Chaitanya (Chaitu) Ekanadham
Special topics outline for oral examination

Theoretical neuroscience

Advisor(s): Eero Simoncelli, Daniel Tranchina

I. Basic concepts of neural coding

A. Correlation functions, STA; measurement of these values; rate/pulse coding

B. Properties of general point processes

- Conditional intensity function, ISI density, Fano factor, coefficient of variation
- Specialization to inhomogeneous/homogeneous Poisson processes
- Time-rescaling theorem

C. Weiner-Volterra series expansion

- Optimal linear kernel and relation to correlation functions and/or STA
- Optimal stimulus for a given linear kernel
- Effect of static nonlinearities

D. Information-theoretic quantities

- Estimating the entropy of {spike times, spike counts}
- Estimating mutual information between stimulus and {spike times, spike counts}
  - Consequences for rate/pulse coding debate

II. Spiking models

A. Basic concepts

- membrane potential, resistance, capacitance, time constant, conductance, equilibrium potential
- Ohm's Law, conservation of current (cable version and space-clamped version), cable equation

B. Hodgkin Huxley equations

- Assumptions - modeled currents and functional form of conductances
- Fast/slow timescale analysis, phase plane analysis

C. Integrate and fire

- Simple LIF equation
  - Solution of V(t), ISI time/firing rate
  - accounting for refractoriness/adaptation
- Stochastic version (diffusive noise model)
  - Langevin's equation, Fokker-Planck equation as a limit of Stein's model
  - Conservation of probability argument to derive Fokker-Planck

D. Generalized Linear Models

- Linear-Nonlinear Poisson (LNP) - statement of model and assumptions
- General model (spike and coupling feedback) - connection with general rate process
- Connection with "soft-threshold" IF model

III. Fitting model parameters

- Estimators for linear filter in the GLM:
  - least squares, STA, Fisher linear discriminant, MLE - relation with Wiener kernels
  - spike-triggered covariance estimator
- comparison of these estimators (conditions for bias,consistency,tractability)

IV. Decoding/discrimination

- Regression - optimal linear decoder and relation with correlation functions
- Bayesian techniques
  - Bayes-optimal solution - definition and challenges for computing
  - MAP solution - when is it accurate (Laplace approximation)? computationally tractable?

References

1. Dayan, P. and Abbott, L. (2001). *Theoretical Neuroscience*. MIT Press.
(Section I, Chapters 1-4)
2. Gerstner, W. and Kistler, W. (2002). *Spiking Neuron Models: Single Neurons, Populations, Plasticity*. Cambridge University Press.
(Section I, Chapters 2-5)
3. Paninski, L. (2007). *Statistical Analysis of Neural data: Online Lecture Notes*. (http://stat.columbia.edu/~liam/teaching/neurostat-spr07/index.html).
4. Rieke, F., Warland, D., de Ruyter van Steveninck, R., and Bialek, W. (1996). *Spikes - Exploring the neural code*. MIT Press, Cambridge, MA.
(Chapters 1-3)