SYDE 556/750

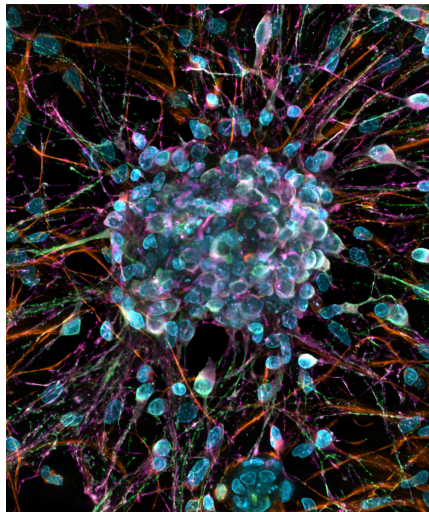**Simulating Neurobiological Systems**
Lecture 2: Neurons

Andreas Stöckel
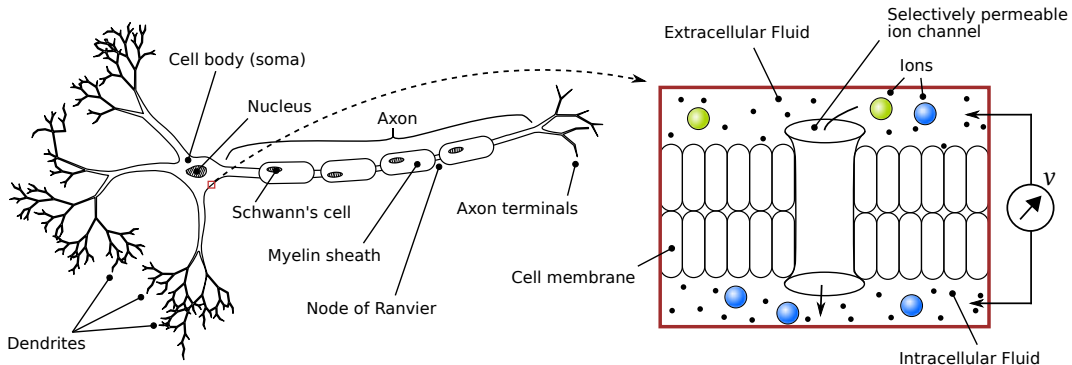
January 9 & 14, 2020

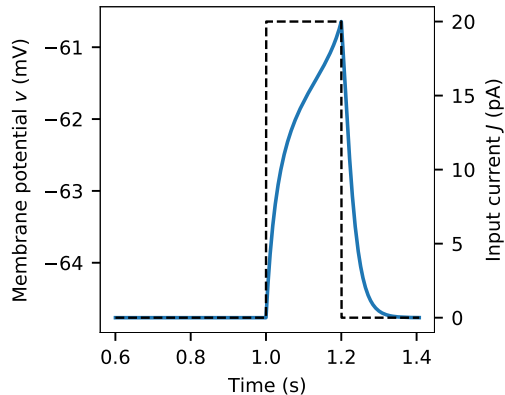
UNIVERSITY OF WATERLOO | FACULTY OF ENGINEERING

Textbook Neuron and Cell Membrane

Injecting a Current Into a Detailed Neuron Model

Computer simulation of an Hodgkin-Huxley type neuron with Traub kinematics (Roger D. Traub and Richard Miles, *Neuronal Networks of the Hippocampus*, Cambridge University Press, 1991)
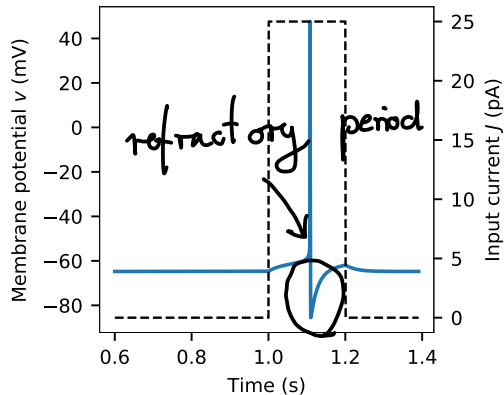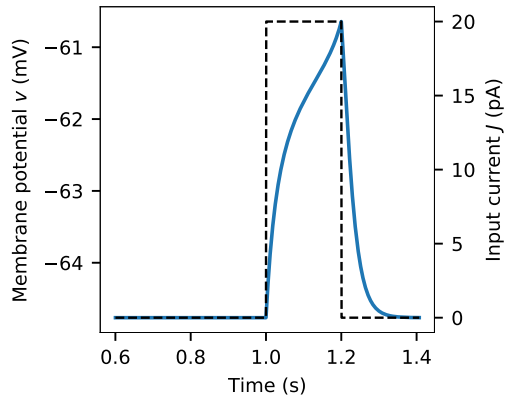
