Generalized Leaky Integrate-and-Fire Model

Building blocks of models for cortical computation

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Lecture plan

1. Motivation: why we study mouse cortex

2. Single neuron models: From dynamical systems to hybrid systems

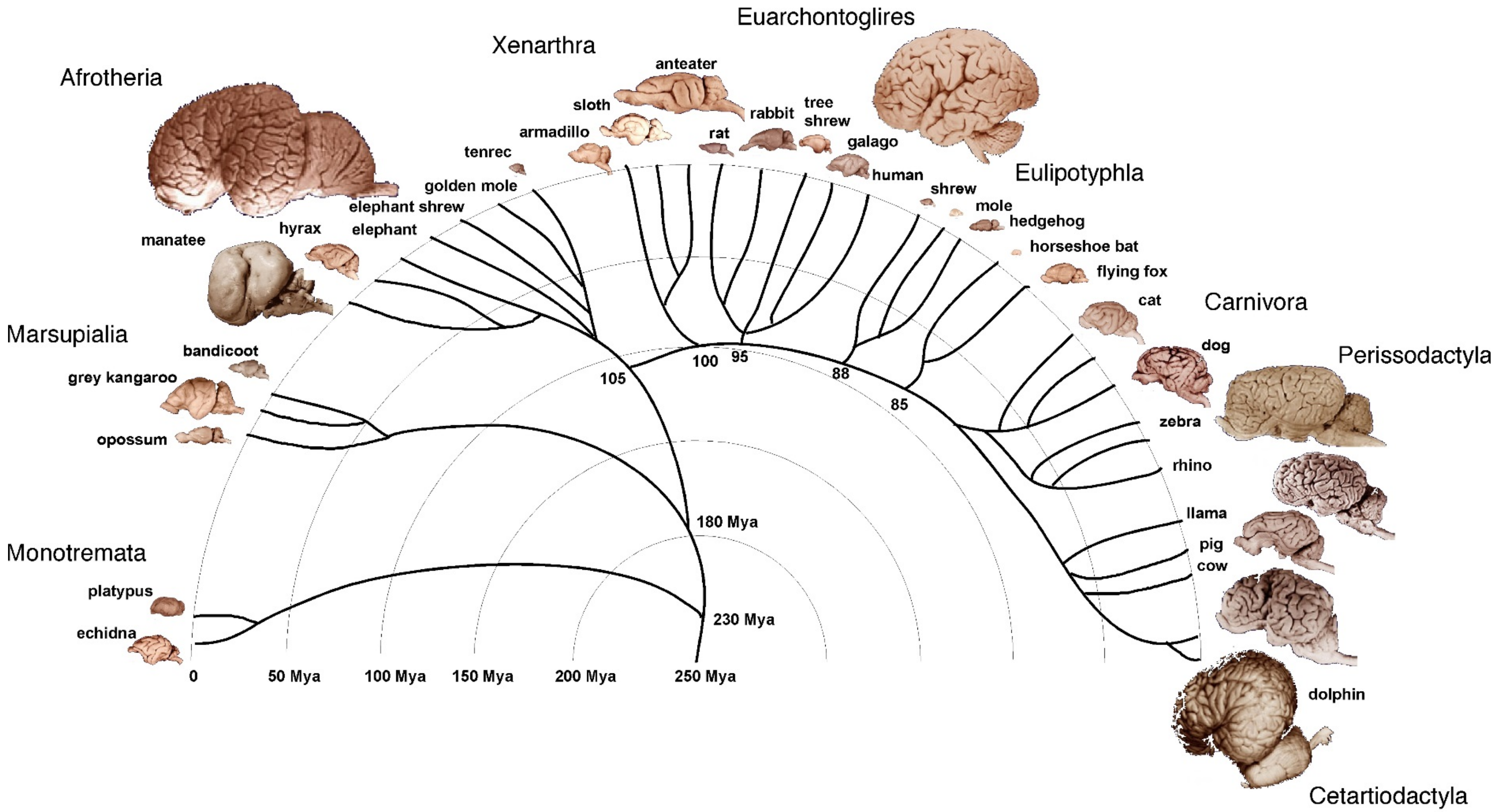
3. Generalized leaky integrate-and-fire model

4. Fitting GLIF models

5. Cell classification using GLIF models

1. Why study cortex?

Cerebral cortex can vary in size



Herculano-Houzel (2012) PNAS

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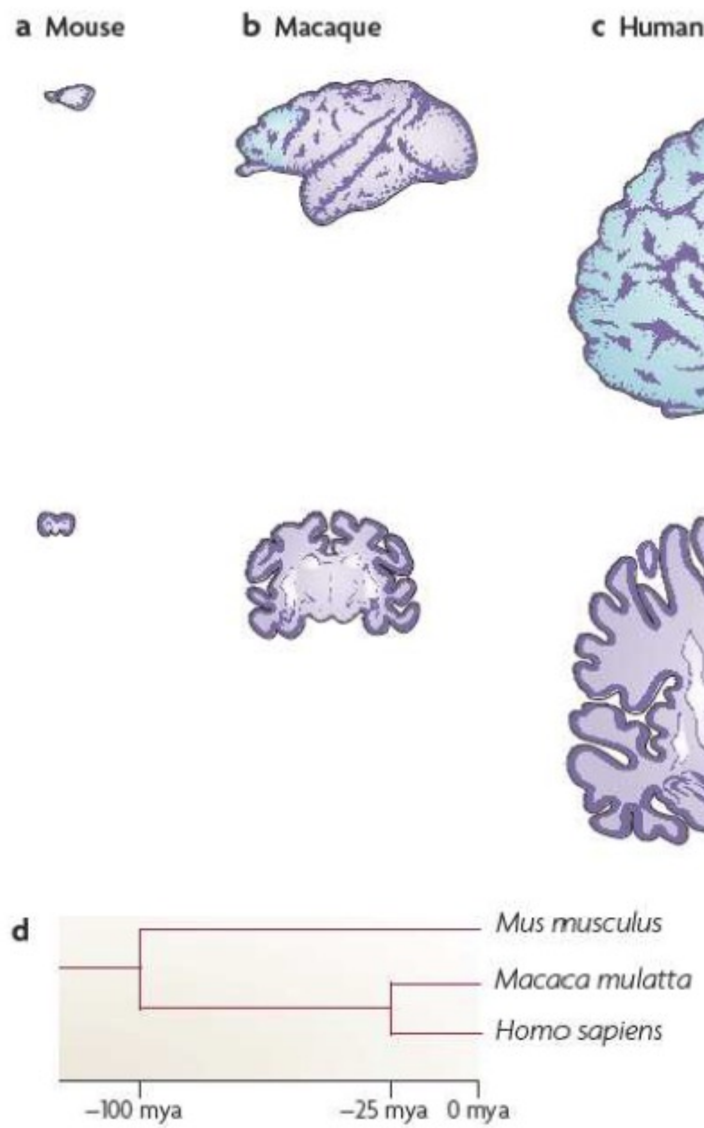
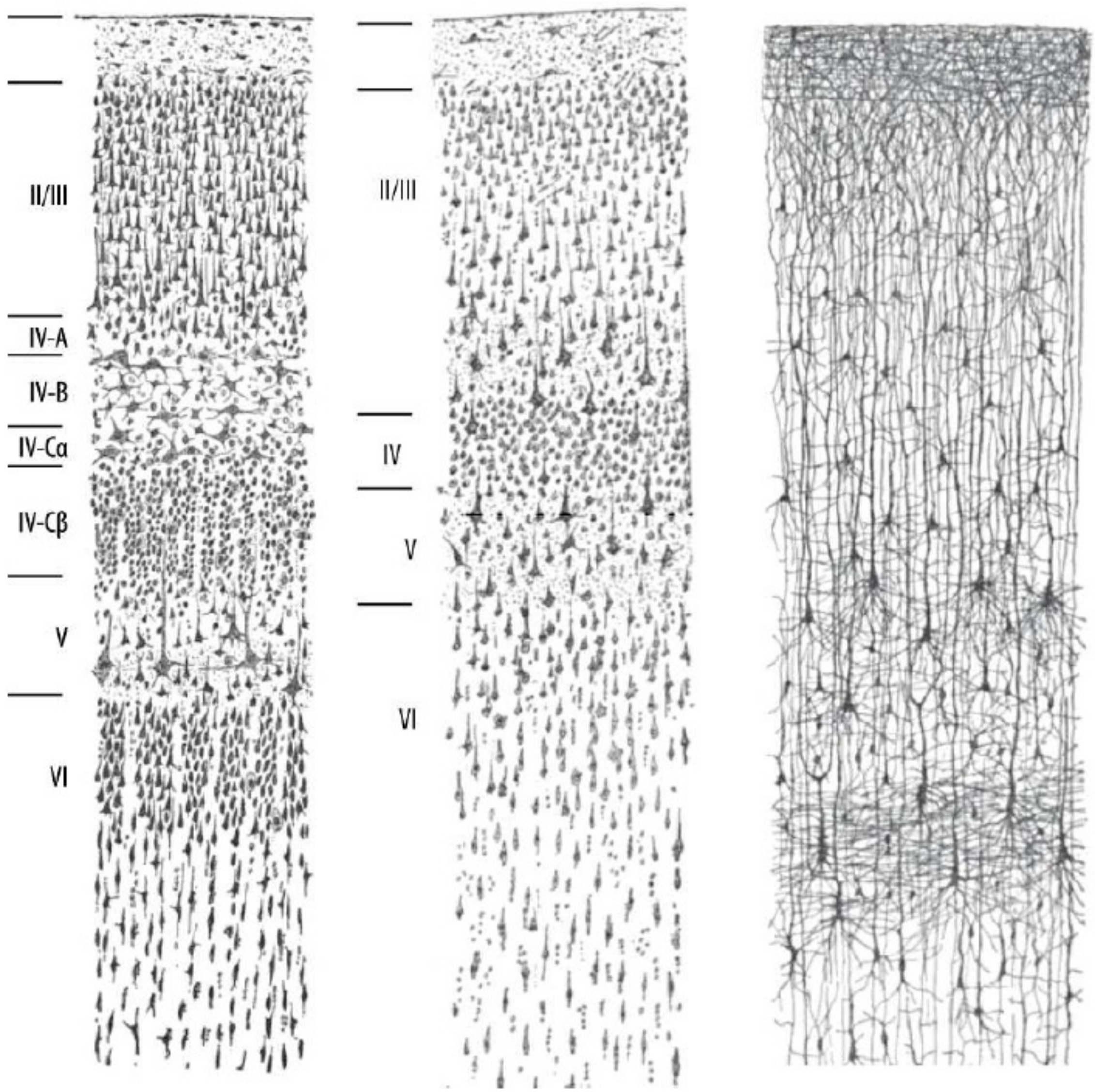
Cerebral cortex can vary in size



Perrenoud, 2012

But the basic microstructure is very similar across areas



Adult V1 Adult M1 Infant

Ramon y Cahal, 1911

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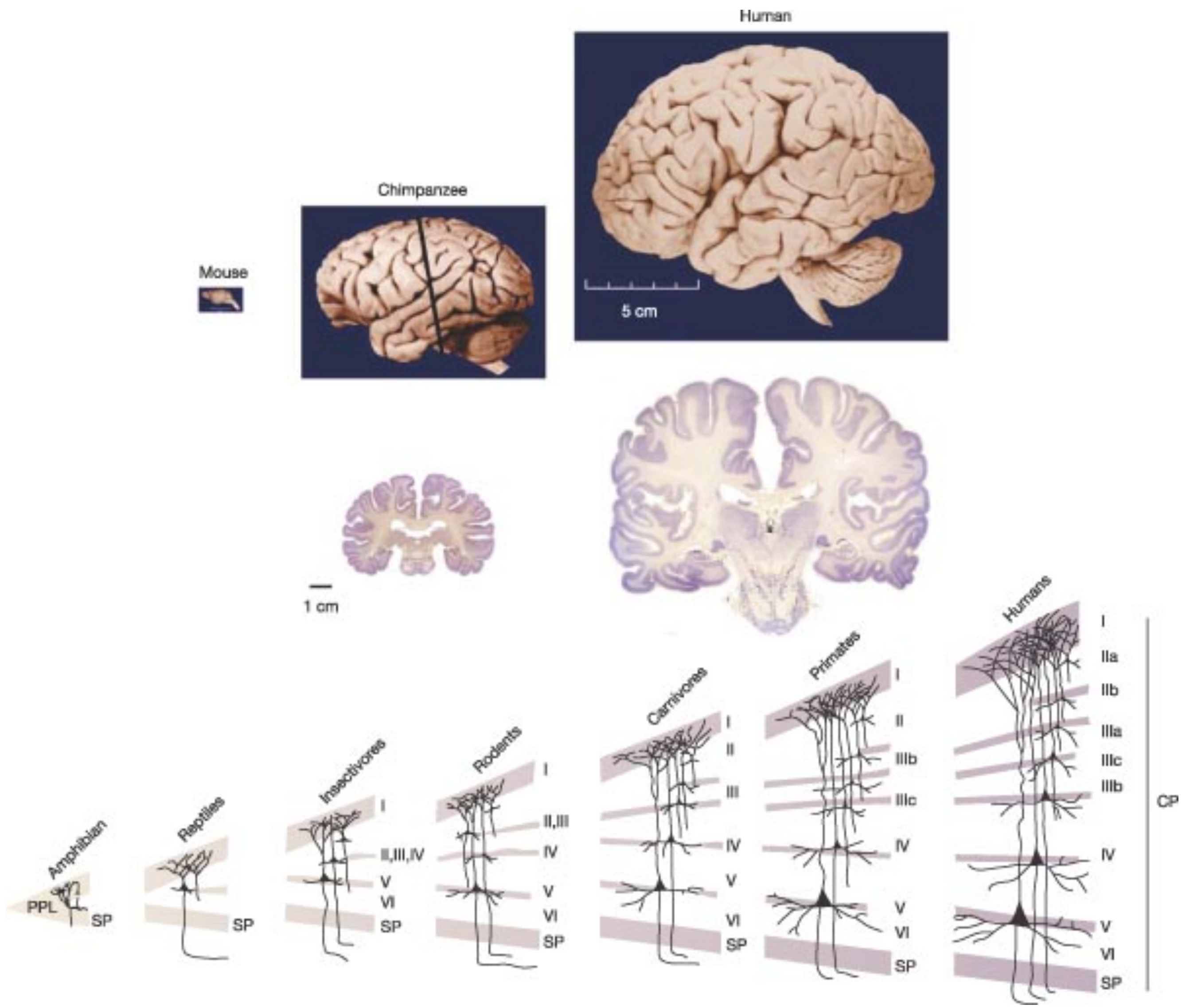
And across species



