Integrate-and-Fire Models

Abstract Models

Model Abstraction
Integrate-and-Fire Models
Non-Spiking Models

Örjan Ekeberg Brain Modeling and Machine Learning

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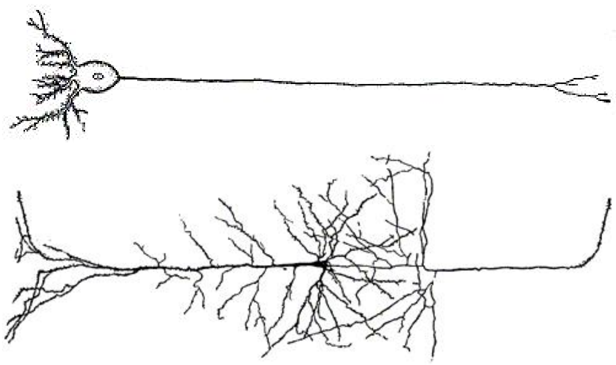
There are too many things going on in real neurons



Model Abstraction

Remove irrelevant details while preserving relevant properties

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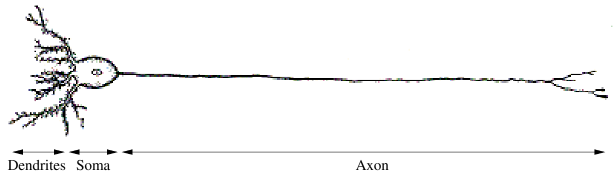
What properties are important to preserve?



- Dendrites
  Passive reception of signals
- Soma (Cell Body)
  Summing, Thresholding
- Axon
  Aktive pulses are transmitted to other cells

Early attempt: McCulloch and Pitts model (1943)

- Two output states: spike or no spike
- No time dynamics, immediate response
- Sufficient number of excitatory input spikes required
- Inhibitory input completely blocks output

Note similarity with digital electronics (gates)

Intrgrate-and-Fire Models

Point neuron model with simplified spikes

- Ignore the precise action potential mechanisms
- Assume linear summation of inputs
- Assume that each incoming spike contributes a constant amount of charge (current pulse)

Reasonable objective

Produce the right spiking frequency for different input levels

Idea

Replace Na/K mechanism with a simple reset mechanism

- Point neuron style integration of input

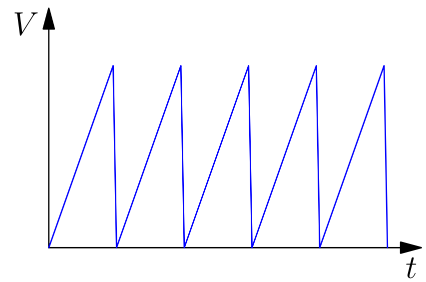
$$C\frac{dV}{dt} = I$$

- Reset Mechanism
  When V reaches a threshold, Θ, the cell fires and V is reset to zero.

What spiking frequency will this model produce?

Constant input current

$$C\frac{dV}{dt} = I$$



- Time to reach threshold

$$T = \frac{\Theta C}{I}$$

- Firing frequency for constant current

$$f = \frac{1}{T} = \frac{I}{\Theta C}$$

Shortcomings of the pure Integrate-and-Fire model

- Infinite “memory” of old inputs
- No silence for low input levels

More realistic alternative: Leaky Integrate-and-Fire Model

- Re-introduce the *leak* current

$$C\frac{dV}{dt} = -GV + I$$

- Standard form

$$\tau\frac{dV}{dt} = -V + RI$$

- Time to reach threshold

$$T = \tau \ln \frac{RI}{RI - \Theta}$$

- Firing frequency

$$f = \frac{1}{\tau \ln \frac{RI}{RI-\Theta}}$$

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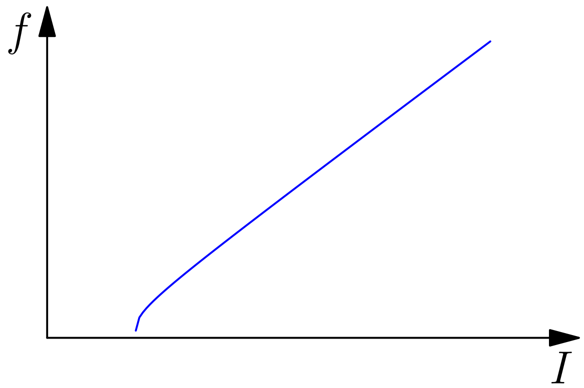
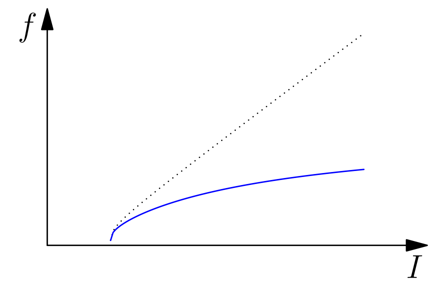


Absolute Refractory Period

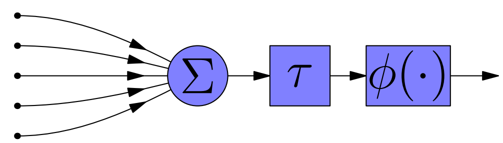
Time after a spike when no new spike can be generated, regardless of input

- Model version:
  Absolute delay, *Delta*, before integration starts after a reset
- Firing frequency

$$f = \frac{1}{\Delta + T} = \frac{1}{\Delta + \tau \ln \frac{RI}{RI - \Theta}}$$



If actual spikes are irrelevant, can't we simply use a scalar output value represeting the frequency?



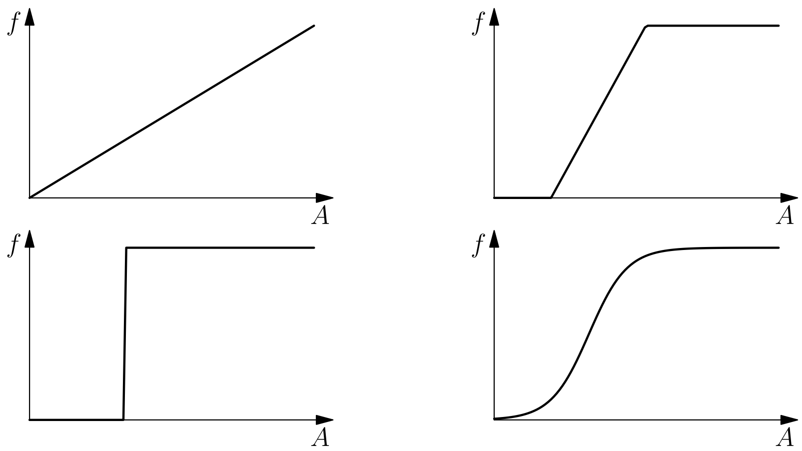
- Leaky integrator

$$\tau \frac{dA}{dt} = I - A$$

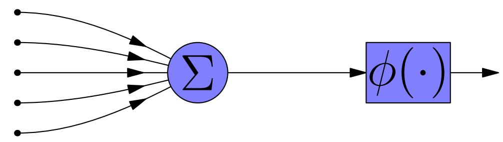
- Squashing function

$$f = \phi(A)$$

Common squashing functions



When dynamics is not important, the integrator can be removed



Standard model used in most Artificial Neural Networks