Stochastic computation in recurrent networks of spiking neurons

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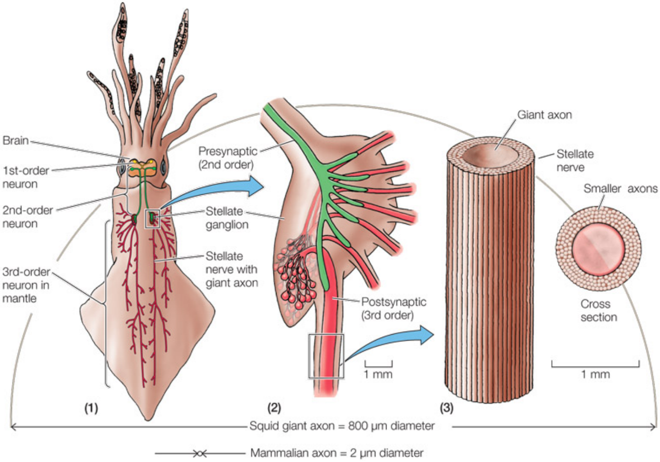
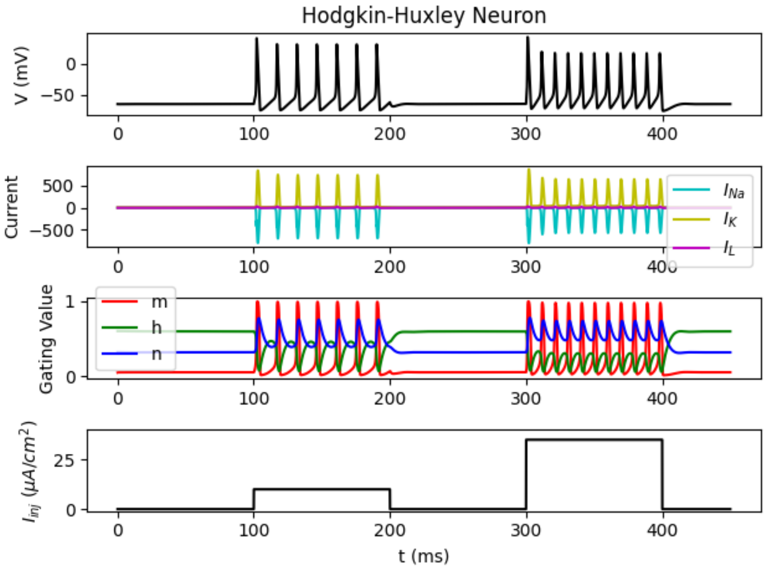
The squid giant axon

Hodkin and Huxley developed a mathematical model for nerve cell communication in 1952 using voltage data from the giant axon of a squid

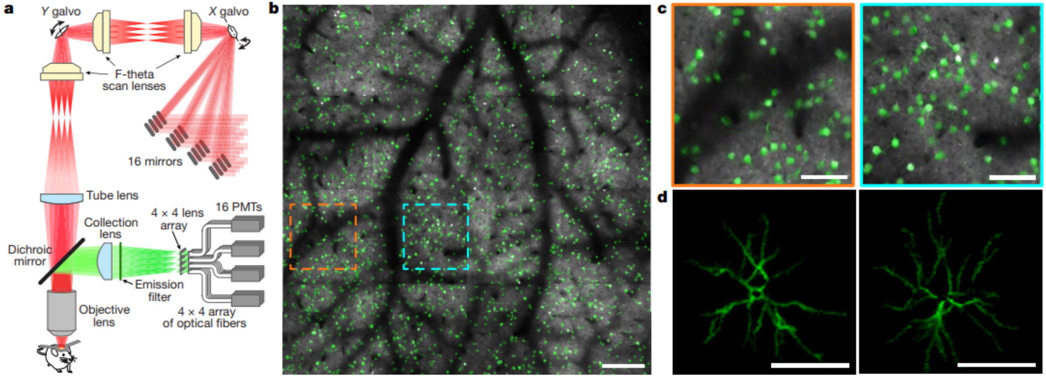


Na^+ and K^+ are the major charge carriers



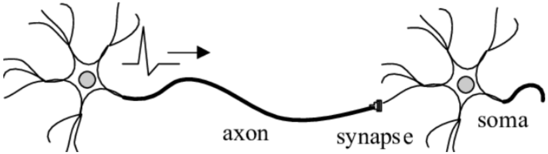
Ca^{2+} sensors enable high-speed two-photon imaging

