CS 6601 Artificial Intelligence
Fall Semester 2022
Final Examination Paper

Duration of Exam: 5 December 2022, 8:00 AM (EDT) - 12 December 2022, 8:00 AM (EDT)

Weight: 20% **No. pages:** 60 **No. Questions:** 10 **Total marks:** 103

Instructions:

- Before solving the exam, you should read the Ed post titled **"Final Exam Next Week"**.
- You should fill out this PDF and submit it on **BOTH Gradescope and Canvas**. We reserve the right to deduct points if you don't submit on both platforms.
- You have an unlimited number of submissions until the deadline. You can either type directly into the PDF or you can print, hand-write, and scan your solutions. If you decide to type into the PDF, **we strongly recommend using Adobe Acrobat 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. Thus, **always make sure to keep a backup of your answers**.
- You should **submit only a single PDF**. Also, **make sure your typed answers appear clearly in the Gradescope Preview**. After each question, a blank page is provided if you wish to highlight some of your calculations. However, you should not expect any points to be awarded for your calculations (only your final answers will be considered). The TAs reserve the right to assign partial credits based on your calculations. Make sure to submit ALL the pages of the exam, not only the completed ones.
- You must **fill out the checklist at the end** of the exam. The exam may not be graded if it is left blank.
- The exam is open-book, open-note, and open video lectures, with no time limit aside from the duration of the exam. 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 platform. In particular, 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 Final Exam with the question number in the subject line (for example, a question on Search would be "Final Exam #2"). Please make different posts for different questions.
- **Global Rounding Rule: Please round all your final answers to 6 decimal places**. Don't round intermediate results. You can use round(answer, 6) function in Python for help. You may not receive full credit if your answers are not given to the specified precision.
- Points breakdown is provided below.

Question No.	1	2	3	4	5	6	7	8	9	10
Points	7	5	6	6	6	11	19.5	13	11	15.5

Problem 1: Game Playing [7 points]

Harry is a struggling sophomore and loves playing games. Often, this habit affects his progress in college as he is unable to turn in assignments on time as he is caught up in completing game missions instead.

This semester Harry took a CS course called Game Playing and Artificial Intelligence where he is learning about how two player and zero-sum games use adversarial search to apply AI and how modern algorithms and machines use these algorithms in everyday applications. Surprisingly, Harry loves this course and has decided to focus on his studies this semester but is unable to solve and understand some questions about the concept of Iterative Deepening. Therefore, he needs a peer to explain to him and solve such questions.

Help Harry gain interest in studies and his potential to be a shining student again by solving the following questions.

(a) (1.5 points) Which of the following is (are) the best ordering of the nodes A, B, C, and D (best ordering is the ordering that produces the most pruning) for alpha-beta pruning evaluation up to depth 2 with Iterative Deepening in an attempt to improve the effectiveness of alpha-beta pruning when running up to depth 3 (see Figure 1). Assume that the procedure uses the information it has acquired up to a given depth to try to improve the order of evaluations later. The static values for nodes A, B, C, and D are given with the definition of S and the depths for the tree are given with definition of D.

- [ ] ABCD
- [x] CDBA
- [x] DCAB
- [x] CDAB

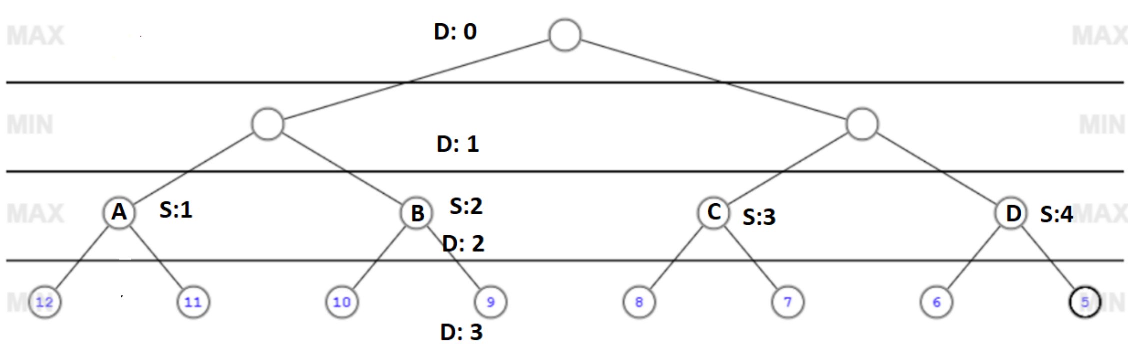

Figure 1: Game Tree

(b) (1.5 points) Which of the following is (are) the best ordering of the nodes A, B, C, and D (best ordering is the ordering that produces the most pruning) for alpha-beta pruning evaluation up to depth 2 with Iterative Deepening in an attempt to improve the effectiveness of alpha-beta pruning when running up to depth 3 (see Figure 2). Again, assume the procedure uses the information it has acquired up to a given depth to try to improve the order of evaluations later. The static values for nodes A, B, C, and D are given with the definition of S and the depths for the tree are given with the definition of D.

☐ ABCD
☐ CDBA
☑ BADC
☐ CDAB

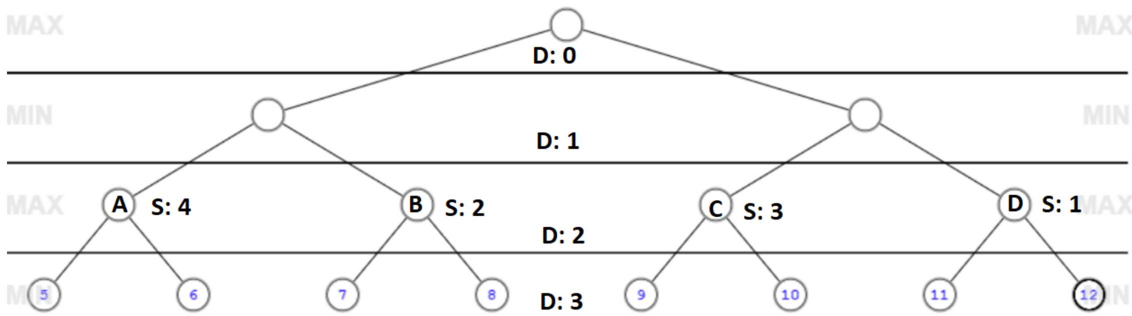

Figure 2: Game Tree

(c) (1.5 points) Solve the given game tree in Figure 3 using minimax:

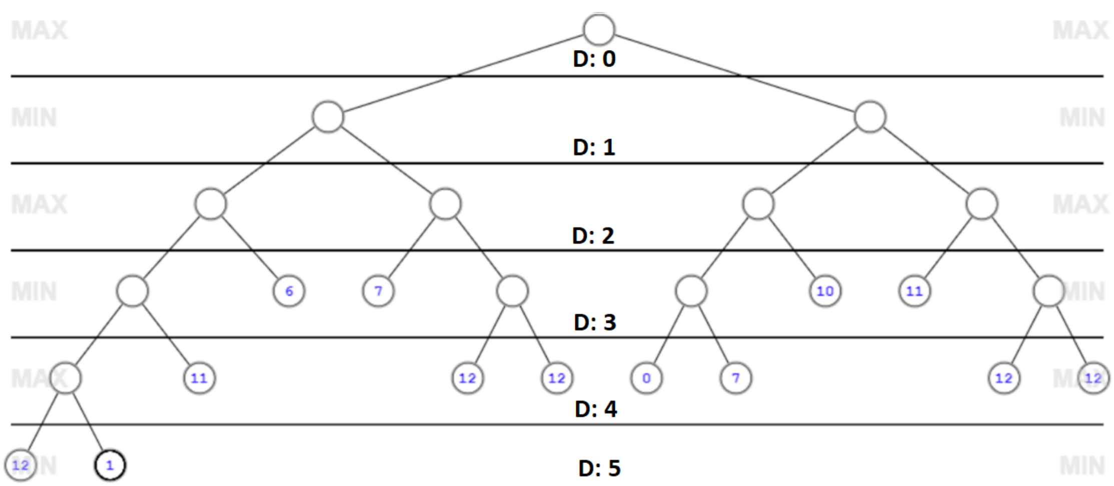

Figure 3: Game Tree

Enter the final propagated value at the top:

Type Your Answer Here: 11

Enter the number of leaf nodes pruned if alpha-beta pruning is applied from left to right to solve the game tree in Figure 3 (we are only counting leaf (terminal) nodes and not branches)

Type Your Answer Here: 4

(d) (2.5 points) For Figure 1 and Figure 2, assume that we run the alpha-beta pruning to depth 3 and ignore the static values assigned at depth 2 previously used for iterative deepening.

