COMS30017
COMPUTATIONAL NEUROSCIENCE

LECTURE: LEAKY INTEGRATE-AND-FIRE MODEL OF NEURON

PART-2

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Frequency-Current (f-I) curves

- Fundamentally, neurons are input-output devices: - Take synaptic inputs from other neurons - Output a series of spikes.

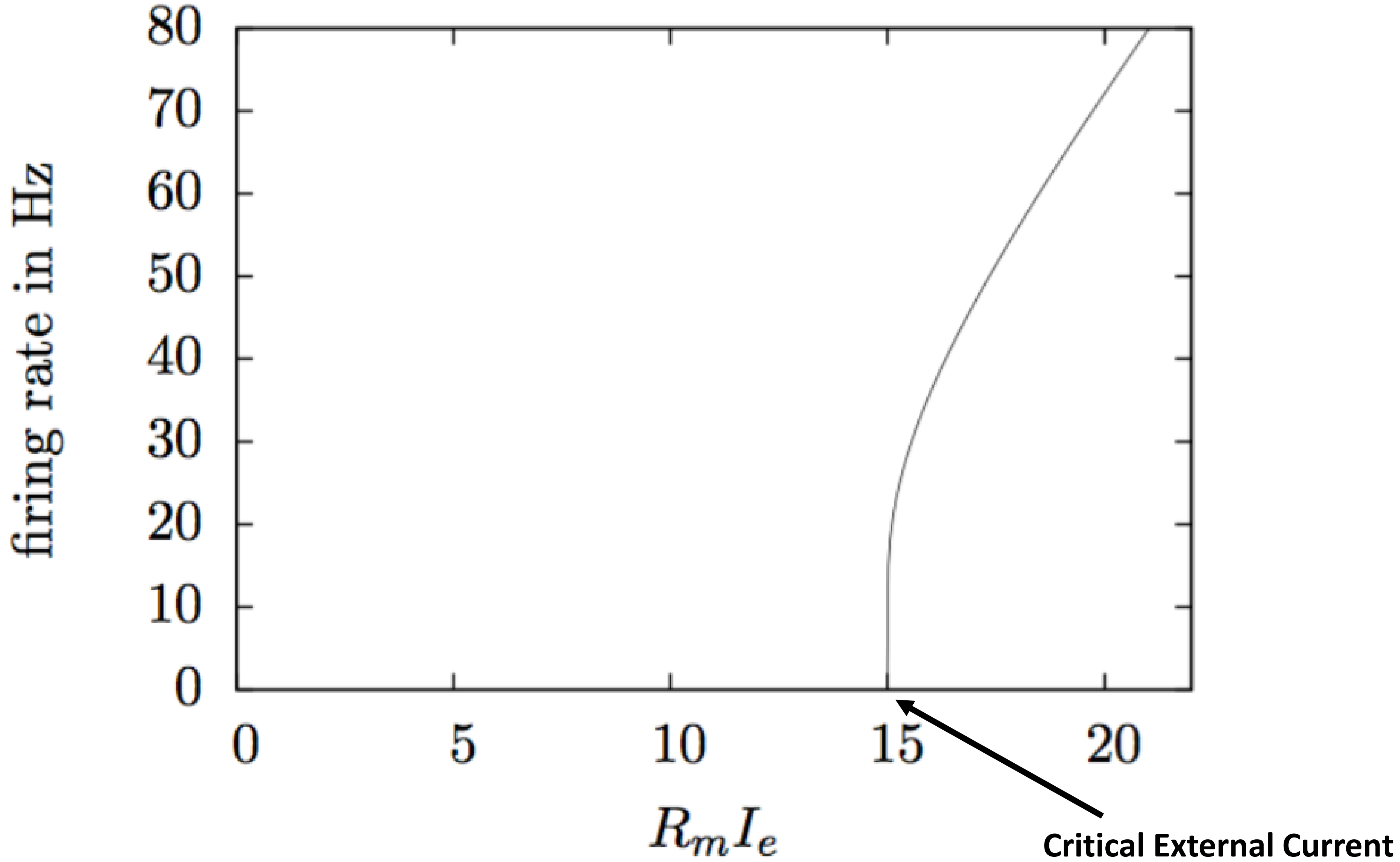
- One common way of characterising a neuron’s input-output function is the frequency-current (f-I) curve.

- The idea is that the experimenter injects current steps of various amplitudes to the neuron’s soma, then records the output firing rate of the neuron.

- Some real examples at: https://celltypes.brain-map.org/data

- For the LIF model we can analytically compute the time to spike, and therefore the spike frequency, as a function of the input current amplitude.

