ESAM 370:
Introduction to Computational Neuroscience

1. Single compartment passive neurons

- Capacitance of phospholipid bilayer
- Typical numbers for neurons
- Intracellular resistance
- Ion channels
- Single compartment passive model

2. Ion channels in more detail

- Equilibrium potential
- Electrogenic transporters
- Sodium-potassium pump
- Diffusion
- Langevin equation
- Nernst-Planck equation
- Goldman-Hodgkin-Katz equation

3. The Hodgkin-Huxley model

- Voltage clamp
- Sodium/Potassium currents
- Current-voltage curves
- Time-dependent conductances
- Conductance gating models
- Hodgkin-Huxley single compartment model
- Refractory period
- Rebound action potential

4. The Fitzhugh-Nagumo model

- Reduction to just 2 equations
- Nullclines
- The phase plane
- Critical points and stability

5. More about ion channels

- Patch clamp recordings
- Single channel currents
- Ion channel conformational structure
- K^+ channel selectivity
- State dependent Markov models
- Gillespie algorithm

6. More about single compartment models

- Basic equations — two formulations
- The zoo of ion channels
- A-type potassium
- Calcium currents
- Calcium-dependent potassium currents
- I_h current
- K_{ir} current

7. Integrate and fire neurons

- Integrate and fire basic equations
- f-I curve
- Implementation in Matlab

8. Synapses

- Electrical synapses
- Chemical synapses
- Excitatory vs. inhibitory receptors
- Ionotropic vs. metabatropic receptors
- Events at the synaptic cleft
- Quantal and probabilistic release
- Simple synapse models
  - Exponential synapse
  - Double exponential synapse
  - Alpha synapse
- Facilitation and depression
- Tsodyks model
- NMDA synapses
- Coupled integrate and fire neurons

9. Izhikevich's simple model

- Basic equations
- firing patterns

10. Derivation of the cable equation

- Neuron morphologies
- Cable equation derivation
- Passive cables
- Relationship to Nernst-Planck equation

11. Solutions of the passive cable equation

- Point current injection — infinite cable
- Branched cables
- Rall's rule
- Equivalent cable
- Point current injection — finite cable
- Time-dependent solutions

12. Numerical solution of the passive cable equation

- Compartment models
- NEURON
- Reconstructed morphologies

13. Stability of the passive cable equation

- Fourier stability analysis
- stability criterion

14. NEURON examples

- Y branch
- Synaptic input
  - Effect of axial and membrane resistance
  - Synaptic summation
  - Effect of inhibition
- Active cables: propagating HH action potential
- Synapses on active dendrites

15. Reconstructing morphologies

- Neurolucida
- Array tomography
- Two-photon imaging

16. Firing rate models

- Experimental justification
- Rate vs. temporal coding
- Spike trains and firing rates
- Poisson processes
- Simulating synapses
- High-rate limit
- Balanced input
- Correlated Gaussian noise

17. Firing rate networks

- Layered networks
- Feedforward networks
- Recurrent networks
- Dale's law
- Linear recurrent networks
- Selective amplification
- Ring network

18. Hopfield associative memory

- Nonlinear recurrent network
- Constructing the weight matrix
- Hopfield iteration
- Crosstalk between patterns

19. Input integration

- Recurrent network with balanced gain/loss
- Network model of eye position memory
- Ratcliff's diffusion model
- Shadlen and Newsome's experiments
- X. J. Wang's model

20. Efficient coding in balanced spiking networks

- Single neuron example
- Multiple neurons
- Example cases

21. The physiology of plasticity and learning

- Hebbian cell assemblies
- Long-term potentiation
- Bliss and Lomo
- Specificity, cooperativity, associativity
- Growth of spines
- Long-term depression
- BCM rule
- Spike-timing dependent plasticity
- Spike timing and firing rate

22. Models of plasticity and learning

- BCM model
- STDP rule

23. Place and grid cells

- Experiments of O'Keefe
- Wilson's results
- Learning of place cells
- Context dependence
- Grid cells
- Grid cell models