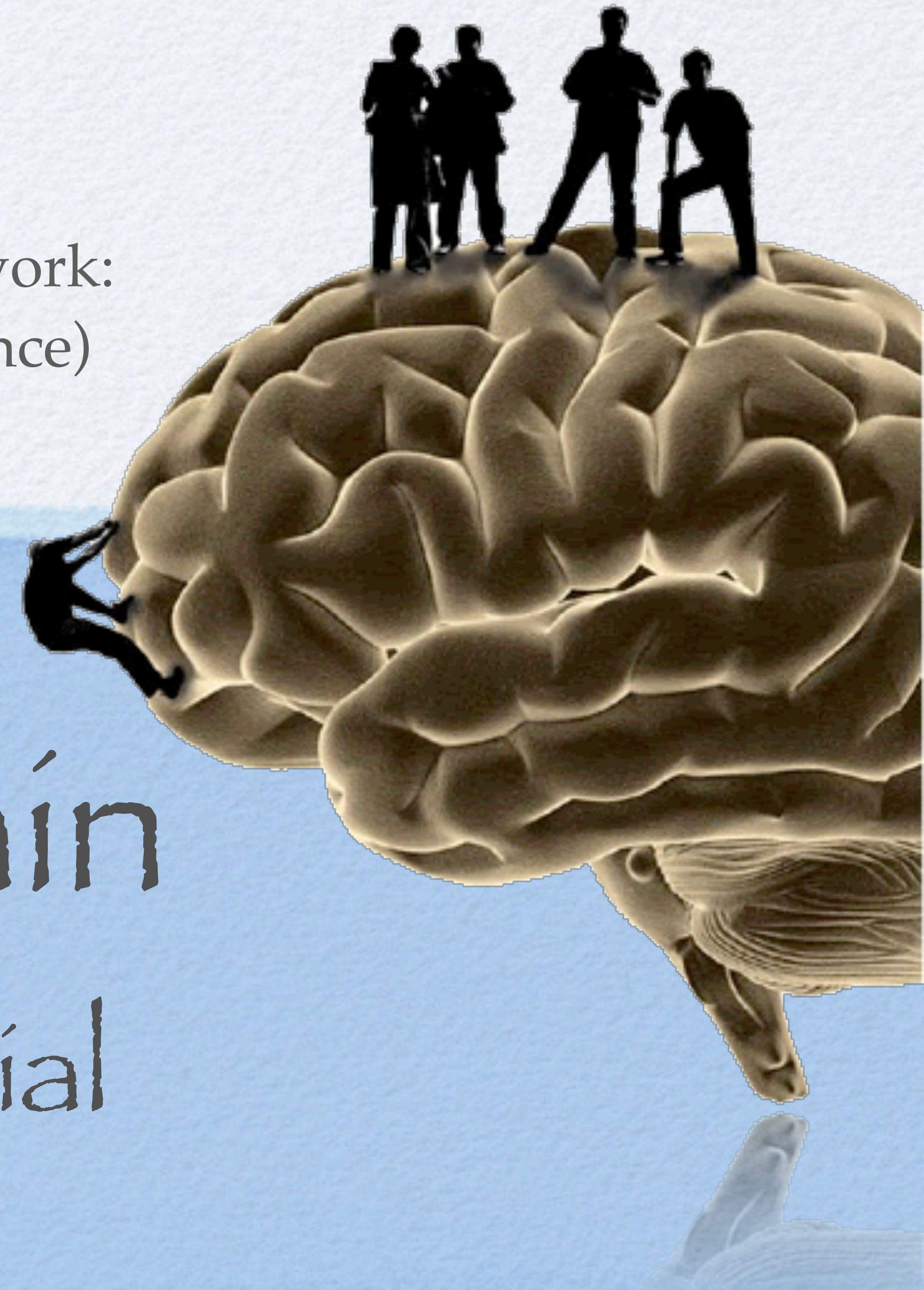
(Nengo and the Neural Engineering Framework: Connecting Cognitive Theory to Neuroscience)



