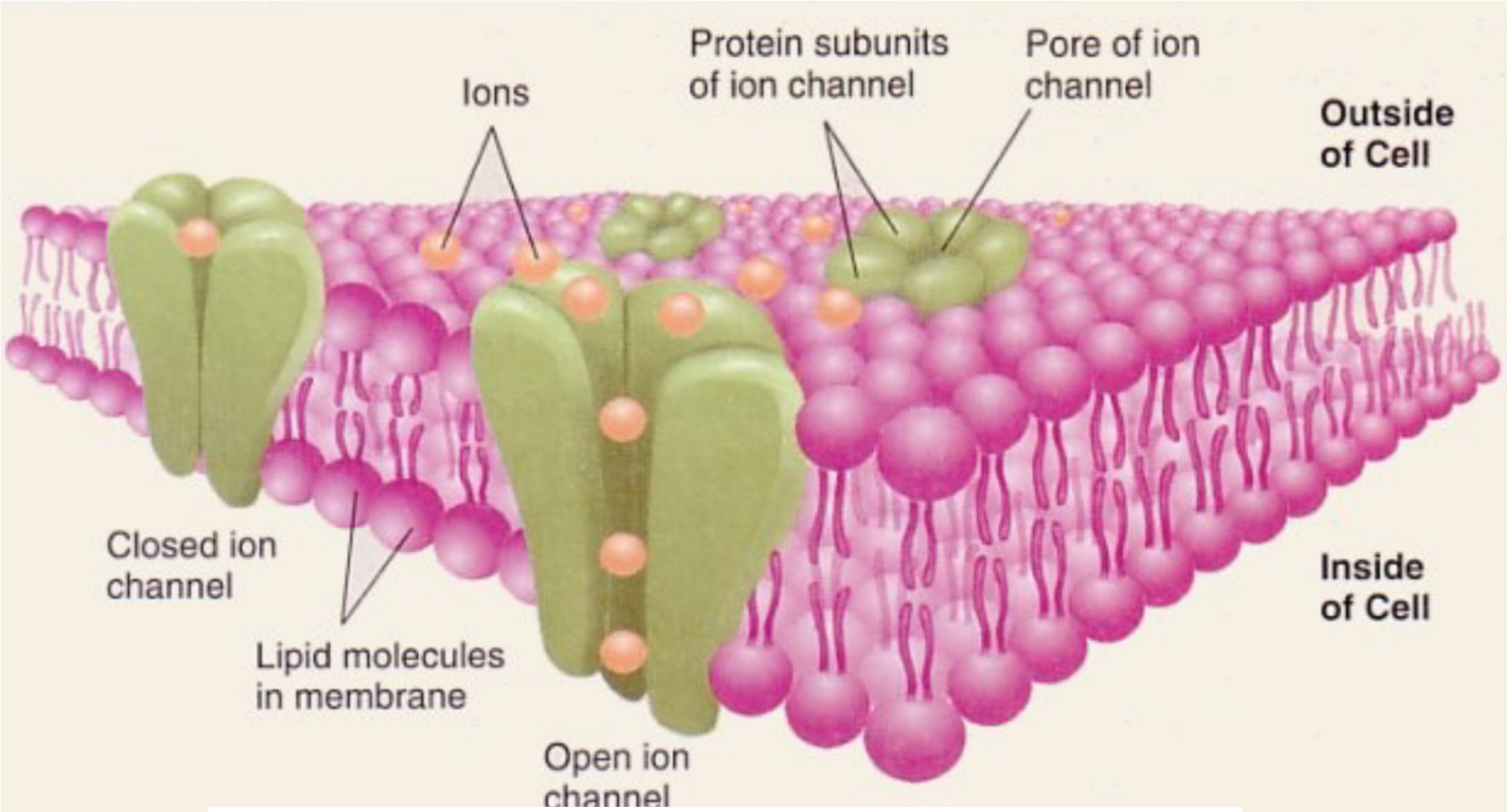
The most common and simplest types of dynamic models come in the form of differential equations

