CN510 2006 Midterm Exam Study Guide

The following material is a superset of what will be asked on the midterm exam. Some exam questions may be exact duplicates of those listed here, and others may be modified but closely related questions. Group studying is perfectly acceptable and encouraged.

I. Short definitions (1 to 2 sentences, with a diagram if applicable):

- Artificial intelligence
- Cognitive psychology
- Cognitive neuroscience
- Neural network modeling
- Short-term memory (including network interpretation)
- Long-term memory (including network interpretation)
- Plasticity
- Hebb's rule
- Sulcus
- Fissure
- Gyrus
- Cytoarchitecture
- Cortical column
- Phrenology
- Aggregate-Field Theory
- Neuron Doctrine
- Cellular Connectionism
- Threshold-linear signal function
- Afferent/efferent pathways
- Decussation
- Magnocellular
- Parvocellular
- Blindsight
- Parkinson's disease (including symptoms and nature of damage in brain)
- Huntington's disease (including symptoms and nature of damage in brain)
- Motor equivalence
- Agnosia
- Astereognosis

- Personal neglect syndrome
- Hemifield neglect
- Plateau potential
- Classical conditioning (describe paradigm)
- Extinction training
- Garcia effect
- Nernst potential
- Electrotonic potential
- Action potential
- Membrane potential
- Depolarization
- Hyperpolarization
- Gated ion channel (name three types of gating)
- On-center, off-surround competitive network
- Psychophysics
- Just noticeable difference
- Weber's law
- Excitatory postsynaptic potential (EPSP)
- Inhibitory postsynaptic potential (IPSP)
- Facilitation
- Potentiation
- Long-term potentiation (LTP)
- Long-term depression (LTD)
- Trigger zone of a neuron
- Sensitization
- Habituation
- Transmitter (including two main classes)
- Synaptic vesicles
- Exocytosis
- Reversal potential (including why it is called ``reversal")
- Eidetic imagery
- Random dot stereogram
- Sampling regime

II. Essay questions:

- Name four experimental techniques that measure four different aspects of neuroanatomy or neurophysiology. Briefly discuss the physiological/anatomical property measured by each technique.
- Describe the strict bottom-up and top-down approaches to studies of nervous system function. Describe potential problems for each approach. Define computational neuroscience within this context.
- What is Marr's doctrine of independence? What problems do Churchland et al point out for this approach?
- Briefly describe the main components of three neural models, each defined at a different "grain" of analysis. That is, choose three models that differ in terms of the amount of neurophysiological detail incorporated into the model.
- Name and discuss three factors that help determine how faithful to neurophysiology a neural model should be.
- Briefly define the following terms with reference to differences and similarities between the typical meanings of the terms: (i) neuroscience, (ii) artificial intelligence, (iii) cognitive psychology, (iv) cognitive neuroscience, (v) cognitive science, (vi) neural network modeling, and (vii) computational neuroscience.
- Given diagrams of the brain and/or spinal cord, draw and label the primary axes (rostral-caudal, dorsal-ventral, anterior-posterior, lateral-medial) and planes (sagittal, axial, coronal) of orientation.
- Given a diagram of the brain like Fig. 1.2a of Principles of Neural Science, label the following areas and provide a one-sentence overview of the basic function of each: (i) spinal cord, (ii) medulla oblongata, (iii) pons, (iv) cerebellum, (v) midbrain, (vi) basal ganglia, (vii) thalamus (part of the diencephalon), and (viii) cerebral cortex.
- Sketch a sagittal view of the human cortex and label the four major lobes. Briefly describe some of the functions performed by each lobe. Also indicate on your sketch the central sulcus and sylvian fissure.
- Define the term "cortical column", state the number of layers in neocortex, and briefly describe the kinds of differences in cortical anatomy used by Brodmann to parcellate the cerebral cortex. How does allocortex differ from neocortex?
- Write down the equation for a leaky integrator neuron. Sketch the response of this neuron to a step input. What will the equilibrium activity of the neuron be if the step input is left on indefinitely? Identify the decay rate parameter in this equation, and describe why it is called a decay rate parameter.
- Given a diagram of a water/barrel system consisting of input pipes, drains, and a leak, write an additive equation that describes the depth of the water in the barrel (including parameters that account for different sizes of pipes, etc.) and relate all of terms of the equation to the components of the water/barrel system. Solve for the equilibrium level of the water if the inputs are fixed and the barrel has infinite height. Describe how the components of this system correspond to the components of an additive neural network. Finally, describe how