How many more leaf nodes (compared to without reordering and using the left-to-right evaluation rule) will be pruned if the correct reordering (from the answer to question (a)) at depth 2 is applied (see Figure 1 and ignore the static values assigned at depth 2 previously used for iterative deepening.)?

Type Your Answer Here: -1

How many more leaf nodes (compared to without reordering and using the left-to-right evaluation rule) will be pruned if the correct reordering (from the answer to question (b)) at depth 2 is applied (see Figure 2 and ignore the static values assigned at depth 2 previously used for iterative deepening.)?

Type Your Answer Here: -2

You can add your notes on this page (if any)

Problem 2: Search [5 points]

Part 1:

It is 10-28-22, and you are eager to recover your own password to treasurydirect.gov, so you could purchase and secure 9.62% annual interest of Series I bonds for the next six months. You remember that the password is 7 to 13 characters long, the first 7 characters are “CS6011@” Now, it is time to figure out the rest of the password by formulating a search problem:

1. The password starts with “CS6011@”.
2. The rest of the password will only contain characters “X”, “Y” or “Z”.
3. All ties are broken alphabetically. For example, if there is a tie, expand “X” first, then “Y”, and then “Z”.
4. The password will be expanded by appending one node (“X”, “Y”, or “Z”) at a time like what you have done in the first assignment.
5. The goal is to find the correct password among the six passwords you had written down before forgetting: CS6011@XXXXXZ, CS6011@XYXXXX, CS6011@XXYXY, CS6011@YZXYXZ, CS6011@ZYXXZ, and CS6011@ZYXZ.
6. Since you don’t want to test all these passwords and get locked out from your account, you will try to repeat the thinking process of how the password was selected.

(a) (0.5 points) You vaguely remember that you have picked the password that returned first when using Breadth First Search (BFS), which one of the following is that password?

- [ ] CS6011@XXXXXZ
- [ ] CS6011@XYXXXX
- [ ] CS6011@XXYXY
- [ ] CS6011@YZXYXZ
- [ ] CS6011@ZYXXZ
- [x] CS6011@ZYXZ

(b) (0.5 points) You tried that password and it didn’t work, now you wonder whether the correct password is the one returned first by iterative deepening Depth First Search (ID-DFS), which one of the following could be that password?

- [ ] CS6011@XXXXXZ
- [ ] CS6011@XYXXXX
- [ ] CS6011@XXYXY
- [ ] CS6011@YZXYXZ
- [ ] CS6011@ZYXXZ
- [x] CS6011@ZYXZ

(c) (0.5 points) Apparently, that is not the right password, so maybe the one you selected is the one returned first by Depth First Search (DFS). If so, which one of the following could be that password?

- [x] CS6011@XXXXXZ
- [ ] CS6011@XYXXXX
- [ ] CS6011@XXYXY
- [ ] CS6011@YZXYXZ
- [ ] CS6011@ZYXXZ
- [ ] CS6011@ZYXZ

(d) (0.5 points) Unfortunately, that password didn't work as well. Now you know you must have used Uniform Cost Search (UCS) when choosing the password. Since you like simple things, you must have set the cost of X, Y, and Z to 1, 2, and 3 respectively. Since you like to make simple things complicated, you must have chosen the Last password returned by UCS, which one could be that password?

- [ ] CS6011@XXXXXZ
- [ ] CS6011@XYXXXX
- [ ] CS6011@XXYXY
- [x] CS6011@YZXYXZ
- [ ] CS6011@ZYXXZ
- [ ] CS6011@ZYXZ

Part 2:
Consider a graph search problem where:

1. There is only one goal node.
2. Cost function cost (m, n) equals the cost from node m to node n, all cost $(m, n) > 0$.
3. Ties will be broken based on alphabetical order.

(e) (1 point) Now, you want to implement a new cost function cost_new(m, n), such that UCS based on this new cost function will always expand the same nodes in the same order as performing DFS on the same graph. Mark all the possible cost_new(m, n) below:

- [ ] cost_new$(m, n) = 1$
- [ ] cost_new$(m, n) = \alpha, \alpha > 0$
- [x] cost_new$(m, n) = -1$
- [x] cost_new$(m, n) = \alpha, \alpha < 0$
- [ ] cost_new$(m, n) = \alpha * \text{cost}(m, n) + \beta$, $\alpha > 0, \beta > 0$
- [ ] cost_new$(m, n) = \alpha * \text{cost}(m, n)$, $\alpha > 0$
- [ ] cost_new$(m, n) = \alpha * \text{cost}(m, n)$, $\alpha < 0$
- [ ] none exists

(f) (1 point) Now, you want to implement a new cost function cost_new(m, n), such that UCS based on this new cost function will always expand the same nodes in the same order as BFS. Mark all the possible cost_new(m, n) below:

- [x] cost_new$(m, n) = 1$
- [x] cost_new$(m, n) = \alpha, \alpha > 0$
- [ ] cost_new$(m, n) = -1$
- [ ] cost_new$(m, n) = \alpha, \alpha < 0$
- [ ] cost_new$(m, n) = \alpha$ * cost$(m, n) + \beta$, $\alpha > 0, \beta > 0$
- [ ] cost_new$(m, n) = \alpha$ * cost(m, n), $\alpha > 0$
- [ ] cost_new$(m, n) = \alpha$ * cost(m, n), $\alpha < 0$
- [ ] none exists

(g) (1 point) Now, you want to implement a new cost function cost_new(m, n), such that UCS based on this new cost function will always expand the same nodes in the same order as UCS using the previous cost(m,n) as cost function. Mark all the possible cost_new(m, n) below:

- [ ] cost_new$(m, n) = 1$
- [ ] cost_new$(m, n) = \alpha, \alpha > 0$
- [ ] cost_new$(m, n) = -1$
- [ ] cost_new$(m, n) = \alpha, \alpha < 0$
- [x] cost_new$(m, n) = \alpha$ * cost$(m, n) + \beta$, $\alpha > 0, \beta > 0$
- [x] cost_new$(m, n) = \alpha$ * cost(m, n), $\alpha > 0$
- [ ] cost_new$(m, n) = \alpha$ * cost(m, n), $\alpha < 0$
- [ ] none exists

You can add your notes on this page (if any)

Problem 3: Optimization Algorithms [6 points]

In this problem, we try to solve the minimum vertex cover problem using simulated annealing. The minimum vertex cover problem can be formulated as follows: Let G be an undirected graph with a set of vertices V and an edge set E. Every edge in E is denoted as (u, v), where u and v are vertices in the set V. A vertex cover is a set of vertices S such that the following property holds:

(1) For all (u, v) in E, either u or v (or both) are in S.

To find the minimum vertex cover, we want to find the smallest set S such that (1) holds. We refer to (1) as the invariant property. You'll see why as we describe the simulated annealing algorithm.

For our graph G, let the set of vertices $V = \{a, b, c, d, e, f, g\}$ and the edge set be $E = \{(a, b), (a, c), (a, d), (a, f), (b, e), (b, g), (c, b), (c, f), (c, e), (d, e), (d, g), (e, g)\}$.
A picture of G is shown in Figure 4:

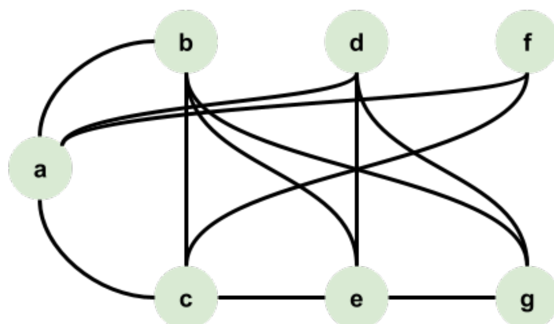

Figure 4: Graph G

We perform simulated annealing as follows.