Injecting a Current Into a Detailed Neuron Model

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The Leaky Integrate-and-Fire Equivalent Circuit

Lapicque, 1907

Reset mechanism

Injecting a Current Ramp into a Detailed Neuron Model

Computer simulation of an Hodgkin-Huxley type neuron with Traub kinematics (Roger D. Traub and Richard Miles, *Neuronal Networks of the Hippocampus*, Cambridge University Press, 1991)
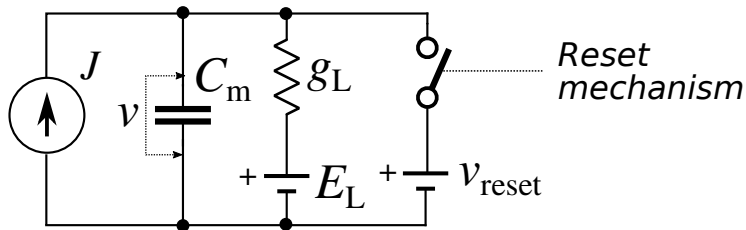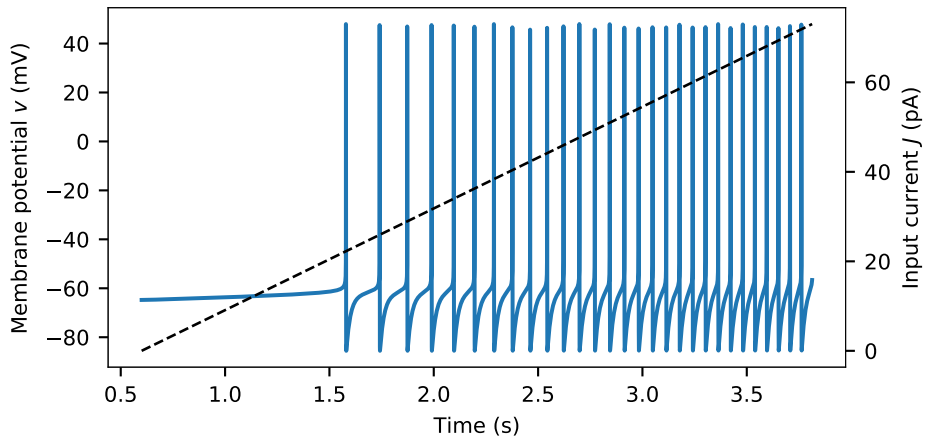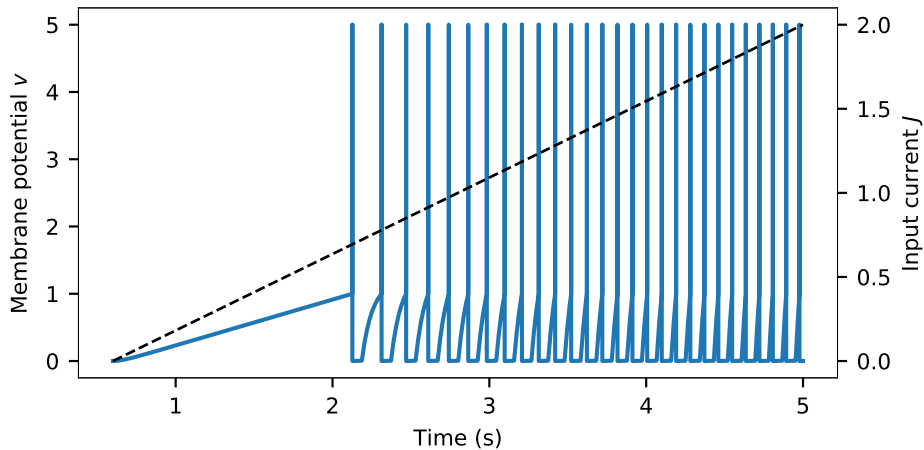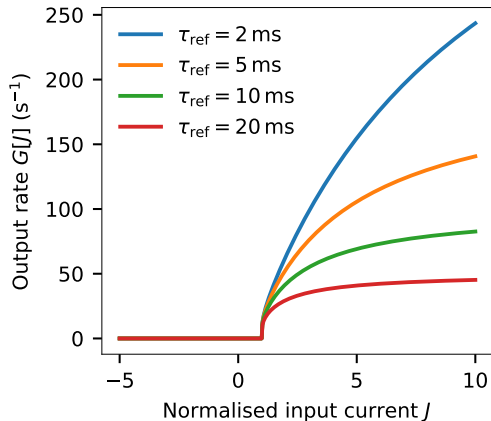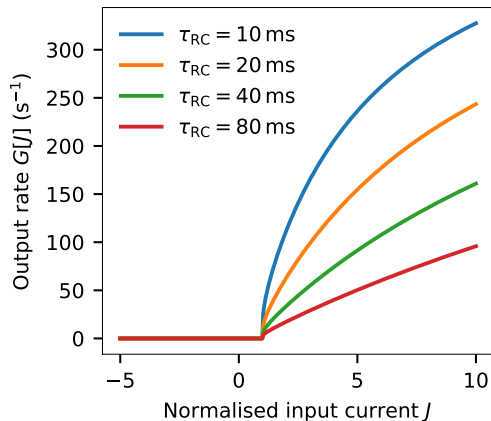
Injecting a Current Ramp into a LIF Neuron Model

