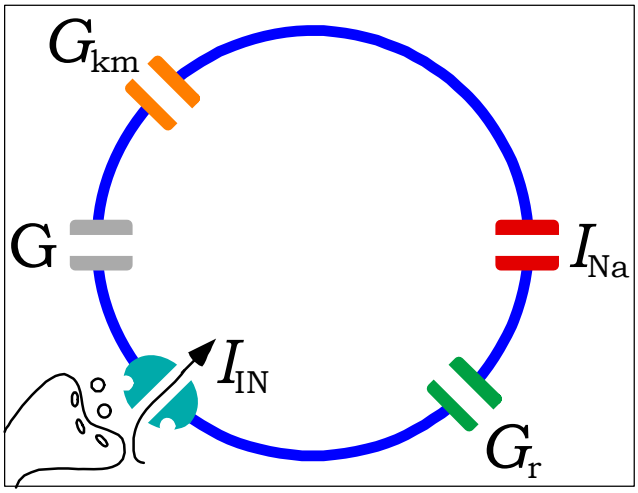
Pyramidal Neuron and Interneuron Models

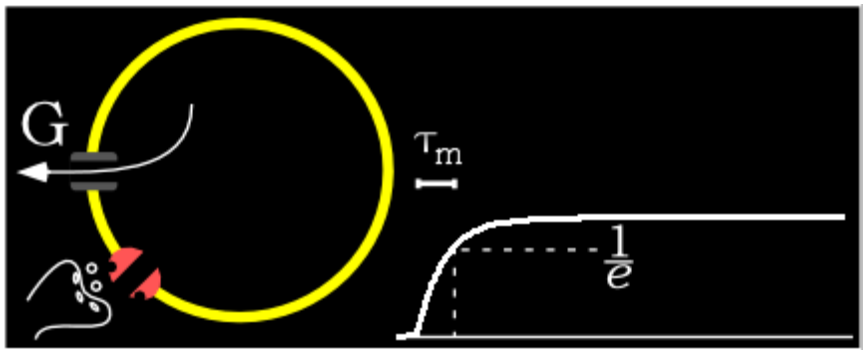


Model neuron with voltage- and ligand-gated channels.

Model neurons have leak (G), sodium (I_{Na}), fast & slow potassium (G_r,G_{km}), and ligand-gated (I_{in}) currents.

Each current has an amplitude, a rise-time, and a decay constant; active currents also have an activation threshold.

Leak Current



Leak current (gray) sets membrane time-constant (step response shown).

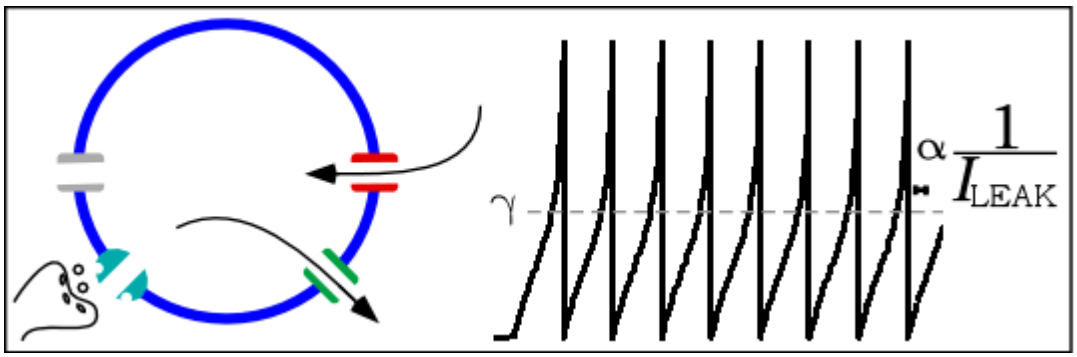
Amplitude: Conductance (G) is set by a bias voltage.

Rise-time and decay-constant: Instantaneous.

Membrane time-constant (τ_m) is set by leak's amplitude—together with the membrane capacitance (fixed).

Membrane time-constant is typically chosen to be about 10ms—determines time-window for temporal integration to occur, together with synaptic decay.

Fast Sodium Current



Fast sodium current (red) generates spike (upswing).

