

**SYDE 556/750**

**Simulating Neurobiological Systems**  
**Lecture 2: Neurons**

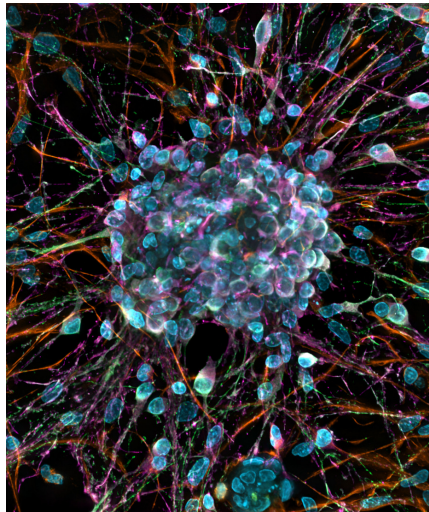
Andreas Stöckel

January 9 & 14, 2020

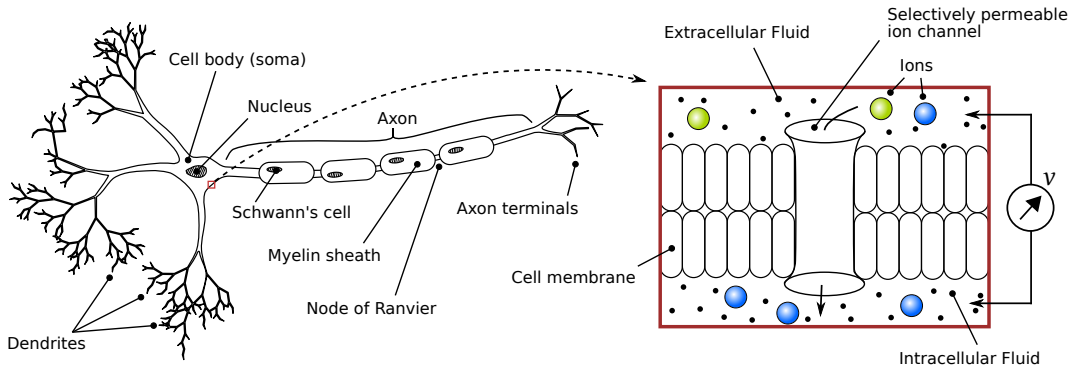


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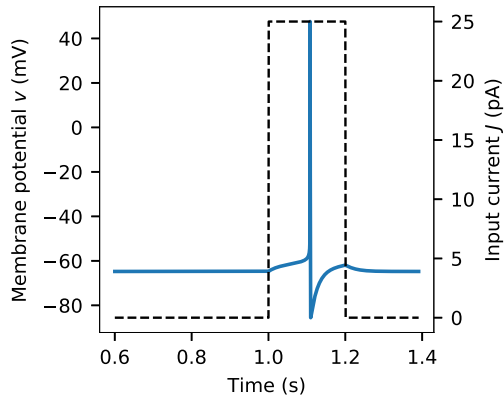
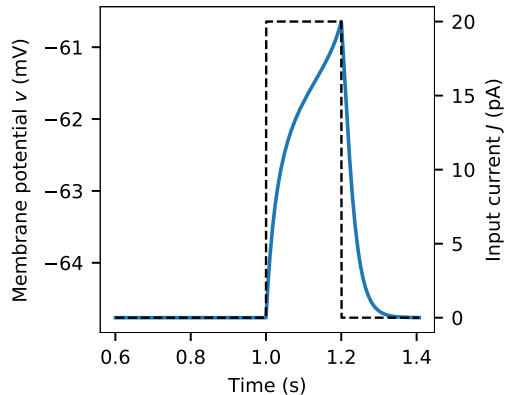
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# Textbook Neuron and Cell Membrane