State Space: Our state space consists of all possible vertex covers for the graph G.

Transitions: When transitioning from one state to another (say from S to T), we randomly pick a vertex v from the graph G. If v is in S, let $T = S \setminus v$ ($S \setminus v$ means remove v from S). If T is a valid vertex cover, we keep T since we have now found a smaller-sized vertex cover. If T is invalid, we discard the change and keep S. If v is not in S, let $T = S \cup v$ ($S \cup v$ means include v in S). We accept T with probability $p = e^{(f(S)-f(T))/K}$ (e is the exponential equation), where $S, T \subset V$ (S and T are subsets of V) and K is the temperature. Define f as follows:

$$f(S) = \sum_{v \in S} deg(v)$$

where $deg(v)$ represents the degree of a vertex v. The degree of a vertex is the number of edges connected to that vertex.

(a) (1 point) As a warm-up question, compute $f(S)$ for $S = \{a, c, d, e, g\}$

Type Your Answer Here: 18

(b) (1 point) Now, given the starting state $S = \{b, c, d, f, e\}$, compute the probability of removing c from S for $K = 8.54$. If you reject or accept the change with certainty, write 0 or 1 respectively.

Type Your Answer Here: 0

(c) (3 points) Fill out the following table shown in Figure 5 starting from state $S = \{b, c, d, f, g\}$. Every time you successfully add a node to the vertex cover, reduce the temperature, K by a factor of 0.5 (so that $K_{next} = 0.5 * K_{current}$). Begin with $K = 7.45$. For any add transitions, if the Random Number is less than the acceptance probability you compute, accept the new state. Otherwise, reject it. Write the new state produced by applying the transition on the next row (you don't need to do this for the last row). Finally, write down the acceptance probability for each transition. If you reject or accept a transition with certainty, write 0 or 1 respectively.

State	Transition	Acceptance Probability	Random Number (Compare)
{b,c,d,f,g}	Remove d	A1	
A3	Add e	A4	0.4
A5	Remove g	A6	
A8	Add a	A9	0.2
A10	Remove b	A11	

Figure 5: Table

Enter the value of A1 here: 0

Enter the value of A3 here: {b, c, d, f, g}

Enter the value of A4 here: 0.584550

Enter the value of A5 here: {b, c, d, e, f, g}

Enter the value of A6 here: 1

Enter the value of A8 here: {b, c, d, e, f}

Enter the value of A9 here: 0.341699

Enter the value of A10 here: {a, b, c, d, e, f}

Enter the value of A11 here: 0

(d) (1 point) How many vertices are in a minimum vertex cover of G?

Type Your Answer Here: 4

You can add your notes on this page (if any)

Problem 4: Constraint Satisfaction Problem [6 points]

The Ninja Turtles are at it having their adventures again. In today's episode, Leo, Mikey, Donny, Ralph are accompanied by Casey and April to defeat Shredder, Krang, Rocksteady and Bebop.

Heroes: Mikey, Donny, Casey, Leo, Ralph, April
Villains: Bebop, Krang, Shredder, Rocksteady

This time, the villains have decided to deploy a bomb in the sewers that will potentially flood a major part of New York City, including one of the turtle's favorite pizza restaurant. The heroes cannot let that happen. When the turtles arrive at the location of the sewers, the turtles find themselves having to deal with many things at the same time, and then have to solve a constraint satisfaction problem, where each of the turtles need to handle one thing or a villain.

- Someone needs to fight **Krang**
- Someone needs to fight **Shredder**
- Someone needs to fight **Bebop**
- Someone needs to fight **Rocksteady**
- There's a **computer** that needs to be hacked in order to diffuse the bomb. For that, they need someone who has a tech background.
- Donny has a lot of knowledge in tech. April is a scientist, so they also have a lot of
- knowledge in tech. The others aren't very good with tech.
- Krang and Bebop decided to pair up to fight two people at the same time. Therefore, the heroes who pair up to fight Krang and Bebop must work well together.
- Shredder and Rocksteady decided to pair up to fight two people at the same time. Therefore, the heroes who pair up to fight Shredder and Rocksteady must work well together.
- There is a **rope** that needs to be cut in order to close a gate, protecting Manhattan if the bomb is to go off. But in order to cut the rope, one needs a metal weapon.
- Mikey, Donny, Casey, and April use nunchucks, a bo-staff, a hockey stick, and a baseball bat, respectively, which none are made of metal
- Ralph and Leo use sais and katannas, which are made of metal.
- Leo and Mikey have trained a lot together, so they fight well together
- Leo and Ralph are often fighting about leadership of the team, so they don't work well together. While they argue, Donny and Mikey train together, so they fight well together.
- Ralph and Casey scout the streets together a lot at night, so they work well together
- April and Donny work well together, since they chat a lot about science.
- The Shredder is a formidable fighter, therefore, whoever is fighting Shredder and Rocksteady needs to make sure that their cumulative (i.e. summed) strength points are higher than 12.

Name	Strength Points
Mikey	6
Ralph	8
Donny	4
Casey	5
April	3
Leo	7

You are now in charge of assigning our heroes to deal with:

- The computer
- The rope
- Shredder
- Krang
- Bebop
- Rocksteady

Example for Answers: Below, you will be asked questions with regards to whether there exists a solution that satisfies given CSPs and if so, what would be all of the possible heroes that could be on each of the listed tasks. This section is to provide you with an example of how to answer. So let's say that, for example, for this CSP, there are multiple solutions that are listed below:

Fight Krang	***Fight Shredder***	***Hack Computer***	***Cut Rope***	***Fight Bebop***	***Fight Rocksteady***
Leo	*April*	*Mikey*	*Ralph*	*Donny*	*Casey*
Leo	*April*	*Mikey*	*Ralph*	*Casey*	*Donny*
April	*Leo*	*Mikey*	*Ralph*	*Donny*	*Casey*
April	*Leo*	*Mikey*	*Ralph*	*Casey*	*Donny*

In this case, there are four solutions that satisfy some CSP, and the first part of the question should be "Yes". Now, to list the all possible heroes who could be on each of the tasks:

- ***Computer:*** *Mikey*
- ***Rope:*** *Ralph*
- ***Shredder:*** *April, Leo*
- ***Krang:*** *April, Leo*
- ***Bebop:*** *Casey, Donny*
- ***Rocksteady:*** *Casey, Donny*

(a) (2 points) Given those constraints, will the heroes succeed in saving their favorite pizzeria? (I.e. Is it possible to find a solution which satisfies this CSP?) If so, who are all of the possible heroes who can be on each of the problems? List the names in alphabetical order, and separated by a comma and a space (e.g. Casey, Donny, Leo). If there are no possibilities, leave the text fields blank.

Yes ★ No ☐

Computer: April

Rope: Leo

Shredder: Casey, Ralph

Krang: Donny, Mikey

Bebop: Donny, Mikey

Rocksteady: Casey, Ralph

(b) (2 points) Our heroes have fought very well, and greatly damaged Shredder, so he ordered to exchange the pairs. Now, Shredder and Rocksteady are no longer paired, and Krang and Bebop are no longer paired up. Instead, you must satisfy the following constraints:

- Krang and Shredder are now paired, so you must choose the heroes that can work well together to fight them.
- Bebop and Rocksteady are now paired, so you must choose the heroes that can work well together to fight them.
- Now, the pair that fights Krang and the Shredder must have a cumulative sum of strength points greater than 12.

The constraints from the previous question should remain the same:

- Someone well versed with tech will deal with the computer to diffuse the bomb
- Someone with a metal weapon will help cut the rope

Given those constraints, will the heroes succeed in saving their favorite pizzeria? (I.e. Is it possible to find a solution which satisfies this CSP?) If so, who are all of the possible heroes who can be on each of the problems? List the names in alphabetical order, and separated by a comma and a space (e.g. Casey, Donny, Leo). If there are no possibilities, leave the text fields blank.

