CS 6601 Midterm – Spring 2022

Please read the following instructions thoroughly.

Fill out this PDF form and submit it on **Gradescope and Canvas**. **You may be penalized points on this exam if you don't submit on both platforms.**

You have unlimited resubmissions until the deadline. You can: **(a)** type directly into the form – we highly recommend using Adobe Reader DC. If you are on MacOS, please do not use Preview, as we have seen **major** issues with it in the past. Other programs may not save your answers, so **please keep a backup**; **(b)** print, hand-write & scan. You can combine the methods as well.

Submit only a single PDF – Make sure your filled in answers appear clearly in the Gradescope Preview. Do not add pages unless absolutely necessary; if you do, please add them at the end of the exam **only**, and clearly label **both** the extra page and the original question page. Submit **ALL** pages of the exam, not only the completed ones.

Do not forget to fill the checklist at the end before turning in the exam. The exam may not be graded if it is left blank.

The exam is open-book, open-note, open video lectures, with no time limit aside from the open period. No internet use is allowed, except for e-text versions of the textbook, this semester's CS6601 course materials, Ed, and any links provided in the PDF itself. No resources outside this semester's 6601 class should be used. Do not discuss the exam on Ed, Slack, or any other form of communication. More generally, do not post **publicly** about the exam. If there is a question for the teaching staff, **please make it private on Ed and tag it as Midterm Exam with the question number in the subject line** (for example, a question on Search would be "Midterm Exam #2"). Please make **different posts for different questions.**

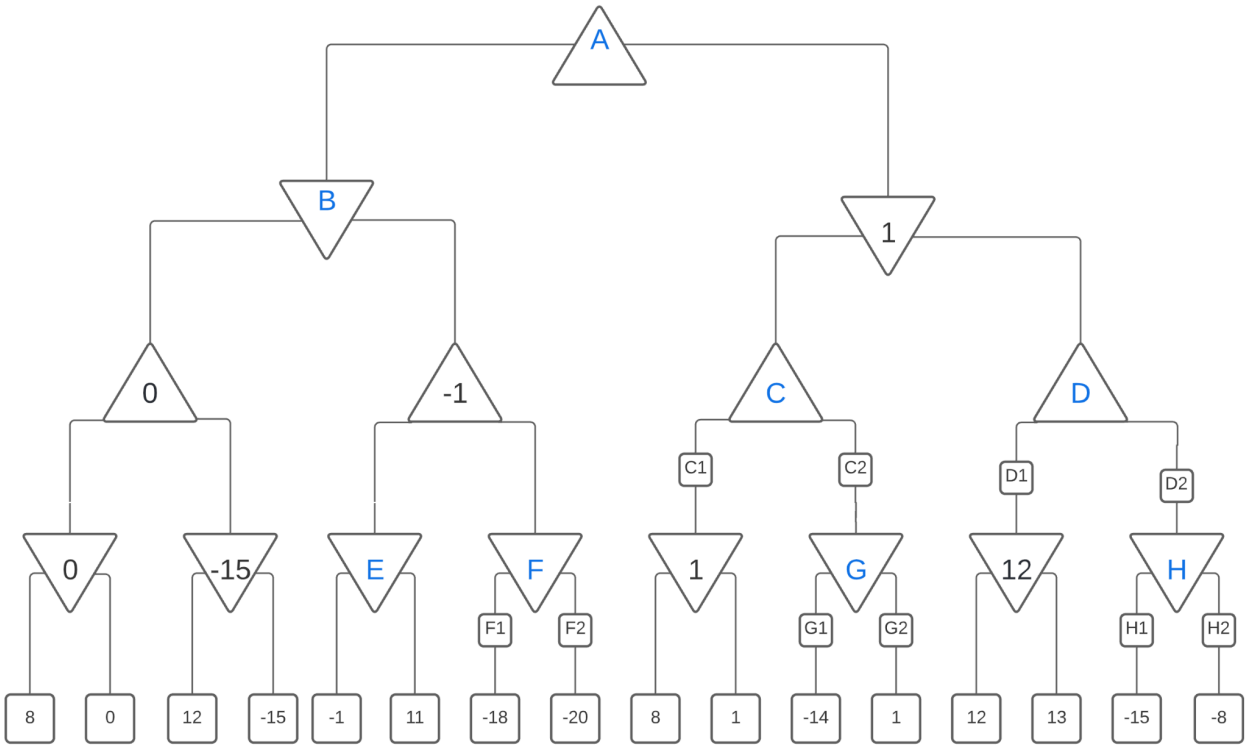
Please round all your final answers to 6 decimal places, don't round intermediate results. You can use `round(your_number, 6)` function in Python for help.
You may not receive full credit if your answers are not given to the specified precision.

Point breakdown (Each question has sub-parts with varying points):

	Q1	Q2	Q3	Q4	Q5	Q6	Total
Pts	**16**	**12**	**18**	**16**	**20**	**18**	**100**

1. Game Playing

(16 Points)