How to build a brain

Cogsci 2010 Tutorial

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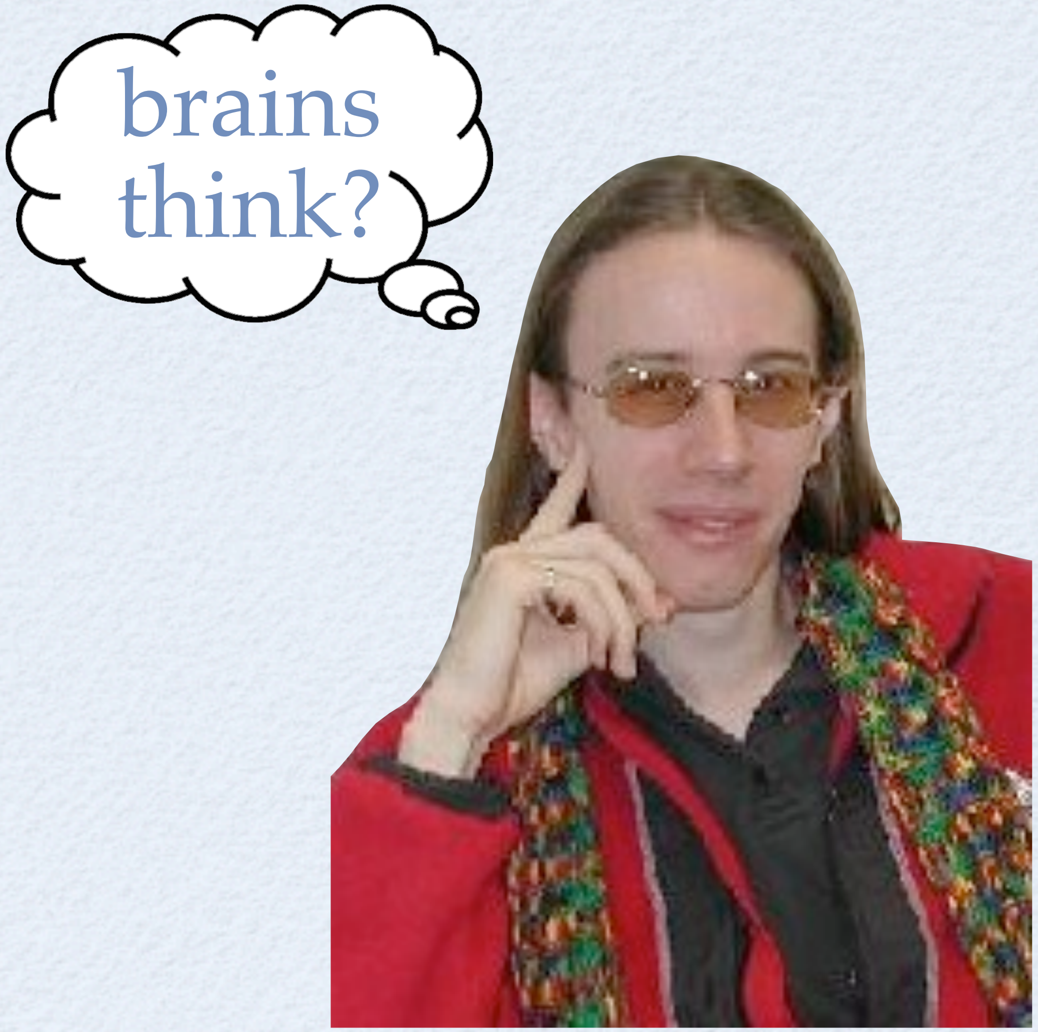
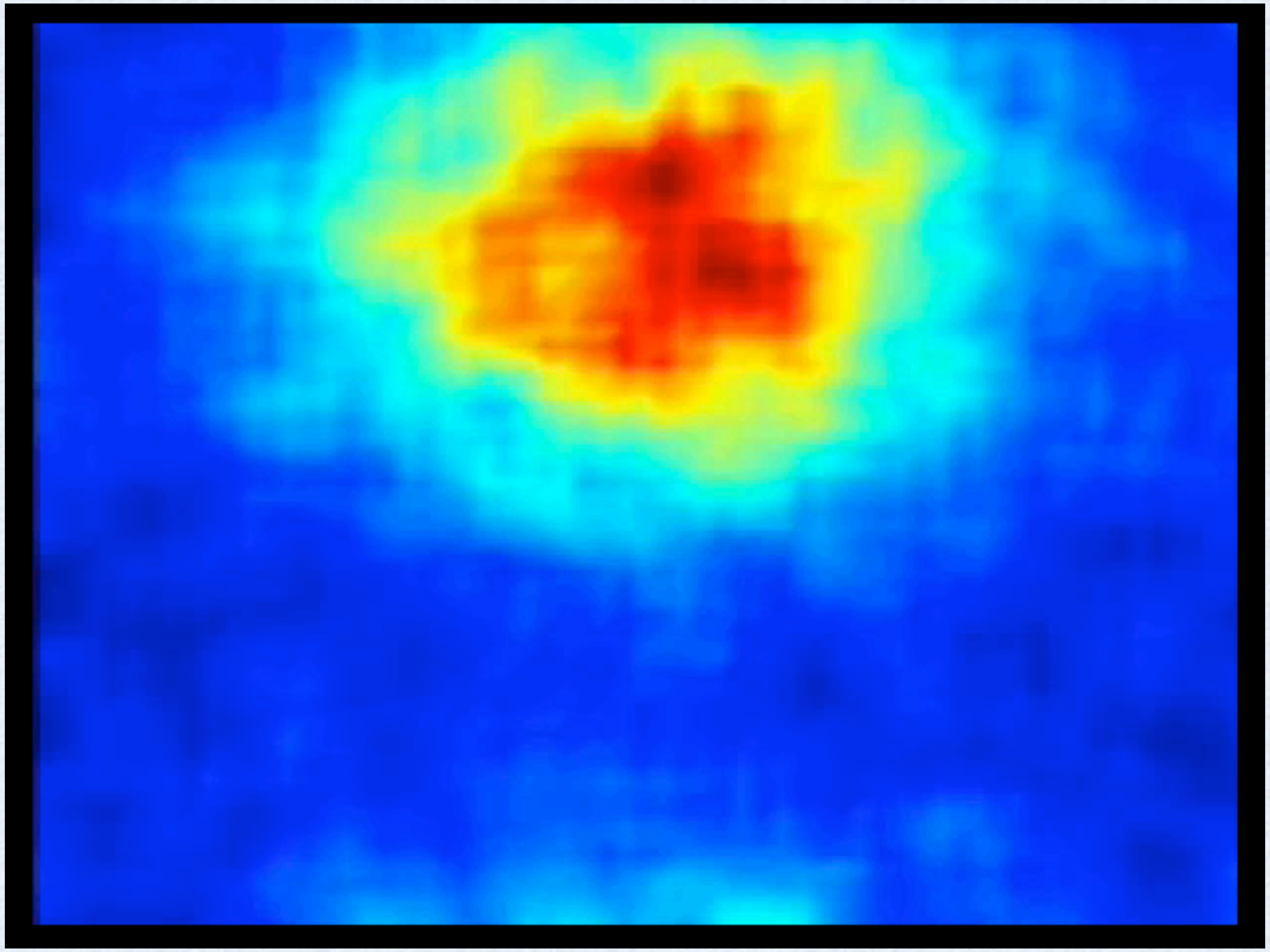
There are animals