An example of f-I curve



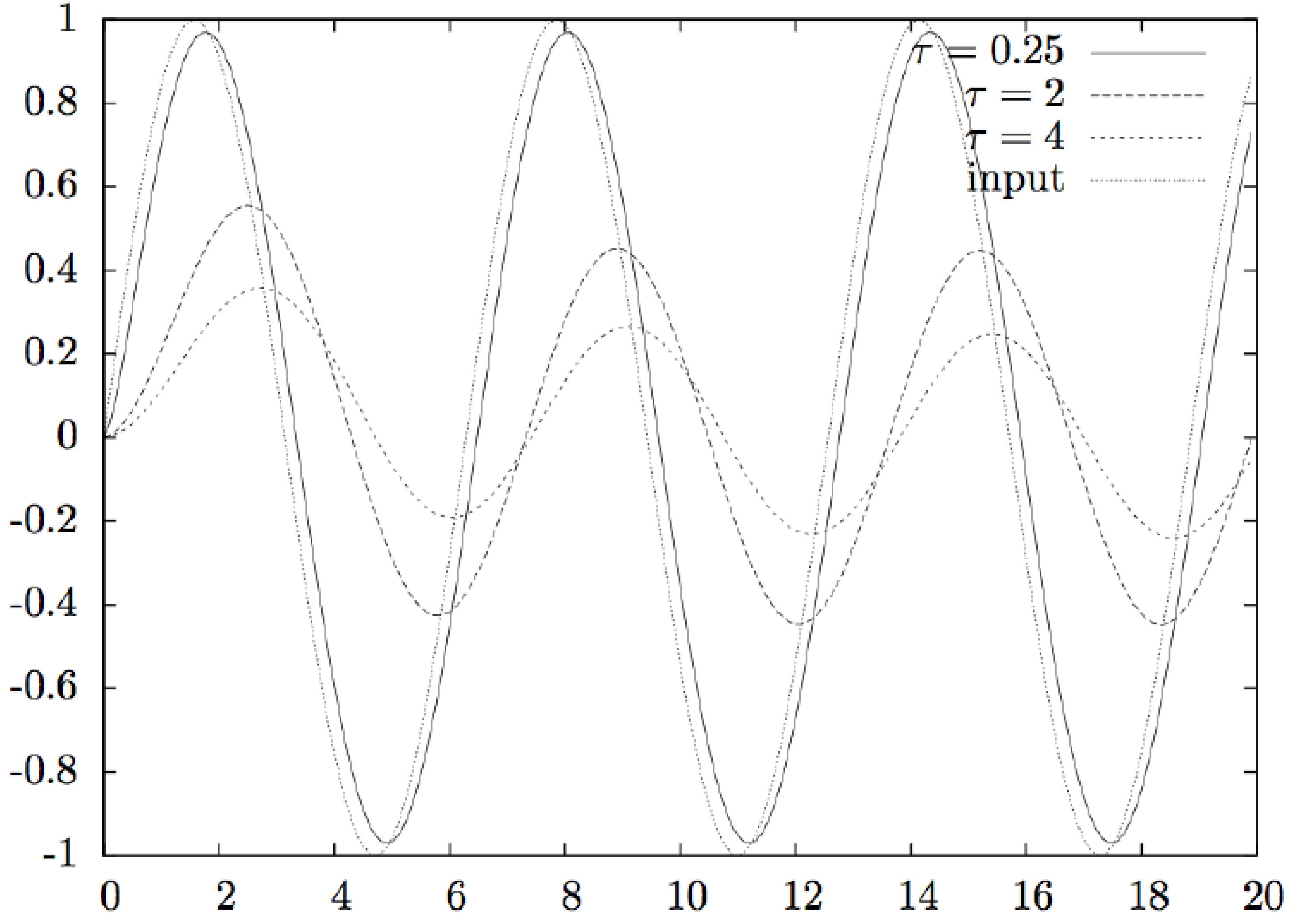
Low-pass filtering by the LIF

- The membrane capacitance acts to slow down the voltage dynamics: it takes time to charge and discharge.

- Quickly changing input signals tend to get averaged out because the membrane voltage can’t change quickly enough to track them.

- Slowly changing input signals, on the other hand, can be tracked by the membrane voltage.

- This implies that the LIF model filters high-frequency signals. In other words it is a “low-pass filter”.



$\tau = 0.25$
$\tau = 2$
$\tau = 4$
input
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
2
4
6
8
10
12
14
16
18
20

Low-pass filtering by the LIF

- We can summarise the input-output transform's frequency dependence by computing the Fourier transform of the LIF voltage in response to a periodic input signal of frequency f.

- This results in term **IMPEDANCE of the LIF model** to the external time-varying input.