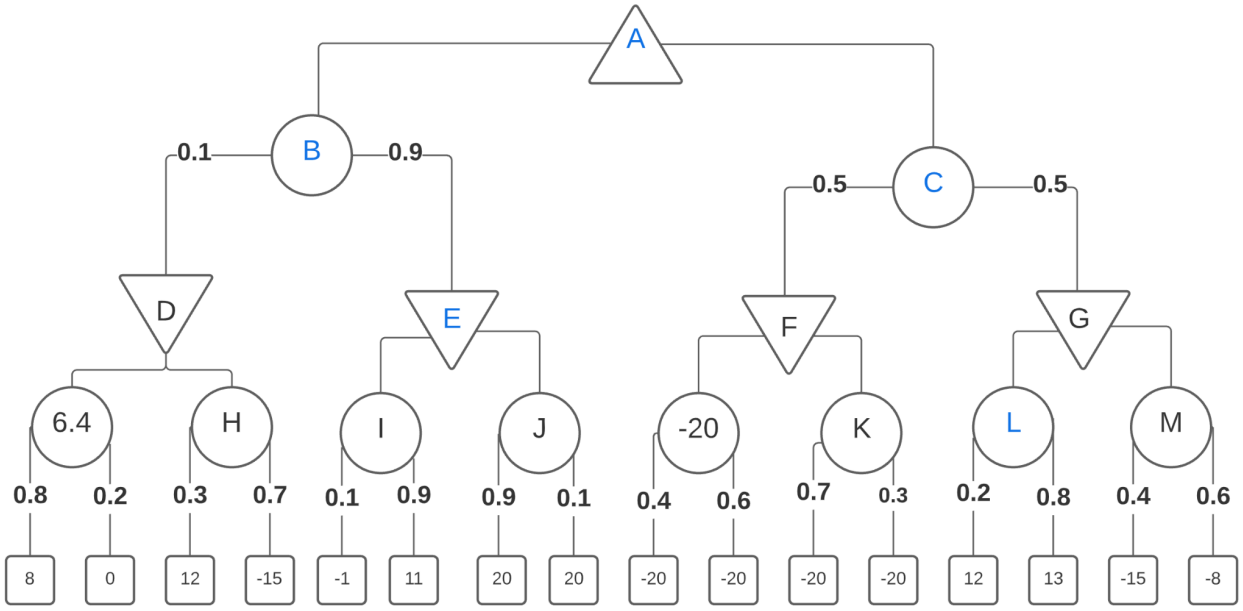
1.1 Consider the minimax game tree given above. Fill in the tree by propagating the values from the bottom level upwards. Write down the value for each node **(3 points)**.

Node A: 1
Node B: -1
Node C: 1
Node D: 12
Node E: -1
Node F: -20
Node G: -14
Node H: -15

1.2 Suppose you want to save time via alpha-beta pruning from left to right. Indicate which of the following branches are going to be pruned. If a branch is pruned, all the sub-branches should also be marked as pruned. For example, if you think branch D2 is going to be pruned, you should mark D2, H1, and H2 as pruned **(5 points)**.

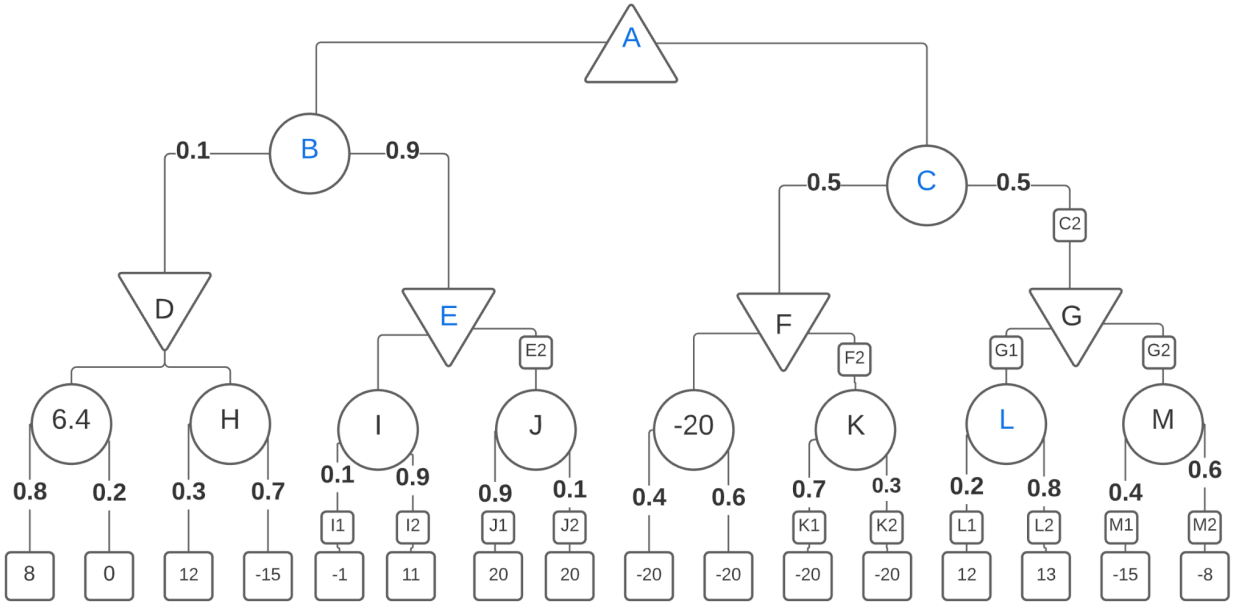
- ☐ F1
- ☐ F2
- ☐ C1
- ☐ C2
- ☐ G1
- ☐ G2
- ☐ D1
- ☑ D2
- ☑ H1
- ☑ H2

1.3 Now suppose you are playing a game that is not deterministic. Fill in the values for the following nodes in the expectimax game tree below **(3 points)**.



Node A: 8.13
Node B: 8.13
Node C: -15.4
Node E: 9.8
Node L: 12.8

1.4 Suppose you want to do alpha-beta pruning on the expectimax tree (going from left to right). Indicate which of the following branches are going to be pruned. If a branch is pruned, all the sub-branches should also be marked as pruned. You may assume that the values are in the range [-20, 20] **(5 points)**.