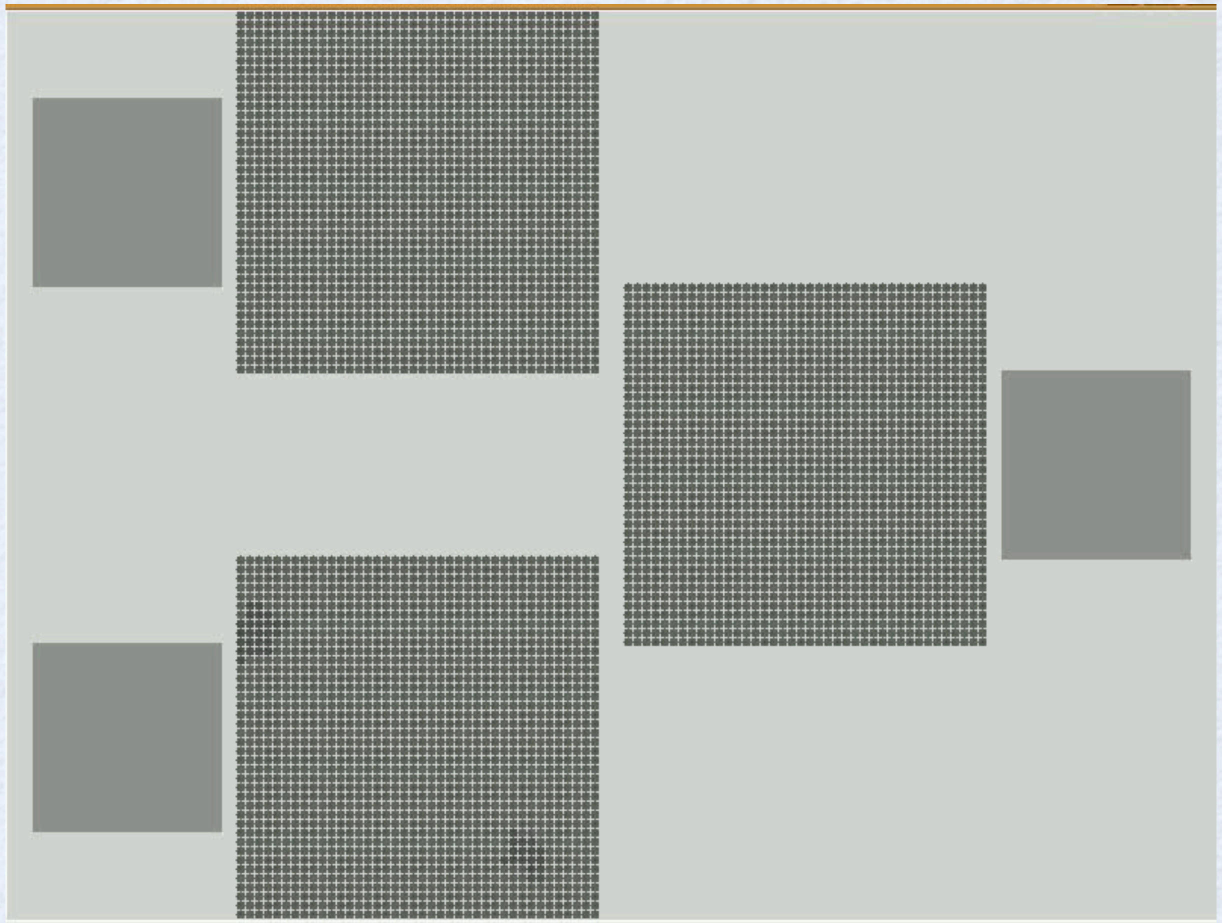
Who behave



Which we want to model



Path integration



Neural binding

Compelling reasons for neurons

- Better contact with more data (single, multi-electrode, LFP, fMRI, ERP, behavioural, etc.)
- Explanations for previous assumptions (e.g. Why a 50ms time step? Why limited productivity? etc.)
- Wider range of manipulations (e.g., brain damage, genetic alteration, degeneration, stimulation, etc.)
- Others? (Neurons limit computational alternatives, neurons impose dynamic constraints, anatomy imposes topological constraints, etc.)

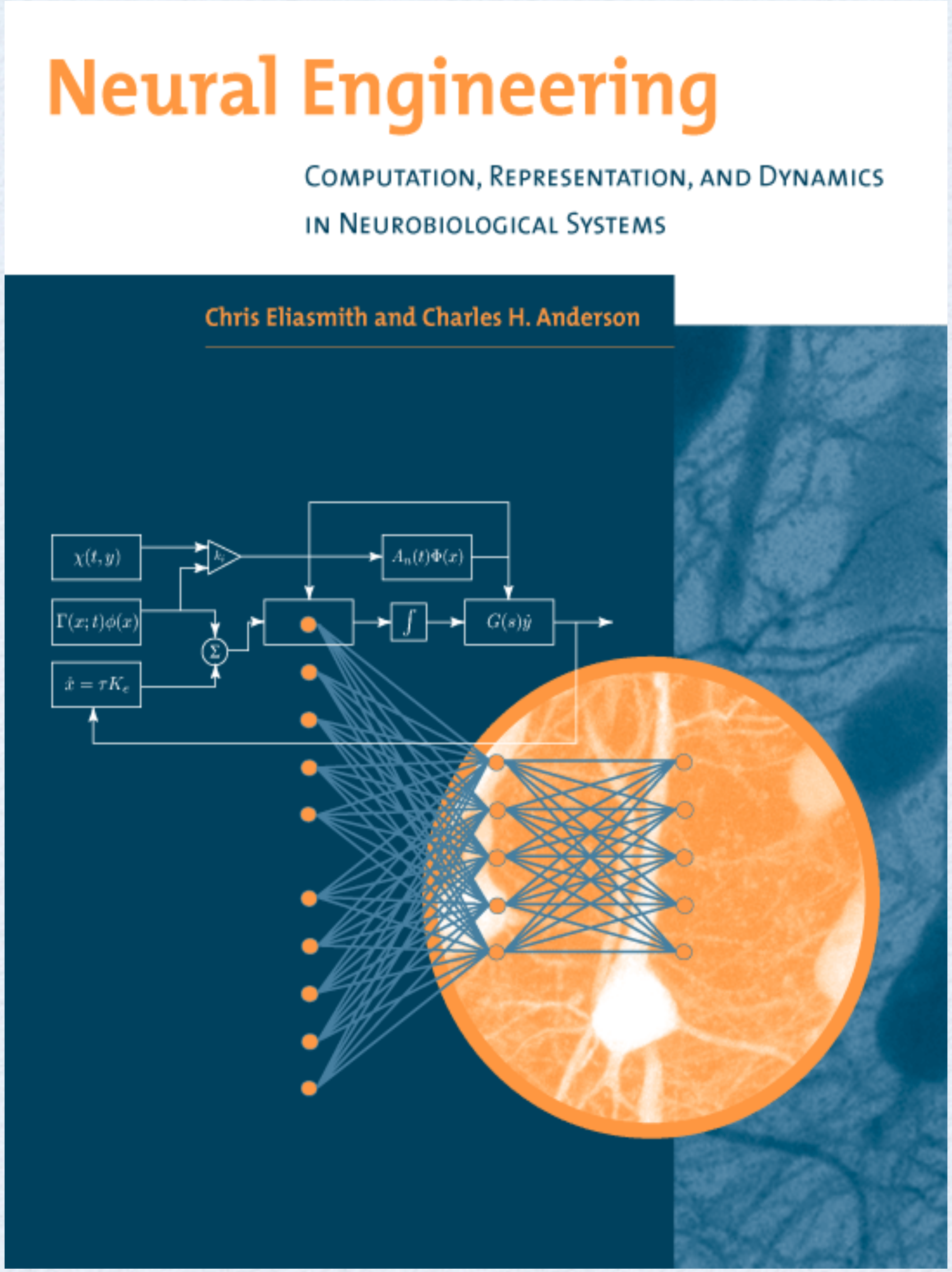
Today

- Introduction
  - Who we are
  - Who you are, why you're here
- Six topics (theory followed by hands-on simulation)

1. 1D representation
2. linear transformation
3. nonlinear transformation
4. dynamics
5. symbol manipulation
6. applications (time permitting)

Please Interrupt!

