Stochastic computation in recurrent networks of spiking neurons

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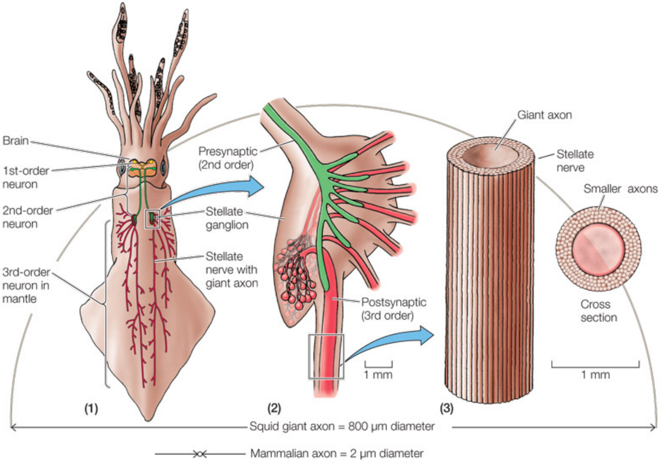
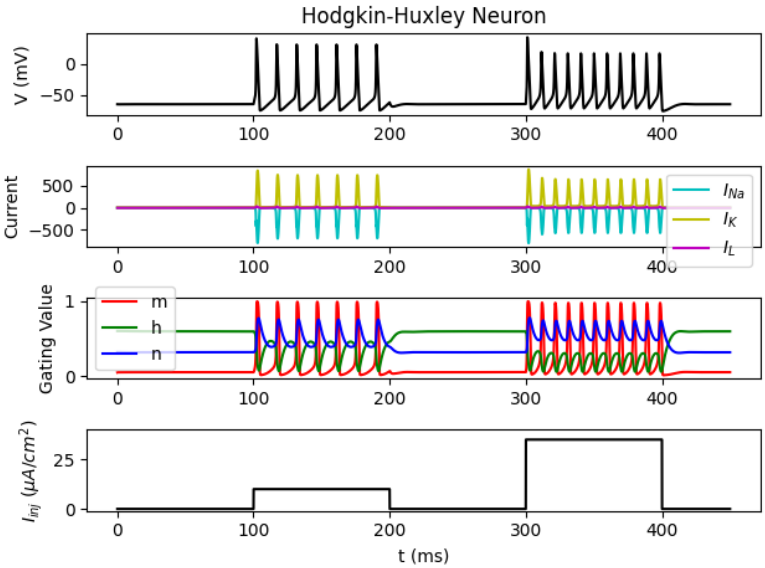
The squid giant axon

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

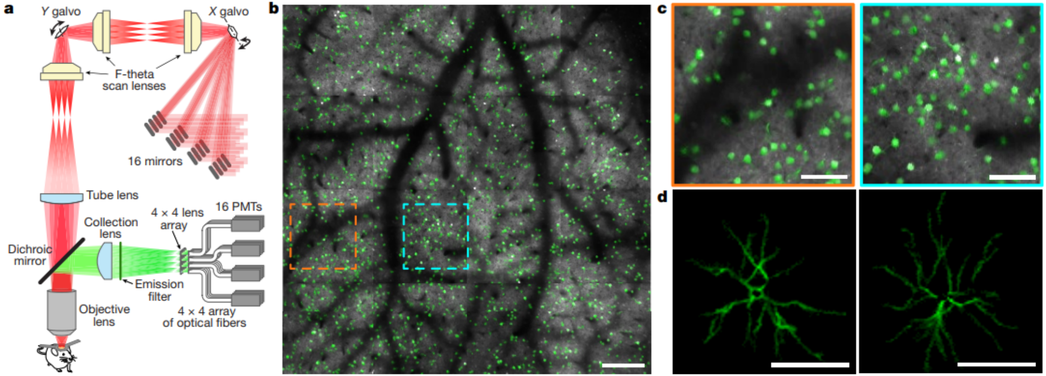


Na^+ and K^+ are the major charge carriers



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

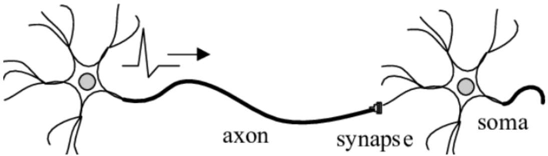
Animal models and experimental technologies have improved drastically