- ☐ E2
- ☐ I1
- ☐ I2
- ☐ J1
- ☐ J2
- ☑ F2
- ☑ K1
- ☑ K2
- ☐ C2
- ☐ G1
- ☐ G2
- ☐ L1
- ☐ L2
- ☐ M1
- ☐ M2

2. Search

(12 Points)

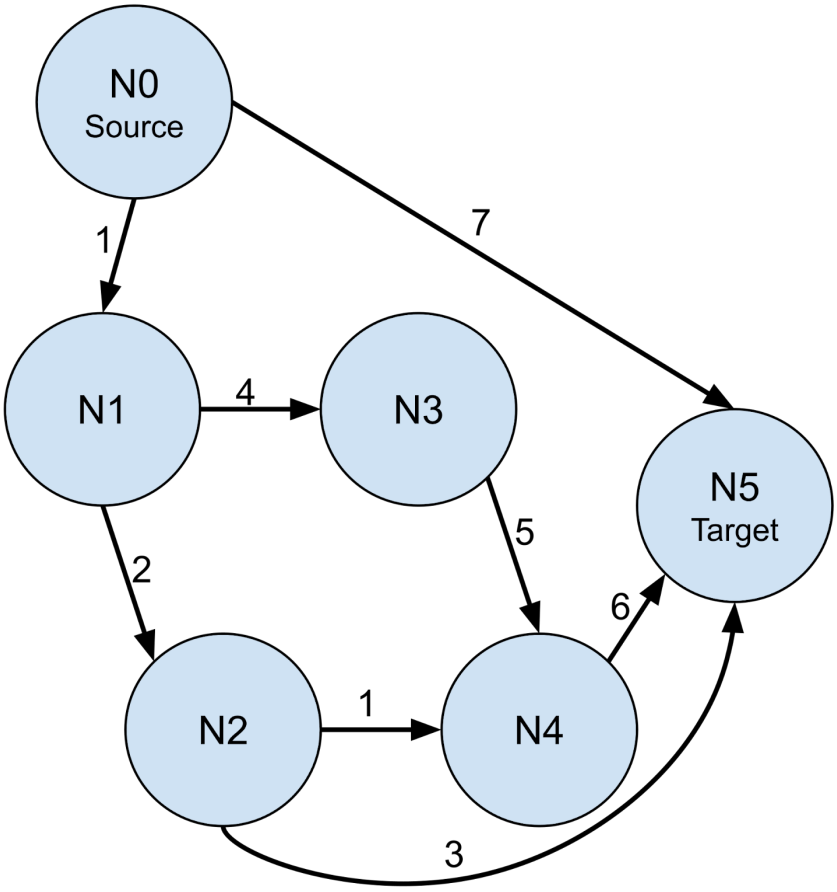


Figure 1

Consider the graph above (Fig:1). We are interested in searching for a path from the ‘source’ node (N0) to the ‘target’ node (N5). The edges in the graph are directed, which means you can only move along the direction of an edge. Edge weights can only take real positive values. While executing the search algorithm(s) in question 1, break any ties in ascending order of the node numbering provided (for example if choosing between N1 and N2, choose N1 because 1 goes before 2). Note that we always start the search from the source node (N0).

2.1 We want to modify the edge weight of edge (**N0-N5**) such that **A* graph search (**using a consistent heuristic and admissible heuristic**)** and **BFS** would return the same source to the target path. What is the longest permissible interval of edge weight for edge N0-N5? Note: An *open interval* excludes its endpoints and is indicated with parentheses. For example, (0, 1) describes an interval greater than 0 and less than 1. A *closed interval* includes its endpoints and is denoted with square brackets. For example, [0, 1] describes an interval greater than or equal to 0 and less than or equal to 1. **(5 points)**

- ○ (0, 2)
- ○ (0, 2]
- ○ (0, 3)
- ○ (2, 3)
- ◉ (0, 6)
- ○ A* and BFS cannot have the same path

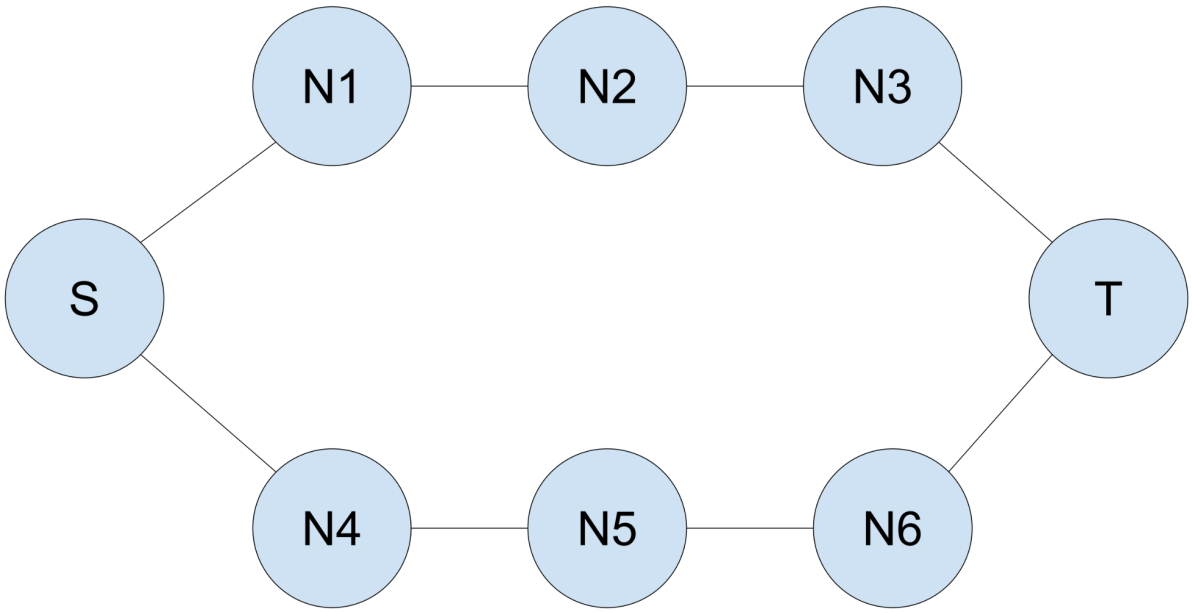


Figure 2

2.2 Consider the graph above (Fig:2). All the edge weights in the above graph are **10**. We are interested in designing a heuristic h for the graph. Node S represents the source node and node T represents the target node (goal node). It is given that h(N6) = 7, but we are given no other information. What is the longest permissible interval for values of h(N4) if h must be admissible and consistent? You may assume that h is nonnegative. **(5 points)**