Theory



Neural Engineering Framework (NEF)

Given:

- Information processing task
- Hardware description

Produce:

- Neural mechanism

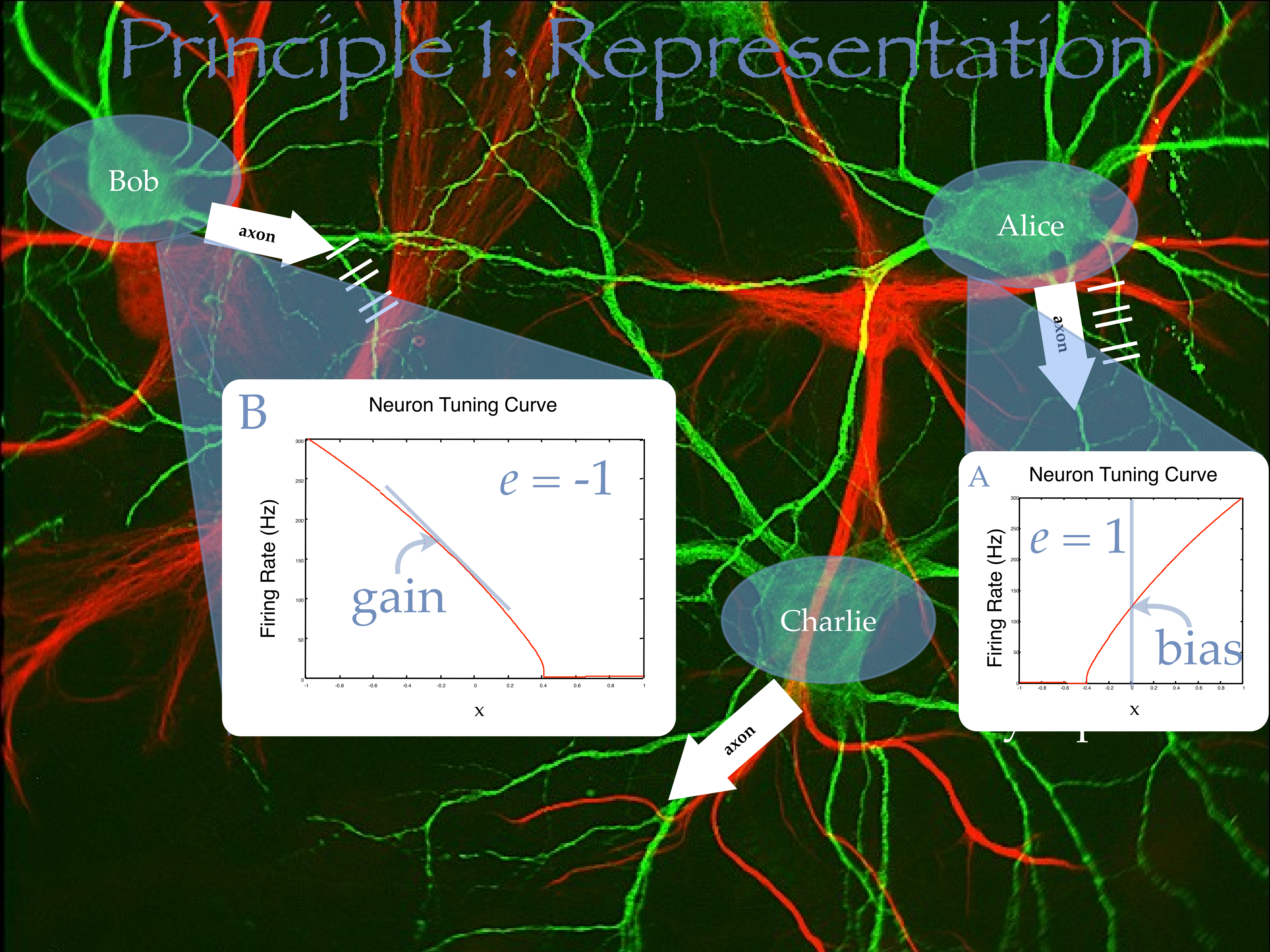
The NEF

- A theory, like Newton's theory of motion:
  - Three basic principles
    - Representation, Transformation, Dynamics
  - General, unified approach
  - Quantitative
  - Wrong!

Representation

- Lossless code (e.g. Morse code):
  - Encoding: $a = f(x)$
  - Decoding: $x = f^{-1}(a)$
- Otherwise (e.g. A/D conversion):
  - Decoding: $\hat{x} = g(a) \approx f^{-1}(a)$

Principle 1: Representation



Nonlinear encoding

- More specifically, we know:

$$J(x) = \alpha x + J^{bias}$$

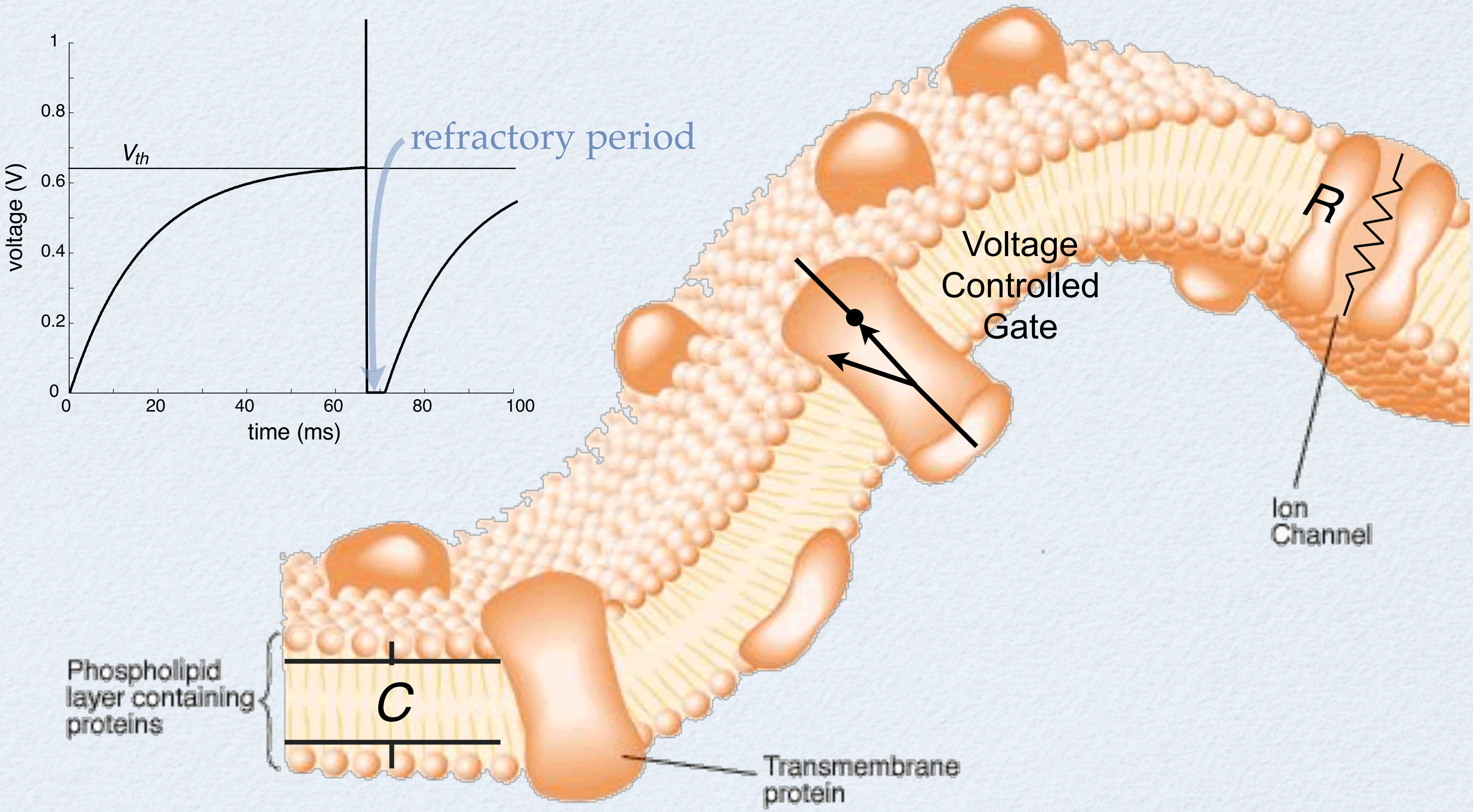
- So

$$a_i(x) = G_i\left[\alpha x + J^{bias}\right]$$

- G_i can be any neural model
    - conductance; rate; leaky integrate-and-fire (LIF)