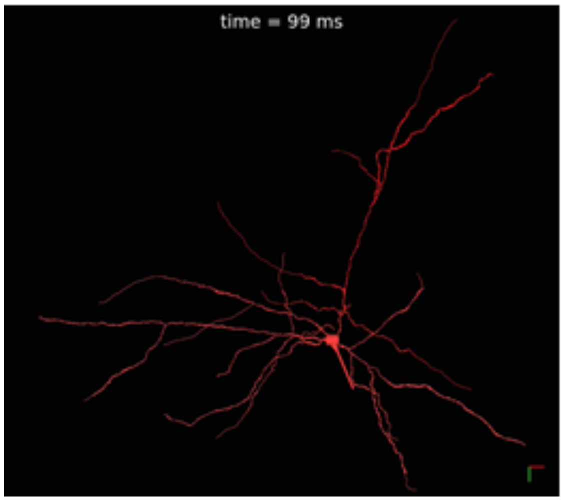
Hill and Walsh, Nature 2005

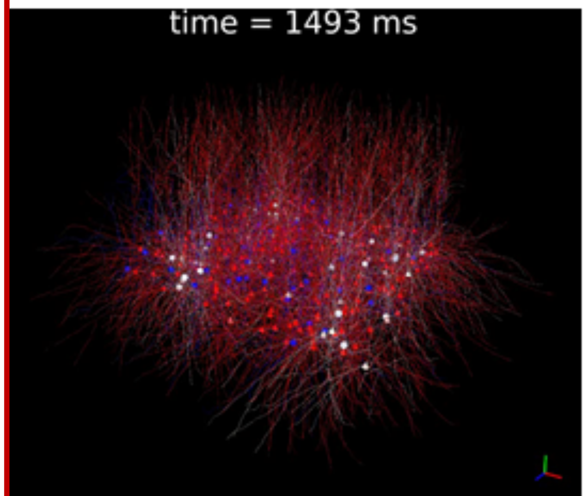
Cortical column computations

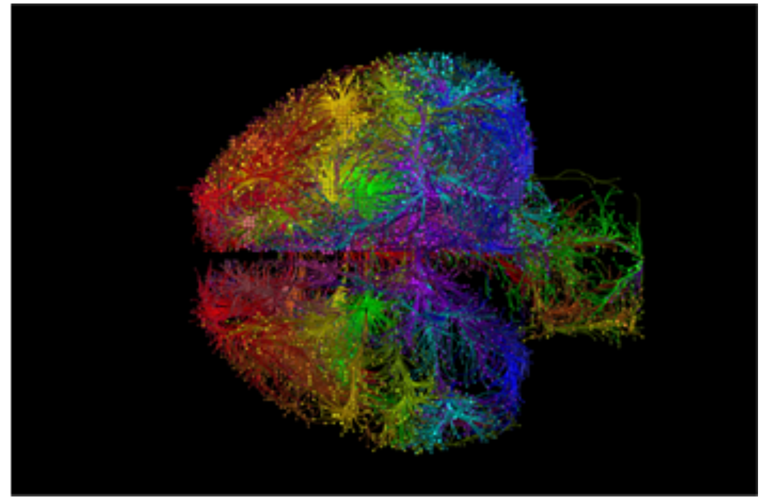
Hope:

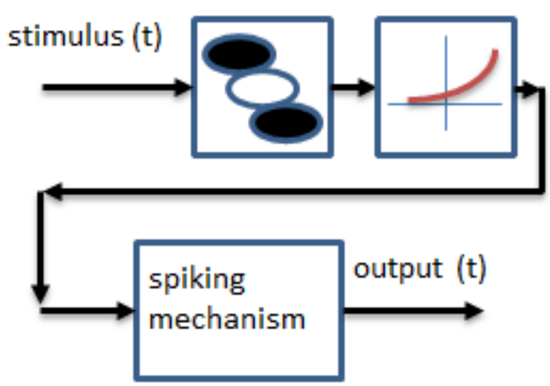
- Cortical columns implement canonical computations
- The function of the cortex arises from a hierarchical organization of such computations

Constructing minimalistic models which reproduce a desired function

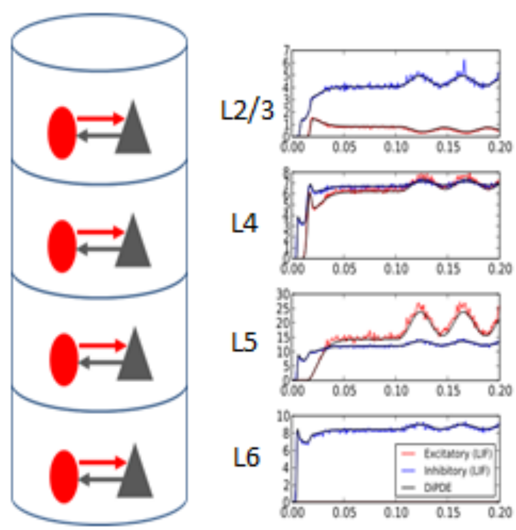




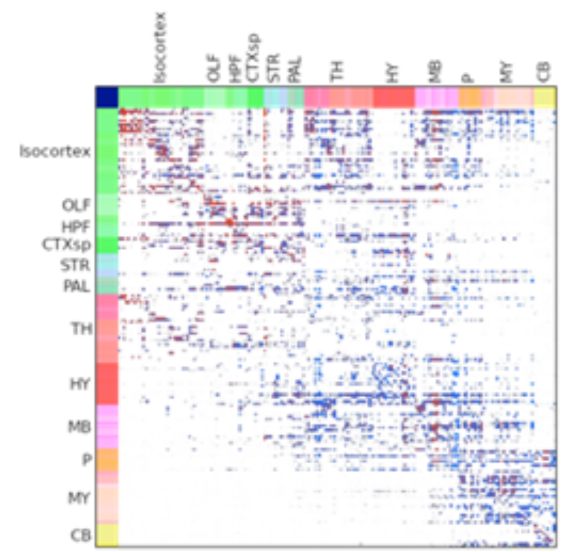




Single neuron activity



Activity in local circuits



Mesoscopic models

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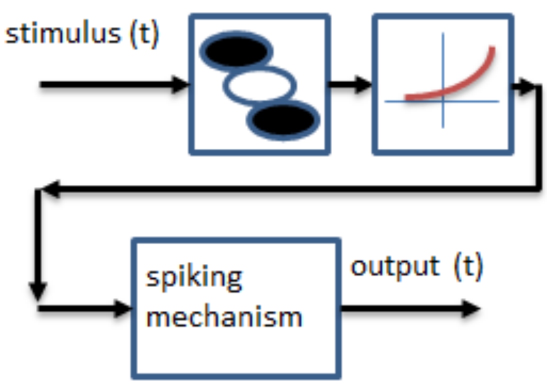
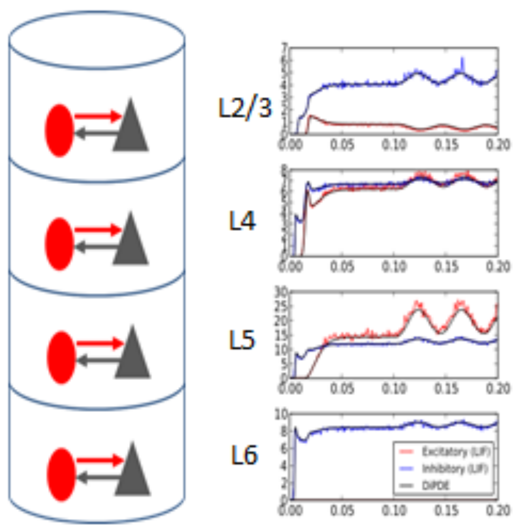
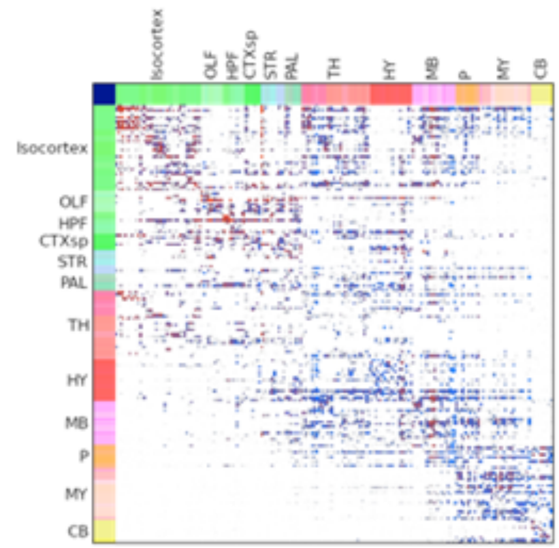
Long term goal:
Integrate models across scales into a model of cortical computation in the mouse visual system



Single neuron activity



Activity in local circuits



Mesoscopic models

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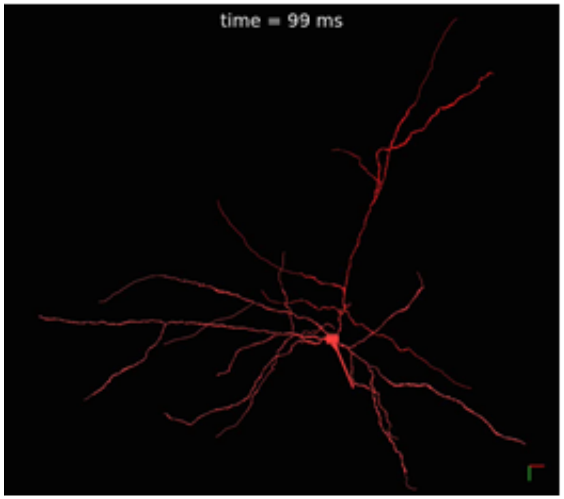
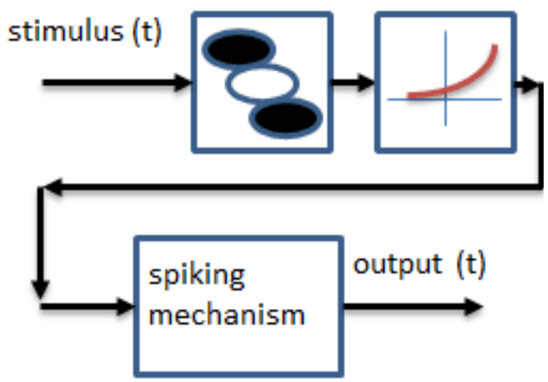
In Vitro single neuron models





Single neuron activity

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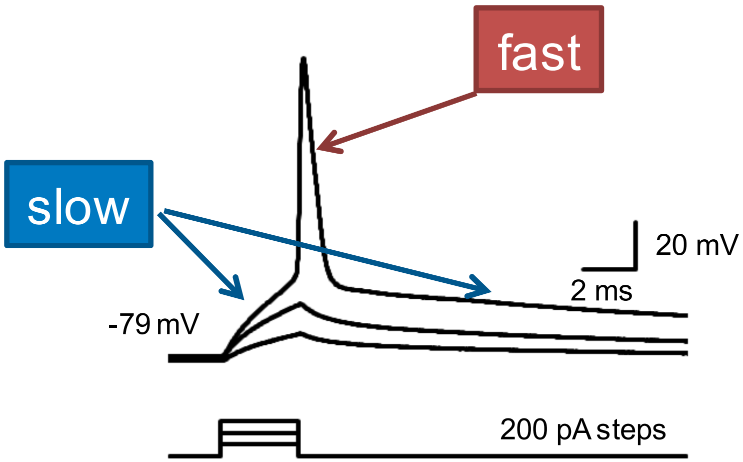
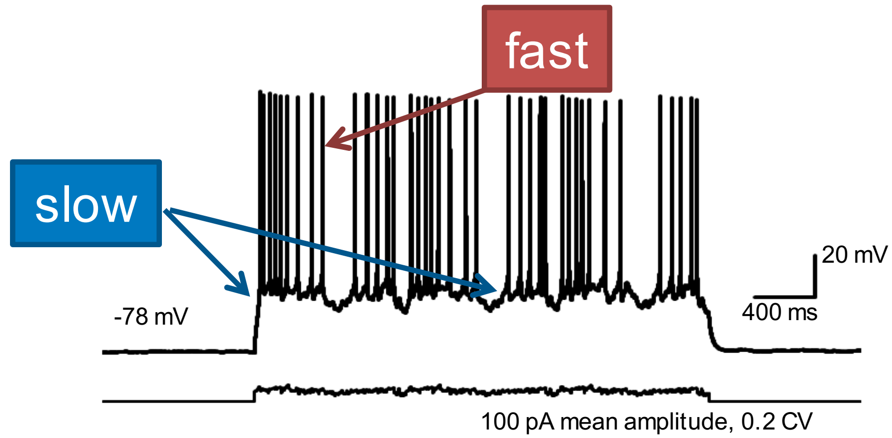
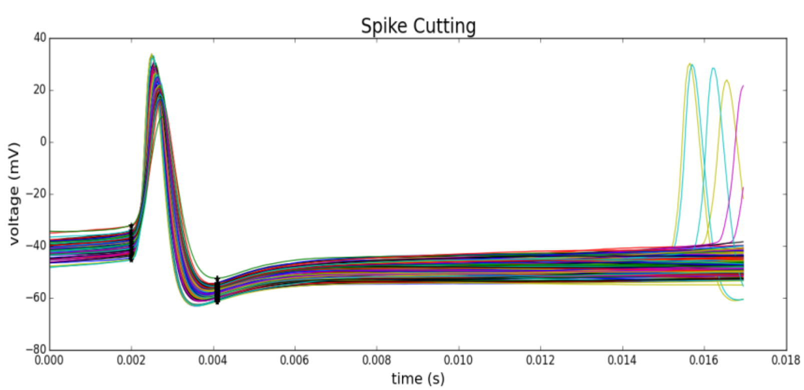
2. Why spiking models?