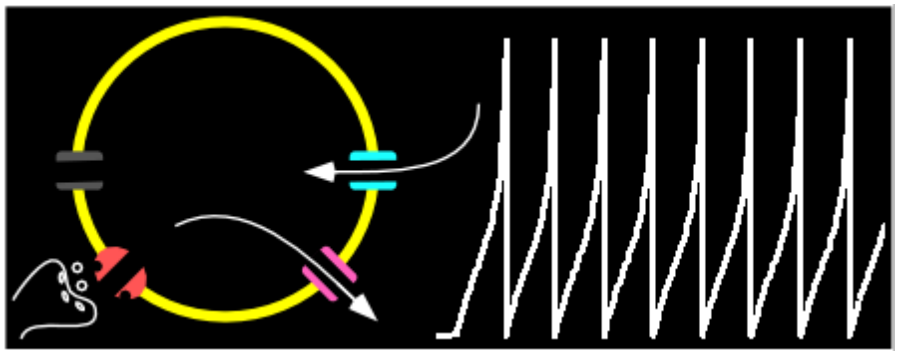
Amplitude: Fixed

Rise-time: Instantaneous.

Decay-constant: Instantaneous

Activation threshold: Set by bias voltage (I_{th})—determines the threshold for spiking (γ), together with leak. Left unchanged for all the labs.

Fast Potassium Current



Fast potassium current (green) terminates spike (downswing).

Amplitude: Fixed.

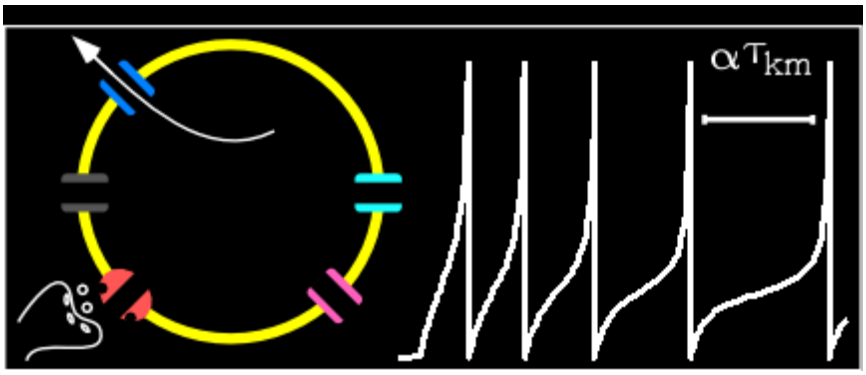
Rise-time: Instantaneous.

Decay-constant: Set by bias voltage (I_{LkRef})—determines refractory period (in lieu of Na inactivation). Set to 1-2 milliseconds in the labs.

Activation threshold: Triggered by spike.

5 of 9

Slow Potassium Current (Pyramidal neuron)



Slow potassium (M) current adapts spike-rate.

Amplitude: Set by bias voltage (G_{km}).

Rise-time: Same as refractory period (I_{LkRef}).

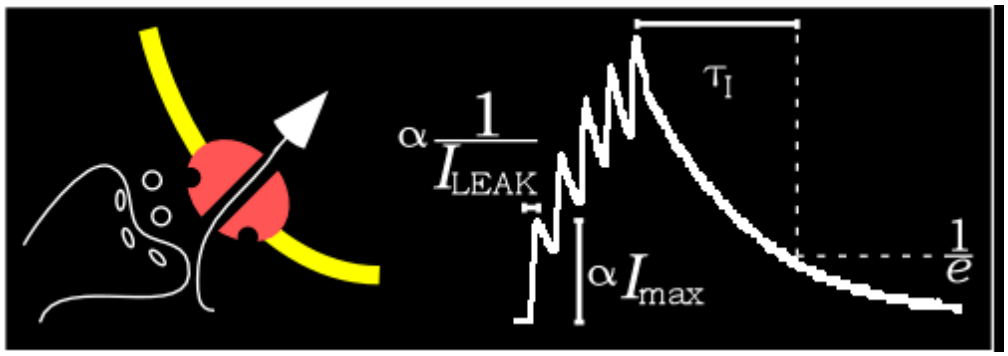
Decay-constant: Set by bias voltage (τ_{km}).

Activation threshold: Triggered by spike.

Also used to limit each neuron to one spike per theta cycle in last two labs.

6 of 9

Slow Synapse (NMDA- or $GABA_B$-like)



Slow synapse has adjustable rise and decay times.

Amplitude: Set by bias voltage (I_{MaxS}).