Leaky integrate-and-fire (LIF) model

Outside the Neuron



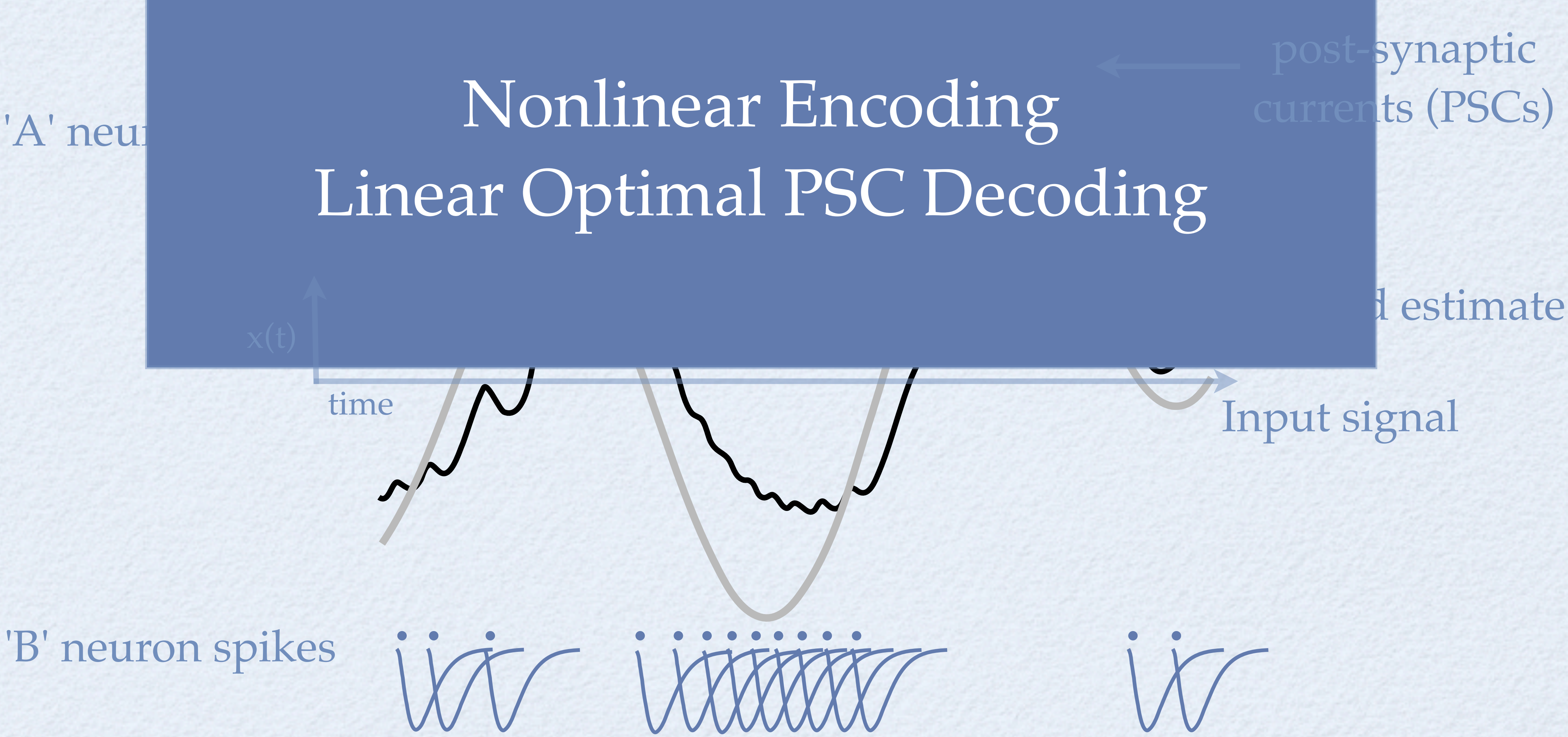
current from dendrites

Inside the Neuron

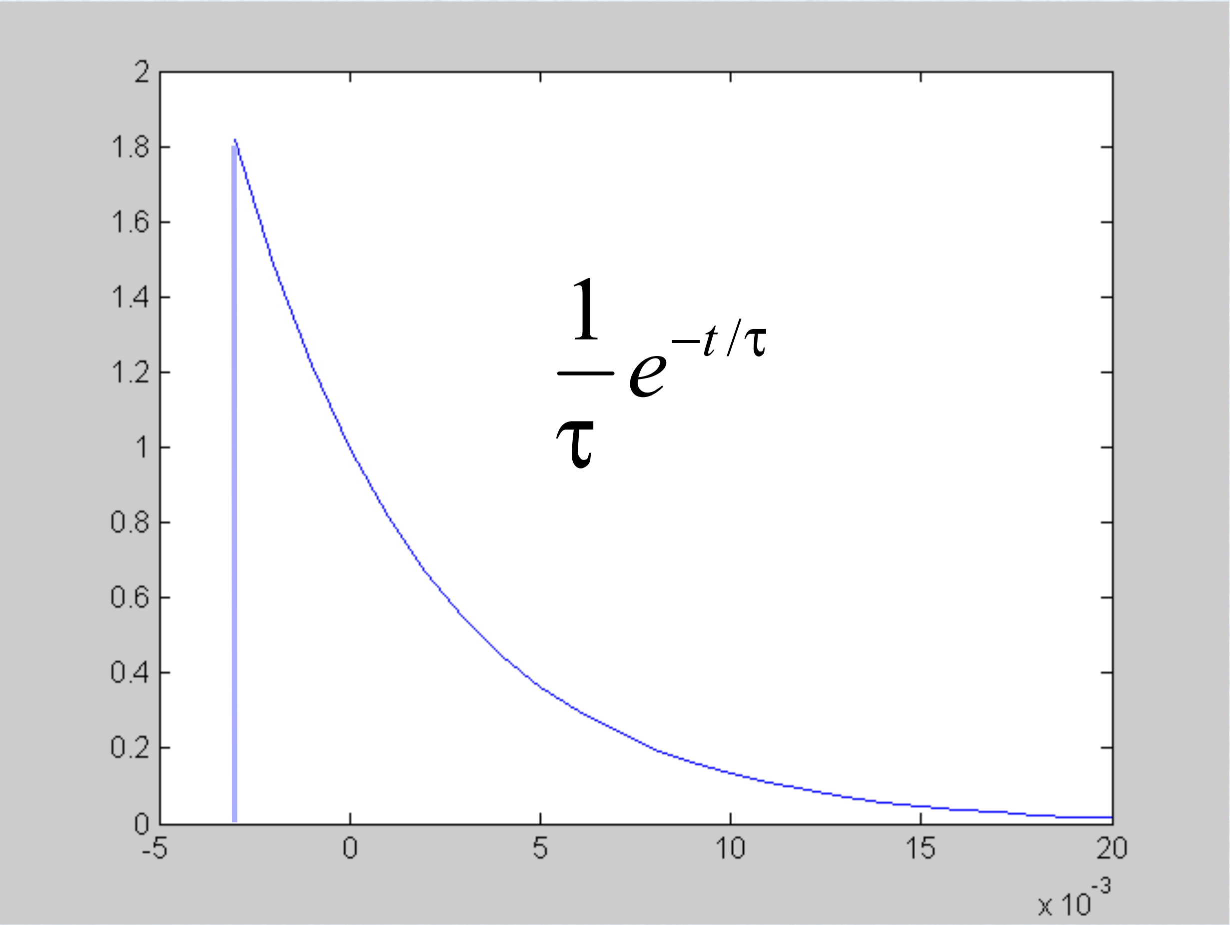
Principle 1: Representation

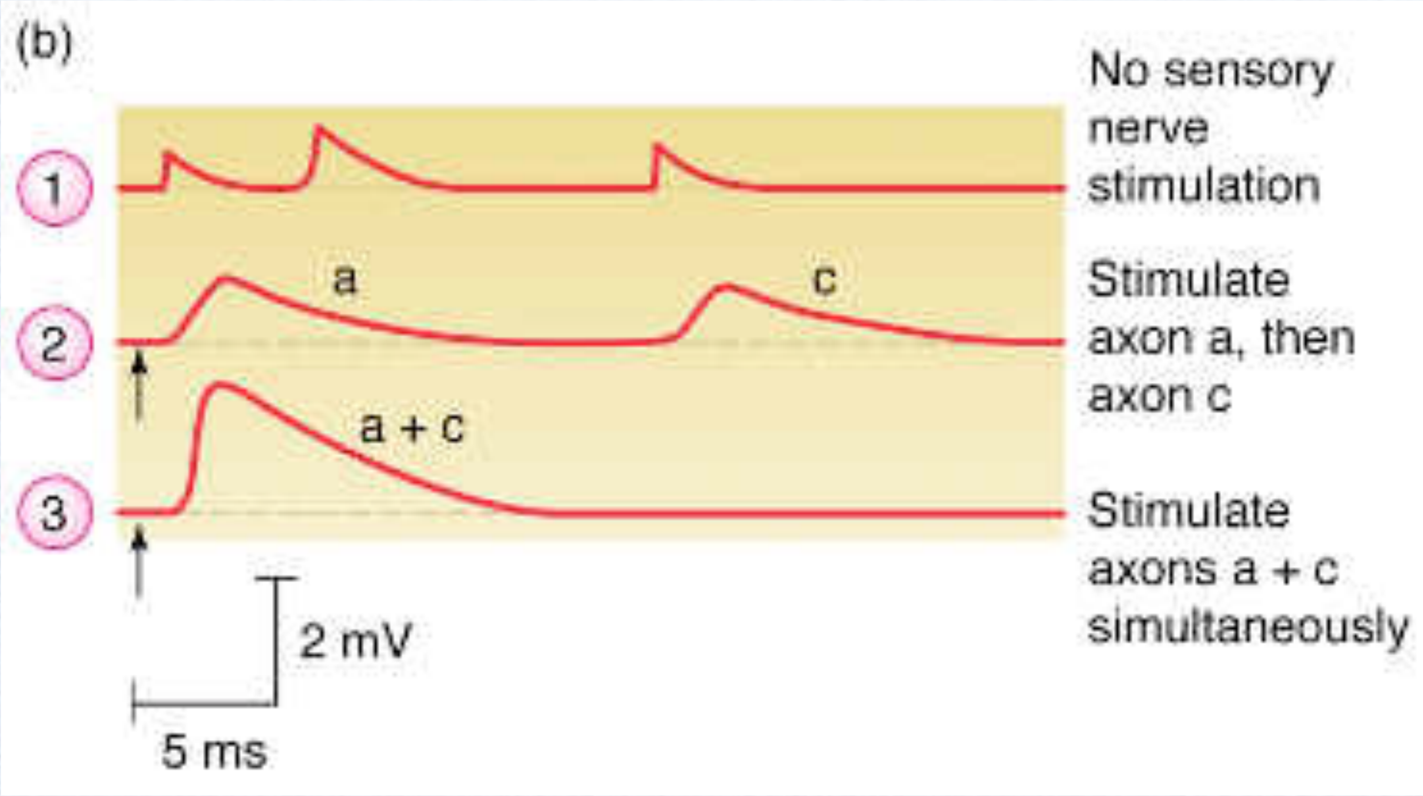
- Need two procedures to define representation
  - encoding (stimulus -> spikes)
  - decoding (spikes -> stimulus; ‘theoretical’)