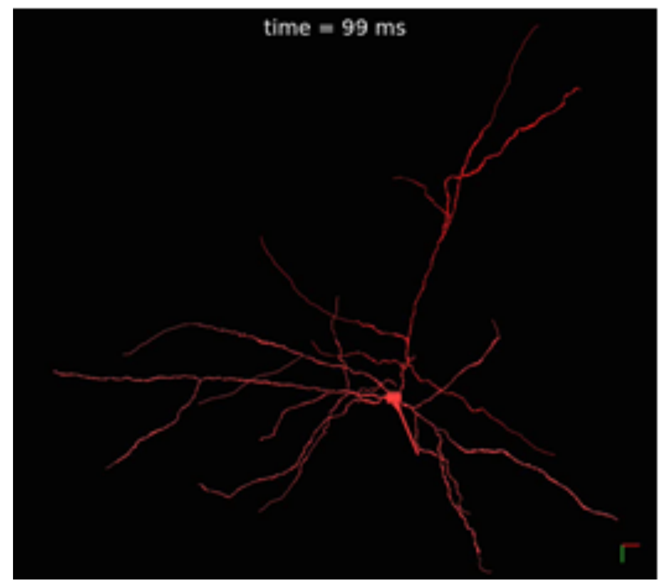
- Time scale separation of the subthreshold vs spiking dynamics





- Spikes are stereotyped





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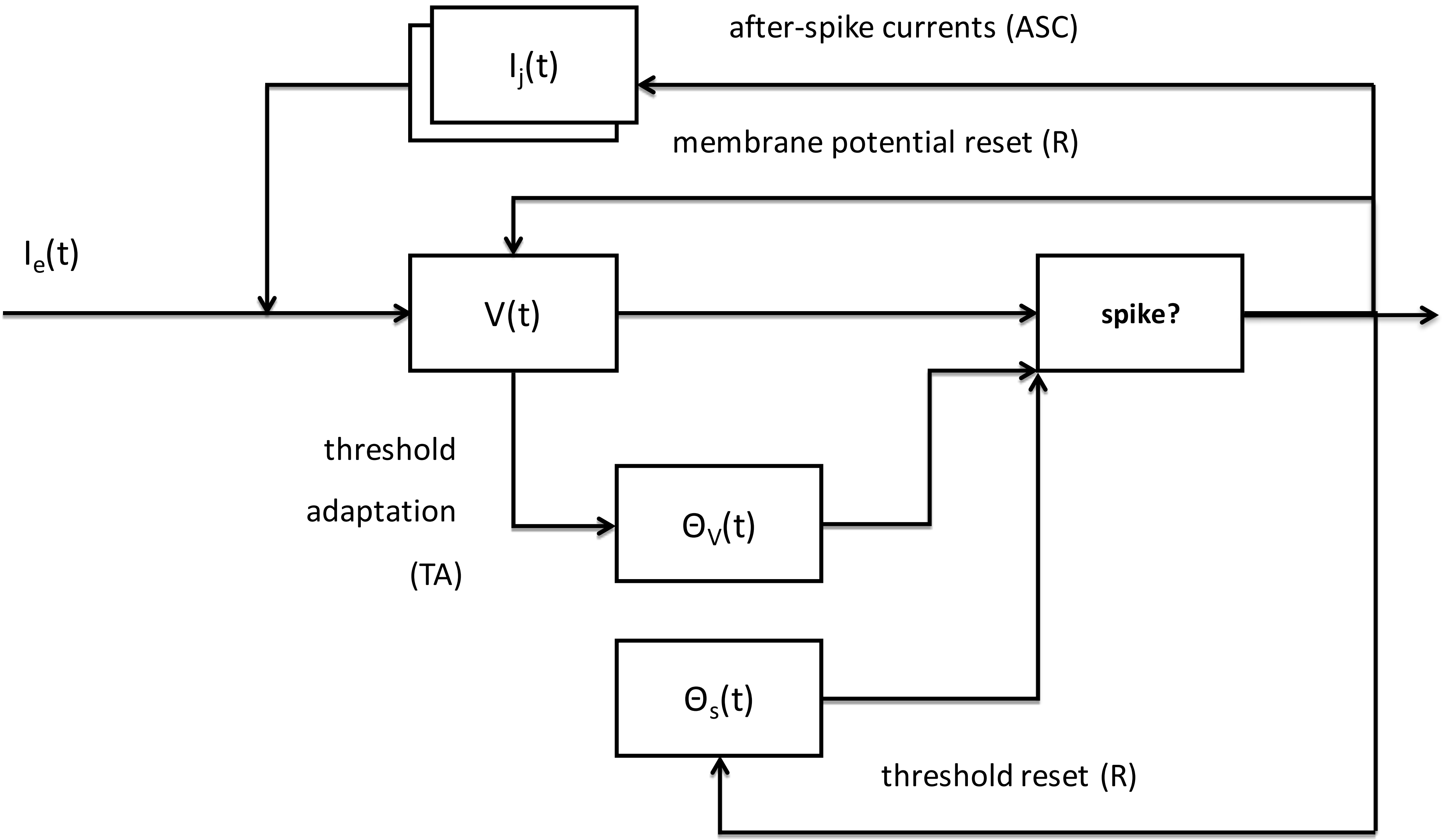
3. Generalized Leaky Integrate and Fire Models



Mihalas and Niebur 2009

Corinne Teeter, Stefan Mihalas

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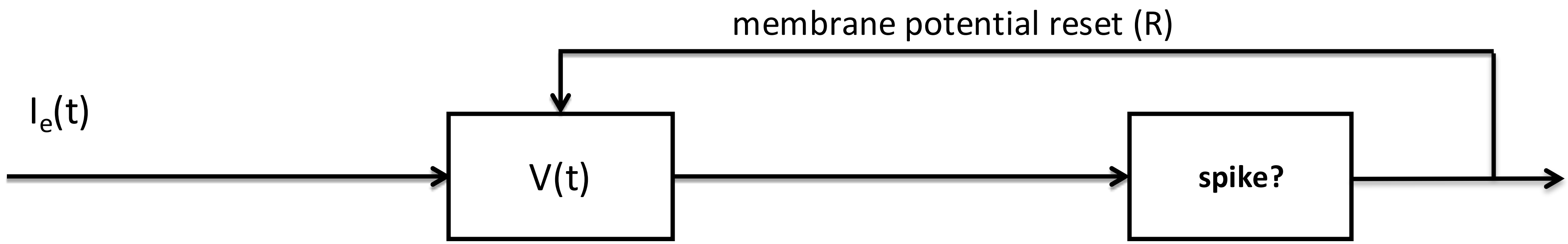
Leaky Integrate and Fire Models

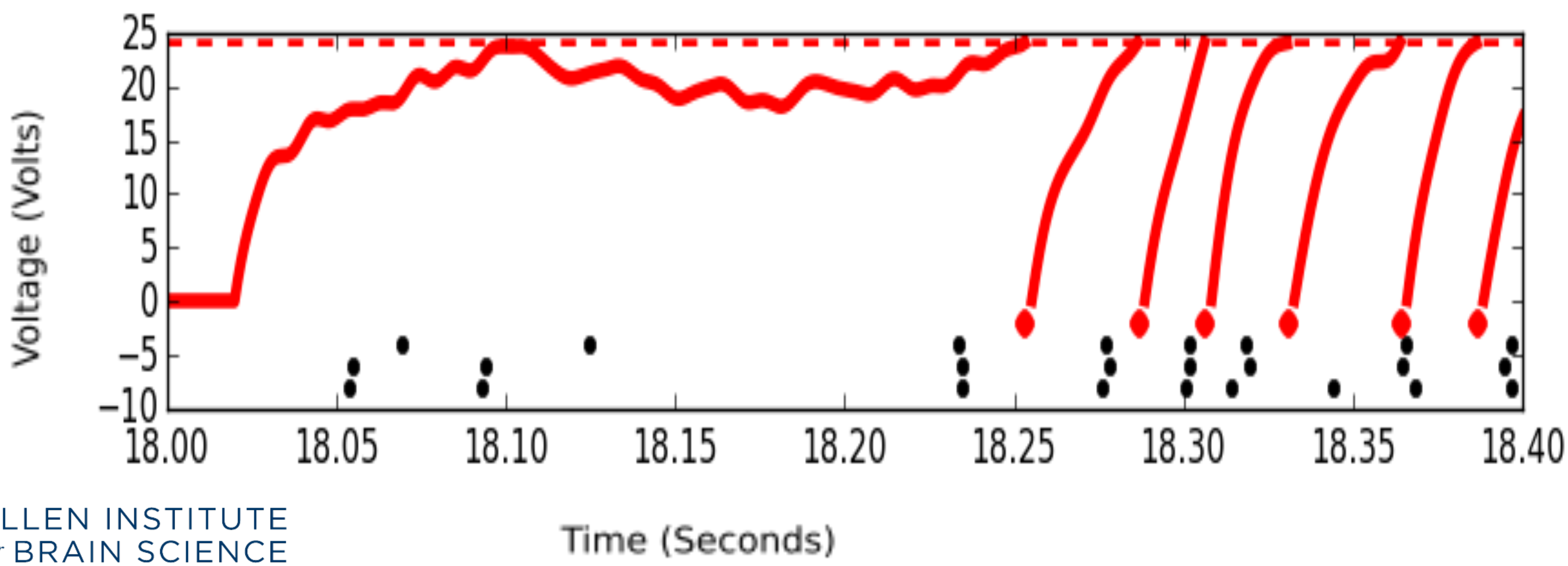


Dynamics: between spikes

$$V'(t) = \frac{1}{C}\left(I_e(t) - G\left(V(t) - E_L\right)\right)$$

Reset: if $V(t) > \Theta_\infty$

$$V(t) \leftarrow V_r$$



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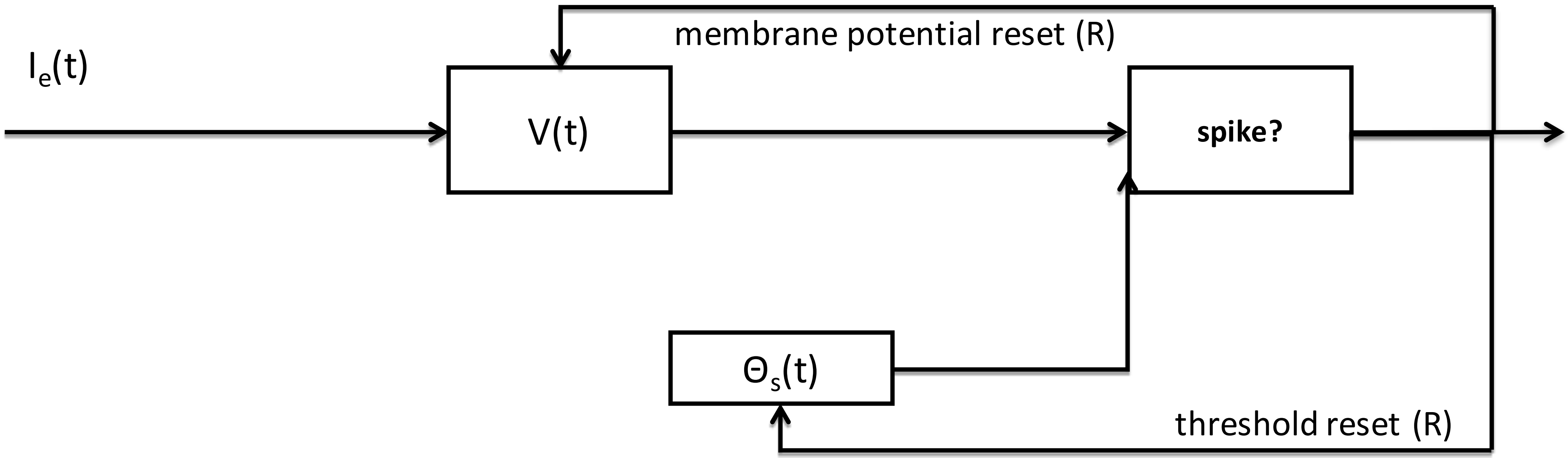
LIF with reset rules



