How to build a brain
Cogsci 2010 Tutorial

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There are animals
Who behave brains think?
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!
Neural Engineering Framework (NEF)

Given:
- Information processing task
- Hardware description

Produce:
- Neural mechanism
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

**Neuron Tuning Curve**

B

- Firing Rate (Hz)
- e = -1
- gain

A

- Firing Rate (Hz)
- e = 1
- bias

**Bob**

**Alice**

**Charlie**
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

Voltage Controlled Gate

refractory period

Voltage

$V_{th}$

 время (мс)

0 20 40 60 80 100

0 0.2 0.4 0.6 0.8 1

Phospholipid layer containing proteins

Transmembrane protein

Ion Channel

$C$

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

\[ \frac{1}{\tau} e^{-t/\tau} \]

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 \( \langle (x - \hat{x})^2 \rangle_x \)
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](http://diwww.epfl.ch/~gerstner/SPNM/node33.html)
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
NPH and Vestibular nuclei
Population tuning

**Activities**

**Distortion**

- Encoding
- Decoding

Graphs showing population tuning with plots for activities and distortion.
Error with/without noise

(a) Square error vs. number of neurons

(b) Square error vs. number of neurons for different models