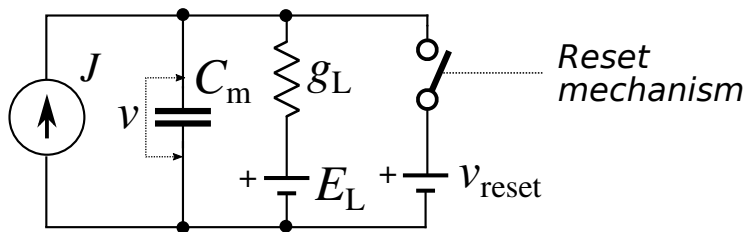


## Injecting a Current Into a Detailed Neuron Model

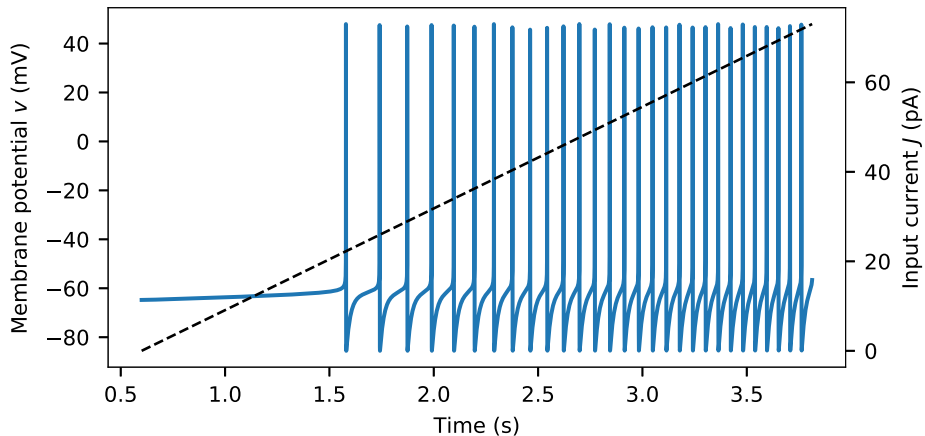


Computer simulation of an Hodgkin-Huxley type neuron with Traub kinematics (Roger D. Traub and Richard Miles, *Neuronal Networks of the Hippocampus*, Cambridge University Press, 1991)