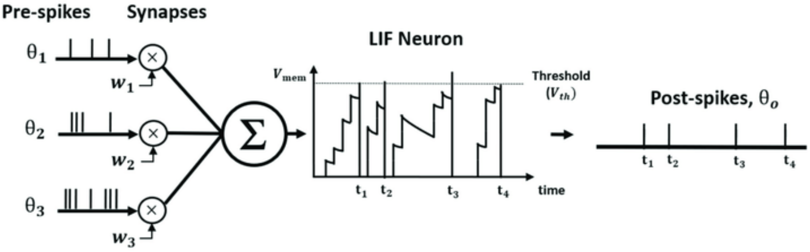


Scale bars: b, 250 um; c, d, 100 um

$4mm^2$ FOV at $\sim$ 8Hz

Spiking neural networks (SNN): integrate and fire models

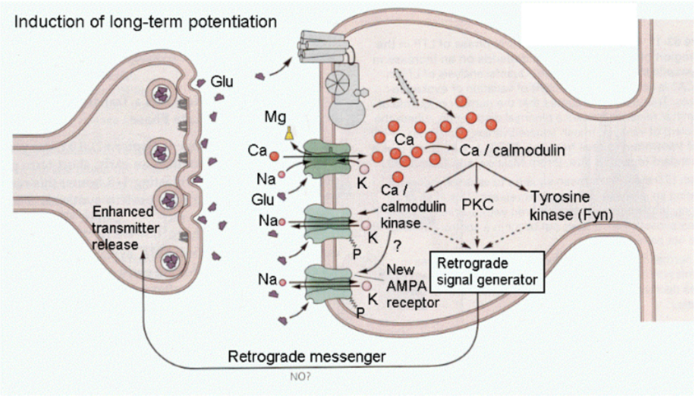




$$\tau \dot{V}(t) = -g_L V(t) + \sum_n w_n \theta_n(t)$$

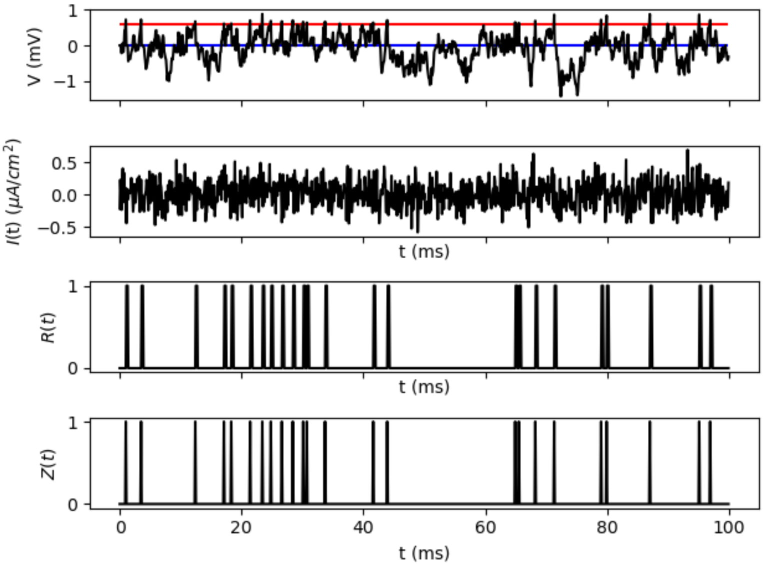
Synaptic strengths are dynamic

w_n represents the change in the post-synaptic membrane potential induced by an action potential at the presynaptic cell ($\sim 1 - 4$mV)

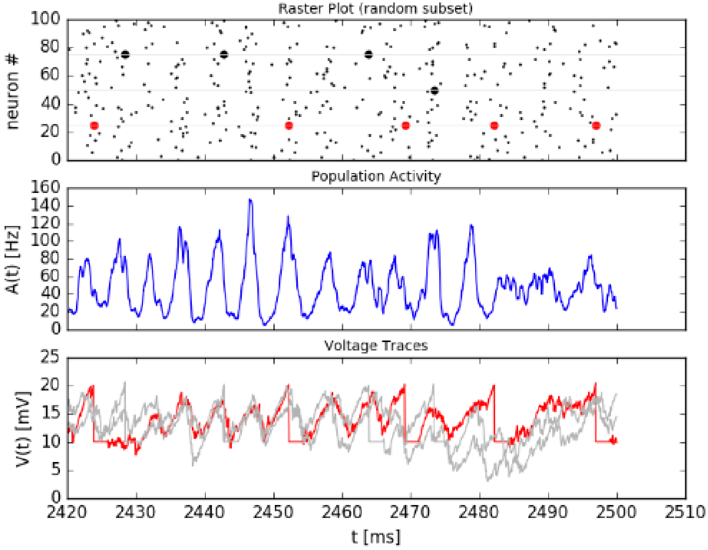


w_n is a result of complex biochemical pathways and is not necessarily a constant (synaptic plasticity)

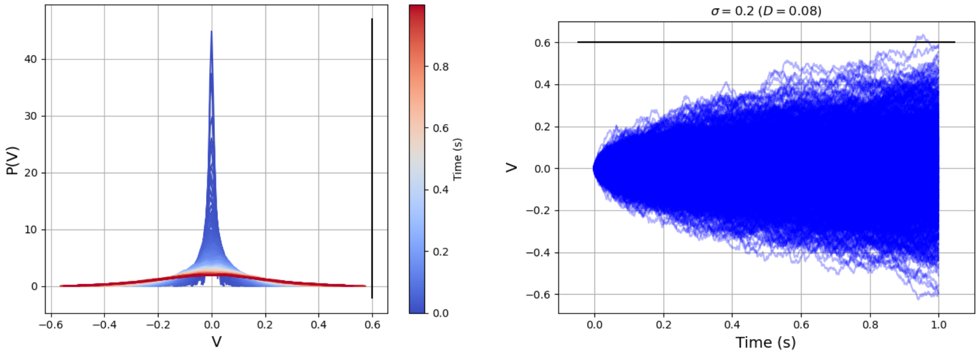
Synaptic current as a stochastic process



An example simulation



Fokker-Planck equation for Brownian motion



(a) (b)

Predicting $I_n(t)$ is hard in complex networks. We instead solve for $P(V, t)$

$$\tau \frac{\partial P}{\partial t} = (\mu(t) - V)\frac{\partial P}{\partial V} + \sqrt{2D}\frac{\partial^2 P}{\partial V^2}$$

Potential applications: neuromorphic computing

- Very low power consumption
- Dynamically remaps the synapses between artificial neurons
- Useful in embedded applications