- ○ [0, 27]
- ○ [0, 7]
- ○ [0, 14]
- ○ [7, 27]
- ◉ [7, 14]

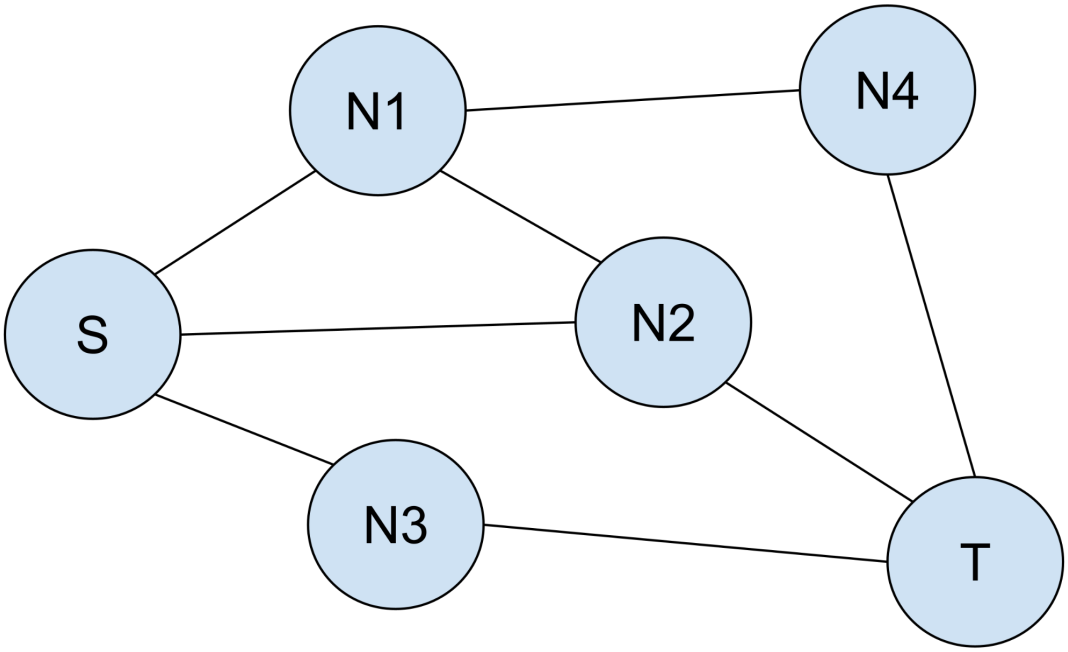


Figure 3

2.3 Consider the graph above (Fig:3). All the edge weights in the above graph are **1.** Node S represents the source node and node T represents the target node. Using DFS, mark which, if any, of the listed paths (from source to target) the algorithm could return. Make sure to mark all paths that could be returned under any tie-breaking scheme or different policies of which child to expand. Note that the DFS being referred to here is the graph-search version, which avoids repeated states and redundant paths. DFS terminates when it finds the target node T. **(2 points)**

- ☐ S-N1-T
- ☑ S-N2-T
- ☑ S-N3-T
- ☐ S-N2-N1-N4-T
- ☐ S-N1-N4-T
- ☐ S-N1-N3-T

3. Optimization Algorithms

(18 Points)

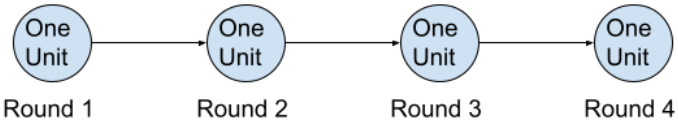
Part A

In this problem, we simulate a battle game type called “Clan Battle”, where units of one’s choice act at certain time frames to fight against a monster, and rewards are distributed based on the amount of damage dealt.

The clan battle in our game consists of **four** rounds. In each round, exactly one unit is chosen from a pool to act in that round. The damage dealt in all the rounds are summed up in order to decide the ranking of the player.

A unit has attack power (*ATK*) and a unique ability. A wise arrangement of the units would deal great damage to the monster, earning you a good rank and bringing precious resources that are critical for building even stronger units.

As a player in the Clan Battle, your task is to assign exactly one unit to each round in order to deal as much damage as possible. Considering the limited computing resources you have, you have decided to go through one iteration of Genetic Algorithm by hand to find an arrangement.



There are several terms and mechanisms that need to be defined:

1. Defense power (*DEF*): The defense power owned by the monster.

2. Attack power (*ATK*): The attacking power of a unit.

3. Broken Defense (*BD*): The amount of broken defense of the monster.

4. Calculation of damage: The damage dealt to the monster in a single round will be

$$ATK \ * \ \frac{100}{(DEF - BD) + 100}$$

   Depending on the *DEF* of the monster and the *ATK* of the unit for that round.
   Note: *BD* is capped to be smaller than or equal to *DEF,* i.e. (*DEF* - *BD*) ≥ 0

The monster has the following stats:

Monster: *DEF*: 100 *BD*: 0

The 6 units could each be put into 1 of the 3 general categories: Attacker, Defense Breaker, and Special Unit. Their stats and abilities are shown below:

Attacker:

Unit 1: *ATK*: 900

Abilities: None

Unit 2: *ATK*: 600

Abilities:
Pre-attack: Boost *BD* by 50 **percent** for the current round

Unit 3: *ATK*: 700

Abilities:
Pre-attack: Boost own ATK to 1200 if two distinct Defense Breakers acted before the current round

Defense Breaker:

Unit 4: *ATK*: 400

Abilities:
Post-attack: Temporarily increases the *BD* of the monster by 50 for the next round. The effect ends after the attack is made in the next round.

Unit 5: *ATK*: 400

Abilities:
Pre-attack: Temporarily increase the *BD* of the monster by 30 for the current round and the next round. The effect ends after the attack is made in the next round.

