Lecture Notes

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LEC #	LEARNING OBJECTIVES	LECTURE NOTES
1	• To understand how the timescale of diffusion relates to length scales • To understand how concentration gradients lead to currents (Fick's First Law) • To understand how charge drift in an electric field leads to currents (Ohm's Law and resistivity)	Overview and Ionic Currents (PDF - 1.7MB)
2	• To understand how neurons respond to injected currents • To understand how membrane capacitance and resistance allows neurons to integrate or smooth their inputs over time (RC model) • To understand how to derive the differential equations for the RC model • To be able to sketch the response of an RC neuron to different current inputs • To understand where the 'batteries' of a neuron come from	RC Circuit and Nernst Potential (PDF - 2.7MB)
3	• To be able to construct a simplified model neuron by replacing the complex spike generating mechanisms of the real neuron (HH model) with a simplified spike generating mechanism • To understand the processes that neurons spend most of their time doing which is integrating inputs in the interval between spikes • To be able to create a quantitative description of the firing rate of neurons in response to current inputs • To provide an easy-to implement model that captures the basic properties of spiking neurons	Nernst Potential and Integrate and Fire Models (PDF - 4.1MB)
4	• To be able to draw the circuit diagram of the HH model • Understand what a voltage clamp is and how it works • Be able to plot the voltage and time dependence of the potassium current and conductance • Be able to explain the time and voltage dependence of the potassium conductance in terms of Hodgkin-Huxley gating variables	Hodgkin Huxley Model Part 1 (PDF - 6.3MB)
5		Hodgkin Huxley Model Part 2 (PDF - 3.3MB)
6	• To be able to draw the 'circuit diagram' of a dendrite • Be able to plot the voltage in a dendrite as a function of distance for leaky and non-leaky dendrite, and understand the concept of a length constant • Know how length constant depends on dendritic radius • Understand the concept of electrotonic length • Be able to draw the circuit diagram a two-compartment model	Dendrites (PDF - 3.2MB)
7	• Be able to add a synapse in an equivalent circuit model • To describe a simple model of synaptic transmission • To be able to describe synaptic transmission as a convolution of a linear kernel with a spike train • To understand synaptic saturation • To understand the different functions of somatic and dendritic inhibition	Synapses (PDF - 3.1MB)
8	• To understand the origin of extracellular spike waveforms and local field potentials • To understand how to extract local field potentials and spike signals by low-pass and high-pass filtering, respectively • To be able to extract spike times as a threshold crossing • To understand what a peri-stimulus time histogram (PSTH) and a tuning curve is • To know how to compute the firing rate of a neuron by smoothing a spike train	Spike Trains (PDF - 2.6MB)

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9	• To be able to mathematically describe a neural response as a linear filter followed by a nonlinear function.
	  ◦ A correlation of a spatial receptive field with the stimulus
	  ◦ A convolution of a temporal receptive field with the stimulus
	• To understand the concept of a Spatio-temporal Receptive Field (STRF) and the concept of 'separability'
	• To understand the idea of a Spike Triggered Average and how to use it to compute a Spatio-temporal Receptive Field and a Spectro-temporal Receptive Field (STRF).
		Receptive Fields (PDF - 2.1MB)

10	• Spike trains are probabilistic (Poisson Process)
	• Be able to use measures of spike train variability
	  ◦ Fano Factor
	  ◦ Interspike Interval (ISI)
	• Understand convolution, cross-correlation, and autocorrelation functions
	• Understand the concept of a Fourier series
		Time Series (PDF - 4.5MB)

11	• Fourier series for symmetric and asymmetric functions • Complex Fourier series • Fourier transform • Discrete Fourier transform (Fast Fourier Transform - FFT) • Power spectrum	Spectral Analysis Part 1 (PDF - 4.3MB)

12	• Fourier Transform Pairs
	• Convolution Theorem
	• Gaussian Noise (Fourier Transform and Power Spectrum)
	• Spectral Estimation
	  ◦ Filtering in the frequency domain
	  ◦ Wiener-Kinchine Theorem
	• Shannon-Nyquist Theorem (and zero padding)
	• Line noise removal
		Spectral Analysis Part 2 (PDF - 3.1MB)

13	• Brief review of Fourier transform pairs and convolution theorem
	• Spectral estimation
	  ◦ Windows and Tapers
	• Spectrograms
	• Multi-taper spectral analysis
	  ◦ How to design the best tapers (DPSS)
	  ◦ Controlling the time-bandwith product
	• Advanced filtering methods
		Spectral Analysis Part 3 (PDF - 2.2MB)

14	• Derive a mathematically tractable model of neural networks (the rate model) • Building receptive fields with neural networks • Vector notation and vector algebra • Neural networks for classification • Perceptrons	Rate Models and Perceptrons (PDF - 3.9MB)
15	• Perceptrons and perceptron learning rule • Neuronal logic, linear separability, and invariance • Two-layer feedforward networks • Matrix algebra review • Matrix transformations	Matrix Operations (PDF - 4.0MB)
16	• More on two-layer feed-forward networks • Matrix transformations (rotated transformations) • Basis sets • Linear independence • Change of basis	Basis Sets (PDF - 2.8MB)

LEC #	LEARNING OBJECTIVES	LECTURE NOTES
17	• Eigenvectors and eigenvalues • Variance and multivariate Gaussian distributions • Computing a covariance matrix from data • Principal Components Analysis (PCA)	Principal Components Analysis (PDF - 4.8MB)
18	• Mathematical description of recurrent networks • Dynamics in simple autapse networks • Dynamics in fully recurrent networks • Recurrent networks for storing memories • Recurrent networks for decision making (winner-take-all)	Recurrent Networks (PDF - 2.2MB)
19	• Recurrent neural networks and memory • The oculomotor system as a model of short term memory and neural integration • Stability in neural integrators • Learning in neural integrators	Neural Integrators (PDF - 2.0MB)
20	• Recurrent networks with lambda greater than one ◦ Attractors • Winner-take-all networks • Attractor networks for long-term memory (Hopfield model) • Energy landscape • Hopfield network capacity	Hopfield Networks (PDF - 2.7MB)