Nonlinear Encoding
Linear Optimal PSC Decoding



Typical PSCs





From: http://www.zoo.utoronto.ca/berry/zoo252/l9/lect9.htm

Optimal linear decoding

- Linear:

$$\hat{x} = \sum_i a_i(x)\phi_i$$

  - Note: Must know tuning curves, a_i

- Q: How to find decoders?
- A: Minimize $\left\langle (x - \hat{x})^2 \right\rangle_x$

Sources of Noise

- Axonal jitter
- Neurotransmitter vesicle release failures
- Different amount of transmitter in each vesicle
- Thermal noise (minor)
- Ion channel noise (the number of channels open or closed fluctuates)
- Network effects
- See also http://diwww.epfl.ch/~gerstner/SPNM/node33.html

Noise

- So, we must consider the decoding under noise:

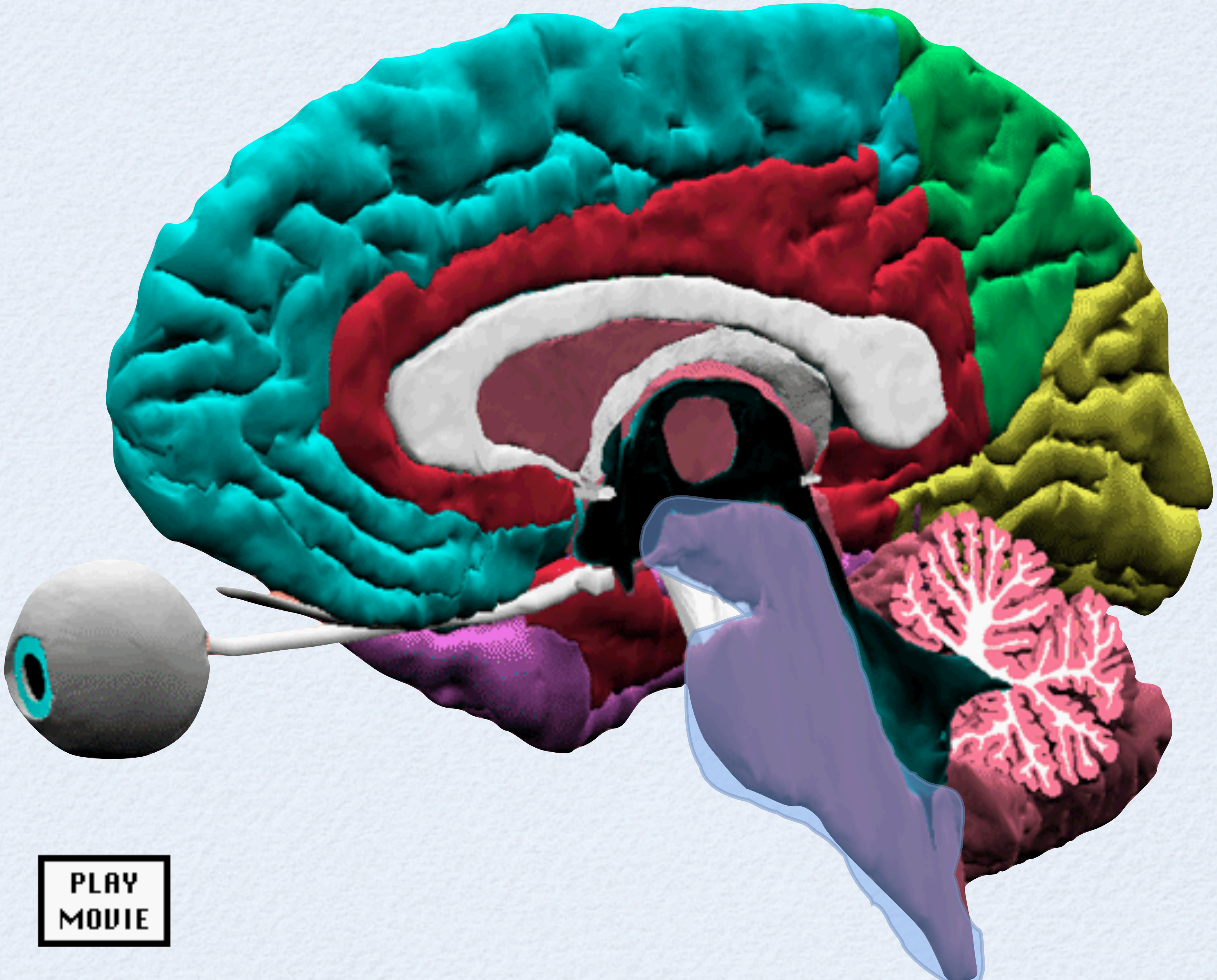
$$\hat{x} = \sum_{i=1}^{N} (a_i(x) + \eta_i)\, \phi_i$$