the system would need to be modified to make it analogous to an additive neural network with modifiable synaptic weights.

- Describe the locations of neurons along the path from the peripheral receptors to the cortex for the auditory, visual, and somatosensory systems. (E.g, somatosensory information is carried by the dorsal root ganglia to neurons in the medulla and thalamus on the way to the primary somatosensory cortex.)
- Describe the location (in terms of sulci and/or gyri) of the primary auditory, visual, somatosensory, and motor cortices.
- Briefly discuss (approx. 3-4 sentences) the role of the basal ganglia in motor control, including descriptions of its interconnectivity with cortex, Parkinson's disease, and Huntington's disease.
- Explain why lesions of the subthalamic nucleus (STN) can relieve some of the symptoms of Parkinson's disease.
- Briefly discuss (approx. 3-4 sentences) the role of the cerebellum in motor control, including a description of the "side loop" concept and a brief treatment of ataxia.
- Given a diagram separating the cortex into primary, higher-order unimodal, and association areas, provide labels for the different regions. Give a one-sentence description of the functionality of each higher-order sensory and motor area.
- **(a)** Draw a neural network architecture capable of learning associations between three sensory stimuli and three motor responses in a classical conditioning situation. Do not worry about learning to inhibit erroneous responses in your network. **(b)** Write down additive equations describing the activities of the neurons in your network and an equation for changing the weights in your network to encode learned associations. Use a passive decay term in your weight equation. **(c)** Assume that sensory stimulus 2 is repeatedly paired with an unconditioned stimulus that leads to motor response 3, but that all other stimuli and responses are only very infrequently paired. Draw sketches of the weight strengths projecting to the cell coding motor response 3 as a function of time under the assumption that all weights start out at a value of 0.5. **(d)** How can the learned association between stimulus 2 and response 3 be reduced after it has been learned? **(e)** Modify your weight change equation to use a gated decay and repeat the sketches from part (c). **(f)** How can the learned association between stimulus 2 and motor response 3 be reduced in this version? **(g)** Which version better explains classical conditioning phenomena and why? **(h)** Name three remaining shortcomings of the model.
- Given an additive classical conditioning network as described in the preceding question, describe how the network equations could be modified so that it is capable of learning to inhibit erroneous responses. What condition on the parameters has to hold to account for the observation that negative reinforcement on a single trial can often permanently suppress an errant response in future trials?
- Given an additive classical conditioning network as described in the preceding questions, describe how the network equations could be modified to account for innate biases in learnability of associations, as in the Garcia effect. Describe how learning can allow the network to overcome these biases when presented with an appropriate set of training trials.