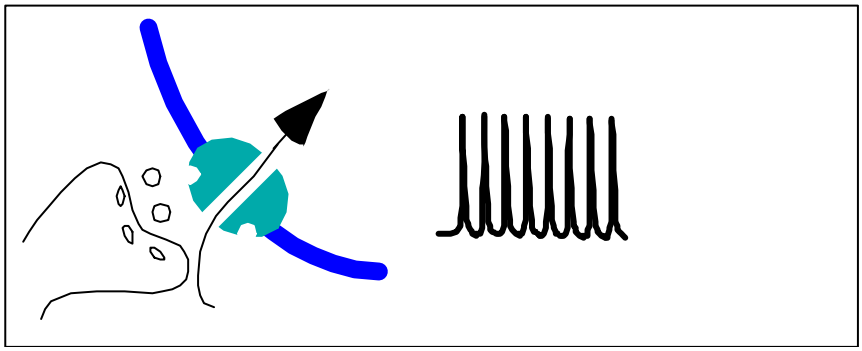
Rise-time: Set by bias voltage (I_{LkS}).

Decay-constant: Set by bias voltage (τ_I).

Activation threshold: Triggered by presynaptic spike.

Two types: One provides excitatory current (with parameters above); the other provides inhibitory conductance (with parameters G_{max}, I_{LkG}, and τ_G).

Fast Synapse (AMPA-like)



Fast synapse produces a current pulse with adjustable width.

Amplitude: Set by bias voltage (I_{MaxF}).

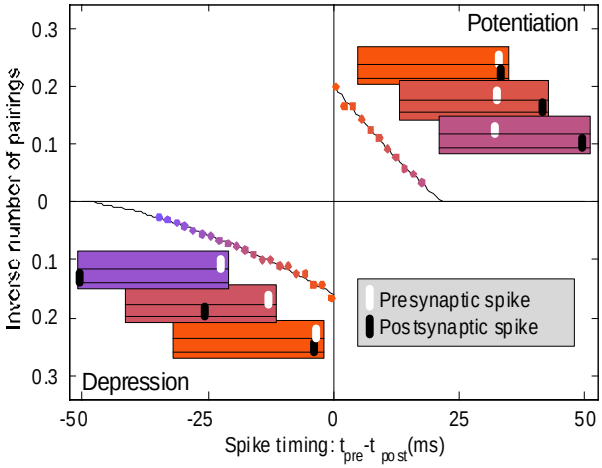
Pulse-width: Set by bias voltage (I_{LkF}).

Rise-time & decay-constant: Instantaneous.

Activation threshold: Triggered by presynaptic spike.

Also used to provide constant excitatory current by making interspike interval shorter than pulse-width.

Plastic Synapses



Potentiation and depression depend on spike timing.

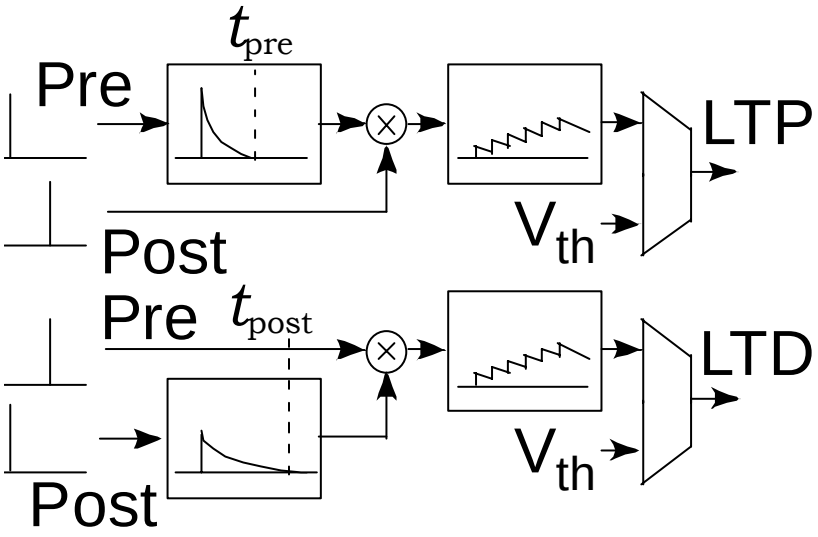
Repeated pre-before-post pairings potentiate synapse; post-before-pre pairings depress it.

Several pairings must occur closely in time for potentiation or depression to occur.

The number required increases as the pairings' pre-post time-interval increases.

Efficacy decays at different rates for potentiation and depression.

STDP Model



Pairings' efficacy is modeled with decay elements and integrators.

The decay constants are determined by decay-elements, one for potentiation and another for depression.

One spike of the pair sets the decay element's output to an adjustable level (V_{QaP},V_{QaD}); it decays thereafter at an adjustable rate (V_{LkP},V_{LkD}). The other samples the decay element's output.

The samples accumulate on an integrator with an adjustable leak (V_{IntLkP},V_{IntLkD}), one for potentiation and another for depression.

Potentiation or depression occurs when the integrator's output exceeds a fixed threshold.