Yes ★ No ☐

Computer: April

Rope: Leo

Shredder: Casey, Ralph

Krang: Casey, Ralph

Bebop: Donny, Mikey

Rocksteady: Donny, Mikey

(c) (2 points) At this point they greatly damaged Shredder's armor, so our heroes do not have to have a cumulative sum of strength points greater than some number anymore. Instead, whoever is working on the computer needs to help whoever is fighting Krang, given that Krang uses an android body. Therefore,

- You must make sure that whoever is fighting Krang must work well with whoever is working on the computer.

All of the other constraint satisfactions from the previous questions remain:

- Krang and Shredder are paired, so you must choose the heroes that can work well together to fight them.
- Bebop and Rocksteady are paired, so you must choose the heroes that can work well together to fight them.
- Someone well versed with tech will deal with the computer to diffuse the bomb
- Someone with a metal weapon will help cut the rope

Given those constraints, will the heroes succeed in saving their favorite pizzeria? (I.e. Is it possible to find a solution which satisfies this CSP?) If so, what are all of the possible heroes who can be on each of the problems? List the names in alphabetical order, and separated by a comma and a space (e.g. Casey, Donny, Leo). If there are no possibilities, leave the text fields blank.

Yes ★ No ☐

Computer: April

Rope: Leo

Shredder: Mikey

Krang: Donny

Bebop: Casey, Ralph

Rocksteady: Casey, Ralph

You can add your notes on this page (if any)

Problem 5: Probability: Life of your TAs [6 points]

Note: During A3, we shared an Ed post titled "Assignment 3 Helpful Probability Formulas". Feel free to use it while solving this section.

Working as a TA for CS 6601 is a very interesting job. Each TA in the team is assigned specific responsibilities. We will now look at some of the tasks we do as a TA and the challenges involved in them. We are hoping to receive your help in addressing those challenges!

Challenge Questions:

Each week, we aim to release multiple "challenge questions" on Ed. These questions are designed based on the content covered in the class. Each semester, a TA is assigned to design new challenge questions, and release the existing ones to the students via Ed posts. We expect that the students will attempt these questions and have a discussion with each other on the ways to solve them, as we have witnessed this practice improving the ability of students to perform well in the exams.

For the TA assigned to handle these challenge questions, the job is to engage in discussion with students who comment on those challenge questions Ed posts. After studying the data corresponding to the responsiveness of the students to these Ed posts, you come up with an interesting observation:

Let us say you have a challenge question Ed post "P". We would denote the comments made by students under "P" as "C_1", "C_2", and so on. You observe that if there is at least one comment made by students under P in a given hour, then the probability of them making at least one comment under P in the next hour increases by 0.1. This is because, when a student puts a comment describing their solutions, the others usually take note of it, verify if it is correct or not, and reply to that comment with their feedback (which is why there is an increase in the probability mentioned above). Note that this increase can go up to 1 (as it is the maximum probability for any event). In this case, eventually, the comments will keep on coming on that Ed post every hour, till the end of time. Similarly, you also observe that if there is not a single comment made by students under P in a given hour, then the probability of them making at least one comment under P in the next hour decreases by 0.1. This is because fewer comments will result in fewer interactions. Note that this decrease can go down to 0 (as it is the minimum probability for any event). In this case, eventually, no comments will be added by students each hour on that Ed post, till the end of time. Based on the information provided above, answer the following question.

(a) (2 points) At a given hour, you are told that the probability of students making at least one comment under P is 0.3. What is the probability that, eventually, there will be at least one comment made each hour by students under the Ed post, till the end of time?

Type your answer here: 0.089844

Exam Performance:

After each exam, the TAs analyze the performance of the students to see where the students went wrong so that those concepts could be reinforced later on. To perform this task, three TAs are assigned: David, Yali, and Paul. Suppose, you have a pool of 100 students $\{S_1, S_2, \ldots, S_{100}\}$ such that the student Si has scored "i" points out of 100 in the exam. For example, S_1 scored 1 out of 100, S_2 scored 2 out of 100, and so on. Out of this pool, each TA will select 6 students in order and at random.

David picked S_4, S_{13}, S_{14}, S_{19}, S_{43}, and S_{87} in this order and he exclaimed: "Wow, I got my picks in an increasing order". Yali, on the other hand, picked S_{64}, S_{31}, S_{24}, S_9, S_3, and S_2 in this order and she exclaimed: "Look guys, I got my picks in a decreasing order". Paul said: "Let me try this as well" and he picked S_{41}, S_{18}, S_{68}, S_5, S_{33}, and S_{52} in this order. Tough luck! His picks are neither in increasing nor decreasing order. After hearing this discussion, Nick joins the party and says: “Now it’s my turn to have the picks!”

(b) (1 point) What is the probability that Nick will have a pick, which is either in an increasing or a decreasing order? Assume that Nick can have his picks from the entire pool of the 100 students.

Type your answer here: 0.002778

Office Hours:
All the TAs in the CS 6601 team are responsible for holding office hours once a week. The main purpose of holding office hours is to help students with their programming as well as conceptual doubts. The number of students who join during office hours depends on how far the deadline is and how difficult the assignment is. Being curious about it, you decide to study the pattern using a probabilistic model.

You observe that at least one student joins the office hours in the duration of 3 minutes with a probability of 0.992. Assume that the probability of a student joining the office hours in a time interval T_1 of length k is the same as well as independent of the probability of a student joining the office hours in a time interval T_2 of length k.

(c) (1 point) What is the probability that at least one student joins the office hours in the duration of 1 minute?

Type your answer here: 0.8

Bot Fight Simulation:
For the Assignment 2 bonus part, the TAs ask the students to work on their most optimal game-playing bots, which are then pitted against each other. In any match between the 2 bots, a number of games are simulated, and the first bot, who defeats the other bot 10 times, wins the match. For the sake of this problem, assume that the extra credits of 10 points would be given to only the best submission, which will be ranked number 1 in the bot fight. When grading this extra credit part, you come across two submissions, which are equally strong in terms of their bot’s ability to win the game. These two submissions have defeated every other submission, and hence, they are facing each other in the finals. Let these two submissions be T_1 and T_2. These two submissions are so equally matched that the probability that either one of them wins against the other submission is 0.5.

Given this information, you start simulating games between T_1 and T_2. After the first 15 games, you observe that the score is 8-7 in favor of T_1 i.e. T_1 has won 8 games and T_2 has won 7 games. What an intense match! Whoever reaches the magic figure of 10 wins will take home the extra credits! At this point, you start feeling sad that the losing submission, despite being so close to victory, would not get anything. Thus, you decide to change the grading policy of this extra credit section. The new grading policy is as follows: At this moment, 15 games have been played and T_1 has won 8 games and T_2 has won 7 games. You will NOT simulate any more games. Instead, you will split the extra credit of 10 points in such a way that the share each submission gets is proportional to the probability with which they have a chance to win the match (whoever would reach 10 wins first wins the match). Remember that the two submissions are so equally matched that the probability that either one of them wins against the other submission is 0.5.

(d) (2 points) If the submission T_2 was made by you, how many extra credit points will you receive?

Type your answer here: 3.125

You can add your notes on this page (if any)

Problem 6: Bayes Nets: There's No Place Like Home [11 points]

Note: We have provided the structure of the Bayesian network along with the story. Also, calculations are not necessary to answer the questions.

Dorothy and her dog Toto find themselves in a precarious position: their house, which was swept away from Kansas by a tornado, has landed on the Wicked Witch of the East. This involuntary manslaughter delights the locals, but not the deceased witch's sister, the Wicked Witch of the West, who directs public, vengeful threats toward Dorothy and Toto.

A self-proclaimed "good" Witch of the North, named Glinda, sends them down a yellow brick road to find the mysterious Wizard of Oz, whom Glinda claims may be able to help them return home to Kansas. So Dorothy embarks down this path, wearing ruby slippers that belonged to the Wicked Witch of the East. Glinda tells her that these slippers must have magical powers.

Along the yellow brick road, Dorothy and Toto meet three new companions: the Scarecrow, who wants a brain; the Tin Man, who desires a heart; and the Cowardly Lion, who lacks courage. Despite intimidation and sabotage attempts from the Wicked Witch of the West, they arrive safely at the Emerald City. They speak with the Wizard of Oz, who appears as a ghastly head above smoke and flames. He tells them that he will grant their wishes, including returning Dorothy to Kansas, only if they bring him the Witch of the West's broomstick. Easier said than done! And to make matters worse, the Wicked Witch has released flying monkeys, which will certainly capture her!