## The Leaky Integrate-and-Fire Equivalent Circuit

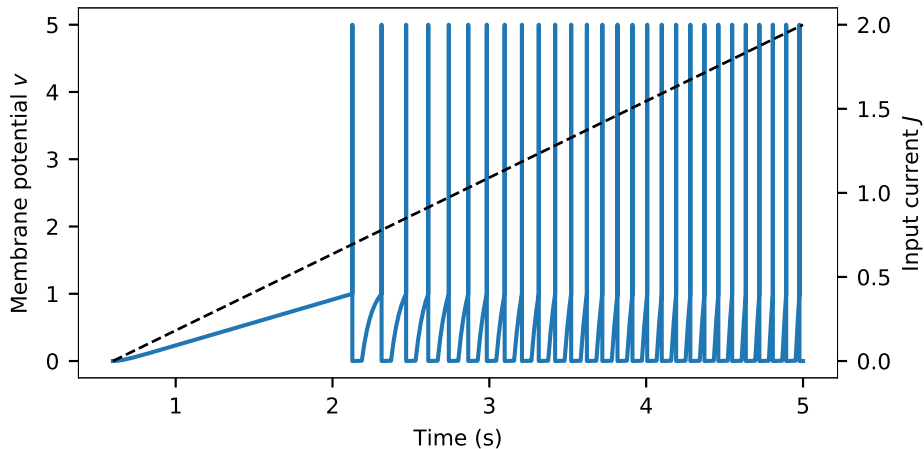


## Injecting a Current Ramp into a Detailed Neuron Model

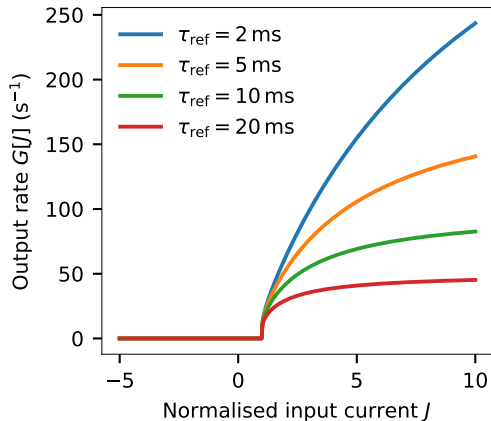
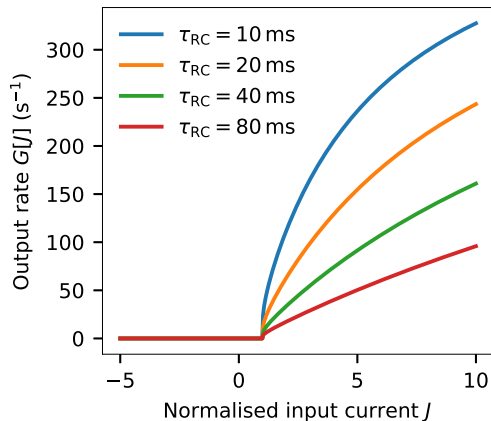


Computer simulation of an Hodgkin-Huxley type neuron with Traub kinematics (Roger D. Traub and Richard Miles, *Neuronal Networks of the Hippocampus*, Cambridge University Press, 1991)

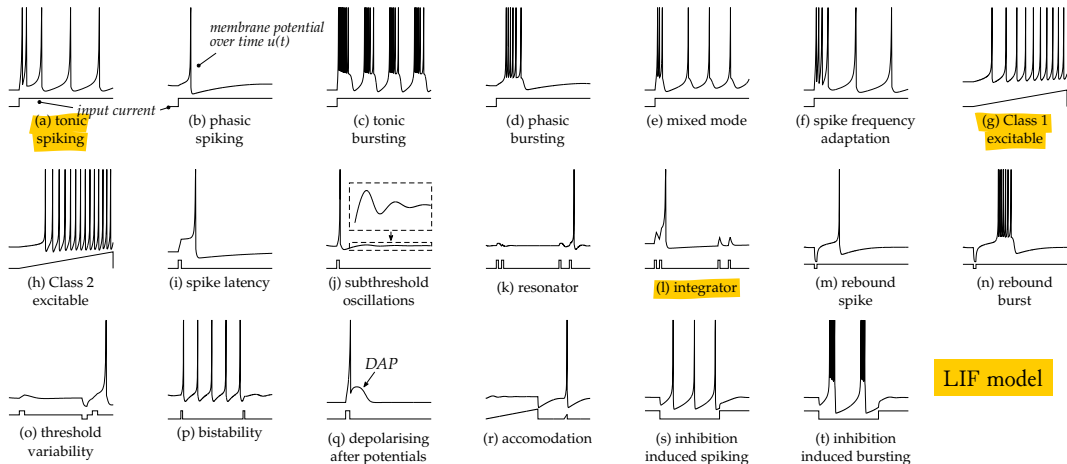
## Injecting a Current Ramp into a LIF Neuron Model