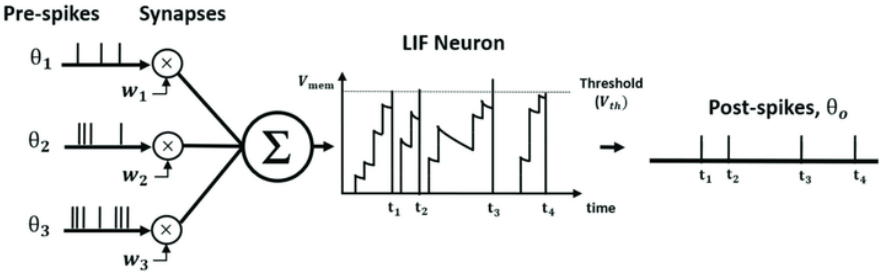
Animal models and experimental technologies have improved drastically
Scale bars: b, 250 um; c, d, 100 um



But our mathematical and physical theories of sensory processing are lacking...

Spiking neural networks: integrate and fire models

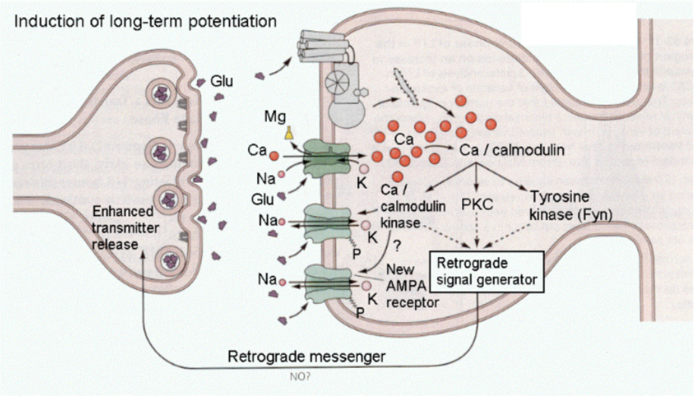




$$\tau \dot{V}(t) = -g_L V(t) + \sum_n w_n \theta_n(t)$$

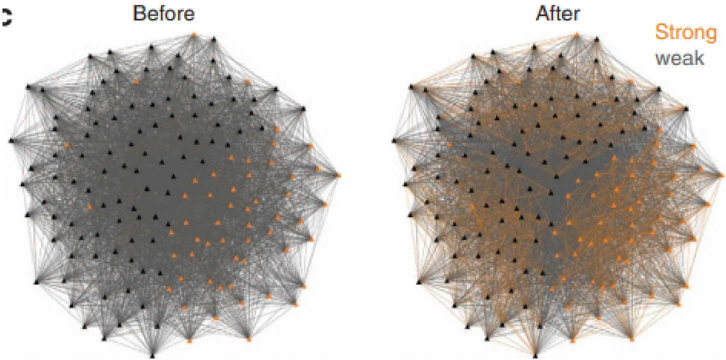
Synaptic strengths are dynamic

w_n represents the change in the post-synaptic membrane potential induced by an action potential at the presynaptic cell



w_n is a result of complex biochemical pathways and is not necessarily a constant (synaptic plasticity)

Langevin dynamics of the membrane potential



Predicting $I(t)$ is hard especially with dynamic synapses. We often model $I(t)$ as a stochastic process e.g., $I(t) = \mu(t) + \sqrt{2D}\eta(t)$

$$\tau \dot{V}(t) = -g_L V(t) + \mu(t) + \sqrt{2D}\eta(t)$$

which is a Langevin equation

Statistical mechanics of networks of neurons