Dorothy, an aspiring AI researcher, decides to build a Bayesian Network to calculate the probability of successfully making it home. This isn't a Hollywood script after all; this is real life, and nothing is certain! The Bayesian Network shown in Figure 6 is built from the description of prior and conditional probabilities in the description below: After Dorothy is captured by the monkeys and brought to the

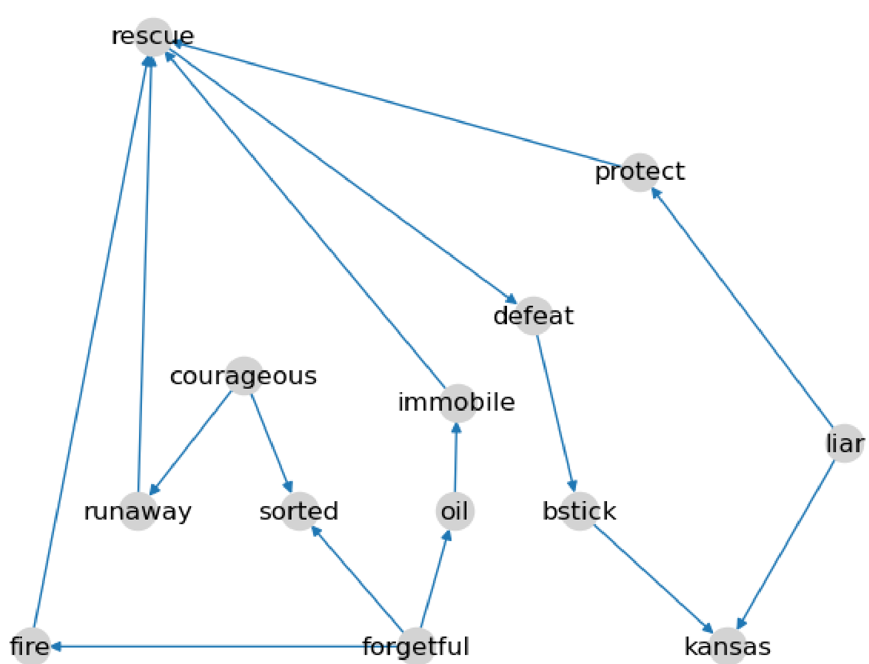

Figure 6: Dorothy's Bayesian Network

witch, her ruby slippers may protect her (call this “protect”). She’s not convinced they are magic; it depends on whether Glinda is a liar!

If Glinda is a liar (call this “liar”), then there is a 0.1 probability the slippers are magic and can protect her. But if Glinda is not a liar, there is a 0.8 probability the slippers can protect her. If the slippers do not save her, then the mission is a failure, and she does not make it home to Kansas. Dorothy places a prior probability on Glinda being a liar at 0.1.

If the slippers do protect her, it would only be temporary, buying time for her friends to come rescue her. Rescuing Dorothy requires her bumbling new friends (the Scarecrow, Cowardly Lion, and Tin Man) to work together. All sorts of things can go wrong!

First, the Tin Man is constantly at risk of rusting, which freezes his joints and renders him immobile (call this “immobile”). If he has received oil within an hour of the rescue attempt (call this “oil”), there’s only a 0.2 probability that he will become immobile. But if he does not receive the oil, the probability of immobility is 0.9!

Unfortunately, the Scarecrow is in charge of the Tin Man’s oil can when Dorothy isn’t around. Due to his lack of a brain, he is often in a forgetful state (call this “forgetful”). When he is in a forgetful state, the risk of forgetting to oil the Tin Man within an hour of the rescue attempt is 0.9. Otherwise, if he is not in a forgetful state, the probability of forgetting to oil the Tin Man is only 0.3.

The Scarecrow, who is made of straw, is also highly flammable and forgets this fact when he’s in a forgetful state! If he’s in a forgetful state during the rescue attempt in the witch’s castle, there’s a 0.8 probability he will catch fire from the candles (call this “fire”). If he’s not in a forgetful state, there’s only a 0.4 probability he’ll catch fire.

Finally, the Cowardly Lion sometimes, but rarely, feels courage. If he is in a courageous state (call this “courageous”), he will join the rescue with probability 1. If he is not in a courageous state that probability drops to 0.2, with a 0.8 probability that he runs away beforehand (call this “runaway”).

In the event that Dorothy requires rescuing (call this “rescue”), the probability of success depends on how many of her friends make it. The Cowardly Lion makes it if he does not run away; the Scarecrow makes it if he does not catch fire; the Tin man makes it if he does not become immobile. If 0 friends make it, then the probability of rescue is 0. If only one friend makes it, the probability of rescue is 0.1. If two friends make it, the probability is .7. If all three make it, the probability is 0.9.

If they do indeed rescue her, they’ll be tired and the probability of defeating the witch (call this “defeat”) is 0.4. If they do not rescue her, they cannot defeat the witch.

If they defeat the Witch, then the probability of retrieving the Witch’s broomstick (call this “bstick”) is 0.9. If they don’t defeat the Witch, that probability is only 0.1.

The Scarecrow’s state of forgetfulness and the Cowardly Lion’s state of courage each hold steady for a full day at a time, and all of the events in this scenario would occur on the same day. In other words, whatever their true states are, they are constant for this whole scenario.

When the Scarecrow is in a forgetful state, he neatly sorts the items in Dorothy’s basket with probability 1 because he forgets that it’s not his basket. When he is not in a forgetful state, he neatly sorts the items with a probability of 0.2, just to be nice. When the Cowardly Lion is not in a courageous state, he neatly sorts the items in Dorothy’s basket with a probability of 0.8 because he’s nervous. When he is in a courageous state, he never neatly sorts the items in the basket. When the Scarecrow is in a forgetful state and the Cowardly Lion is not in a courageous state, their probabilities of sorting the basket are independent of each other; either one or both may sort it to place it in a sorted state, with a probability that can be derived from the above information (think of it like flipping two weighted coins and estimating the probability of at least one landing heads). No one else ever neatly sorts the items in Dorothy's basket; not even Dorothy herself (we'll call a sorted basket, "sorted"). The basket begins each day unsorted, and any sorting (if it happens) is done first thing in the day, but Dorothy may not check her basket until later.

The base rate probability that the Scarecrow is in a forgetful state is 0.7, and that the Cowardly Lion is in a courageous state is 0.2.

Finally, even if Dorothy survives all of the above and gets the witch's broomstick, the Wizard would still need to grant her wish! Whether the Wizard is able to do this is dependent on whether Glinda is a liar, which would make her recommendation to seek the Wizard a lie. If Glinda was not a liar, then the probability that the Wizard can help her get back to Kansas, if she retrieves the broomstick, is 1 (call this "kansas"). If she is a liar, then the probability the Wizard can help her get back is only 0.2, even if she retrieves the broomstick. The Wizard will not help her get back to Kansas if they do not have the broomstick.

To help answer the following questions, we are providing the structure of Dorothy's Bayesian Network, which is shown in Figure 6. **Also, note that it is possible to answer all parts without performing calculations.**

Please treat the information within each question as independent from the other questions. In other words, the questions do not build on each other; they only rely on the original story, plus whatever new information they individually provide in isolation from the other questions.

(a) (1 point) Before observing any events or data, which of the following events are independent of the Cowardly Lion's courageous state ("courageous") for the day in question? (Multiple Option Correct MCQ)

- [x] "protect" (ruby slippers will protect Dorothy)
- [x] "forgetful" (Scarecrow's forgetful state)
- [ ] "sorted" (the items in Dorothy's basket are neatly sorted)
- [x] "oil" (The Tin Man gets oil)
- [x] "immobile" (The Tin Man become immobile)
- [ ] "runaway" (The Cowardly Lion runs away)
- [x] "fire" (The Scarecrow catches fire)
- [x] "liar" (Glinda is a Liar)
- [ ] "rescue" (Dorothy is rescued from the witch by her new friends)
- [ ] "defeat" (Defeats the Witch)
- [ ] "bstick" (Dorothy retrieving the Wicked Witch's broomstick)
- [ ] "kansas" (The Wizard is able to help Dorothy get home)

(b) (3 points) Suppose Dorothy wants to use Variable Elimination with her Bayesian Network to get the probability of whether the basket is sorted (the "sorted" node) before knowing any other evidence. Which of the following nodes are required to calculate this probability with as few nodes as possible?

