Introduction to Spiking Neural Networks

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Spiking Neural Networks (SNNs)

- Spiking neural networks (SNNs) aim to utilize mechanisms from biological neurons to bridge the computational and efficiency gaps between the human brain and machine learning systems

- Why "spiking"?
  - The "spiking" neurons communicate using binary spikes. This makes SNNs inherently temporal in nature.

- SNNs rely on neuromorphic hardware and sensors that are optimized around their properties;
  - Spikes
    - Multiplication replaced by memory read-out of the input weight (1 * weight)
  - Sparsity
    - Majority of activations is zero most of the time. Sparse tensors are cheap to store.
  - Static suppression (a.k.a. event-driven processing)
    - Information is processed only when values change. This significantly reduces computation.

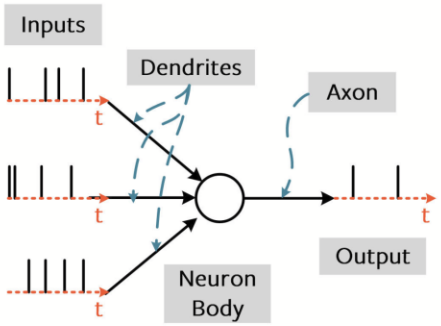
Reference for this slide: Jason K. Eshraghian, Max Ward, Emre O. Neftci, Xinxin Wang, Gregor Lenz, Girish Dwivedi, Mohammed Bennamoun, Doo Seok Jeong, and Wei D. Lu. Training spiking neural networks using lessons from deep learning. Proceedings of the IEEE, 111(9):1016–1054, 2023.

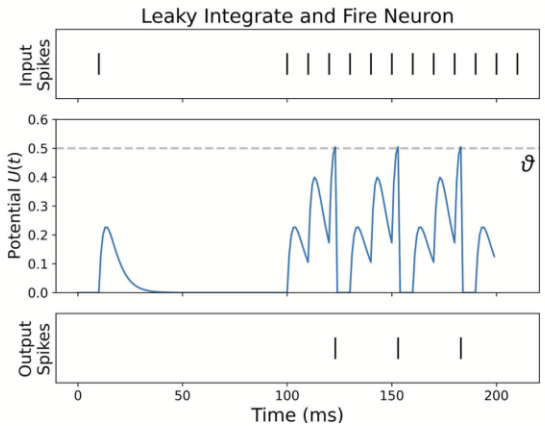
Leaky-Integrate-and-Fire (LIF) Neuron

- What is the LIF neuron model good for?
  - Often used in deep learning for its **favorable trade-off** between biological plausibility and computational efficiency

- How does the LIF neuron work?
  - **Weighted input spikes** are integrated into **"membrane potential"** (scalar internal state)
  - If the **membrane potential** exceeds a set threshold, a **spike** is emitted

- Why is it called "leaky"?
  - The membrane potential **exponentially decays**, i.e. "leaks"
  - The "**membrane time constant**" governs how fast it decays





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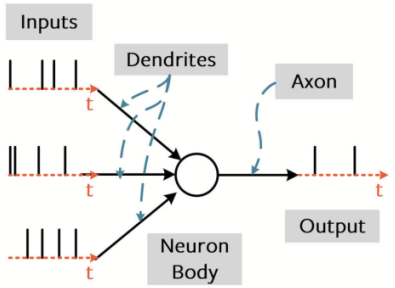
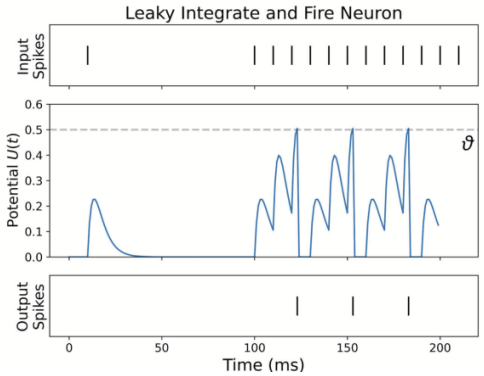
Time discretization

- LIF neuron resting state (continuous):

$$\tau \frac{dV(t)}{dt} = -(V(t) - V_{rest}) + X(t)$$





- t … time (continuous)
- τ … membrane time constant
- V(t) … membrane potential
- X(t) … sum of weighted input spikes
- V_rest … resting membrane potential

- Discretized form (V_rest = 0):

$$\tau \left(V'[t] - V[t-1]\right) = -V[t-1] + X[t]$$

- t … time (discrete)

- Introduces approximation errors

End of the introduction.