- Given a simple feedforward network diagram, write down both additive and shunting (with and without hyperpolarization term) equations that could be used to describe the neurons in the diagram.
- Describe the sequence of events up to and during the generation of an action potential in a neuron. Be sure to discuss the roles of: (i) external inputs, (ii) the initial concentrations of K+ and Na+ ions, (iii) voltage-gated ion channels and their thresholds, (iv) the relative time courses of Na+ and K+ ion conductances.
- Draw the electrical equivalent circuit of a neuron as discussed in class, including membrane capacitance and Na+, Cl-, and K+ ion channels. Derive the Hodgkin-Huxley-like equation describing the rate of change of membrane potential as a function of ion conductances, Nernst potentials, membrane capacitance, and the membrane potential for this equivalent circuit. Show the steps of your derivation.
- What are the relative values of the Nernst potentials for Na+, K+, and Cl- ? (Can answer this by stating typical values for the squid axon or simply by ranking from highest potential to lowest potential.) What do these Nernst potentials have to do with the range of possible membrane potentials for the neuron?
- Define the term "shunting" in the electronics sense and describe why the shunting equation is called "shunting".
- Describe how opening up K+ ion channels can inhibit a neuron. Include in your answer a treatment of how a neuron at rest potential can be hyperpolarized and how a neuron with excitatory inputs can be prevented from firing by appropriately timed inhibitory inputs.
- Given a feedforward shunting equation, give neurophysiological interpretations of the variables and parameters in the equation based on comparisons to the Hodgkin-Huxley equation.
- Using an example such as the processing of a visual scene under different lighting conditions, describe the concept of "factorization of pattern and energy" and point out why it is often an important property for a neural system.
- Given a shunting equation, define and discuss ``automatic gain control'' as it applies to the equation.
- Describe in words and diagrams the shift property of a feedforward shunting network. Using the retina of the mudpuppy as an example, describe how this property can greatly increase sensitivity to changes in input intensity in a network of neurons with fixed dynamic range. Finally, identify what has been "traded off" for this increased sensitivity.
- Draw a simple two cell network (including inputs) that can be used to test whether a feedforward shunting network can explain Weber's law as seen in the psychophysical results of Cornsweet and Pinsker (1965). Derive Weber's law from the shunting equation for this network, identifying the condition that must hold for the network to strictly reproduce Weber's law.
- Describe the processes of temporal summation and spatial summation of synaptic inputs at the trigger zone of a neuron. Include in your description an explanation of why the trigger zone is called the ``trigger zone''. Discuss how the neuron's length constant and time

constant factor into determining whether or not a particular set of synaptic inputs will fire the neuron.

- Describe the events up to and including transmitter release in a presynaptic neuron. Include in your discussion the roles of the presynaptic membrane potential, voltage-gated Ca++ channels, and exocytosis. Finally, discuss why it is important to quickly remove transmitter from the synaptic cleft, and state three ways this can be accomplished.
- Describe the major steps involved in transmission at a typical second messenger synapse once the presynaptic cell has released transmitter into the synaptic cleft. Include the ``first messenger'', G-proteins, the second messenger, and protein kinase in your description.
- Using the Hodgkin-Huxley equation solved at equilibrium, describe how the opening of K+ or Cl- channels can have an inhibitory effect. Using a similar rationale, describe why opening channels permeable to both Na+ and K+ can have an excitatory effect.
- Discuss the long-term changes in ion channel conductance believed to be partially responsible for (i) long-term sensitization and (ii) long-term habituation in Aplysia. Be sure to specify whether the changes affect channels in the presynaptic or postsynaptic membrane and why the changes lead to increased/decreased efficacy of synaptic transmission. Finally, briefly discuss the larger-scale structural changes that also act to change efficacy in habituation and sensitization.
- Describe Alkon's local interaction model of synaptic modification, including a discussion of how it differs from the Hebbian model.
- Describe the outstar explanation of eidetic imagery in Julesz' random dot stereogram experiment.
- Given a diagram of the boxes and arrows in the DIRECT model, provide correct labels for those boxes and arrows.
- Without regard to learning, explain how a fully trained DIRECT model functions to solve the problems of reaching with a new tool and blind reaching without a tool.
- Describe the basic cycle used to train the DIRECT model, and explain how outstar learning supports the learning of a forward kinematic mapping and an inverse differential kinematic mapping.
- Describe two shortcomings of the DIRECT model and one modification that can overcome both of them.
- What did you find most informative about HW1?
- What did you find most informative about HW2?
- What did you find most informative about HW3?