- ☐ "protect" (ruby slippers will protect Dorothy)
- ☑ "forgetful" (Scarecrow's forgetful state)
- ☑ "sorted" (the items in Dorothy's basket are neatly sorted)
- ☐ "oil" (The Tin Man gets oil)
- ☐ "immobile" (The Tin Man become immobile)
- ☐ "runaway" (The Cowardly Lion runs away)
- ☐ "fire" (The Scarecrow catches fire)
- ☐ "liar" (Glinda is a Liar)
- ☐ "rescue" (Dorothy is rescued from the witch by her new friends)
- ☐ "defeat" (Defeats the Witch)
- ☐ "bstick" (Dorothy retrieving the Wicked Witch's broomstick)
- ☐ "kansas" (The Wizard is able to help Dorothy get home)
- ☑ "courageous" (The Cowardly Lion is in a courageous state)

(c) (1 point) Which event nodes are in the Markov blanket for the node of Dorothy retrieving the Wicked Witch's broomstick ("bstick")?

- ☐ "protect" (ruby slippers will protect Dorothy)
- ☐ "forgetful" (Scarecrow's forgetful state)
- ☐ "sorted" (the items in Dorothy's basket are neatly sorted)
- ☐ "oil" (The Tin Man gets oil)
- ☐ "immobile" (The Tin Man become immobile)
- ☐ "runaway" (The Cowardly Lion runs away)
- ☐ "fire" (The Scarecrow catches fire)
- ☑ "liar" (Glinda is a Liar)
- ☐ "rescue" (Dorothy is rescued from the witch by her new friends)
- ☑ "defeat" (Defeats the Witch)
- ☑ "kansas" (The Wizard is able to help Dorothy get home)
- ☐ "courageous" (The Cowardly Lion is in a courageous state)

(d) (3 points) Suppose Dorothy needs to be rescued after her slippers magically protect her from the Witch. And suppose we know with certainty that the Cowardly Lion did not (and will not) run away and that Dorothy's basket is neatly sorted. Do the following probabilities go up, down, or remain unchanged within the Bayesian Network compared to the original story?
Hint: it's possible to answer these without doing calculations.

The probability that the Scarecrow will catch fire:

Up ★ Down ☐ Same ☐

The probability that the Tin Man will become immobile with rust:

Up ★ Down ☐ Same ☐

The probability that Wizard will be able to help Dorothy get home, given that she can get the broomstick:

Up ★ Down ☐ Same ☐

(e) (3 points) Suppose we know that Dorothy is rescued from the Wicked Witch by at least one of her friends (after the ruby slippers temporarily protect her), and we update the Bayesian Network probabilities accordingly. Mark the following as True or False
Note: Consider each in isolation from the other; no partial credit:
Note: To score 3 points on this question, ALL the 3 answers MUST be correct. Any mistake will result in 0 points on this question.

If we learn that Dorothy and her friends defeat the Witch, then this helps us update the probability that Dorothy's basket is nearly sorted.

True ☐ False ★

If we learn that Dorothy gets home to Kansas, then we know with certainty Glinda was not a liar.

True ☐ False ★

If we learn that Dorothy and her friends defeat the Witch, then this helps us update the probability that Glinda is a liar.

True ☐ False ★

You can add your notes on this page (if any)

Problem 7: Machine Learning [19.5 points]

Part 1:

We are trying to build a binary classifier from the dataset shown in Figure 7. The dataset has 10 records, 3 features (A, B, C), and binary labels (0, 1).

A	B	C	Label
1	2	1	1
1	2	3	0
2	3	2	0
2	0	3	1
1	3	2	0
0	0	3	1
0	1	0	0
1	3	1	0
0	2	1	1
2	2	3	1

Figure 7: Dataset

(a) (1 point) We choose a decision tree as the classifier. Assume the splitting rule is based on the unique values of each feature. For example, there are 4 unique values (0, 1, 2, 3) in Feature 'B', so 4 splitted sub-groups exist for Feature 'B'. With this assumption, calculate the Information Gain (not Gini Gain) for Feature 'A' and 'B' when starting to build the decision tree from the root node. (Note: You can reference The Canvas Module 7. Machine Learning Lecture 32 - 33 to answer this question. Also, please round to the 6-place decimal place for each answer.)

Information Gain (A): $\boxed{0.124511}$

Information Gain (B): $\boxed{0.675489}$

(b) (1 point) Assume we now choose K-Nearest Neighbor (KNN) as the classifier. A new feature vector has value (1,1,1) for feature (A, B, C). When we use Euclidean distance and K= 3, what will be the predicted label for this feature vector?

0 ☐ 1 ★

(c) (1 point) Assume we now choose K-Nearest Neighbor (KNN) as the classifier. A new feature vector has value (1,1,1) for feature (A, B, C). When we use Manhattan distance and K=5, what will be the predicted label for this feature vector?

0 ★ 1 ☐

(d) (1 point) Assume that this dataset is a cybersecurity attack dataset and it has been expanded to $\sim 10,000$ instances. This dataset is a balanced dataset (That means, the number of instances with labels 0 and 1 are almost identical). Assume that 0 represents the non-existence of a critical cyberattack and 1 represents the existence of that critical cyberattack. We are trying to use this dataset to build a machine learning classifier and detect this cyberattack as accurately as possible. Any undetected cyberattack can result in extremely negative financial loss and information security breaches. Our core goal is to correctly identify the existence of this cyberattack for all instances that actually have this cyberattack, and not to miss detecting any actual cyberattack instance. To realize this goal, we might have to risk the wrong classification of a few non-attack instances as attack instances. However, this type of misclassification is still acceptable, as our core objective is met and we can further investigate each misclassified instance to see whether it is an actual attack instance or not. Finally, we decide to use the confusion matrix, precision, recall, and accuracy as indicators to evaluate the performance of this classifier. Based on the above facts and considerations, what is the most important performance index that we should maximize?

Accuracy ☐ Precision (class 0) ☐ Precision (class 1) ☐ Recall (class 0) ☐ Recall (class 1) ★

Part 2:

We are now building a deep neural network to train an image classification model. The input dataset is the MNIST dataset. It contains $\sim 60,000$ training black and white images with size $28 * 28$ for each integer from 0 to 9. The image shown in Figure 8 is an example collection of training images:

Figure 8: MNIST Dataset

(e) (1 point) Assume that we use a fully-connected neural network architecture shown in Figure 9.

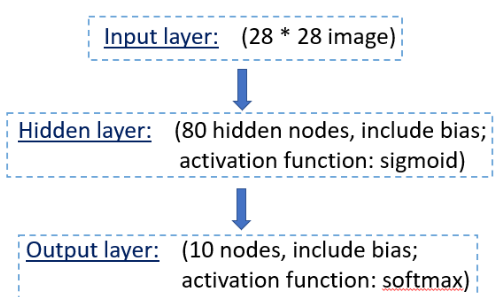

Figure 9: Fully-Connected Neural Network

Assume that we will first flatten each 28 * 28 input image in the input layer. How many learning parameters are included in this neural network?

Type your answer here: 63610

(f) (1 point) Assume that the curves shown in Figure 10 are the change of errors from training and testing samples, when the neural network has an increasing number of nodes in the hidden layer. How do the bias and variance change across different regions of this plot (in the Red Rectangle Region 1 and 2 respectively)?.