They describe the rate of change of some variable, say *u*, as a function *u* and other variables

$$\frac{du}{dt} = \text{change per unit time} = \text{sum of production rates} - \text{sum of removal rates.}$$

$$c_m \frac{dV}{dt} = -i_m + \frac{I_e}{A}.$$

Ion channels

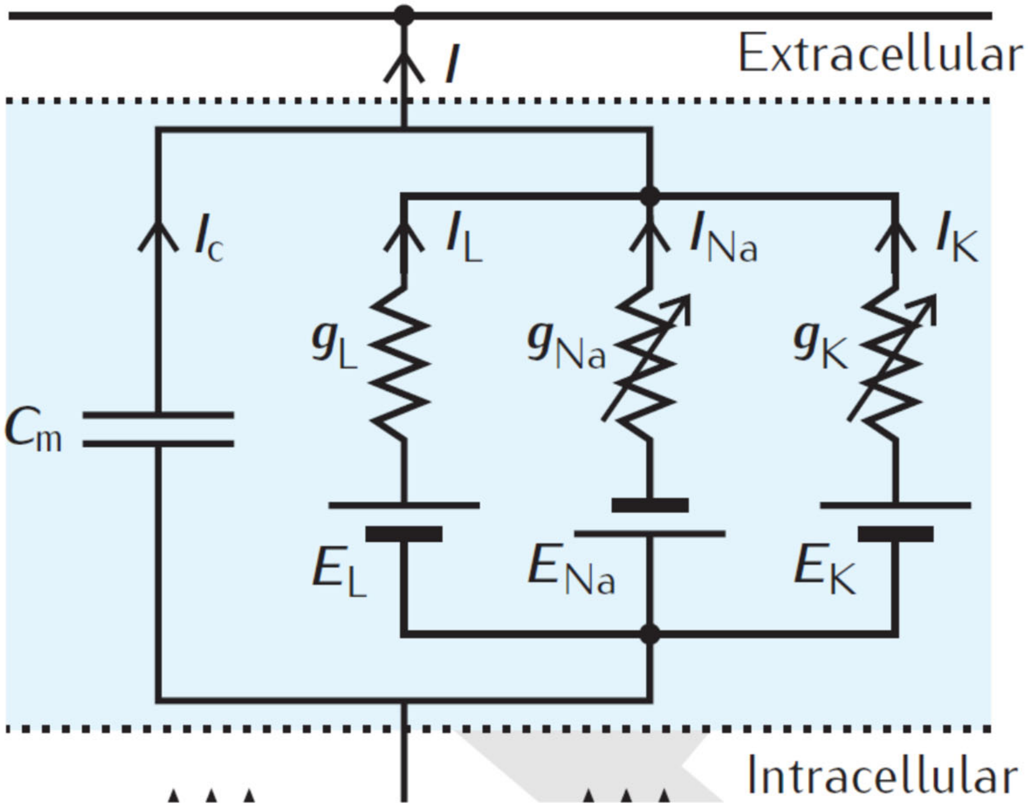