Dynamics: between spikes

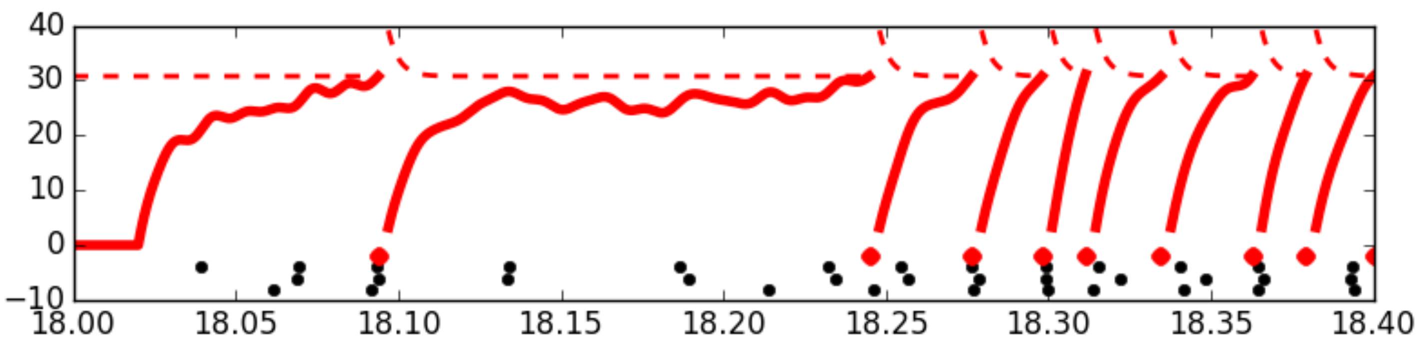
$$V'(t) = \frac{1}{C}\left(I_e + \sum_j I_j(t) - G\left(V(t) - E_L\right)\right)$$

$$\Theta_s'(t) = -b_s \Theta_s(t)$$

Reset: if $V(t) > \Theta_\infty + \Theta_s(t)$

$$V(t_+) \leftarrow E_L + f_v \times \left(V(t_-) - E_L\right) - \delta V$$

$$\Theta_s(t_+) \leftarrow \Theta_s(t_+) + \delta\Theta_s$$



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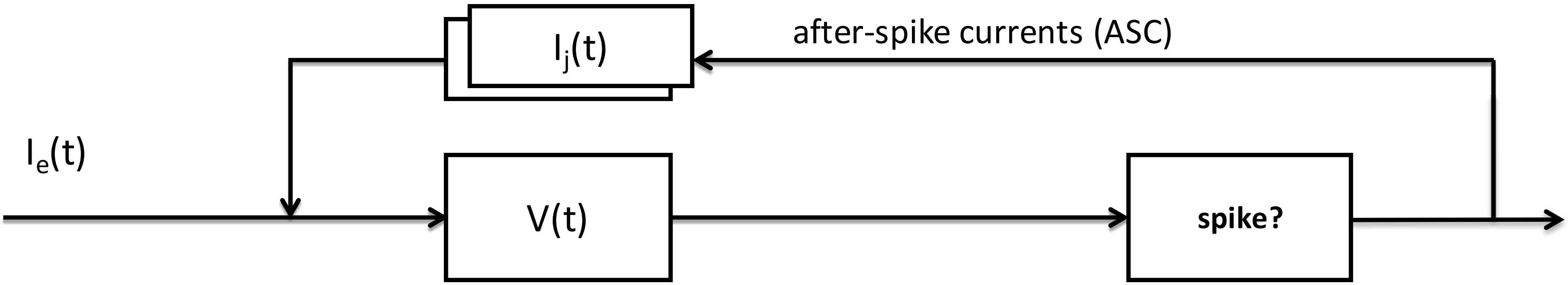
LIF with after-spike currents - optimization



Dynamics: between spikes

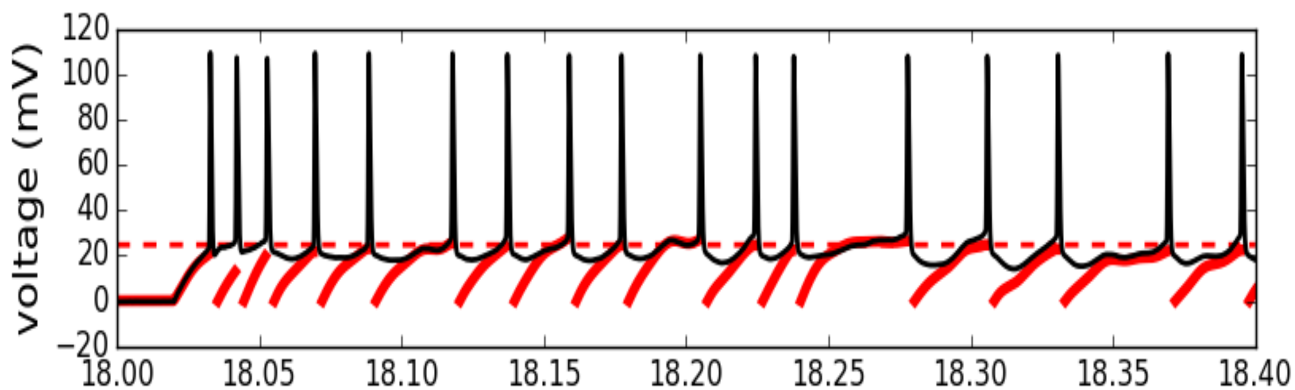
$$I_j'(t) = -k_j I_j(t);\ j = 1, \ldots, N$$

$$V'(t) = \frac{1}{C}\left(I_e(t) + \sum_j I_j(t) - G\,(V(t) - E_L)\right)$$

Reset: if $V(t) > \Theta_\infty$

$$I_j(t_+) \leftarrow R_j \times I_j(t_-) + A_j$$

$$V(t_+) \leftarrow V_r$$



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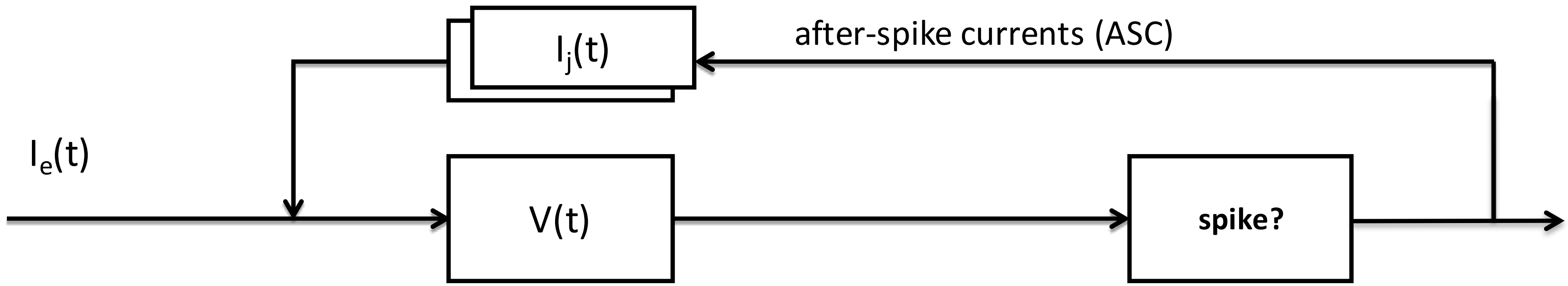
LIF with after-spike currents



Dynamics: between spikes

$$I_j'(t) = -k_j I_j(t);\; j = 1, \ldots, N$$

$$V'(t) = \frac{1}{C}\left(I_e(t) + \sum_j I_j(t) - G\left(V(t) - E_L\right)\right)$$

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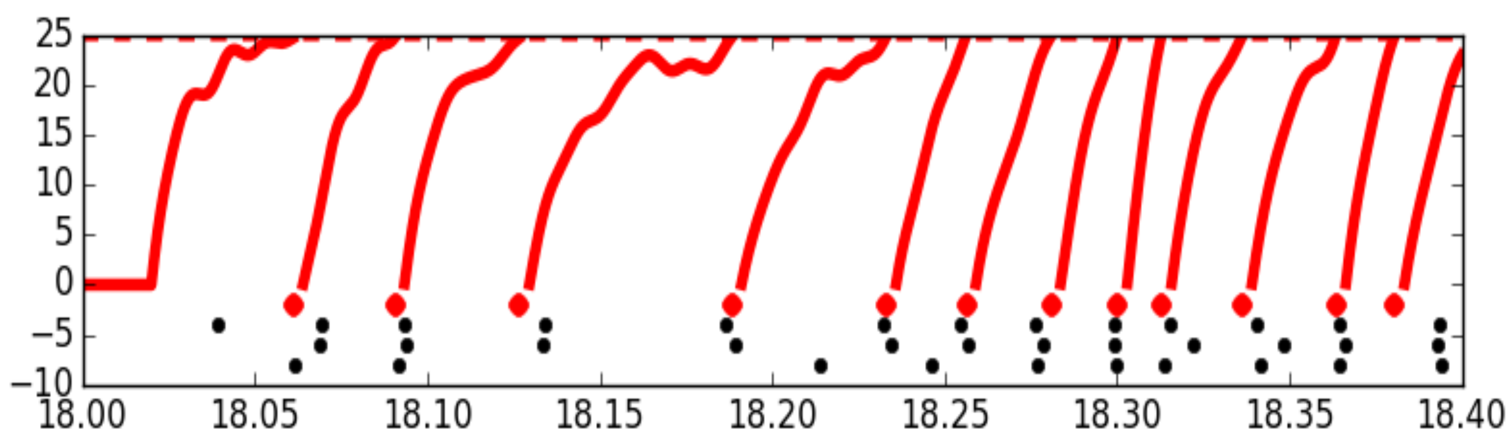

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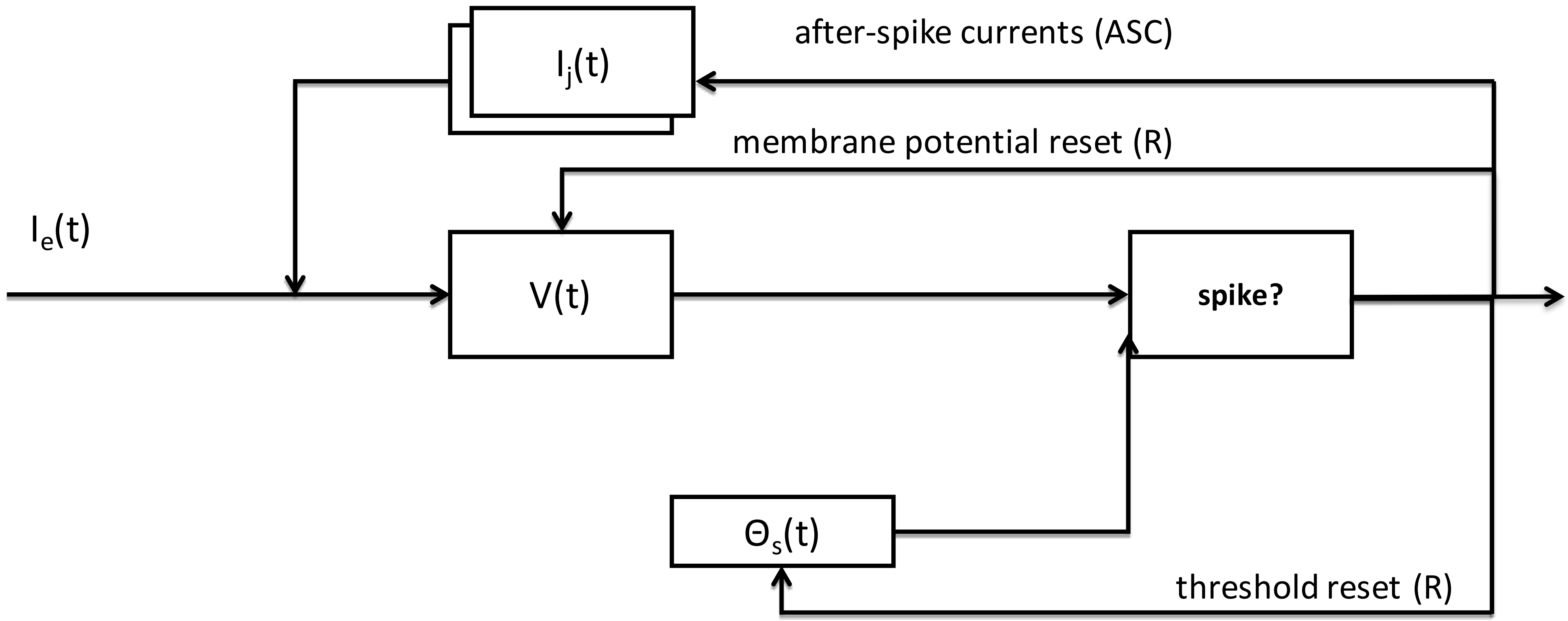
LIF with after-spike currents and voltage dependent threshold