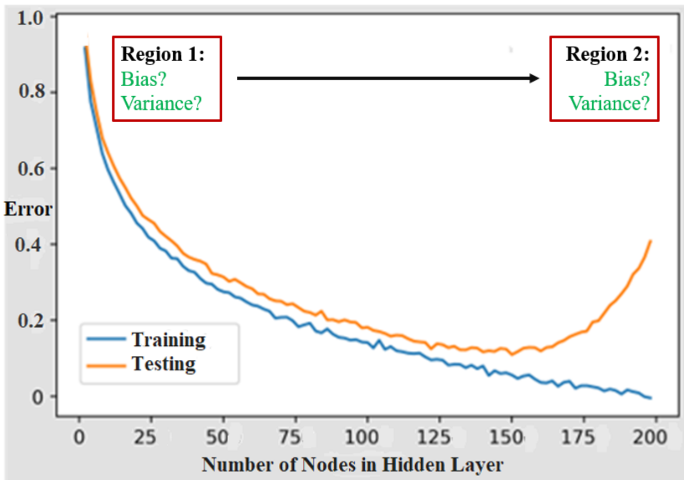

Figure 10: Error Curves

- ✔ **Region 1:** High Bias, Low Variance; **Region 2:** Low Bias, High Variance
- ☐ **Region 1:** Low Bias, High Variance; **Region 2:** High Bias, Low Variance
- ☐ **Region 1:** High Bias, High Variance; **Region 2:** Low Bias, Low Variance
- ☐ **Region 1:** Low Bias, Low Variance; **Region 2:** High Bias, High Variance

(g) (2 points) Assume that when we stop the training process, we discover that our trained neural network model has significantly lower testing accuracy than training accuracy. We realize that our trained model might have an overfitting issue. What could be the possible solutions to reduce overfitting for training our neural network model? (Multiple Option Correct MCQ)

- ✔ Use the cross-validation strategy.
- ✔ Reduce the complexity of our network and use a simpler network.
- ✔ Use the early stopping strategy in the training process.
- ✔ Add dropout layers to the network (*Reference: Section 21.5.4 in AIMA textbook 4th Edition*).
- ✔ Use data augmentation in the training process.
- ✔ Use L1 and (or) L2 regularization.
- ☐ Increase the learning rate.
- ☐ Reduce the learning rate.

(h) (1 point) In the model training process, we notice that some activation functions can reduce the training loss at a reasonable pace. Meanwhile, some activation functions can reduce the training loss extremely slowly and even not reduce it at all. This is called the Vanishing Gradient issue. Vanishing Gradient issue refers to the below scenario: When the derivatives of some activation functions are very close to 0, the updated weight values for some nodes can be very small and the weight updating process can even stop. Which of the below activation functions can possibly result in the Vanishing Gradient problem (e.g., multiplication of large numbers of gradients that have very small absolute values)? Please select all correct answers. (*Section 21.5.4 in AIMA textbook 4th Edition* has more explanation about the Vanishing Gradient issue. You could also check Figure 11 to better understand each listed activation function.)

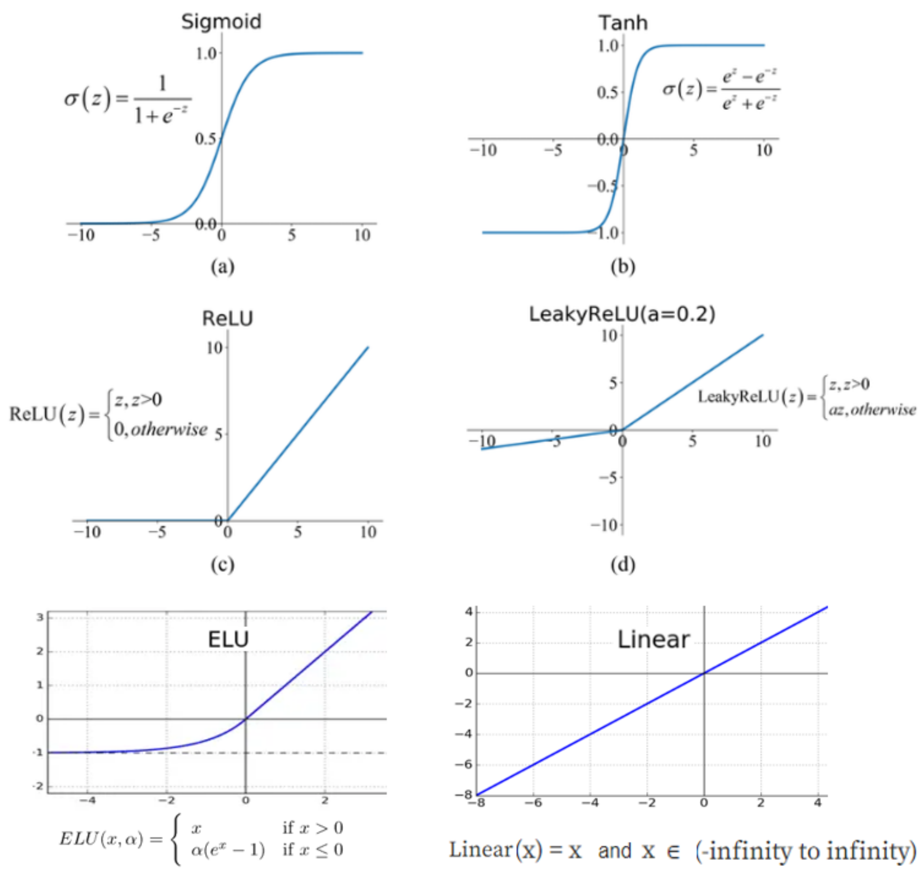

Figure 11: Activation Functions

- [x] Sigmoid
- [x] Hyperbolic Tangent (Tanh)
- [ ] Relu (Rectified Linear Unit)
- [ ] Leaky Relu (Leaky Rectified Linear Unit)
- [ ] Elu (Exponential Linear Unit)
- [ ] Linear

Part 3:

We find that using the fully-connected deep neural networks (in Part 2) to perform image classification requires too many parameters, and takes a long training time. So, we switch to another special neural network to train our image classification model. This special neural network includes the basic concepts of convolutional filter & operation, padding, stride, and pooling.

1. **Convolutional filter and operations:** Convolutional filter is a $n * n$ (n is a positive integer; $n \geq 2$) matrix filled with numbers. Convolutional filter slides through the image from left to right and also from top to bottom. Convolutional operation will calculate the sum of pair-wise multiplication results for each element in the convolutional filter and its matching element in the same position of the image region.
2. **Padding:** Padding is the operation to add pixels to the border of an image to facilitate the convolution operation. Different padding methods exist.
3. **Stride:** Stride shows how many pixel positions a convolutional filter will move from left to right (and also from top to bottom), when it slides through an image to make convolutional operations.
4. **Pooling:** Pooling is an important operation to reduce the dimension of output and the number of learning parameters in each layer as well as computation time on the network. Popular pooling methods include maximum pooling and average pooling.

(a) (6.5 points) Figure 12 shows an example of replication padding on the $3 * 3$ pixel matrix. Each added new pixel in the orange/yellow area is just to duplicate its nearest pixel in the blue area. Then assume that we apply the $2 * 2$ convolutional filter [[0,1], [1,2]] shown in Figure 13 with

3 * 3 Pixel Matrix

4	8	2
7	3	0
1	0	5

Pixel Matrix after Replication Padding

4	4	8	2	2
4	4	8	2	2
7	7	3	0	0
1	1	0	5	5
1	1	0	5	5

Figure 12: Padding Operation

Stride 1 to make convolutional operation on the $5 * 5$ image shown in Figure 12 with replication padding result. Later, we can generate the new $4 * 4$ pixel matrix.

0	1
1	2

Figure 13: $2 * 2$ Convolutional Filter

Now, refer to the Figure 14 to understand some example steps of Convolution Operation.