Special Unit:

Unit 6: *ATK*: 1200

Abilities:
Post-attack: Fix the *DEF* of the monster to 150 and *BD* to 0 for the following rounds. **This ability has the highest priority over others.**

Example individual:

{3, 2, 4, 2}	Allocating Units 3, 2, 4, 2 to rounds 1, 2, 3, 4 respectively

With an initial population of

Individual 1: {1, 5, 2, 6}

Individual 2: {1, 2, 4, 3}

Individual 3: {4, 3, 6, 3}

Individual 4: {2, 4, 2, 4}

The fitness function is defined to be the final damage dealt to the monster after 4 rounds. You should round the results of the fitness function to 2 decimal places. When the fitness scores are equal, use any order to break the tie.

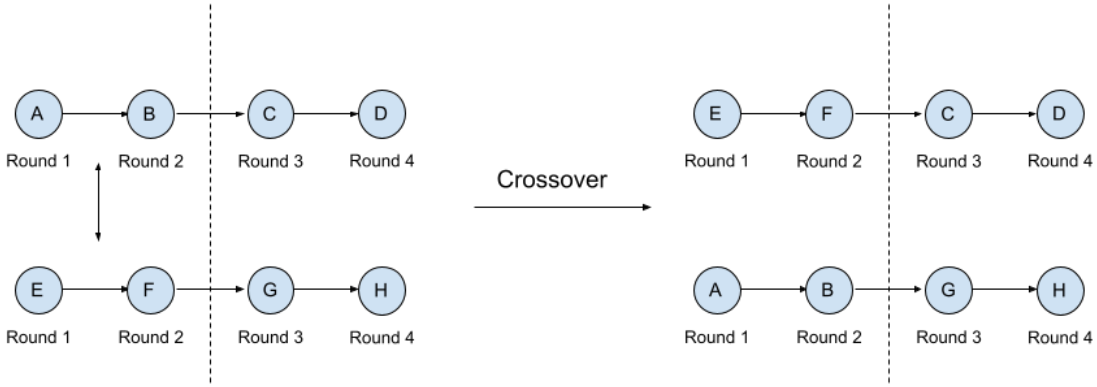
Selection

3.A.1 Rank the initial population in descending order of the fitness scores and put the results in the table below. **(4 points)**

Rank	Individual	Fitness Score
1	{1, 5, 2, 6}	1672.39
2	{4, 3, 6, 3}	1546.67
3	{1, 2, 4, 3}	1416.67
4	{2, 4, 2, 4}	1180

Crossover

3.A.2 The crossover point is set to be the middle of the four rounds. Perform the crossover procedure on the pair of individuals with ranks 1 and 2, then on the pair of individuals with ranks 3 and 4. Sort the results in descending order of fitness scores. Put the generated individuals in the table below. **(4 points)**



Rank	Individual	Fitness Score
1	{1, 5, 6, 3}	1671.18
2	{4, 3, 2, 6}	1566.67
3	{1, 2, 2, 4}	1250
4	{2, 4, 4, 3}	1233.33

Mutation

Mutations should happen on a probabilistic basis. For the simplicity of this question, the mutations and their positions are given.

3.A.3 The notation [A, B] would indicate a mutation to unit A in round B. Please keep the relative positions of the individuals in the crossover table, apply the mutation and fill the new fitness scores in the table below. **(4 points)**

Rank In Crossover	Mutation Array	(Mutated) Individual	Fitness Score
1	[6, 1]	{6, 5, 6, 3}	1400
2	None	{4, 3, 2, 6}	1566.67
3	None	{1, 2, 2, 4}	1250
4	[2, 3]	{2, 4, 2, 3}	1330

Part B

3.B.1 For a search problem with many local optima, which of the following algorithms would most probably give the best performance in general, assuming *k* is greater than 1? **(3 points)**

- ○ *k* parallel Hill Climbing with random restart
- ◉ Beam Search with *k* states

3.B.2 What are the possible optimizations that could be made to the Genetic Algorithm, in case there will be many local optima? Check all that apply. **(3 points)**

- ☑ Selection of more diverse initial population
- ☐ Make the individuals more consistent by reducing the chance of mutation
- ☑ Run parallel Genetic Algorithms with different settings of crossover points
- ☐ None of the above

4. Constraint Satisfaction

(16 Points)

NBIDIA is planning to launch their latest Ray tracing GPU, the 3090Ti. To handle distribution, they have contracted the work to CS6601 students.

There are a total of 5 trucks – T1, T2, T3, T4, T5, responsible for supplying the GPUs to the stores. The infrastructure has only 2 parking docks (L1, L2). Dock L2 can service only small trucks while Dock L1 can service long trucks as well. Therefore, at any point of time, the infrastructure can host a maximum of 2 trucks.

The trucks are serviceable at only 4 specific time slots – S1, S2, S3, S4 for each parking dock.

Constraints:

1) Truck T2 can only come in during time slot S1.

2) The latest slot truck T1 is allowed to use is slot S2.

3) Truck T4 has to arrive before Truck T3.

4) The earliest Truck T4 can arrive is slot S3

5) It is not possible for trucks to use the same parking dock at any given time.

6) T1, T2, T3 are long trucks and are only serviceable in parking dock L1

7) Trucks T4, T5 can utilize any of the Parking docks.

8) Truck T5 must come as early as possible.

9) Trucks T4 and T5 always use the same parking dock.

10) Truck T3 must come in as early as possible.

Questions:

4.1 Which of the following are variables in the given CSP? Mark all that apply. **(3 points)**

- ☑ S1
- ☑ L2
- ☑ T3
- ☑ S2

4.2 Let the domain of the variables be tuples of the form **(Time Slot, Parking Dock).** For the given CSP, mark all that apply. **(3 points)**

Note: T2[0] refers to the time slot of T2. T2[1] refers to the parking dock of T2.