$$CV = Q$$

$$I = -g(V - E_r)$$

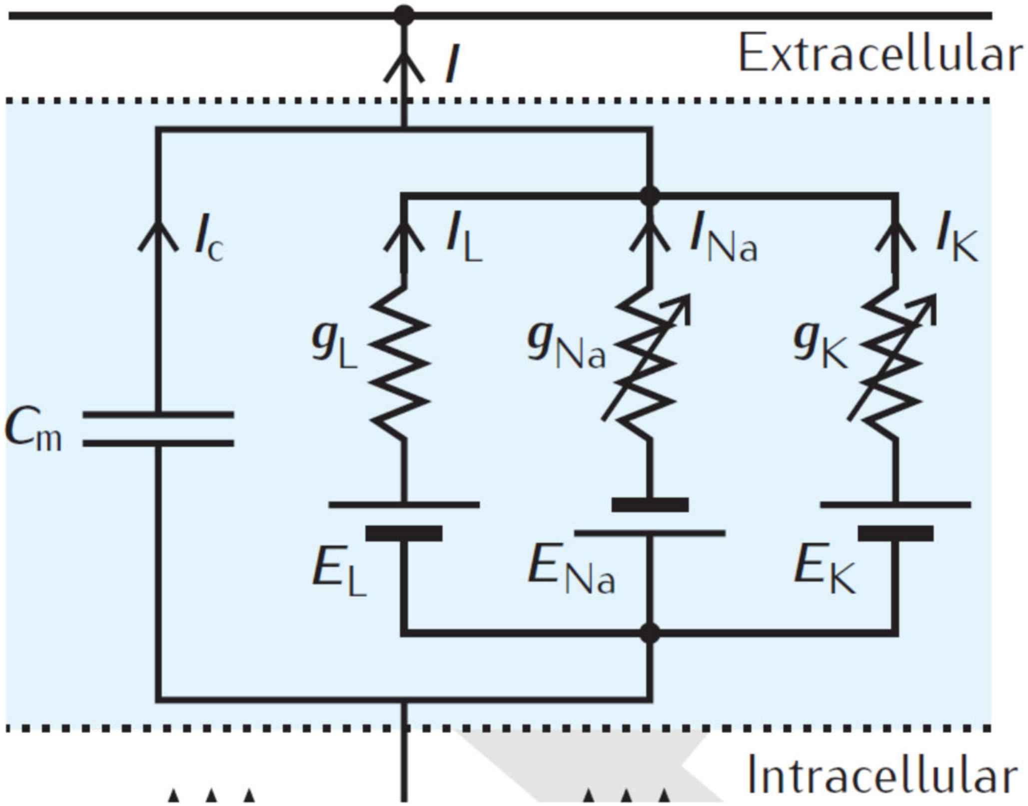
$$C\frac{dV}{dt} = \frac{dQ}{dt} = I$$

The Equivalent Electronic Circuit of a Neuron



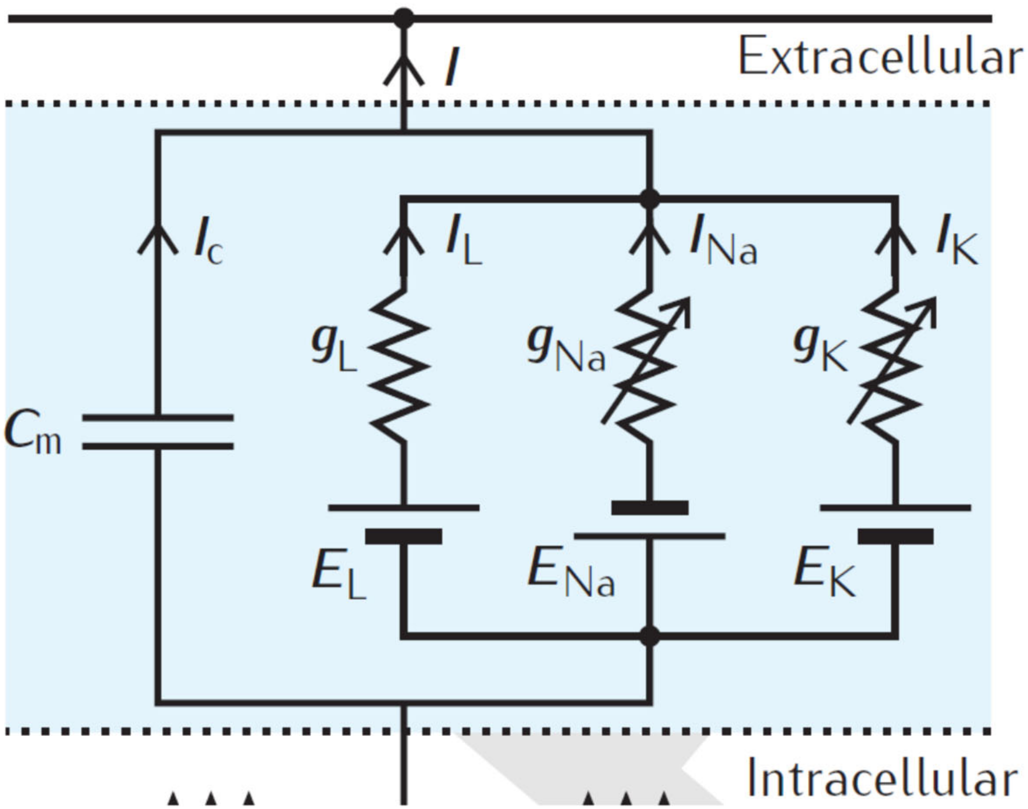
$$C_m \frac{dV}{dt} = -\sum_i g_i(V)(V - E_i) - \bar{g}_L(V - E_L) + I_e$$