Dynamics: between spikes

$$I_j'(t) = -k_j I_j(t);\; j = 1, \ldots, N$$

$$V'(t) = \frac{1}{C}\left(I_e(t) + \sum_j I_j(t) - G\left(V(t) - E_L\right)\right)$$

$$\Theta_s'(t) = -b_s \Theta_s(t)$$

Reset: if $V(t) > \Theta_\infty + \Theta_s(t)$

$$I_j(t_+) \leftarrow f_j \times I_j(t_-) + \delta I_j$$

$$V(t_+) \leftarrow E_L + f_v \times (V(t_-) - E_L) - \delta V$$

$$\Theta_s(t_+) \leftarrow \Theta_s(t_-) + \delta\Theta_s$$

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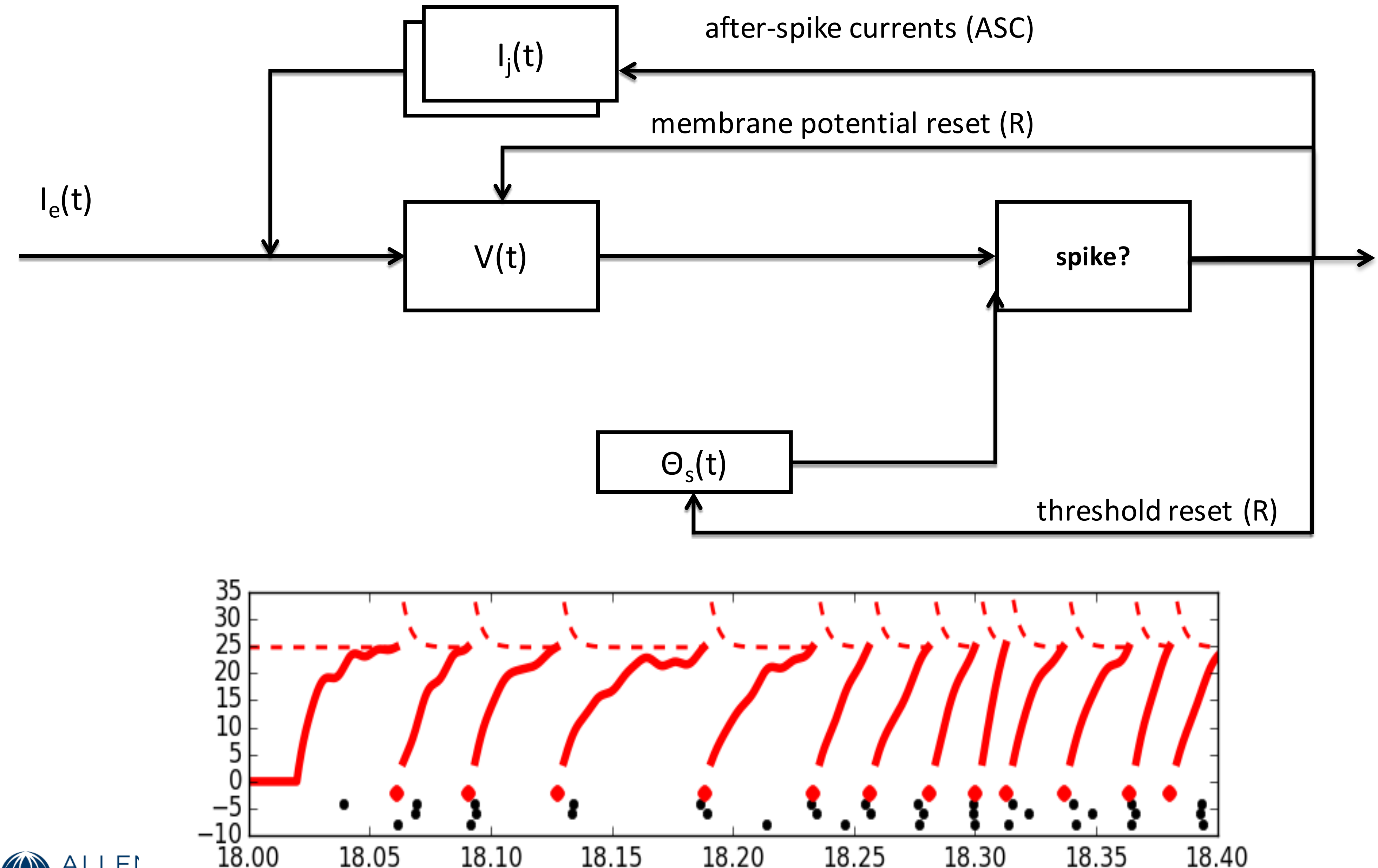
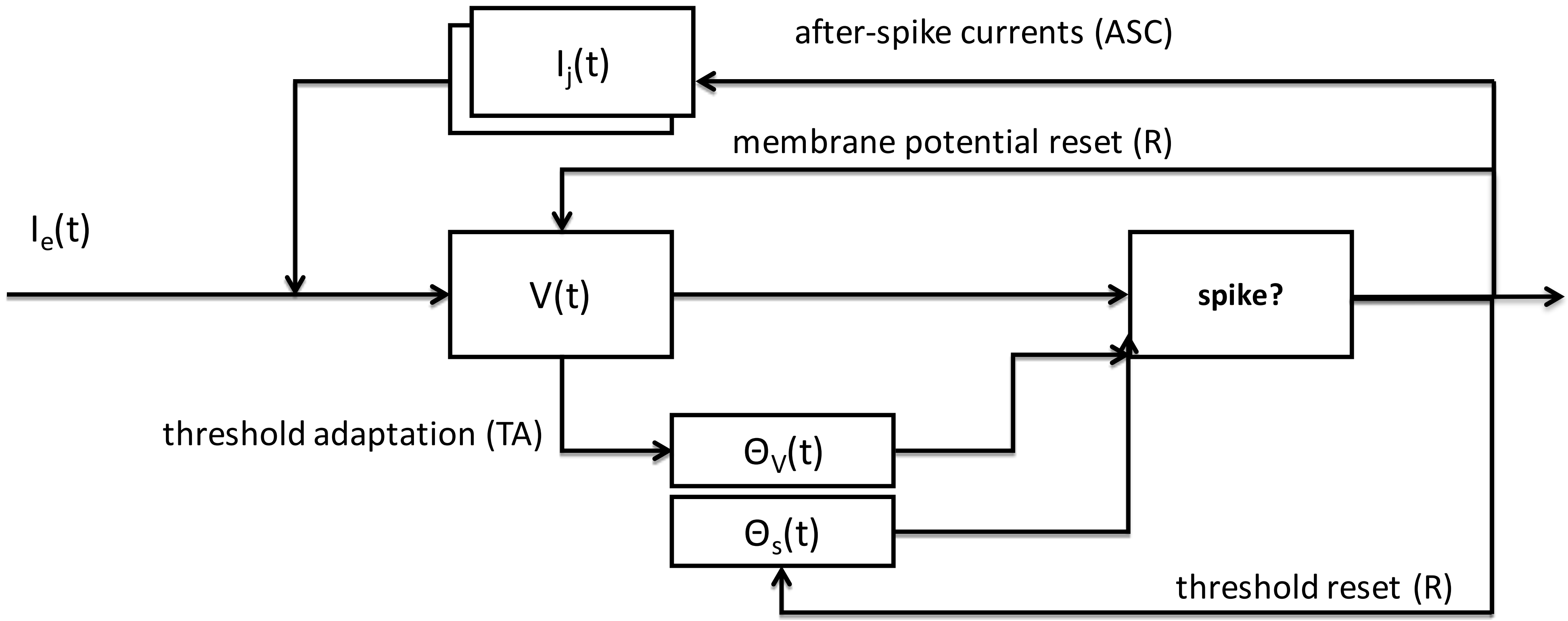
LIF with after-spike currents and voltage dependent threshold



LIF with after-spike currents spiking and voltage dependent threshold



Dynamics: between spikes

$$I_j'(t) = -k_j I_j(t);\ j = 1, ..., N$$

$$V'(t) = \frac{1}{C}\left(I_e(t) + \sum_j I_j(t) - G\left(V(t) - E_L\right)\right)$$

$$\Theta_s'(t) = -b_s \Theta_s(t)$$

$$\Theta_v'(t) = a(V(t) - E_L) - b_v(\Theta_v(t) - \Theta_\infty)$$

Reset: if $V(t) > \Theta_v(t) + \Theta_s(t)$

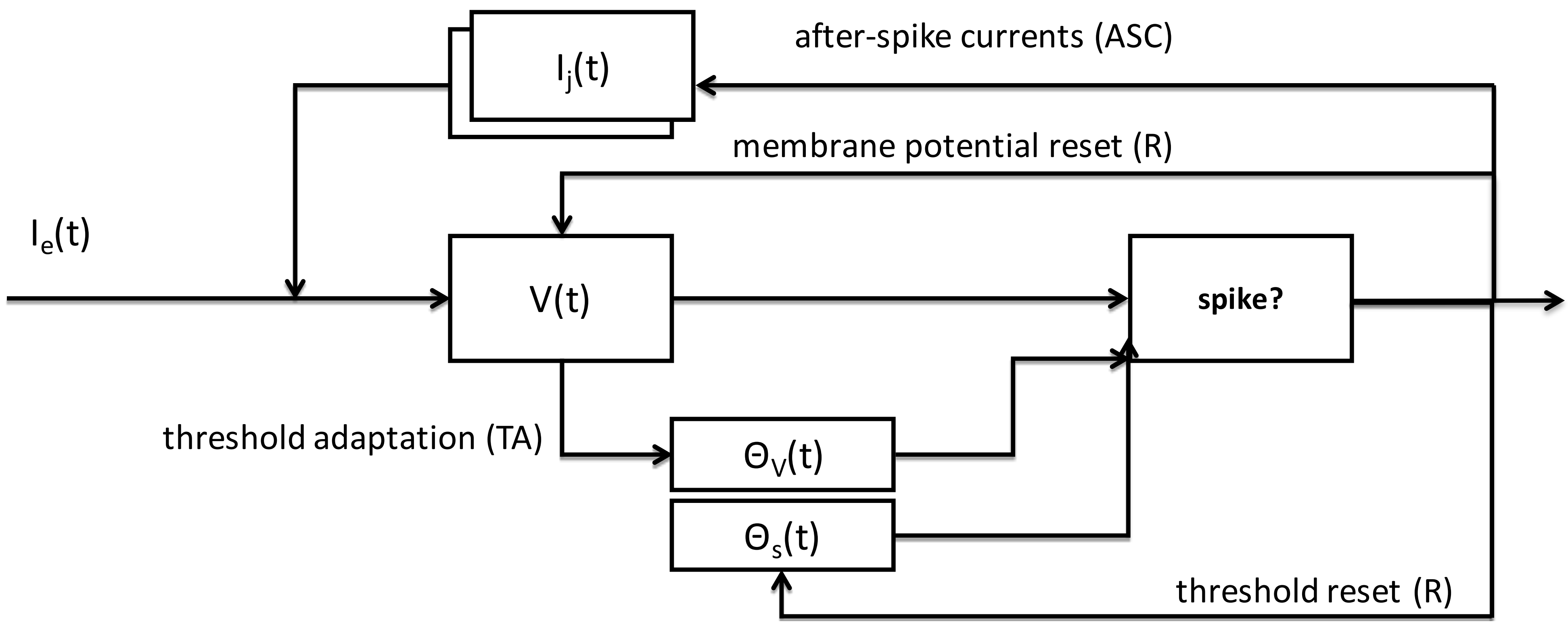
$$I_j(t_+) \leftarrow f_j \times I_j(t_-) + \delta I_j$$

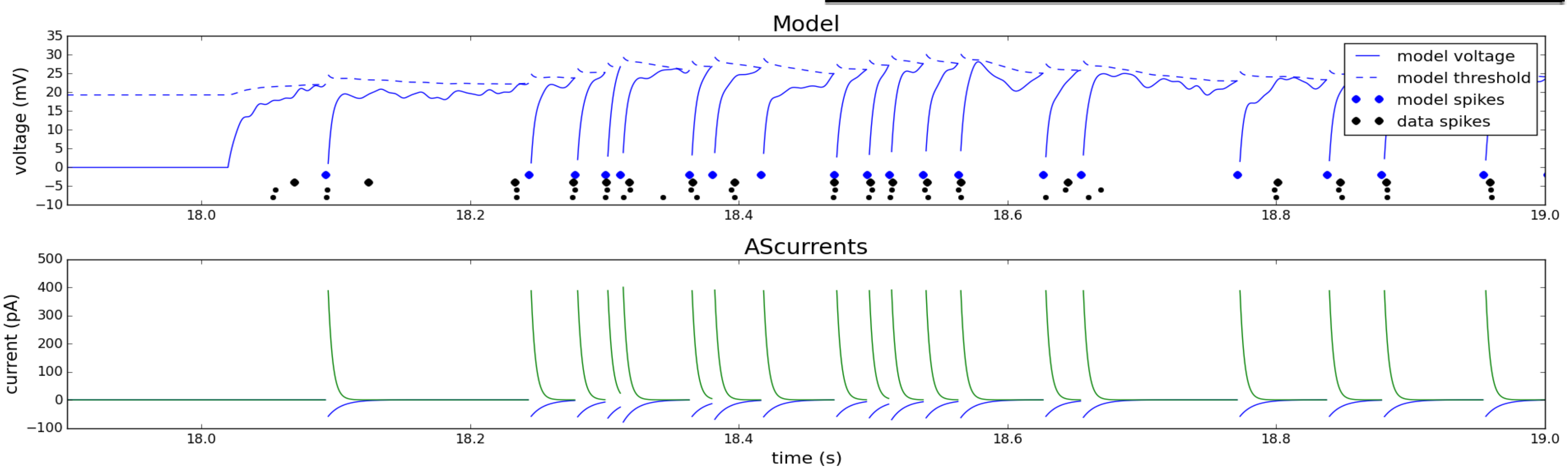
$$V(t_+) \leftarrow E_L + f_v \times (V(t_-) - E_L) - \delta V$$

