An Electronic Neuron with Input-Specific Spiking

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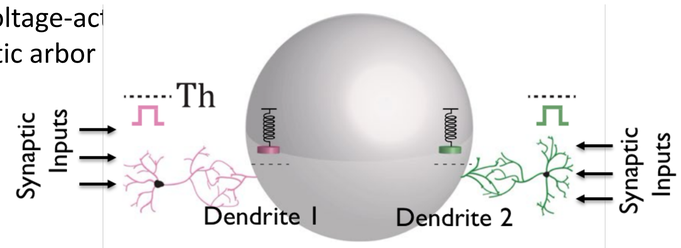
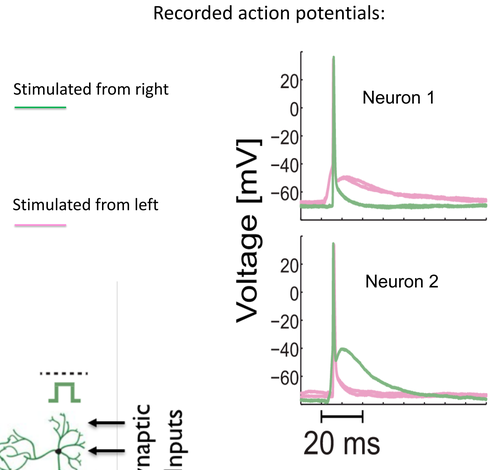
Approach: Use spike shapes to indicate different sources of neural stimulation in a single analog electronic neuron

1. Neurons spiking differently signal different input sources

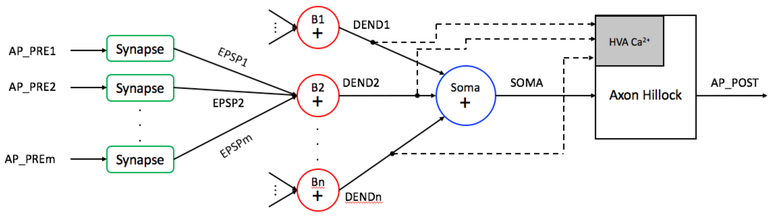
- Rat cortical neuron spikes have different shapes depending on the spatial location of stimulation Sardi et al. (2017) Nature SclentIfIc **REPORTS** *(2017)*
- Shapes vary from fast vs. slow repolarizing spike with a tail
- The slowly-repolarizing tail could be caused by high-voltage-act dendritic arbor

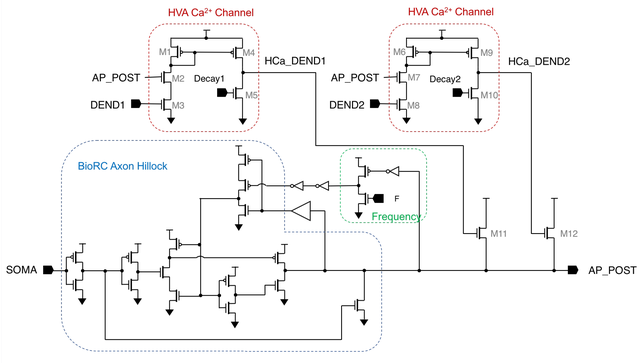




2. A neuron circuit that emits spikes with different shapes depending on specific stimulation patterns

- Axon hillock emits a spike *AP_POST* when *SOMA* is over the threshold for firing.
- *DEND* potentials also stimulate high voltage-activated (HVA) Ca^{2+} channels on the cell that affect the shape of *AP_POST*.





BLOCK DIAGRAM OF A MULTI-DENDRITE NEURON WITH HVA CA^{2+} CHANNELS

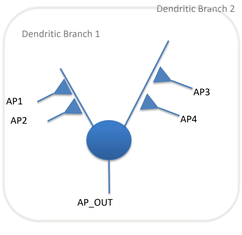
Frequency:
Controls the rate of spiking with a control voltage F.

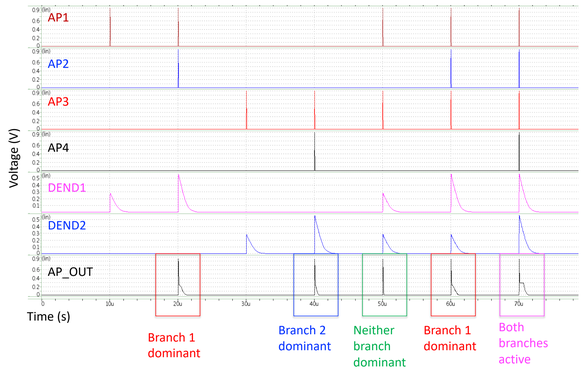
HVA Ca^{2+} Channel:
Controls the repolarization tail shape output action potential AP_POST.
Each channel is activated by one dendritic potential.
Tail shapes tuned with control voltage.