- [x] T4[0] < T3[0]
- [x] T1[0] <= S2
- [ ] T4[1] = T3[1]
- [ ] T4 = T5

4.3 Complete the adjacency matrix for the constraint graph. **(5 points)**

Note: Assign '1' for a link between corresponding Truck nodes. Else, assign 0.

An example of an adjacency matrix is shown in the below figure. As can be seen from the graph, Node 0 is connected to node 1 and 4. In the matrix, Row 0 has 1s for 1 and 4 respectively and so on.

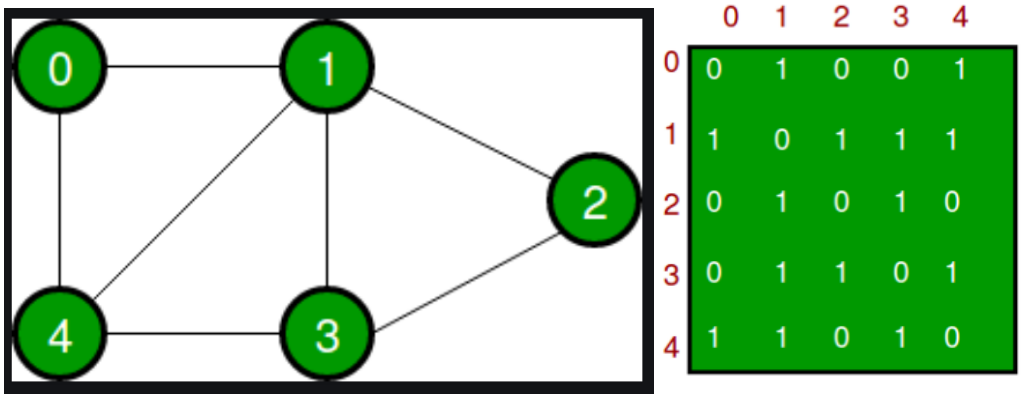


Figure: Example adjacency matrix

	T1	T2	T3	T4	T5
T1	0	1	1	0	0
T2	1	0	1	0	0
T3	1	1	0	1	0
T4	0	0	1	0	1
T5	0	0	0	1	0

4.4 What is the time slot and parking dock each truck needs to use? **(5 points)**

Truck ID	Time Slot ID	Parking Dock
T1	S2	L1
T2	S1	L1
T3	S4	L1
T4	S3	L2
T5	S1	L2

5. Probability

(20 Points)

After getting accepted into the Ph.D. program, it is the 25th of August, your 1st day working as a researcher in Thad's lab (Hurray!). To celebrate the occasion, Thad takes you out to lunch, where he talks about the thrill and the agony when it comes to publishing research works. Sometimes, no matter how good your manuscript is, the review process of some big conferences can get frustrating! To avoid the most common pitfalls, he also shares some of his tricks to improve the chances of a manuscript getting accepted! To end on a high note, Thad decides to motivate you by playing the following game:

5.1 There are two conferences, AAAI and KDD, where he likes to submit his research works. Both these conferences have the following three paper submission deadlines -- the 30th of December, 1st of March (next year), and 15th of May (next year). AAAI follows a much more involved review process than KDD. Hence, the probability of a paper getting accepted into AAAI is much smaller than in KDD. You are planning to submit your works on all three dates. However, due to conference guidelines, you are not allowed to make a submission two times in a row at the same conference i.e. you have to decide between the submission sequences AAAI-KDD-AAAI and KDD-AAAI-KDD. If you are able to get your papers accepted at least two times in a row, Thad is going to gift you a 1000$ coupon. To maximize your chances of winning this prize, which submission sequence would you follow? **(1 point)**

KDD-AAAI-KDD

To explain the logic behind your choice, for the following questions fill in the blanks by choosing the correct option **(3 points)**

5.2 Let "a" be the probability that the paper gets accepted at AAAI. Let "b" be the probability that the paper gets accepted at KDD. Clearly, ___

- ○ a > b
- ○ a = b
- ◉ a < b

5.3 Now, given the submission sequence AAAI-KDD-AAAI there are ___ ways in which your papers can get accepted at least 2 times in a row and given the submission sequence KDD-AAAI-KDD, there are ___ ways in which your papers can get accepted at least 2 times in a row.

- (●) 2, 2
- ( ) 3, 3
- ( ) 4, 4

5.4 In the case of AAAI-KDD-AAAI, the total probability (P1) that your papers get accepted at least two times in a row (in terms of “a” and “b”) is ___

- ( ) ab(2-b)
- (●) ab(1-b)
- ( ) ab(1-a)
- ( ) ab(2-a)

5.5 In the case of KDD-AAAI-KDD, the total probability (P2) that your papers get accepted at least two times in a row (in terms of “a” and “b”) is ___

- ( ) ab(2-b)
- ( ) ab(1-b)
- (●) ab(1-a)
- ( ) ab(2-a)