Exploring the LIF Rate Approximation

Limitations of the LIF Neuron Model

(a) tonic spiking

(b) phasic spiking

(c) tonic bursting

(d) phasic bursting

(e) mixed mode

(f) spike frequency adaptation

(g) Class 1 excitable

(h) Class 2 excitable

(i) spike latency

(j) subthreshold oscillations

(k) resonator

(l) integrator

(m) rebound spike

(n) rebound burst

(o) threshold variability

(p) bistability

(q) depolarising after potentials

(r) accomodation

(s) inhibition induced spiking

(t) inhibition induced bursting

Limitations of the LIF Neuron Model

(a) tonic spiking

(b) phasic spiking — *membrane potential over time u(t)*, *input current*

(c) tonic bursting

(d) phasic bursting

(e) mixed mode

(f) spike frequency adaptation

(g) Class 1 excitable

(h) Class 2 excitable

(i) spike latency

(j) subthreshold oscillations

(k) resonator

(l) integrator

(m) rebound spike

(n) rebound burst

(o) threshold variability

(p) bistability

(q) depolarising after potentials — *DAP*

(r) accomodation

(s) inhibition induced spiking

(t) inhibition induced bursting

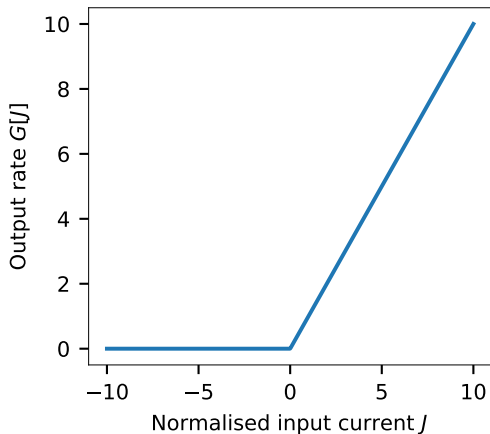LIF model

Artifical Rate Neurons: LIF

$$G[J] = \frac{1}{\tau_{\text{ref}} - \tau_{\text{RC}} \log\left(1 - \frac{1}{J}\right)}$$

