

430.457
Introduction to Intelligent Systems

Midterm

Prof. Songhwai Oh

Fall 2024

Student Name:

Student ID:

1	/ 20
2	/ 40
3	/ 40
Total	/ 100

IMPORTANT:

- Read all problems carefully and start with easier ones.
- You need to show all your steps for full credit.

Problem 1: Short Answers [20 pts]

- (a) Compare hidden Markov models, Kalman filtering, and dynamic Bayesian networks. [6pt]
- (b) Discuss at least two benefits of Bayesian networks. [4pt]
- (c) Consider a hidden Markov model. Derive a recursive equation for computing the probabilities to the most likely path:

$$\mathbf{m}_{1:t} = \max_{\mathbf{x}_1, \dots, \mathbf{x}_{t-1}} P(\mathbf{x}_1, \dots, \mathbf{x}_{t-1}, \mathbf{X}_t | \mathbf{e}_{1:t}),$$

where $\mathbf{X}_t$ is the state at time t and $\mathbf{e}_t$ is the measurement at time t . [6pt]

- (d) Describe a Monte Carlo method and discuss when it can be used. [4pt]

(blank page)

Problem 2: [40 pts]

You are hired by Tesla, Inc. to design the Optimus Gen 3, a robot that can talk in a different speech style and make a different gesture based on the user's mood. A user's mood determines her voice and facial expression. The robot talks in a different speech style based on the voice and facial expression of the user and makes a different gesture based on the user's facial expression. The voice of the user is perceived by processing sound using a microphone and the facial expression is obtained by performing a facial expression recognition algorithm on captured images of the user. For this problem consider the following random variables: M (user's mood), V (user's voice), F (user's facial expression), S (robot's speech style), and G (robot's gesture).

- (a) Draw a Bayesian network for this problem.
- (b) Write down the joint distribution of all variables.
- (c) Since the voice and facial expression of the user are determined by recognition algorithms from sensed data, it seems the user's mood does not play a role in determining the robot's speech style and gesture. Explain benefits of having a node about the user's mood.
- (d) Give an example of generating an event from the Bayesian network using direct sampling.
- (e) Explain why the samples from direct sampling can give a consistent estimate.
- (f) Suppose that we want to estimate the mood of the user by observing the robot's speech style and gesture using Gibbs sampling. Provide one round of Gibbs sampling for this Bayesian network.

(blank page)

(blank page)

Problem 3: [40 pts]

After successfully completing your work on the Optimus Gen 3 at Tesla, Inc., you have joined SpaceX for Mars exploration. Before humans can explore Mars, you have decided to deploy the Optimus Gen 4 robot for cleaning the base camp set up in Mars. To your surprise, the mood of the robot changes daily and it operates probabilistically based on its mood. You suspect that the robot has two emotional moods (happy and unhappy) and its mood is happy with higher probability if the previous day's mood was also happy. The robot cleans the base with high probability if it is in a happy mode and it cleaned the base the previous day. You can only observe a part of the base from a distant satellite orbiting Mars once a day.

Based on daily reports, you want to infer the robot's mood and whether the base has been cleaned or not. For this problem consider the following three random variables: R_t (*true* if a satellite reports a cleaned base part on day t), C_t (*true* if the robot cleans the base on day t), and M_t (the mood of the robot on day t).

- (a) Draw a dynamic Bayesian network for this problem (unrolled in time, from $t = 0$ to $t = 3$).
- (b) Write down the joint distribution of all variables (from $t = 0$ to $t = T$).
- (c) Derive a filtering algorithm for estimating C_t and M_t given $R_{1:t}$.
- (d) Derive a smoothing algorithm for estimating C_k and M_k given $R_{1:t}$, for $1 \leq k \leq t$.

(blank page)

(blank page)