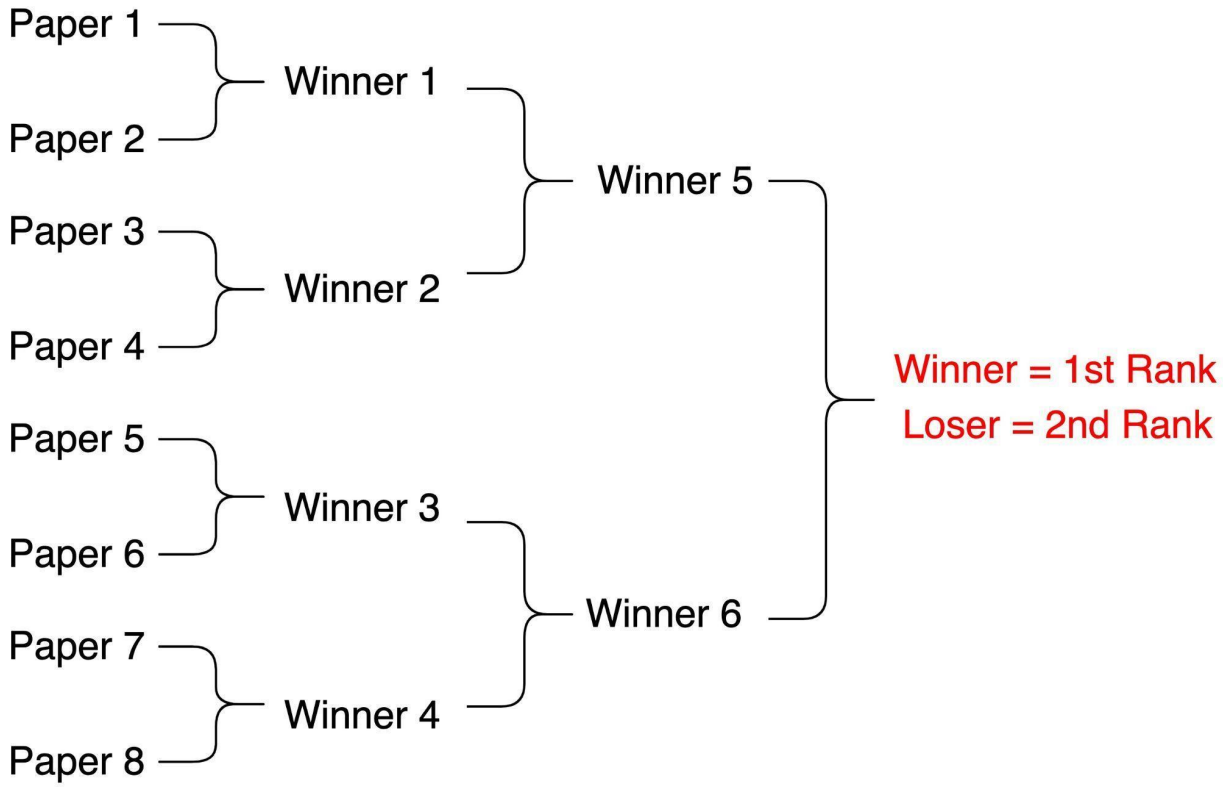
By working hard on your research and following Thad’s tricks to improve the quality of your papers, you manage to win the 1000$ prize. Well done! Now, equipped with the experience in publishing at top conferences, you decide to take things to the next level. In your weekly meeting with Thad, you express your desire to keep submitting the papers to only the topmost conference in your domain, which is CVPR. Thad is extremely happy to hear about your goal and decides to motivate you by playing yet another game with you:

5.6 CVPR has a unique way of dealing with its submissions. A paper submission made to CVPR can result in one of the four outcomes: (1) accepted as a full-length paper with a probability of 0.05, (2) accepted as a workshop paper with a probability of 0.15, (3) accepted as a poster with a probability of 0.2, (4) rejected for publication in any of the formats. Thad is willing to give you rewards based on these outcomes. The reward for a full-length paper, workshop paper, and poster is 1000$, 750$, and 500$ respectively. You can only submit one paper at one time. Meanwhile, you can keep submitting as many (infinite) times as you want, and collect the rewards in case your paper gets accepted in any format! However, in the case one of your papers gets rejected, the game ends there with no future additional reward. Each paper that gets accepted can only be accepted once and only in one category (full-length, workshop, or poster). Let "X" be the random variable representing the amount that you win from this game. What is the value of E[X]? **(6 points)**

87.5

Suppose you make two submissions to CVPR, and after its review process, you get a notification that both your papers are accepted! You immediately decide to share this good news with Thad. To your surprise, he has more good news-- He has received an email from the conference chair stating that out of the 4096 submissions in total, the two papers submitted by you ranks 1st and 2nd among the submissions! Clearly, no other papers have made contributions as substantial as your two papers.

Now, CVPR has announced two "Best Paper Awards" this time for the 1st and the 2nd ranked papers. The papers would be ranked by following a single-elimination tournament. As an example, a single-elimination tournament between 8 papers is shown below:



Note that when a stronger paper is matched against a weaker paper, the weaker paper gets eliminated each time. Papers are randomly matched against each other at the beginning.