- The absolute value of the impedance is equal to the ratio of the voltage amplitude to the current amplitude.

$$|Z(f)| = \frac{R_m}{\sqrt{1 + (2\pi f \tau_m)^2}}$$

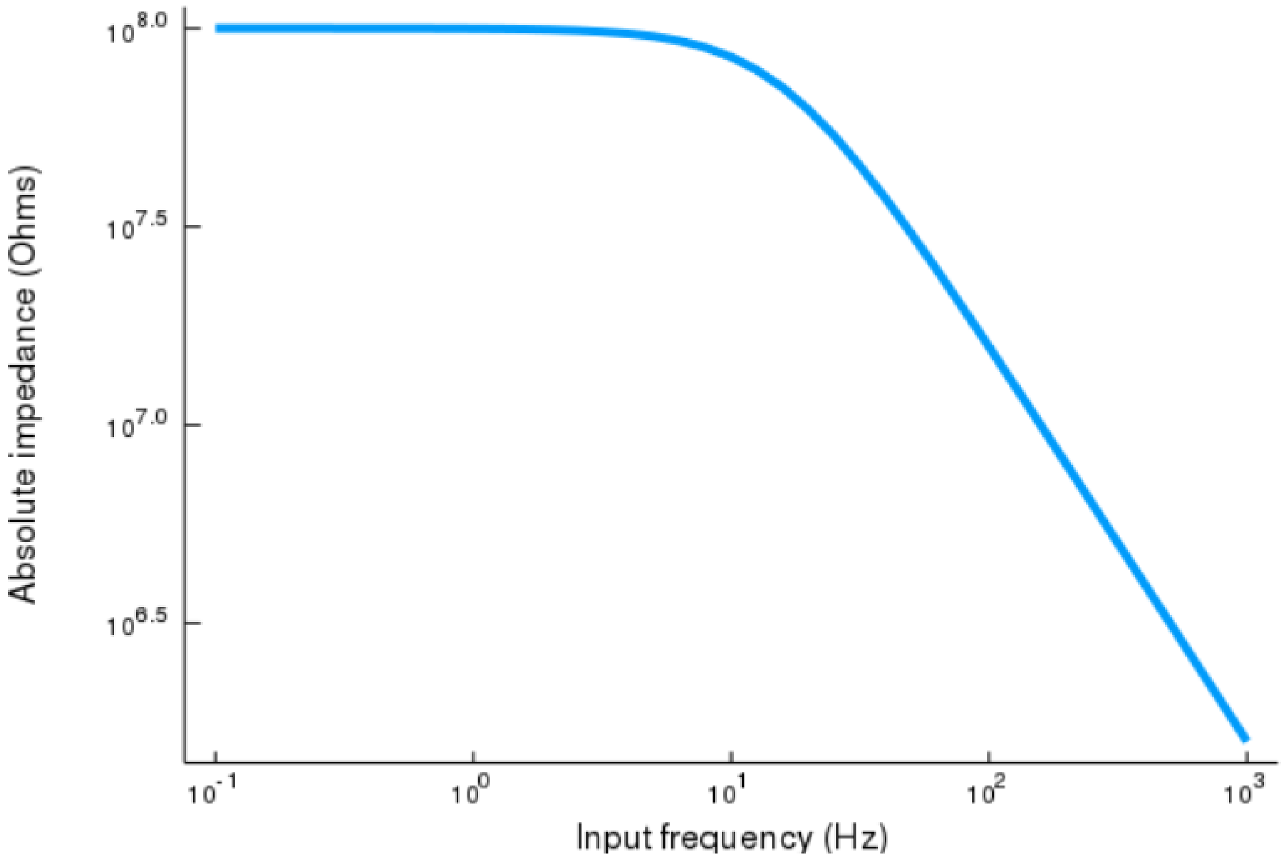
Unit in Ohms, *Ω*

$$\tau_m \frac{dV_m}{dt} = (V_{rest} - V_m) + \boxed{R_m I_{ext}}$$

- If $f = 0, |Z(f)| = R_m$
- If f increases, $|Z(f)| \ll R_m$

Higher is the Impedance of the LIF, the neuron will have stronger sense of the external input and, thus, will also respond strongly!!

Impedance of LIF towards the frequency of external time-varying current



R_m = 100 MOhms, τ_m = 10 ms

Extensions to the LIF

The leaky integrate-and-fire neuron is a basic model. Over the years many extensions have been designed to make it more realistic:

- A refractory period.

- A mechanism for spike-frequency adaptation.

- A dynamic spike threshold value.

Further Reading

Conor's notes :https://github.com/coms30127/2019_20/notes/14_integrate_and_fire_cjh_notes.pdf

Excellent book:
Neuronal Dynamics
From single neurons to networks and models of cognition
Wulfram Gerstner, Werner M. Kistler, Richard Naud and Liam Paninski

Freely Available online: https://neuronaldynamics.epfl.ch/index.html