$$\Theta_s(t_+) \leftarrow \Theta_s(t_+) + \delta\Theta_s$$

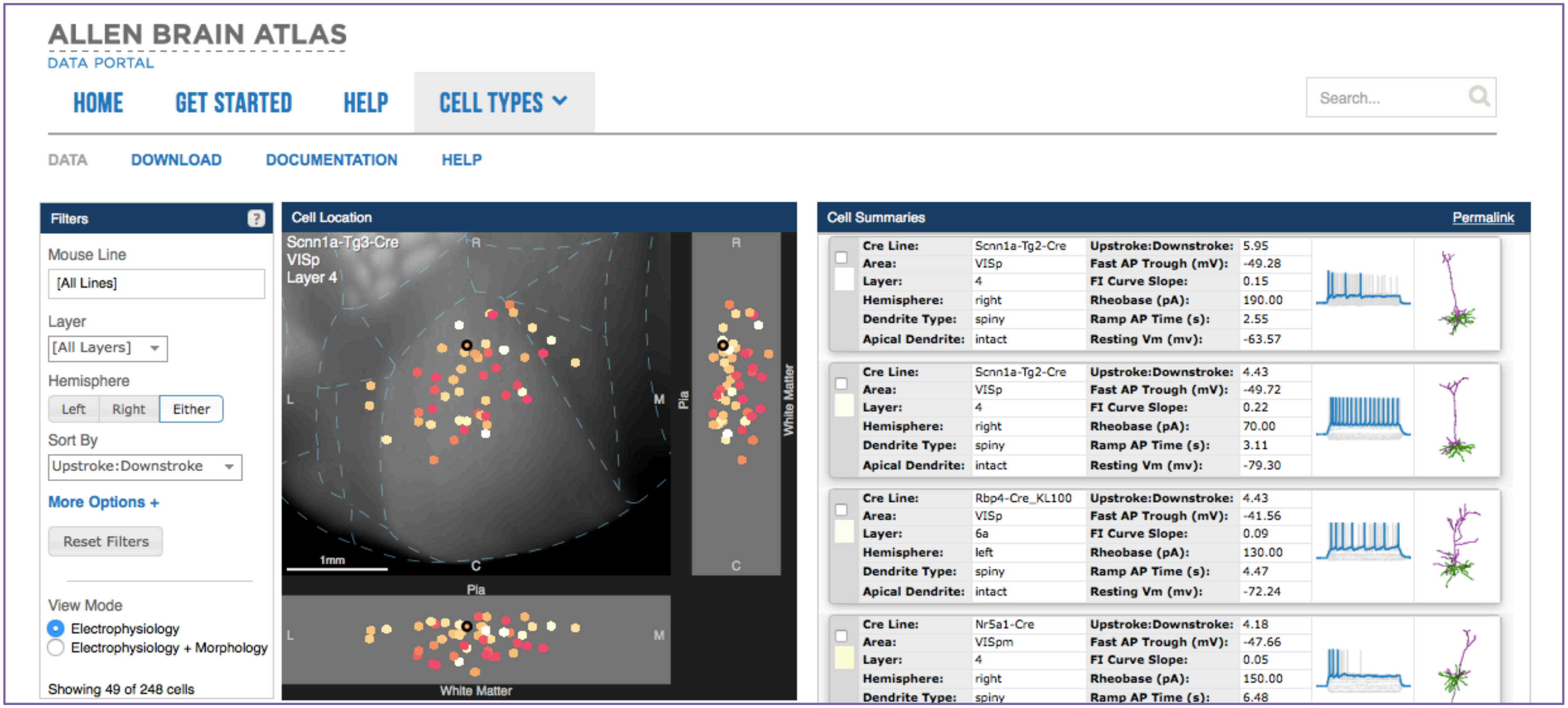
$$\Theta_v(t_+) \leftarrow \Theta_v(t_-)$$

LIF with after-spike currents spiking and voltage dependent threshold





4. Allen Cell Types Database



Search and Filter Options

Cell Positions in Common Coordinate Framework

Summary of Cell Characteristics (*Click for additional details*)

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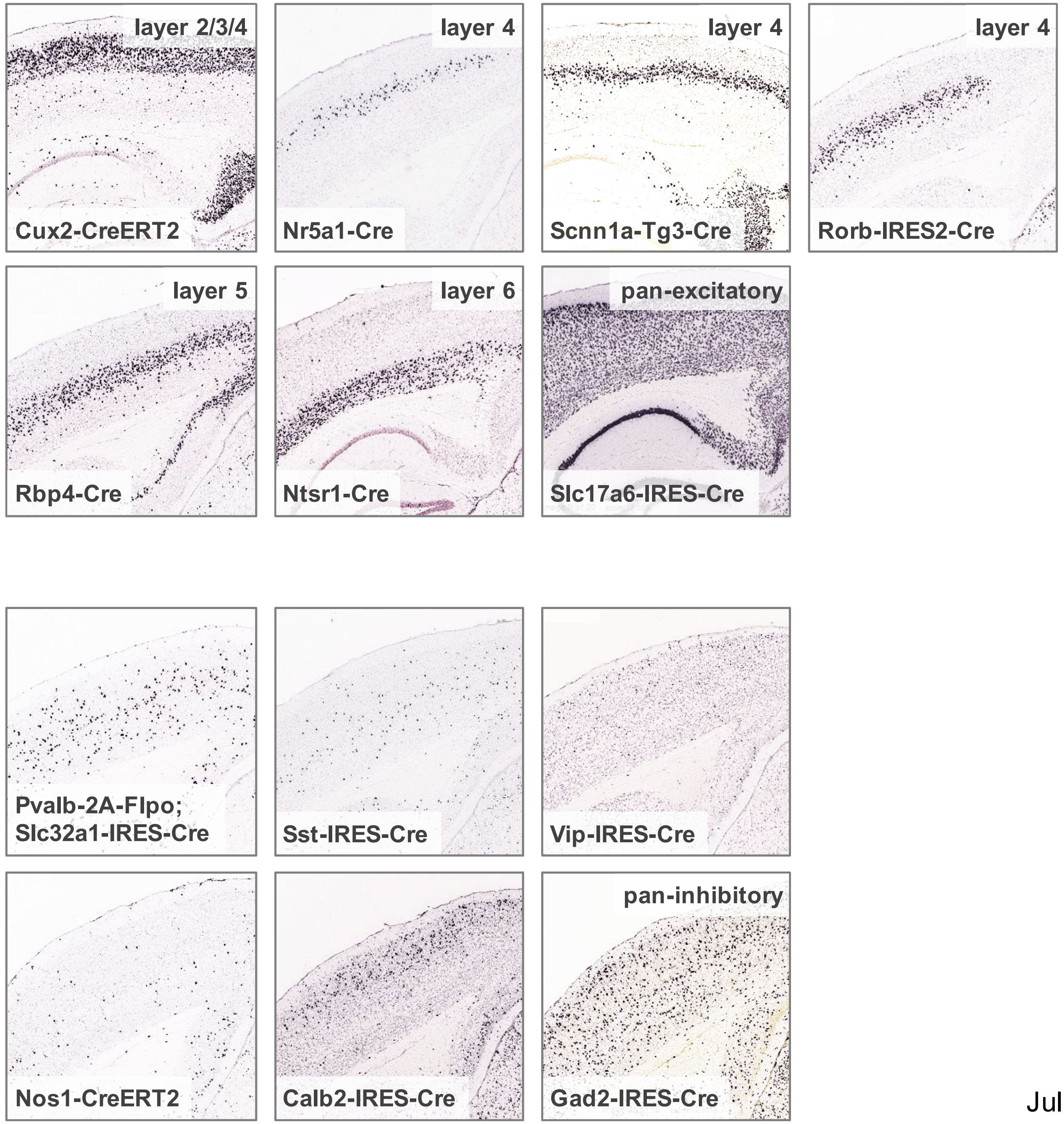
Jim Berg, Hongkui Zeng

alleninstitute.org | brain-map.org

Genetic Markers via Cre Lines

Excitatory neurons

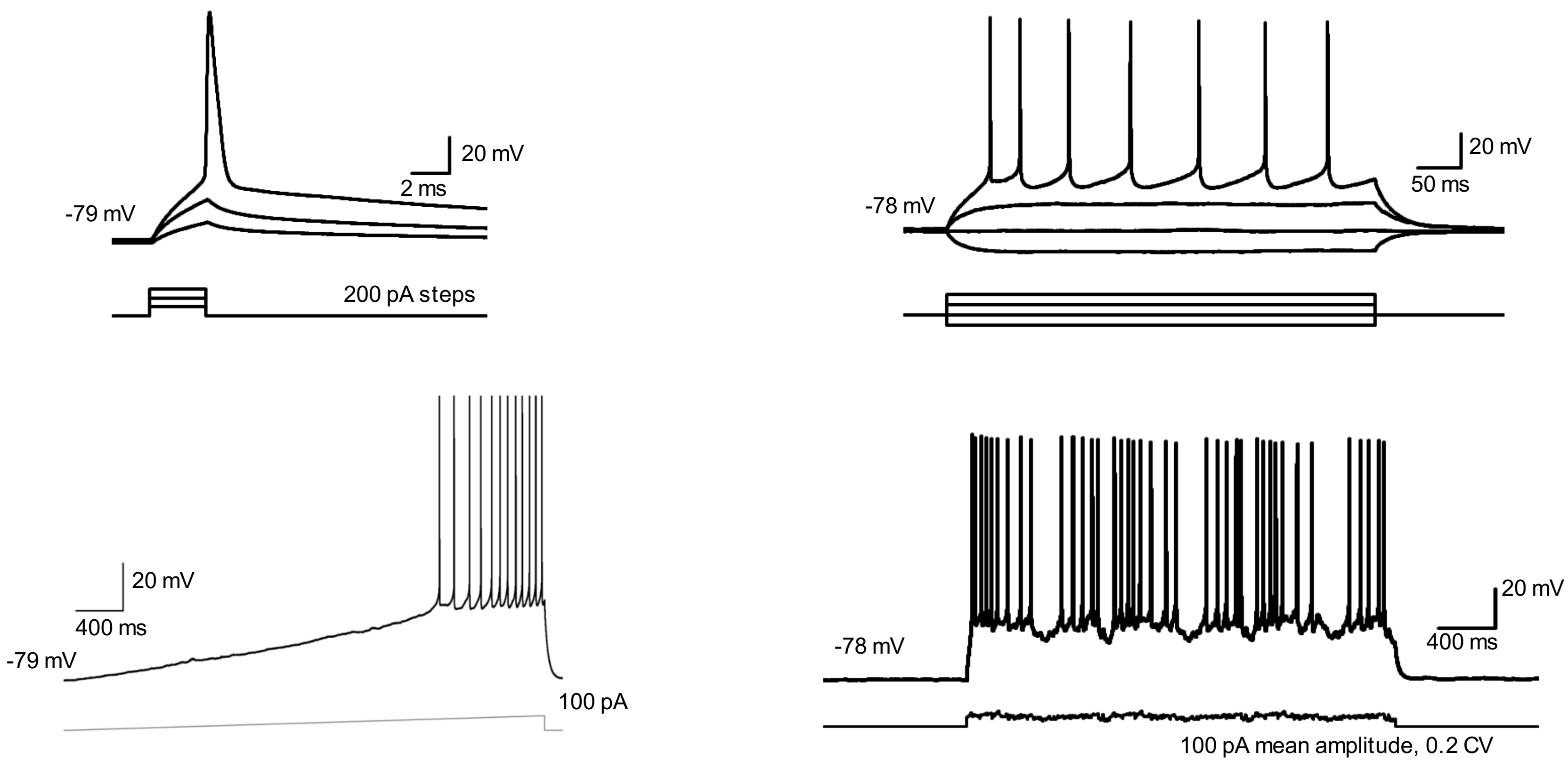
Inhibitory neurons



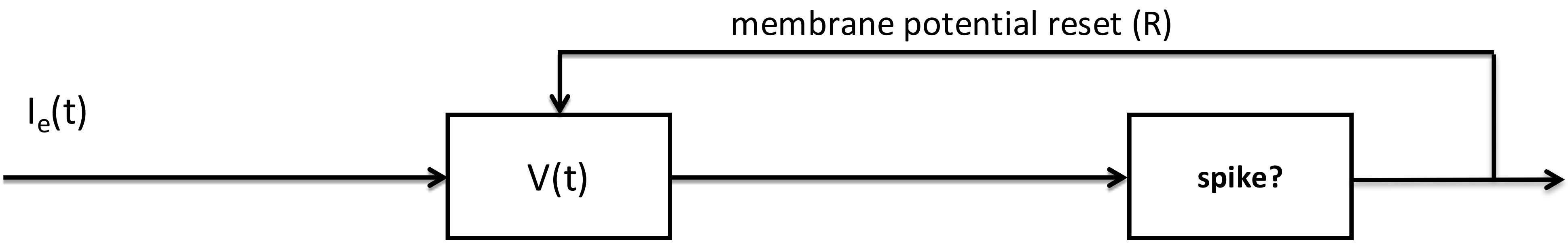
Julie Harris

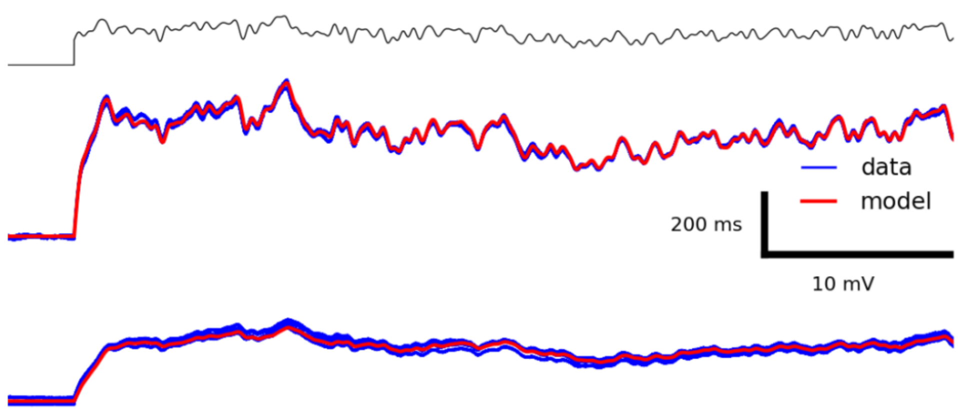
Electrophysiology Protocol

Instantaneous threshold | Adaptive threshold | Subthreshold, Rheobase & Suprathreshold | Naturalistic response

