Introduction

Below, we outline some key concepts and ideas you should be comfortable with for Midterm 2. Under each topic, we have divided this into three sections:

1. Items to know
2. Things to be able to work through when given information/formulae
3. Items out of scope

Note that this list is not exhaustive, but we hope it is illustrative. We encourage you to review the course textbook, section materials, homework materials, and the midterm practice problems for a full picture.

1 Clustering

1.1 Items to know

- K-means objective, Lloyd's algorithm
- Hierarchical agglomerative clustering, dendrograms, and the various linkage criteria. How do the different linkage criteria affect what kinds of clusters are learned?
- Curse of dimensionality in HAC

1.2 Things to be able to work through when given information/equations

- Gaussian mixture models (formulation, use of EM, comparison to K-means)

1.3 Items out of scope

- Conditions under which GMM have linear vs quadratic class boundaries

2 Mixture Models and Topic Models

2.1 Items to know

- Expectation maximization: understand the idea of expected complete-data likelihood, the E-step and the M-step, and relationship to the MLE problem. (Know how to use EM, but no need to memorize specific algebraic forms of solutions to the E-step or M-step for particular models).
- Understand the typical kinds of applications of mixture models
- Understand topic models (no need to memorize its specific form)
- How to express a model as a directed graphical model (DGM); idea of latent vs. observed variables, handling parameters as random variables, and the plate notation (see Graphical models lecture).

2.2 Things to be able to work through when given information/equations

- Understand how to work with the Gaussian mixture model (no need to memorize its specific form)
- Understand how to work with the mixture of multinominal model (no need to memorize its specific form)
- Understand how to work with the topic model (no need to memorize its specific form)

2.3 Items out of scope

- Factor analysis
- Variational autoencoder

3 Dimensionality reduction

3.1 Items to know

- Understand the PCA loss function, and interpretation/formulation as reconstruction loss (no need to memorize)
- Know how to use eigenvectors on empirical covariance matrix for PCA (but don't memorize)
- Understand motivations and typical applications

3.2 Things to be able to work through when given information/equations

- How to compute the empirical covariance matrix for a low-dimensional (i.e. 2 dimensional) toy example
- How to reason about the eigenvectors of a low-dimensional (i.e. 2 x 2) matrix
- Applying a PCA subspace to a simple data set

3.3 Items out of scope

- The probabilistic interpretation of PCA
- Kernel PCA
- Variance preservation view of PCA

4 Graphical models and Bayes nets

4.1 Items to know

- Understand the graphical representation of a Bayesian network (BN), as well as the role of conditional probability tables (CPTs)
- Idea of polytree requirement
- Plate notation
- Understand the distribution defined by a Bayesian network (BN), the role of local conditional independence properties, and typical applications.

4.2 Things to be able to work through when given information/equations

- Can construct a BN for a given variable ordering (e.g., add A, then B and required edges to A, then C and required edges to A and B...), understand the effect of different orderings
- Know how to use variable elimination for inference, and understand the use of leaves-first ordering and the importance of a good elimination order
- How to deduce independence / dependence rules between variables via d-separation, given a specific Bayes Net

4.3 Items out of scope

- How to learn parameters in a Bayes Net
- MCMC/Gibbs sampling (and Markov blanket), rejection sampling
- Variational methods
- Undirected graphical models such as Markov random fields (including inference in undirected models)
- Factor graphs

5 Hidden Markov Models

5.1 Items to know

- Know the form of the HMM, the distribution it defines, the conditional Independence properties, and understand the typical kinds of applications
- Inference: understand the inference questions of interest

5.2 Things to be able to work through when given information/equations

- Learning: the use of EM (no need to memorize the E or M step rules).
- The forward-backward algorithm (no need to memorize the α- and β definitions), the Viterbi algorithm for finding the max probability sequence of hidden states (no need to memorize the recurrence), and can understand how to work with α and β values for inference.

5.3 Items out of scope

- Kalman filters

6 Markov Decision Processes

6.1 Items to know

- Know the form of the MDP model, how to model problems via MDPs, understand the typical kinds of applications of MDPs
- Finite horizon planning: understand the planning objective, the MDP value function, policy evaluation, and the use of value iteration for planning. No need to memorize formulas.
- Infinite horizon: understand the planning objective, the MDP value function, policy evaluation, Bellman equations, value iteration (VI), policy iteration (PI) including policy evaluation, and how VI and PI compare. No need to memorize formulas.

6.2 Things to be able to work through when given information/equations

- How to apply policy iteration, policy evaluation, or value iteration to a specific toy problem, given the update formulas
- Computational complexity of different update steps

6.3 Items out of scope

- Specifics of any particular gridworld model or other MDP model
- Expectimax algorithm

7 Reinforcement Learning

7.1 Items to know

- Understand typical applications, the difference between RL and planning, and the idea of exploration vs exploitation
- Understand the difference between model-based and model-free learning
- Understand the Q-function, the alternate form of Bellman equations using the Q-function

- Understand the structure of a temporal-difference reinforcement learning algorithm, the use of epsilon-greedy, and the difference between SARSA and Q-learning. No need to memorize formulas.
- The idea of policy learning

7.2 Things to be able to work through when given information/equations

- How to apply the update rule for SARSA or Q-learning to a specific toy problem

7.3 Items out of scope

- Deep Q-learning
- Stochastic gradient descent view on temporal difference learning
- The idea of handling large state (or action) spaces via basis functions