The Equivalent Electronic Circuit of a Neuron



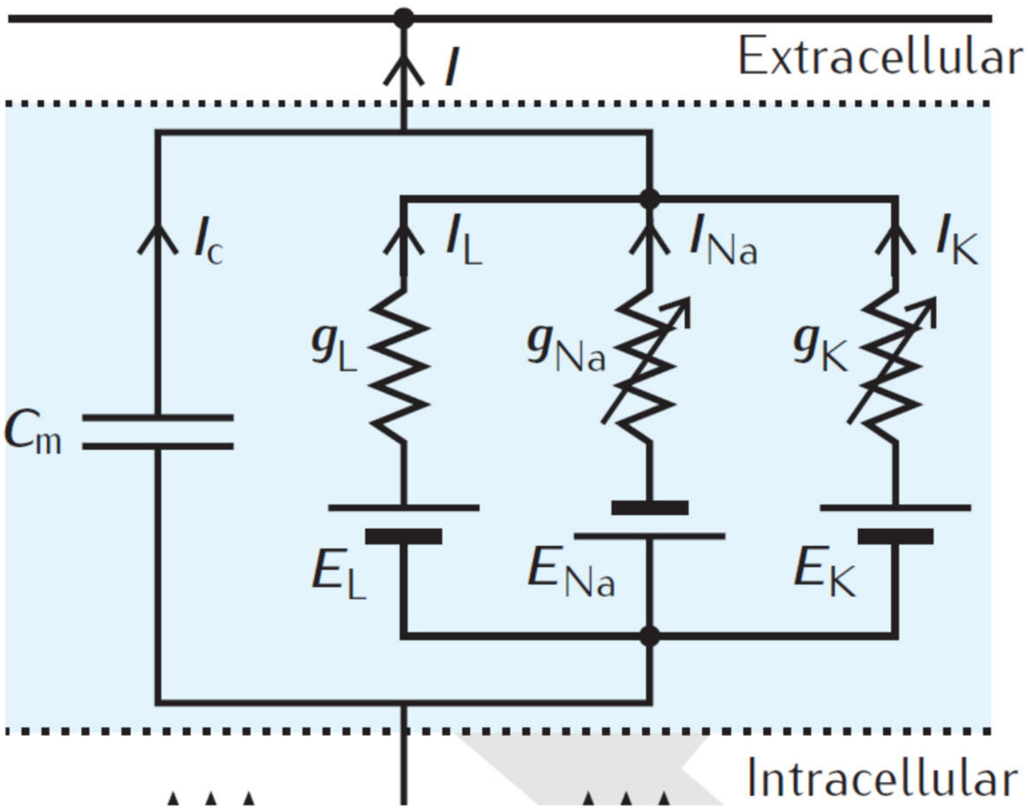
$$I_m(t) + C\frac{dV(t)}{dt} = I_e(t)$$

The Equivalent Electronic Circuit of a Neuron



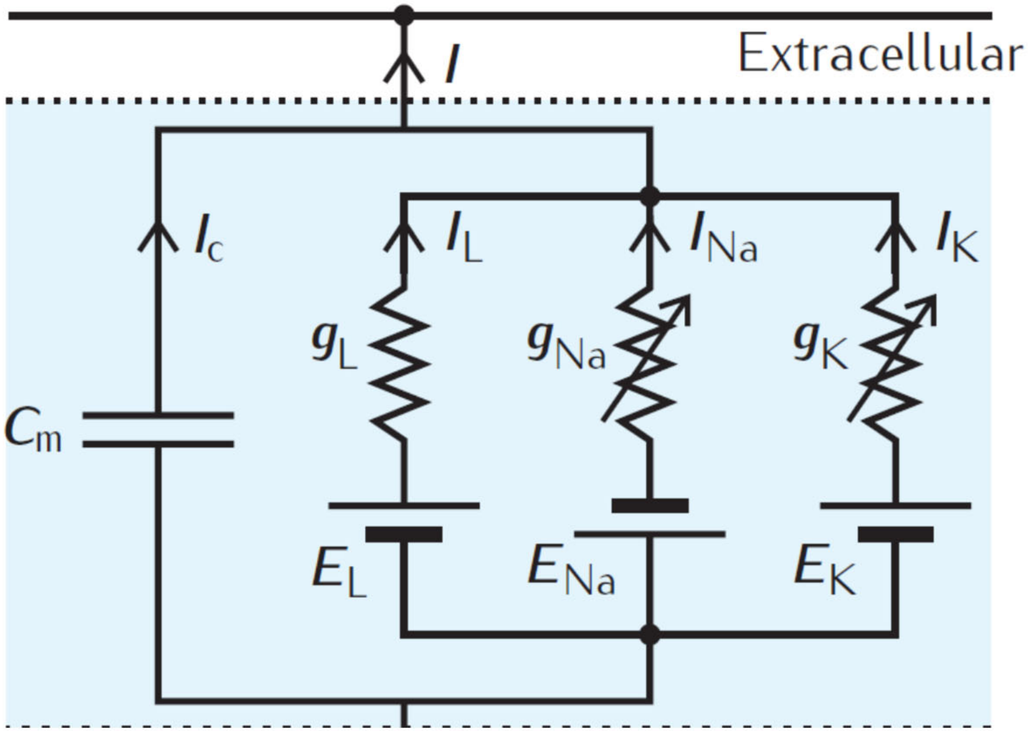
$$I_m = I_{Na} + I_K + I_L$$

The Equivalent Electronic Circuit of a Neuron



$$I_{Na} = G_{Na}(V,t)\left(V - E_{Na}\right) \qquad I_K = G_K(V,t)(V - E_K) \qquad I_L = G_L(V - E_L)$$

The Equivalent Electronic Circuit of a Neuron



$$I_{Na} = G_{Na}(V,t)\left(V - E_{Na}\right)$$

$$I_K = G_K(V,t)(V - E_K)$$

$$I_L = G_L(V - E_L)$$

The sodium conductance is time-dependent and voltage-dependent

The potassium conductance is time-dependent and voltage-dependent

The leak conductance is neither time-dependent nor voltage-dependent

$$E_{Na} = +55mV$$

$$E_K = -75mV$$

$$E_L = -50mV$$

Hodgkin-Huxley (heroic)