- Hence, minimize

$$\left\langle (x - \hat{x})^2 \right\rangle_{x,\eta_i}$$

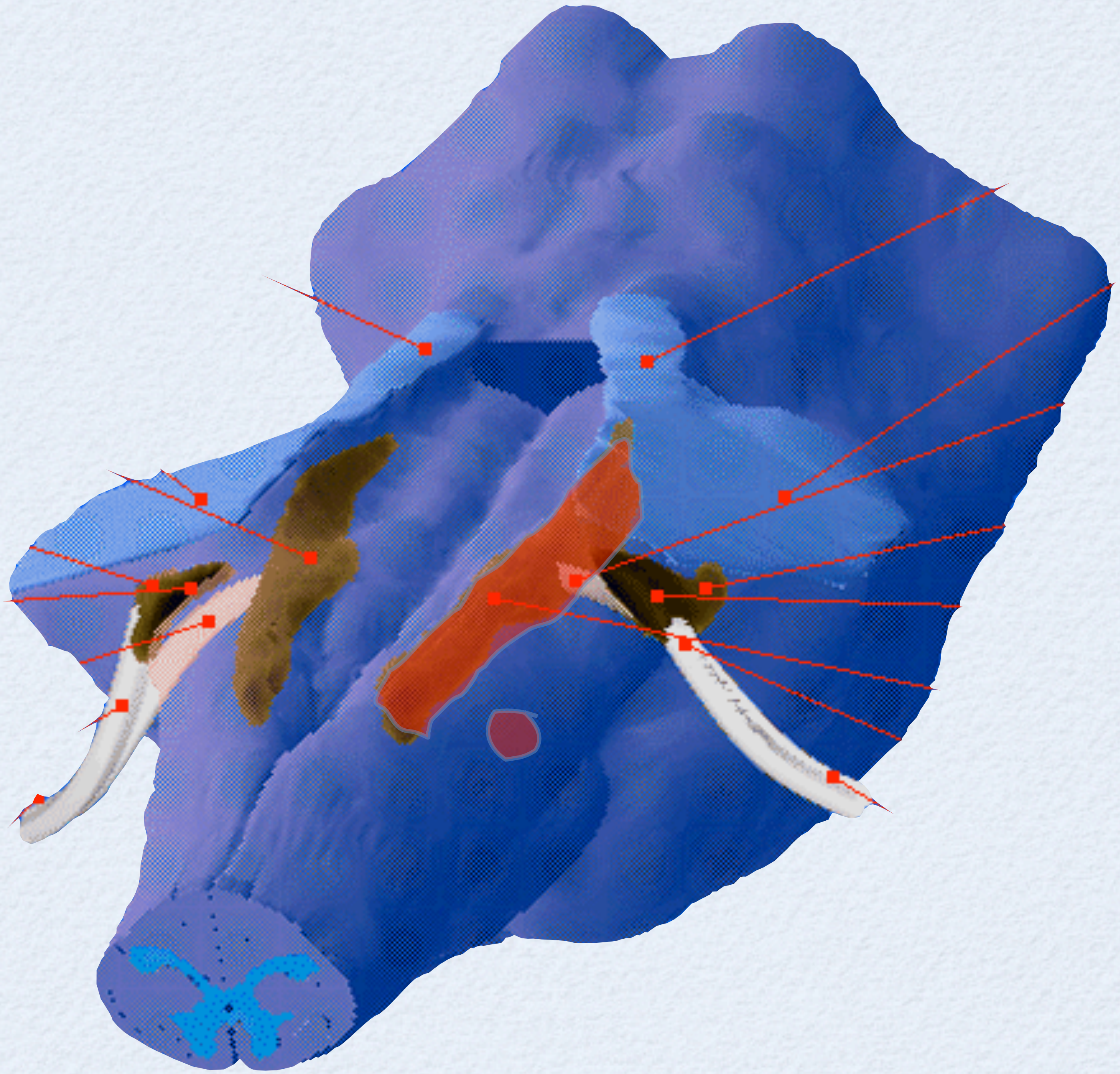
Brain stem

- The neural integrator represents eye position



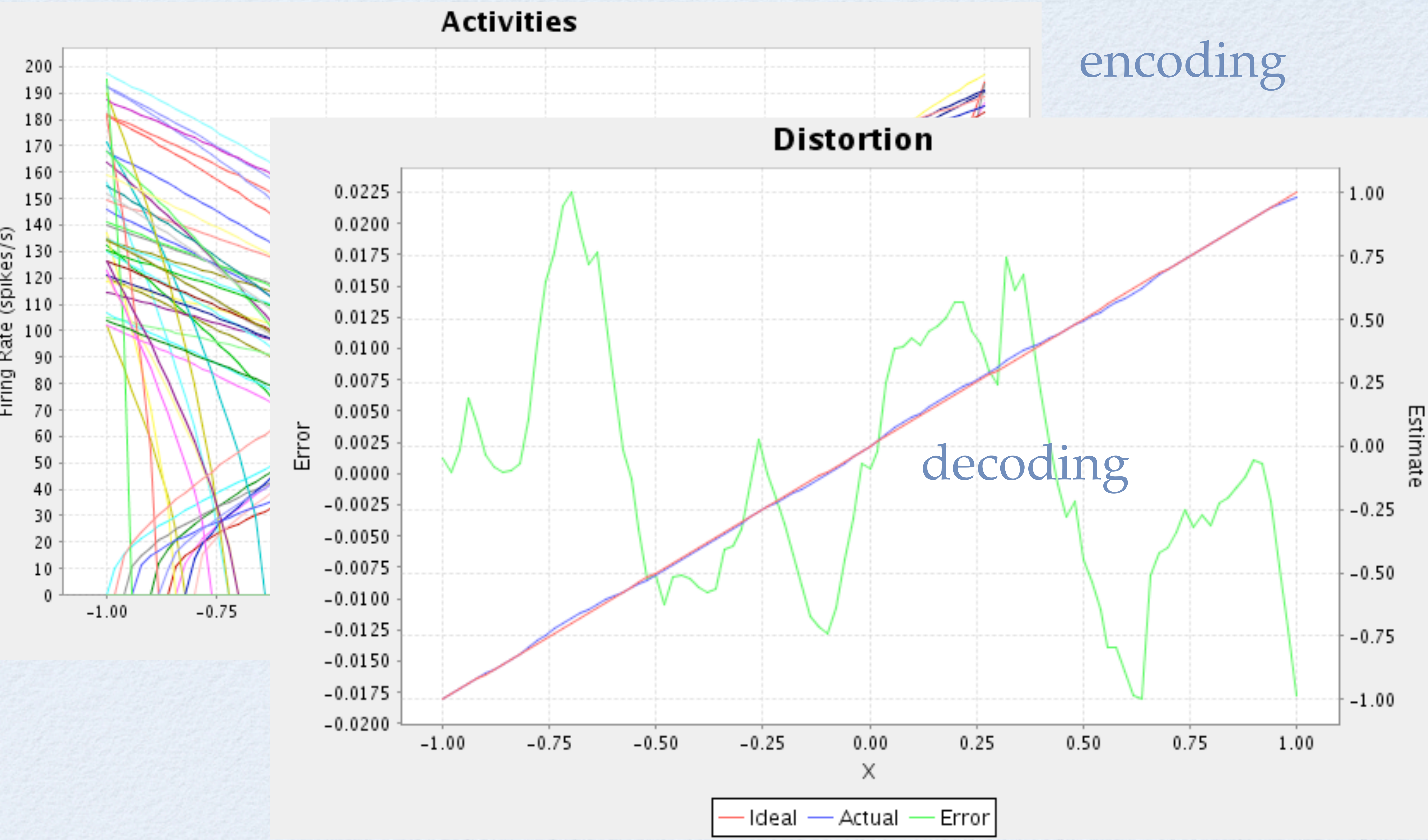
PLAY MOVIE

NPH and Vestibular nuclei



Population tuning

encoding



Error with/without noise*