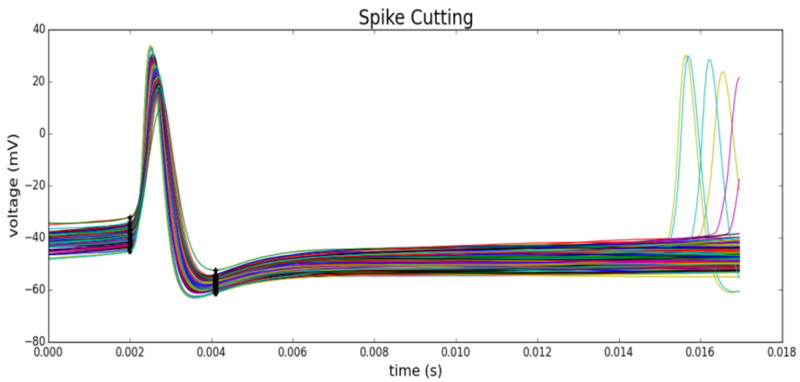


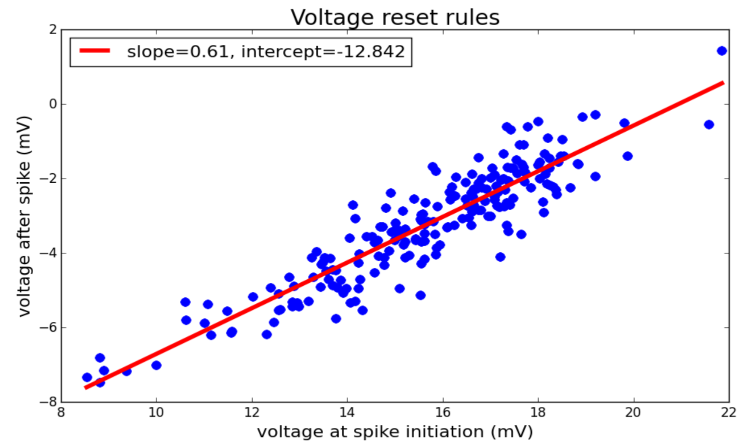
Leaky Integrate and Fire Models - optimization

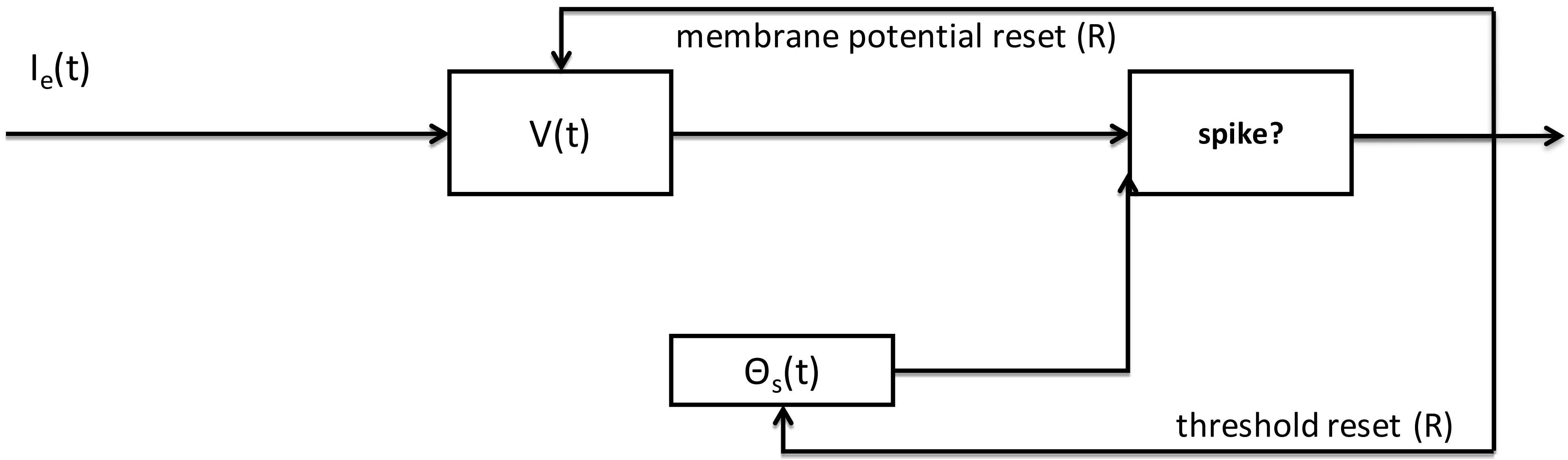


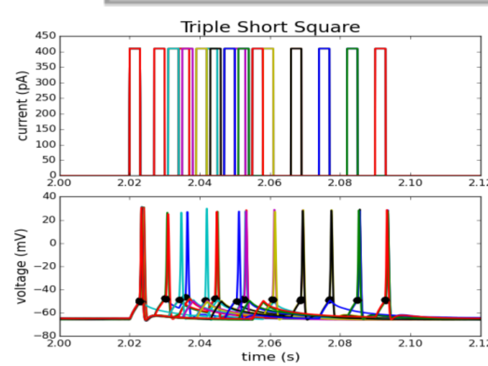


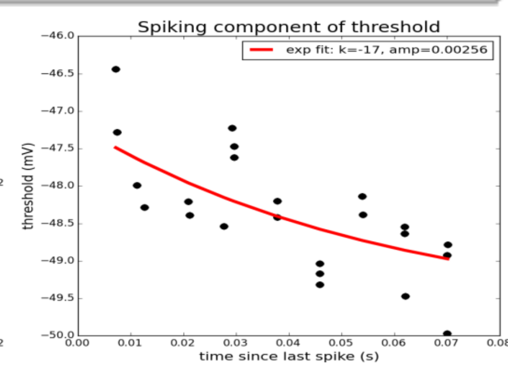
LIF with reset rules - optimization











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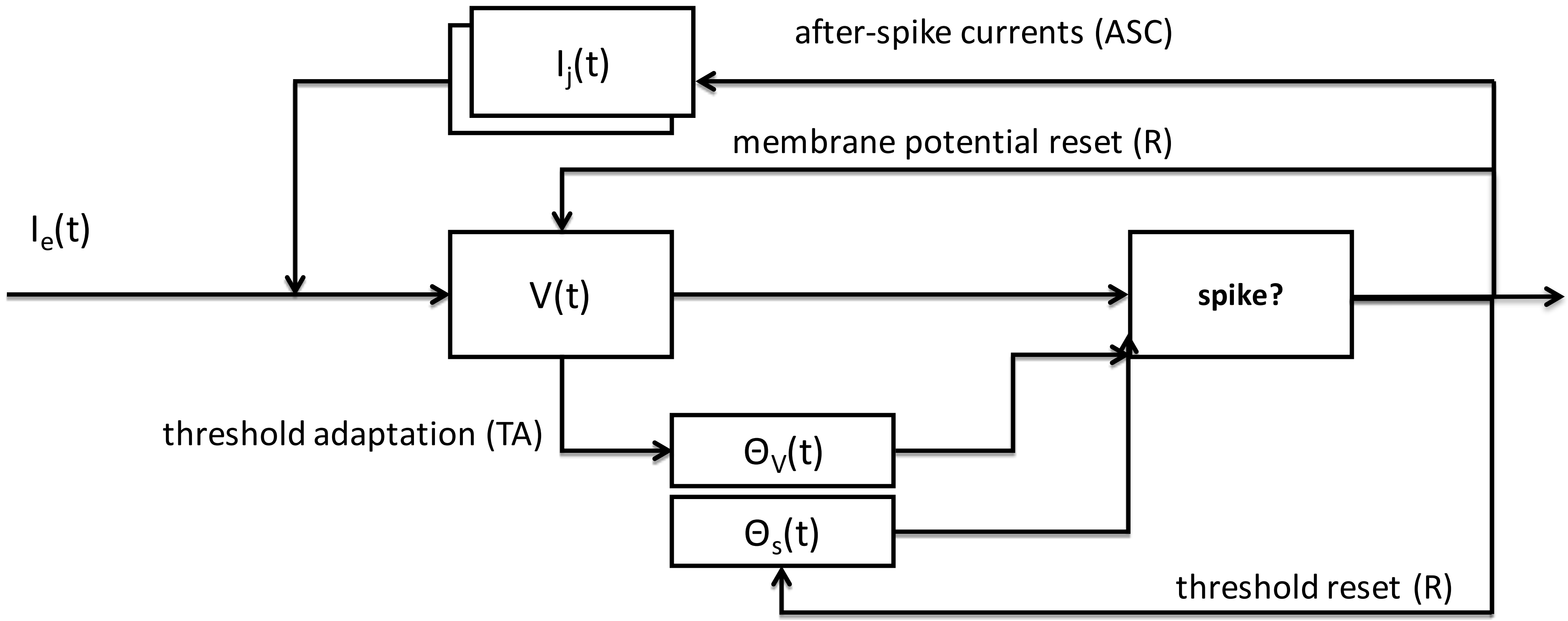
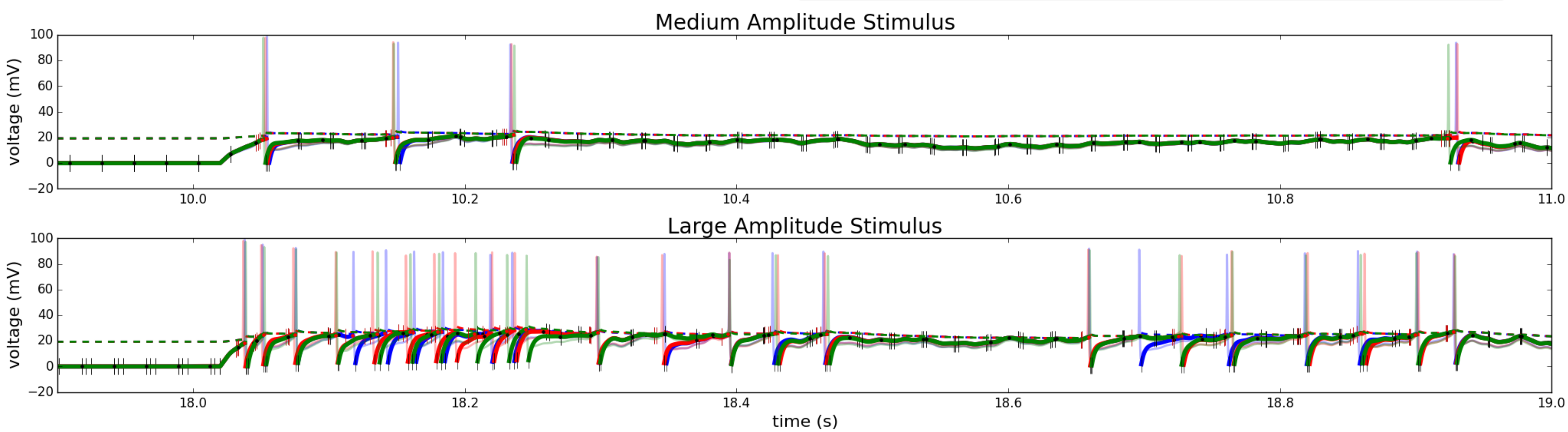
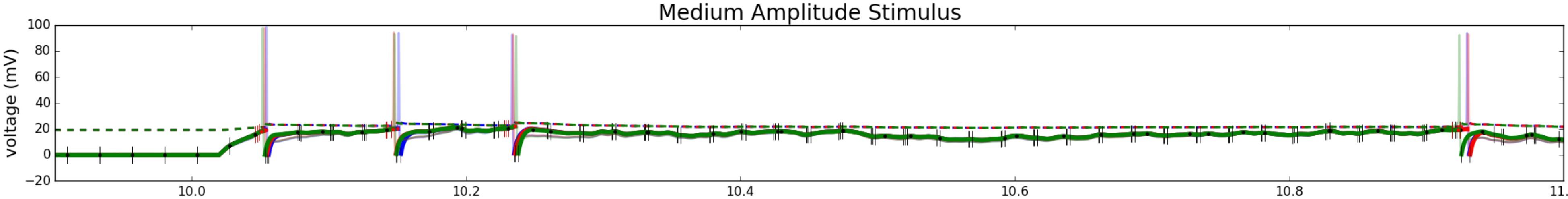
LIF R ASC AT - optimization





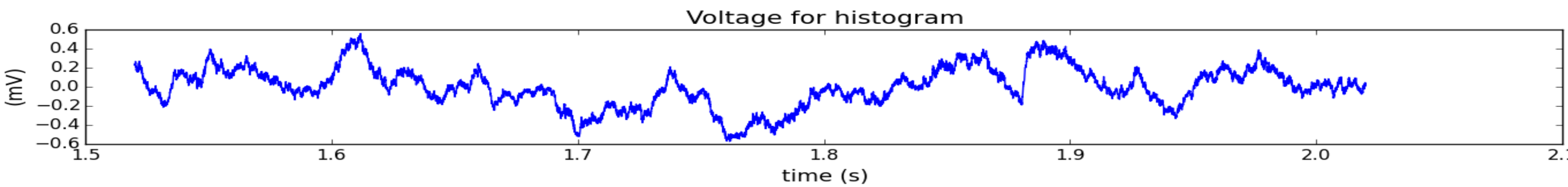
LIF R ASC AT – optimization
Maximum likelihood based on internal noise (MLIN)

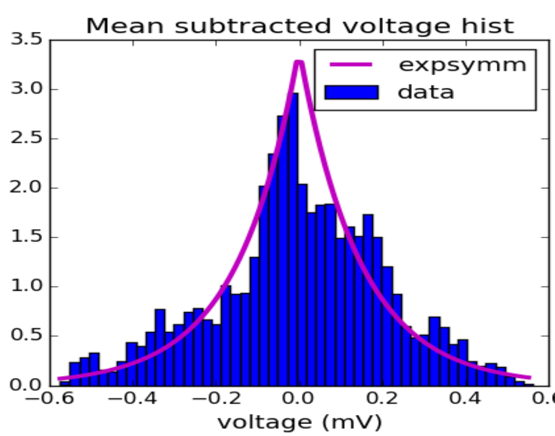


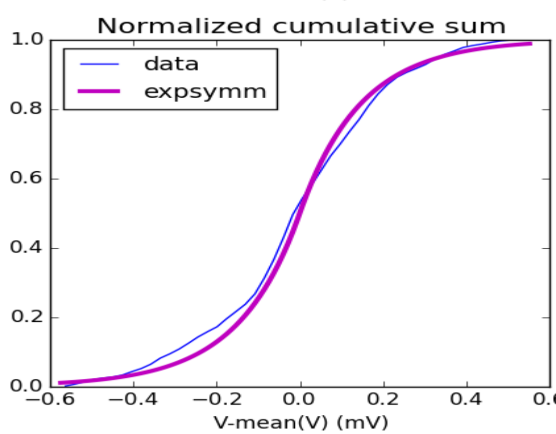
$$p_{spike}(t) = \int_{\Delta V(t)}^{\infty} p(v)dv = \int_{\Delta V(t)}^{\infty} \frac{1}{2\delta v} exp(-\frac{|v|}{\delta v})dv = 1 - c(\Delta V(t))$$