Usefulness to neurobiological systems modellers:

➕ Biologically motivated

➕ Captures saturation effects

🟡 Relatively slow to evaluate numerically (for machine-learning people)

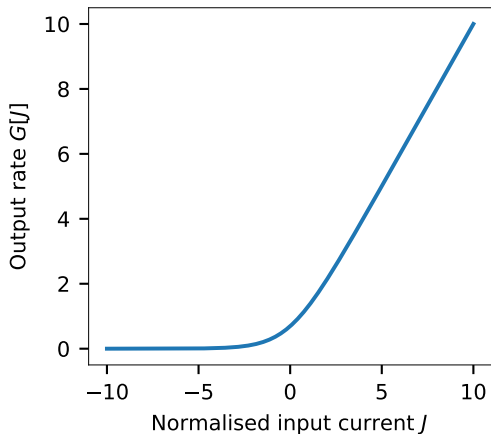➖ Spike onset is smooth in noisy systems

Artifical Rate Neurons: ReLU

$$G[J] = \max\{0, J\}$$

Usefulness to neurobiological systems modellers:

- ➕ Fast to evaluate
- 🟡 Rough approximation of the LIF response curve
- ➖ Does not capture saturation effects
- ➖ Spike onset is smooth in noisy systems
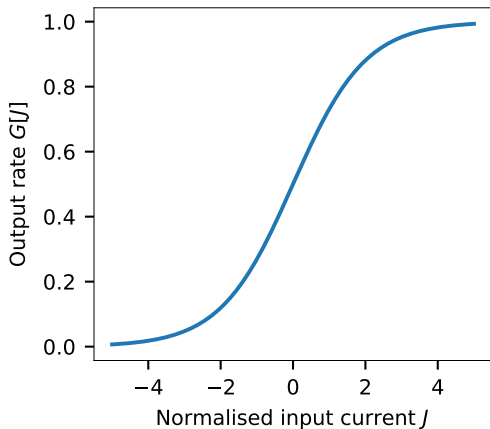
Artifical Rate Neurons: Smooth ReLU (Softplus)

$$G[J] = \log(1 + \exp(J))$$

Usefulness to neurobiological systems modellers:

🟢 Models smooth spike onset

🟡 Rough approximation of the LIF response curve

🔴 Does not capture saturation effects
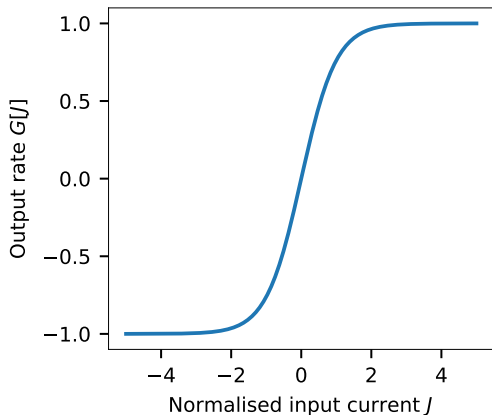
Artifical Rate Neurons: Logistic Function

$$G[J] = \frac{1}{1 + e^{-J}}$$

Usefulness to neurobiological systems modellers:

- Models smooth spike onset and saturation (?)

Artifical Rate Neurons: Hyperbolic Tangent

$$G[J] = \tanh(J) = \frac{e^J - e^{-J}}{e^J + e^{-J}}$$

Usefulness to neurobiological systems modellers:

- 🟡 Models smooth spike onset and saturation (?)
- 🔴 Negative rates