5.7 What is the probability that you will receive both the "Best Paper Awards"? **(2 points)**

0.012207 %

5.8 What is the probability that you will receive only one "Best Paper Award"? **(1 point)**

0.024414 %

5.9 What is the probability that you will receive none of the two "Best Paper Awards"? **(1 point)**

99.975586 %

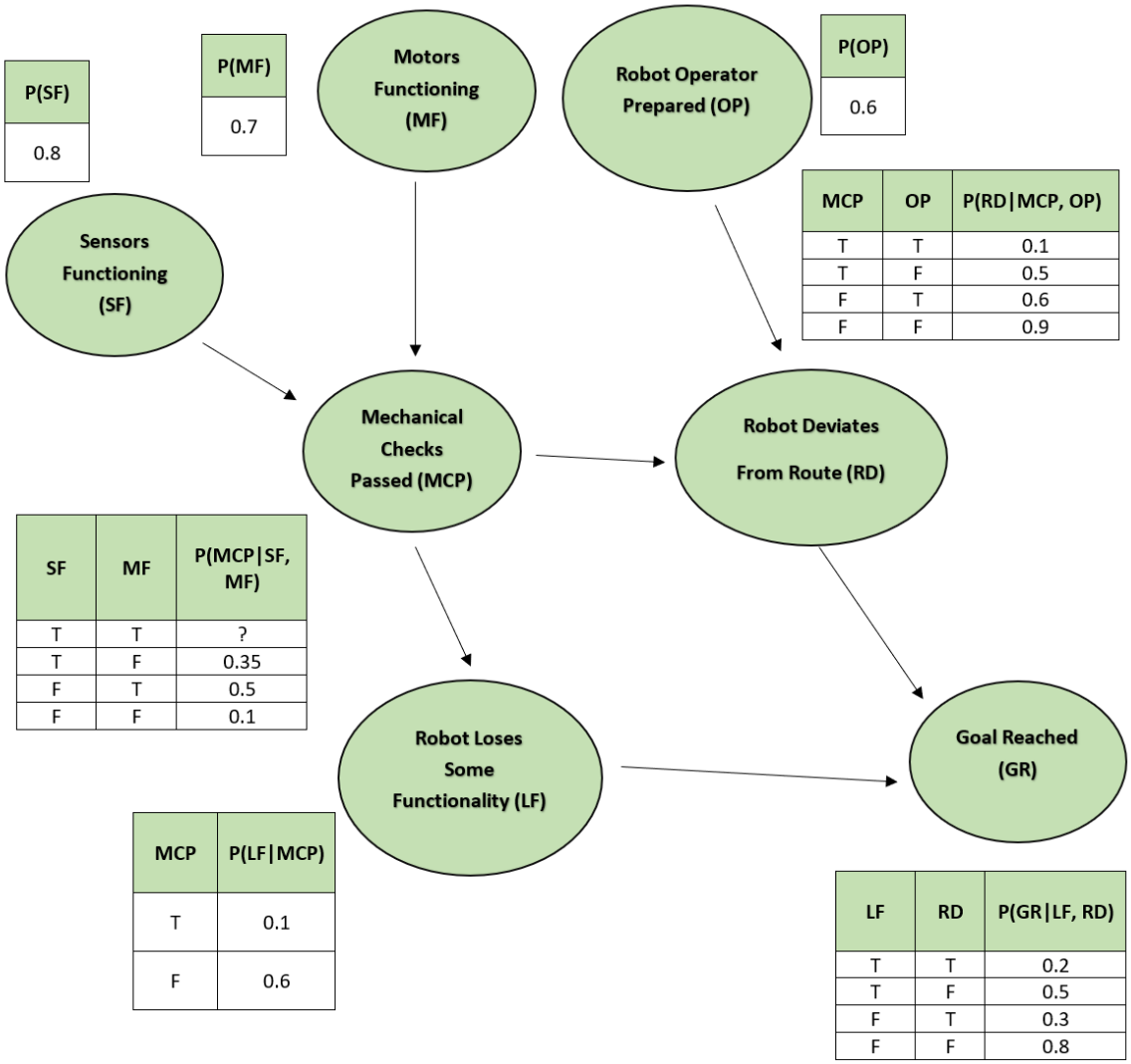
5.10 Your work from CVPR that received the "Best Paper Award" is a big hit in the research community and everyone is amazed by it. The conference administration staff is expecting this paper to receive at least one citation in three days with a probability of 0.992! What is the probability that this paper receives at least one citation in one day? Assume that probability of receiving a citation in a time interval T1 of length k is the same as well as independent of receiving a citation in the time interval T2 of length k, where T1 and T2 do not overlap. **(6 points)**

33.06667 %

6. Bayes Nets

(18 Points)

You and your team must deploy your newly developed robot for an annual competition with hopes of navigating to a certain goal position. You know that the robot will be checked for mechanical failures and is more likely to pass if both the motors and sensors are functioning correctly. You also know that the robot may deviate from the route you have planned for it, influenced by whether mechanical checks were passed and whether the robot's operator is prepared for the task. The robot is also more likely to lose some functionality along the way if the mechanical checks were not passed. Whether the robot reaches the goal is influenced by both whether it deviates from its route and whether it loses functionality during its journey. This information can be seen in the following Bayes Net representation. Some values in the mechanical checks passed (MCP) table are omitted intentionally.



P(SF)
0.8

P(MF)
0.7

P(OP)
0.6

MCP	OP	P(RD|MCP, OP)
T	T	0.1
T	F	0.5
F	T	0.6
F	F	0.9

SF	MF	P(MCP|SF, MF)
T	T	?
T	F	0.35
F	T	0.5
F	F	0.1

MCP	P(LF|MCP)
T	0.1
F	0.6

LF	RD	P(GR|LF, RD)
T	T	0.2
T	F	0.5
F	T	0.3
F	F	0.8

Using the Bayes Net and probability tables given, calculate the following probabilities. Please follow the exam rounding guidelines.

6.1 What is the probability that the robot reaches the goal given that mechanical checks are passed and the operator is prepared, P(GR|MCP, OP)? (**5 points)**

0.54

You are told that the probability of the robot deviating from the route is 31.584% given the operator is prepared, P(RD|OP) = 0.31584.

6.2 What is the probability of passing mechanical checks given both the sensors and motors are functioning, P(MCP|SF,MF)? **(9 points)**

0.825

6.3 Which of the following are true? Mark all that apply. (Independence is represented as in the format in this example: A ⊥ B | C means that A is independent of B given C). **(4 points)**

☑ GR ⊥ SF | MCP

☐ SF is in the Markov Blanket of MF.

☑ P(LF|RD) = P(LF)

☑ MCP ⊥ OP | RD

☐ OP is in the Markov Blanket of LF.

Checklist

And now mark the checklist below making sure you have taken care of each of the points mentioned:

- ☑ I have read the pinned Ed post with the title ‘Midterm Exam Clarifications Thread’, and I am familiar with all of the clarifications made by the Teaching staff.
- ☑ All answers with more than 6 digits after the decimal point have been rounded to 6 decimal places.
- ☑ All pages are being uploaded in the correct order that they were presented to me, and none of the pages are missing/removed.
- ☑ Any extra pages **(including blanks)** are only attached at the END of this exam, after page 25 with clear pointers to wherever the actual answer is in the PDF (reference properly).
- ☑ I am submitting only one PDF and nothing else (no docx, doc, etc.).
- ☑ The PDF I am submitting is not blank (unless I want it to be).
- ☑ **I will go over the uploaded pictures on Gradescope and make sure that all the answers are clearly visible. I acknowledge that I am aware that dull / illegible / uneven scans will not be graded.**
- ☑ I have submitted a copy of the PDF to Canvas.