Habib University

CS 452 – Probabilistic Graphical Models

Fall' 2024

Assignment 1 – Modeling and Reasoning with Bayesian Networks

Total Points: 50

Objective:

This assignment is designed to assess students' understanding of the fundamentals of Bayesian network modeling and reasoning. It highlights key concepts such as conditional independence and the Markov property. Through this assignment, students will gain insight into how Bayesian networks model real-world uncertainties and how they are used for reasoning and making inferences.

Q 1 – **[08 Points] Playing with Joint Probabilities:** Given the Bayesian Network below:

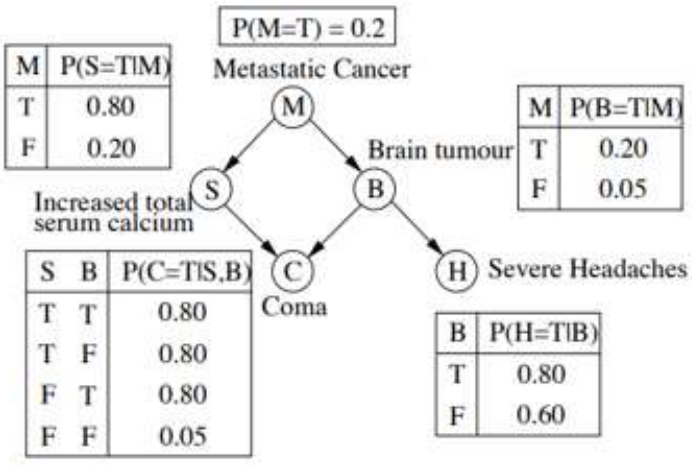

Figure 1- Metastatic Cancer BN

a- Generate complete joint problem distribution table for the variables modelled in this Bayesian networks. Compute their joint probabilities using the Conditional Probability Table (CPT) given above.

b- Compute Marginal Probabilities of all variables.

c- Given a person has 'severe headache' and his serum calcium is not increased as per the tests, what are the chances now that the person will have

   a. Metastatic Cancer
   b. Brain Tumor

   You have to compute these posterior probabilities form the joint probability table.

d- Prove, from JPT, that C $\perp$H |B.

**Note: You have to show your working along with all the formulas that you have used. You can do this working on paper by hand OR in excel.*

Q2 – **[12 points] Applying Markov Property and Conditional Independence** - This question refers to the graphical models shown in Figure 2, which encode a set of independencies among the following variables: Season (S), Flu (F), Dehydration (D), Chills (C), Headache (H), Nausea (N), Dizziness (Z).

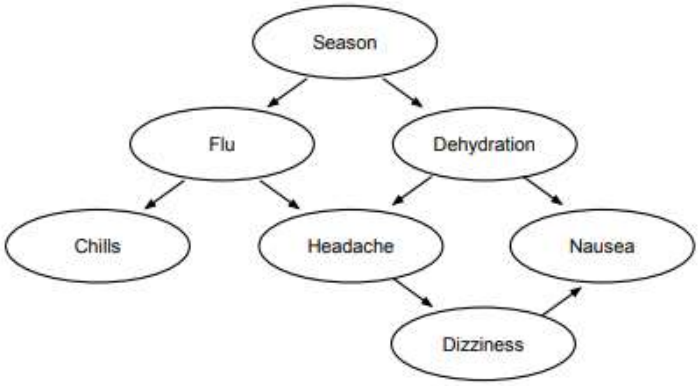

Figure 2- Seasonal Flu BN

Indicate whether the following independence statements are true or false according to this model. Provide a very brief justification of your answer (no more than 1 sentence).

a) Season ⊥ Chills
b) Season ⊥ Chills | Flu
c) Season ⊥ Headache | Flu
d) Season ⊥ Headache | Flu, Dehydration
e) Season ⊥ Nausea | Dehydration
f) Season ⊥ Nausea | Dehydration, Headache
g) Flu ⊥ Dehydration
h) Flu ⊥ Dehydration | Season, Headache
i) Flu ⊥ Dehydration | Season
j) Flu ⊥ Dehydration | Season, Nausea
k) Chills ⊥ Nausea
l) Chills ⊥ Nausea | Headache

Q3 – [10 Points] Bayesian Networks in action - At Habib University, there is concern over a possible unauthorized access incident in the university's restricted server room. The investigation centers around several key factors: the occurrence of unauthorized access (U), signs of a forced entry into the server room (F), activation of the security alarm system (A), detection of movement by campus security cameras (C), and the completion of routine security checks by campus personnel (S). The server room door was found damaged, suggesting a potential forced entry. Around 2:00 AM, the security alarm was activated, but there was a noticeable delay in response, which could indicate a malfunction. At the same time, security cameras recorded unusual

movement in the server room area. Additionally, the security personnel log showed an unexplained absence during the critical period when the cameras detected activity. This scenario presents a complex situation involving potential breaches and lapses in security measures, making it an ideal example for applying Bayesian networks to evaluate the likelihood of unauthorized access based on observed evidence and security system status.

a) Construct in GeNIE a Bayesian Network to model this scenario.
b) Specify prior and conditional probabilities as per your understanding of the domain.
c) Compute given probabilities from your model:
    i. If the motion sensors detected movement, what is the probability that the lab door was forced open?
    ii. What is the probability that the security guard was not alert if an unauthorized access occurred and the door was found forced open?
    iii. What is the probability that the alarm was triggered if no forced entry was detected but motion was observed?
d) Give some examples of predictive, diagnostic and explaining-away reasoning that you can perform in this scenario.

**Note: Please mention any assumptions that you may have taken regarding this scenario. Your assumptions must not contradict with the actual scenario.*

Q 4 – [20 points] Bayesian Networks in the real-world - Come up with a real and contextualized problem involving reasoning with evidence and uncertainty.

a) Write down a text description of the problem. Make the problem sufficiently complex that your network has at least 8 nodes and is multiply-connected (i.e., not a tree or a polytree).
b) Model the problem using a Bayesian network. User GeNIE to construct the Bayesian network.
c) Specify meaningful probabilities for all nodes.
d) Show the beliefs for each node in the network before any evidence is added.
e) Which nodes are d-separated with no evidence added?
f) Show how the beliefs change in a form of “diagnostic reasoning” when evidence about at least one of the domain variables is added. Which nodes are d-separated with this evidence added?
g) Show how the beliefs change in a form of “predictive reasoning” when evidence about at least one of the domain variables is added. Which nodes are d-separated with this evidence added?
h) Show how the beliefs change through “explaining away” when particular combinations of evidence are added.
i) Show how the beliefs change when you change the priors for a root node (rather than adding evidence).

The assessments will be based on how thoughtful and relevant your scenario is, as well as how accurately you model it with a clear and intuitive set of probabilities. You are highly encouraged to build models for the scenarios that are non-trivial and represent novel applications of Bayesian networks.

Submission Instructions:

The assignment should be submitted as a zip file that includes a PDF, excel file (if any) and GeNIe models (XDSL files) for Questions 3 and 4. The PDF should contain your answers to all the questions, along with images of the relevant Bayesian models as needed.