Guiding Questions on Brain and Computation: Part II

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Chapter 7: Associators and Synaptic Plasticity

Q1: What is Hebbian learning? Describe the structure of function of an associative neuron (node). Describe the structure and function of an associative network. How does the network learn? How can you use the associative node to explain the classical conditioning paradigm (e.g. Pavlovian learning).

Q2: What's the biochemical basis of Hebbian learning? What is synaptic plasticity of the brain? How does the activity-dependent synaptic plasticity differ from longlasting synaptic changes? What are LTP and LTD? Explain their mechanisms. How are they related to Hebbian learning?

Q3: Give a general mathematical formulation for Hebbian learning? What does the equation describe? What terms (factors) are there? How are they related? Describe Hebbian learning with spiking neuron models. Describe Hebbian learning with rate-coding neuron models.

Q4: Why is synaptic scaling necessary? How can it be done? How does Oja's rule address this? How is STD related to this?

Q5: What are the main features of associators and Hebbian learning? Discuss in particular in terms of pattern completion, prototype learning, and graceful degradation. Hebbian learning rules are biologically faithful, local, and online. Explain these properties and discuss how useful they are for machine learning.

Chapter 8: Auto-associative Memory and Network Dynamics

Q1: Describe the structure and function of an auto-associative node and auto-associative network. What are the functional roles of the recurrence in the auto-associative node and network? Why are they useful or necessary? Explain by distinguishing the roles in terms of short-term memory and long-term memory.

Q2: What are point-attractor networks? What is Grossberg-Hopfield (GH) model? What's the network dynamics of the GH model? What kinds of neural system does it describe? What's the neuron type adopted in the model? How can the Hebbian learning be used to train the GH model? How much cross-talk does happen if many patterns are loaded into the GH autoassociators?

Q3: What is the memory capacity (load capacity) of the noiseless GH model with standard Hebbian learning? What happens if the patterns are noisy. Compare the GH model and spin-glass model in statistical physics. Give a phase diagram of the attractor network based on GH model learned with Hebbian imprinting (loading). What are spurious states? Can noise be helpful for the behavior of the dynamical system, i.e. attractor networks?

Q4: What is the basic idea of sparse attractor neural networks? What is expansion coding? How can you measure the sparseness of the representation? How can you control the sparseness in attractor networks?

Chapter 9: Continuous Attractor and Competitive Networks

Q1: How are the continuous attractor neural networks (CANNs) different from the point attractor neural networks (PANNs)? Explain the mechanisms of CANNs by showing how the body or head direction is represented. How do the hippocampal neurons in a rodent respond to the subject's location (places) to a maze? What shape does the place-field in hippocampus of the rodent have?

Q2: Give a network model of spatial representations. Using 20 nodes, for example, in the model, how does a head direction be represented?

Q3: We wish to use a continuous attractor neural network (CANN) to represent head directions, i.e. in a continuous set of patterns. Give a neural field representation of Hebbian rule for the excitatory weights. Assume we use Gaussian profile around a preferred direction. Describe the displacement between the head direction provided by the external input and the optimal firing direction of a cell. Using this displacement, give the Hebbian rule, i.e. what is the contribution to each weight component?

Chapter 10: Supervised Learning and Reward Systems

Q1: Describe the differences of the following control schemes: i) feedback controller, ii) forward controller, iii) inverse model controller, iv) adaptive critic controller.

Q2: Consider a single-layer mapping neural network. Describe its architecture having the inputs and output units. We want to train the network based on training examples. How is the error defined? What is the gradient of the error function? How are the weight values changed? Give the delta rule for weight update. Derive the delta rule. Give the online learning procedure for the delta-rule algorithm. How does a batch learning scheme different from the online learning scheme?

Q3: Describe the temporal delta rule for a reward system. Give an architecture of the neural implementation of temporal delta rule. Taking into account all the future rewards, how is the reinforcement value formulated?

Q4: Consider the temporal difference learning, a method that learns to predict future reward contingencies. How is it implemented in a neural network? What is the predicted reinforcement value at time *t*. What is the predicted correct reinforcement value at previous time step *t-1*? Give the formula for the temporal difference error.