Axon hillock circuit with effects from 2 dendrites

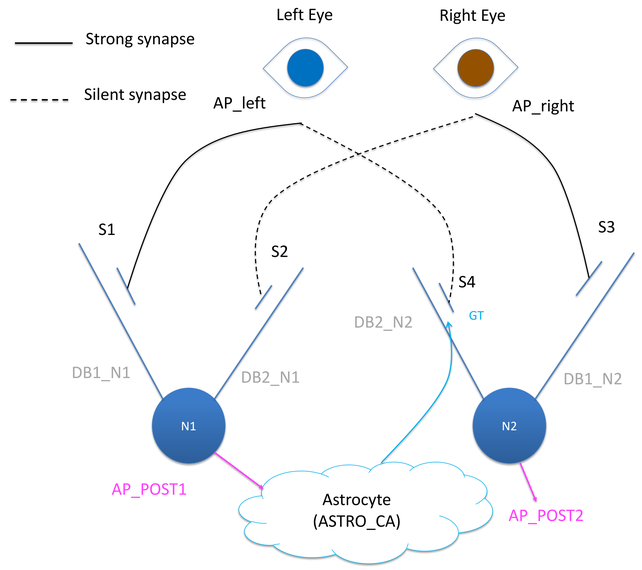
3. Simulation results: a neuron with input-specific spiking

- Neuron spikes if at least 2 inputs are given.
- HVA Ca^{2+} channel activation at a branch requires at least 2 inputs on that branch.
- HVA Ca^{2+} channels for each branch were configured with different decays (Decay1=0.22V, Decay2=0.24V)





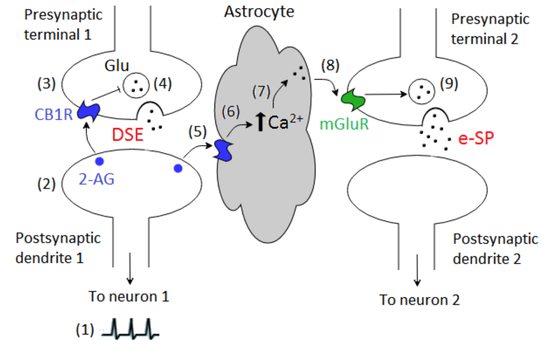
4. Example Astrocyte-mediated signal re-routing in a bio-inspired damaged ocular network



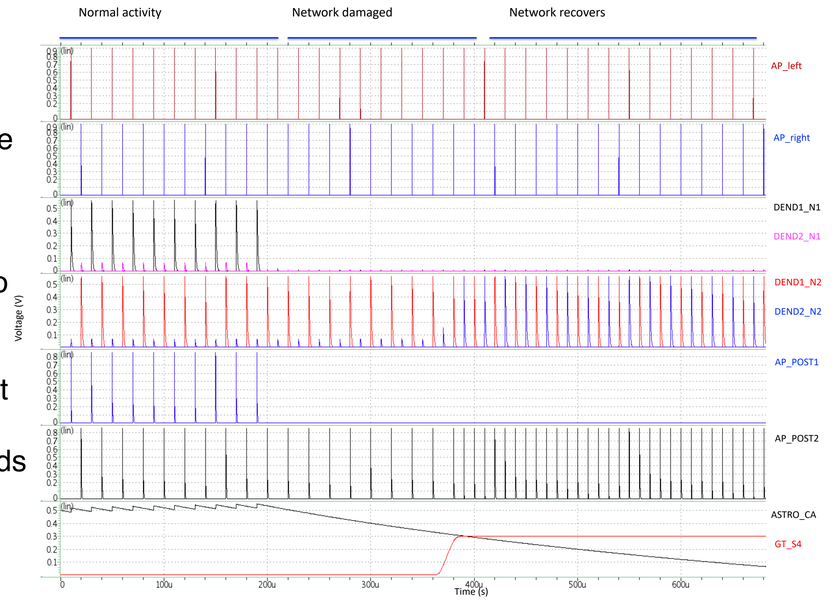
- S1 and S3 are strong synapses.
- S2 and S4 begin as weak or silent synapses.
- Initially, N1 preferentially responds to left eye activity (AP_left), and N2 preferentially responds to right eye activity (AP_right).
- An astrocyte monitors activity of neuron N1 (AP_POST1).
- If the astrocyte detects low activity in N1, it stimulates synapse S4 with gliotransmitters (GT), strengthening it.

5. Mimic astrocyte mechanism to preserve homeostasis

- We designed astromorphic circuits that monitor neuromorphic network activity over long time scales and initiate plasticity mechanisms in order to maintain stable firing rates.
- We placed the input-selective neuron in a self-repairing astrocyte-neuromorphic network.
  - »Output selectivity of re-routed signals can be encoded by spike shape



- AP_left and AP_right stimulate with spikes every 20us.
- At 200us, neuron N1 is simulated to have a fault by grounding all its weights, making it unresponsive.
- Astrocyte responds to activity in N1 (AP_POST1).



We demonstrated that our astrocyte-neuromorphic circuits can produce plasticity for self-repair and homeostasis