Neuronal Dynamics: Computational Neuroscience of Single Neurons

Week 7 – Optimizing Neuron Models For Coding and Decoding

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7.1 What is a good neuron model?
- Models and data

7.2 AdEx model
- Firing patterns and analysis

7.3 Spike Response Model (SRM)
- Integral formulation

7.4 Generalized Linear Model (GLM)
- Adding noise to the SRM

7.5 Parameter Estimation
- Quadratic and convex optimization

7.6 Modeling in vitro data
- how long lasts the effect of a spike?

7.7. Helping Humans

Week 7 – part 7: Helping Humans
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7.7 Helping Humans
Neuronal Dynamics – Review: Models and Data

- Predict spike times
- Predict subthreshold voltage
- Easy to interpret (not a ‘black box’)
- Variety of phenomena
- Systematic: ‘optimize’ parameters

BUT so far limited to in vitro
Now: extracellular recordings

Model of ‘Encoding’

A) Predict spike times, given stimulus
B) Predict subthreshold voltage
C) Easy to interpret (not a ‘black box’)
D) Flexible enough to account for a variety of phenomena
E) Systematic procedure to ‘optimize’ parameters
Neuronal Dynamics – 7.7 Estimation of receptive fields

Estimation of spatial (and temporal) receptive fields

\[ u(t) = \sum k_k I_{K-k} + u_{rest} \]

LNP

firing intensity \( \rho(t) = f(u(t) - \theta(t)) \)
LNP = Linear-Nonlinear-Poisson

Special case of

GLM = Generalized Linear Model
GLM for prediction of retinal ganglion ON cell activity

Pillow et al. 2008
Neuronal Dynamics – 7.7 GLM with lateral coupling

**A. LNP model**
- Linear filter
- Nonlinearity
- Poisson spiking

**B. Soft-Threshold IF model**
- Linear filter
- Leaky integrator
- "Soft threshold"
- Post-spike current

**C. Generalized Linear Model (GLM)**
- Linear filter
- Nonlinearity
- Probabilistic spiking
- Post-spike current
- Cell 1 parameters
- Coupling currents
- Cell 2 parameters
One cell in a Network of Ganglion cells

Pillow et al. 2008
Neuronal Dynamics – 7.7 Model of ENCODING

A) Predict spike times, given stimulus
B) Predict subthreshold voltage
C) Easy to interpret (not a ‘black box’)
D) Flexible enough to account for a variety of phenomena
E) Systematic procedure to ‘optimize’ parameters
Neuronal Dynamics – 7.7 ENCODING and Decoding

Model of ‘Encoding’
Generalized Linear Model (GLM)
- flexible model
- systematic optimization of parameters

Model of ‘Decoding’
The same GLM works!
- flexible model
- systematic optimization of parameters
Neuronal Dynamics – 7.7 Model of DECODING

Predict stimulus!

Model of ‘Decoding’:
predict stimulus, given spike times
Neuronal Dynamics – 7.7 Helping Humans

Application: Neuroprosthetics

Predict intended arm movement, given Spike Times

Model of ‘Decoding’

Many groups worldwide work on this problem!
Neuronal Dynamics – 7.7 Basic neuroprosthetics

Application: Neuroprosthetics

Decode the intended arm movement

Hand velocity

Fig. 11.12: Decoding had velocity from spiking activity in area MI of cortex. The real hand velocity (thin black line) is compared to the decoded velocity (thick black line) for the x— (top) and the y—componenets (bottom). Modified from Truccolo et al. (2005).
Mathematical models for neuroscience help humans

The end
Neuronal Dynamics week 7– Suggested Reading/selected references

Reading: W. Gerstner, W.M. Kistler, R. Naud and L. Paninski,
Neuronal Dynamics: from single neurons to networks and models of cognition. Ch. 6,10,11: Cambridge, 2014

Nonlinear and adaptive IF

Optimization methods for neuron models, max likelihood, and GLM

Encoding and Decoding