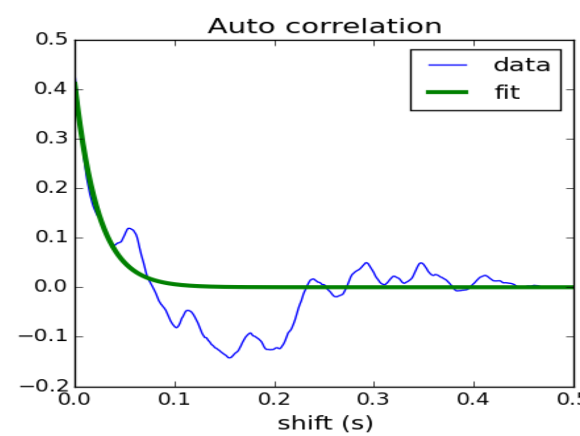
$$p_{spikes} = \prod_{t\in t_s} p_{spike}(t)$$

$$LLIN = Log\left(p_{spikes}p_{nospikes}\right) = \sum_{t\in t_s}(1 - c(\Delta V(t))) + \sum_{t\in t_{grid}} c(\Delta V_{grid})$$

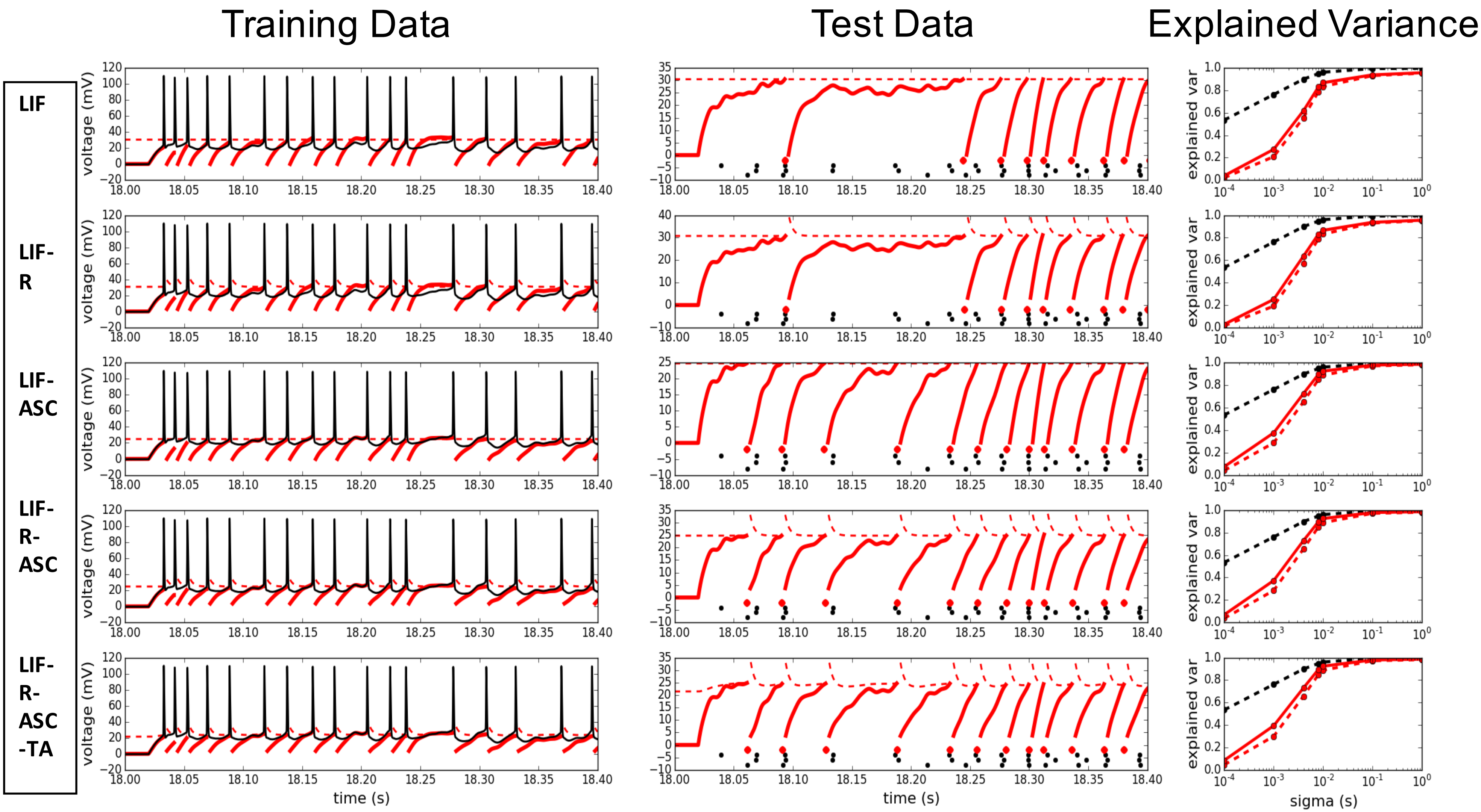








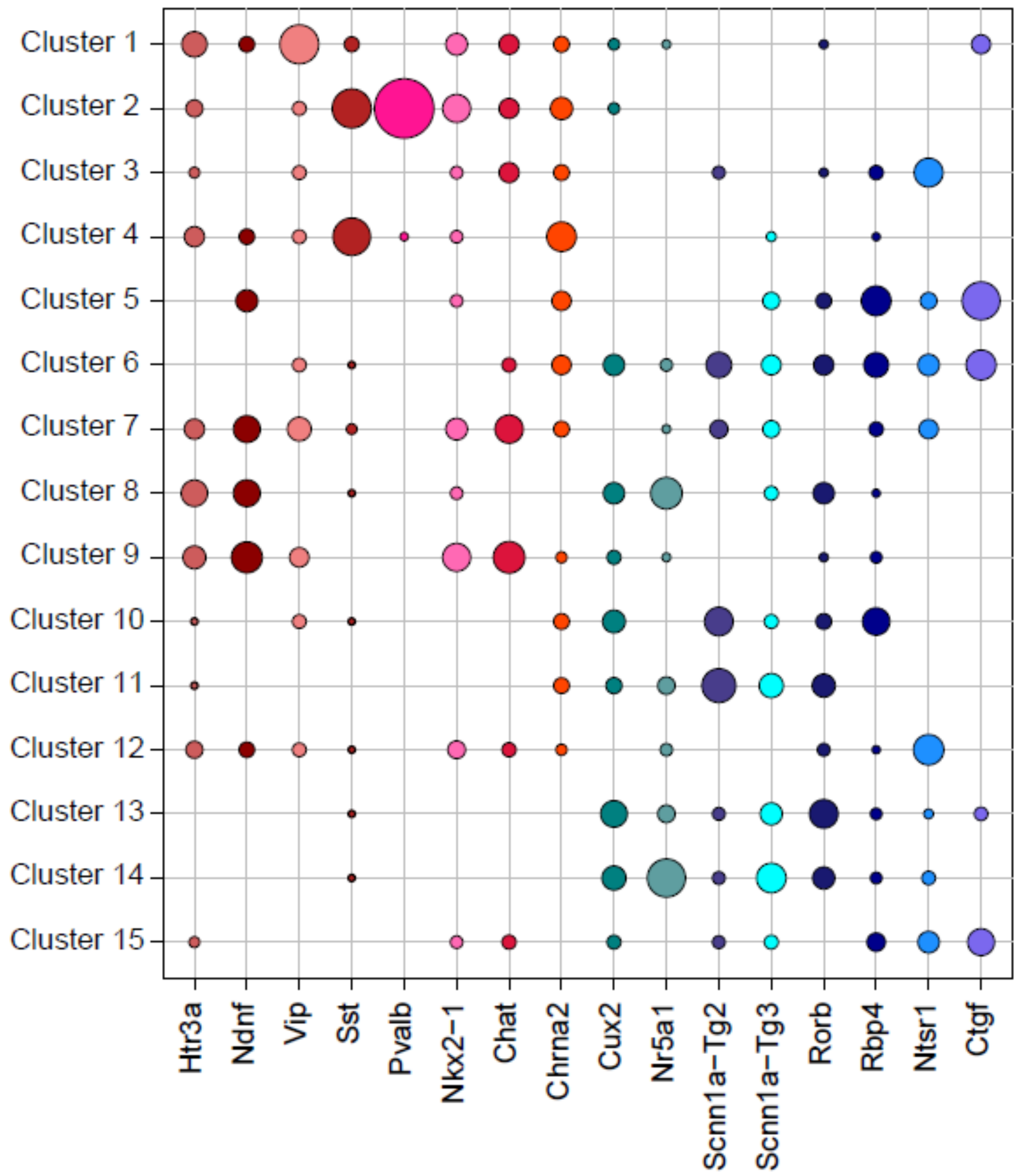
Generalized Leaky Integrate and Fire Models



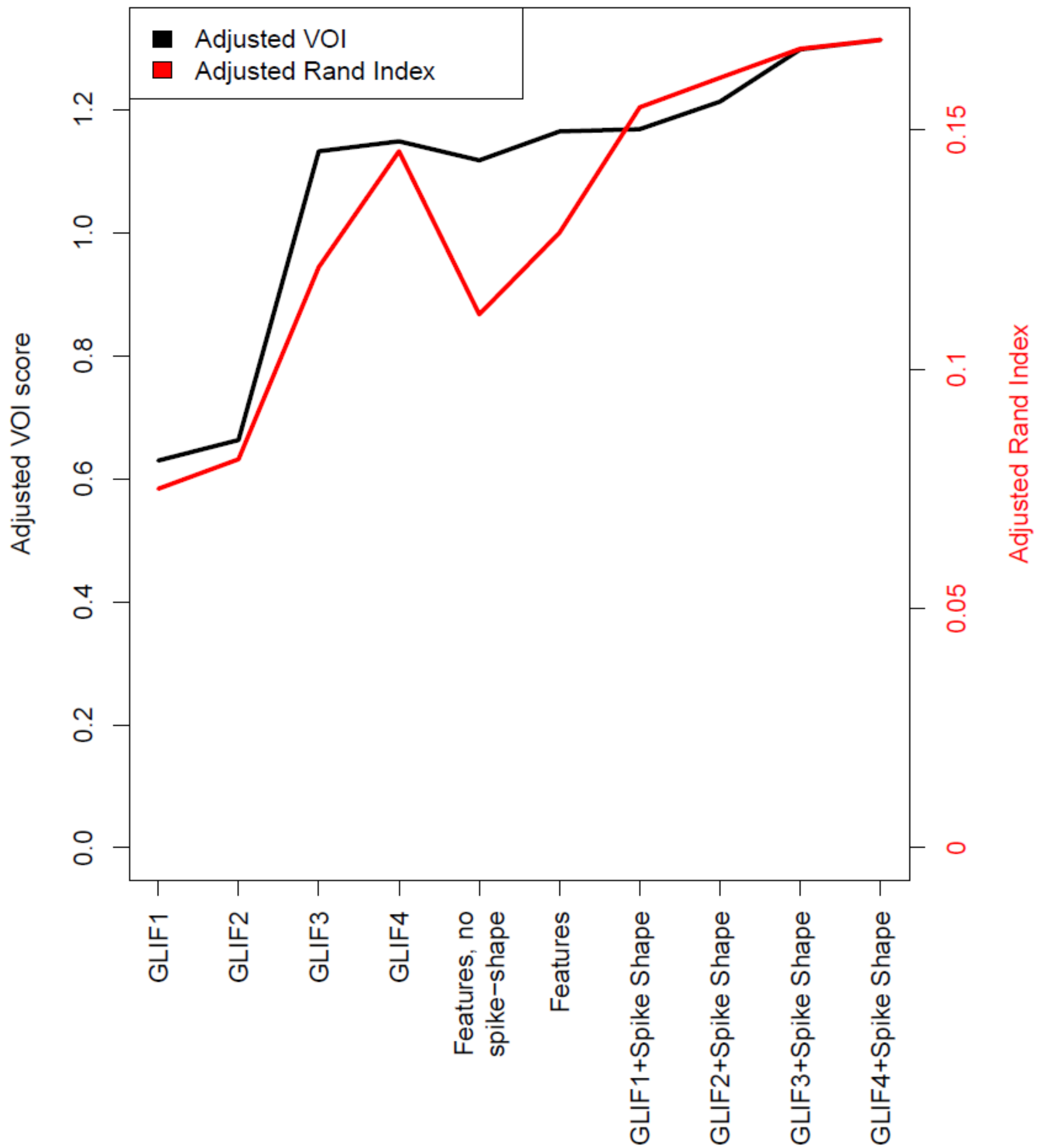
Average explained variance

- Glif 5: 75% - excitatory 84% for inhibitory
- Biophysical perisomatic – 65%
- Biophysical all-active – 69%

Defining cell types based on models



Comparison between model/feature clusters and Cre line partitioning



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Single Cell Type Models Conclusion

- A large diversity of neurons can be characterized and modeled
- GLIF models still outperform detailed biophysical ones due to individual recording length limitation
- Parameters in GLIF models can be used to classify cell types
- visit our website: http://www.brain-map.org/