## Exploring the LIF Rate Approximation

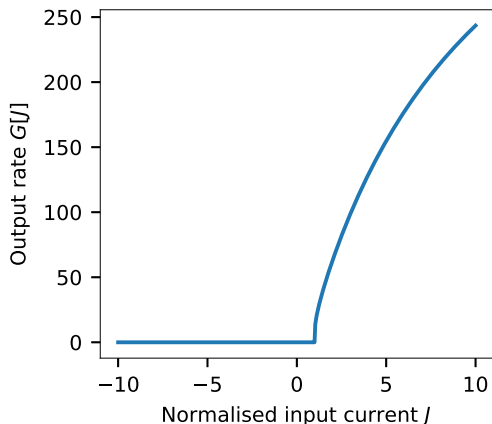


# Limitations of the LIF Neuron Model





## Artificial Rate Neurons: LIF

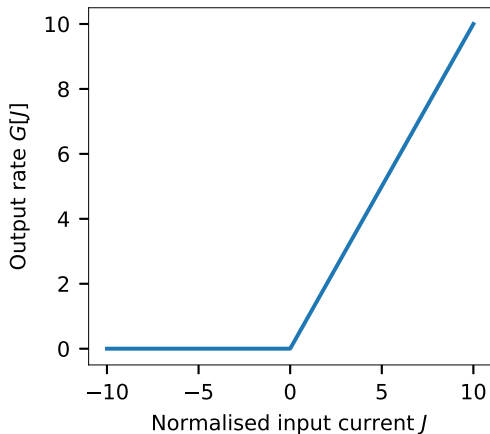


$$G[J] = \frac{1}{\tau_{\text{ref}} - \tau_{\text{RC}} \log \left(1 - \frac{1}{J}\right)}$$

### 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

# Artificial Rate Neurons: ReLU

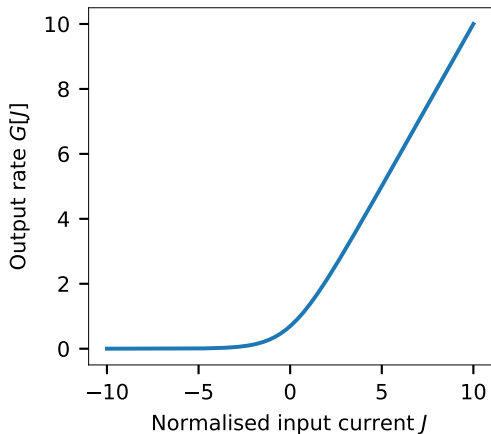


$$G[J] = \max\{0, J\}$$

## 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

## Artificial Rate Neurons: Smooth ReLU (Softplus)

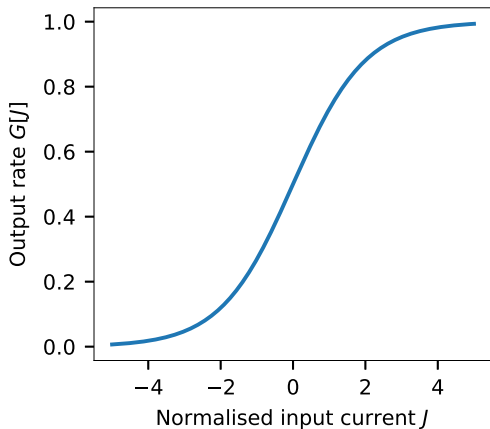


$$G[J] = \log(1 + \exp(J))$$

**Usefulness to neurobiological systems modellers:**

- ⊕ Models smooth spike onset
- Rough approximation of the LIF response curve
- ⊖ Does not capture saturation effects

## Artificial Rate Neurons: Logistic Function

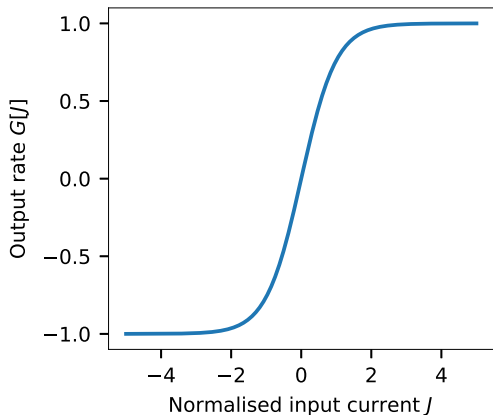


$$G[J] = \frac{1}{1 + e^{-J}}$$

**Usefulness to neurobiological systems modellers:**

- Models smooth spike onset and saturation (?)

# Artificial 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

# Image sources

## **Title slide**

Image of rat primary cortical neurons in culture.

Author: ZEISS Microscopy, <http://www.zeiss.com/celldiscoverer>.

From Wikimedia.