Empirical model that describes the ionic conductance and **generation of action potential**

Published in 1952

Nobel Prize in Medicine or Physiology in 1963

Work reflects a combination of experimental work, theoretical hypothesis, computational data fitting, and model prediction

HH model in action

$$C\frac{dV}{dt} = -g_K n^4(V - E_K) - g_{Na} m^3 h(V - E_{Na}) - g_L(V - E_L) - I_e$$

Start with initial contition $V_m = V_0$ at time step t_0

Compute:

$n_\infty(V)$ and $\tau_n(V)$ $m_\infty(V)$ and $\tau_m(V)$ $h_\infty(V)$ and $\tau_h(V)$

$n(t) = n(t-1) + \frac{dn}{dt}\Delta t$ $m(t) = m(t-1) + \frac{dm}{dt}\Delta t$ $h(t) = h(t-1) + \frac{dh}{dt}\Delta t$

$I_K = \bar{G}_K n^4(V - E_K)$ $I_{Na} = \bar{G}_{Na} m^3 h(V - E_{Na})$ $I_L = \bar{G}_L(V - E_L)$

Total membrane current $I_m = I_K + I_{Na} + I_L$

Compute τ_{mem} *and* V_∞

$V_m(t) = V_m(t-1) + \frac{dV_m}{dt}\Delta t$