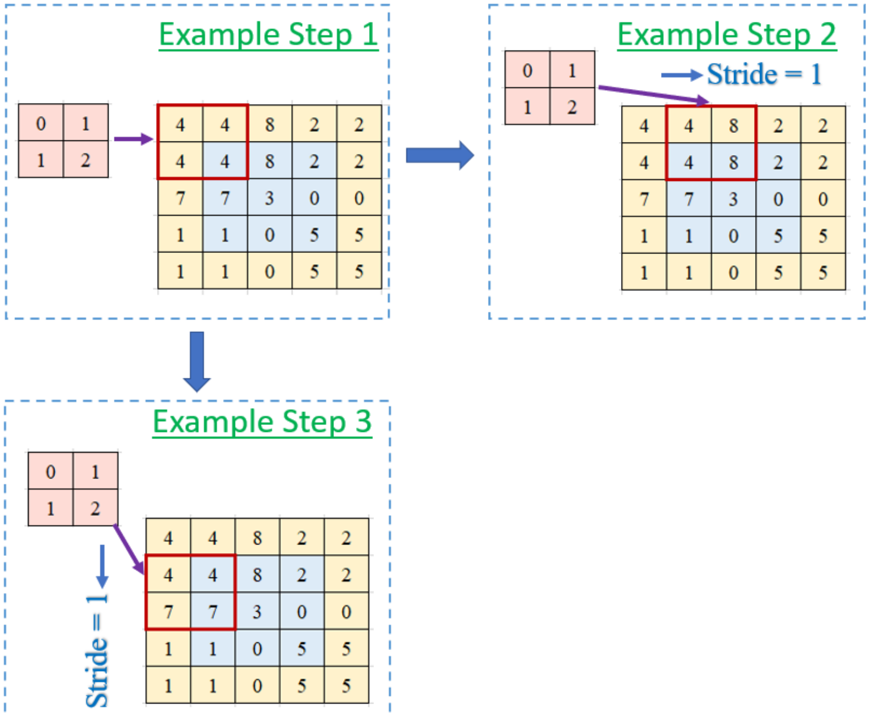

Figure 14: Example steps of Convolution Operation

1. **Example Step 1:** The first new generated pixel can be the left corner pixel. Its value is $0 * 4 + 1 * 4 + 1 * 4 + 2 * 4 = 16$.
2. **Example Step 2:** From Step 1, we move the convolutional filter right for 1 cell. Then the new generated pixel can be $0 * 4 + 1 * 8 + 1 * 4 + 2 * 8 = 28$.
3. **Example Step 3:** From Step 1, we move the convolutional filter down for 1 cell. Then the new generated pixel can be $0 * 4 + 1 * 4 + 1 * 7 + 2 * 7 = 25$.

The 3 result pixel values from Example Step 1, 2, and 3 have been filled to the relevant purple cells of the $4 * 4$ result matrix shown in Figure 15. Following the procedures from Example Step 1 to 3, please fill in the remaining thirteen new pixel values in the green cell area.

16	28	A	B
25	C	D	E
F	G	H	I
J	K	L	M

Figure 15: Result Matrix after Convolutional Operations

Enter the value of "A" here: 14

Enter the value of "B" here: 8

Enter the value of "C" here: 21

Enter the value of "D" here: 5

Enter the value of "E" here: 2

Enter the value of "F" here: 10

Enter the value of "G" here: 4

Enter the value of "H" here: 10

Enter the value of "I" here: 15

Enter the value of "J" here: 4

Enter the value of "K" here: 1

Enter the value of "L" here: 15

Enter the value of "M" here: 20

(b) (2 points) Maximum pooling is to first divide an image into several disjointed sub-regions and each sub-region has $n * n$ (n is a positive integer value and $n \geq 2$) pixel elements. Then, it will extract the maximum value from each $n * n$ sub-region. The $4 * 4$ gray image shown in Figure 16 is an image that awaits pooling operation. In the lower $2 * 2$ blue cells shown in Figure 17, fill in the result of $2 * 2$ maximum pooling for its $4 * 4$ gray image shown in Figure 16.

15	10	2	6
7	4	0	8
3	12	20	3
5	1	10	0

Figure 16: The Image Awaiting Pooling Operation

A	B
C	D

Figure 17: Maximum Pooling $2 * 2$ Result

Enter the value of "A" here: 15

Enter the value of "B" here: 8

Enter the value of "C" here: 12

Enter the value of "D" here: 20

(c) (2 points) Average pooling is another pooling method that is very similar to maximum pooling. Average pooling is to first divide an image into several disjointed sub-regions and each sub-region has $n * n$ (n is a positive integer value and $n \geq 2$) pixel elements. Then, it will extract the average value from each $n*n$ sub-region. Please use the same image (Figure 16) to perform average pooling. In the $2 * 2$ purple cells shown in Figure 18, fill in the result of $2 * 2$ average pooling result for the above $4 * 4$ gray image (Figure 16). **Please round to the nearest integer value.**

A	B
C	D

Figure 18: Average Pooling $2 * 2$ Result

Enter the value of "A" here: 9

Enter the value of "B" here: 4

Enter the value of "C" here: 5

Enter the value of "D" here: 8

You can add your notes on this page (if any)

Problem 8: Pattern Recognition through Time [13 points]

Dynamic Time Warping (DTW) - Tutorial

Dynamic time warping is an algorithm that can be used to determine the similarity between two time-series sequences. We can perform DTW with two signals and a grid,

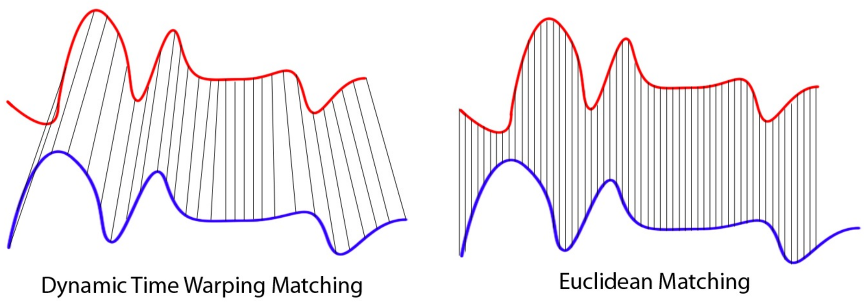

Figure 19: DTW and Euclidean Matching

A = [4,6,8,8,5,4,3,7]

B = [3,4,6,9,8,5,2,6]

where each square is computed as shown in Figure 20.

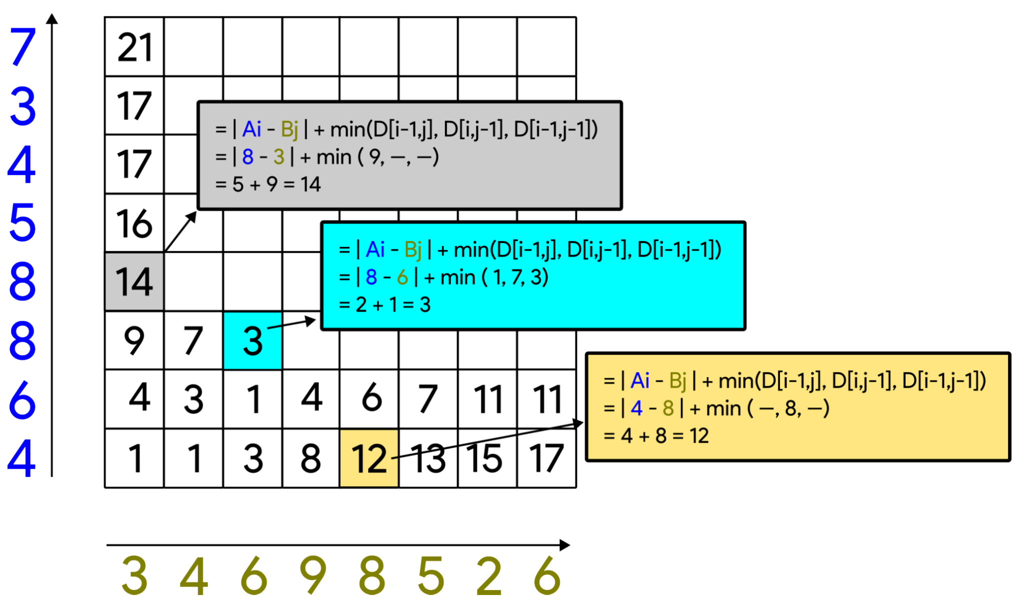

Figure 20: Working of DTW

Identify the lowest path along the grid, from the start (bottom left) to the end (top right). At each step, you can move diagonally, left, or down. In the case of a tie with the same values, **move diagonally**.

The path from our example, as shown in Figure 21 is $1-1-1-2-2-2-3-4-5$, going from the start (bottom left) to the end (top right).

Question:

Dr. Ye Wenjie is an astrophysicist at Red Coast Base who monitors solar radiation. Dr. Wenjie routinely performs dynamic time warping on the data she collects. One day, she steps outside for some fresh air

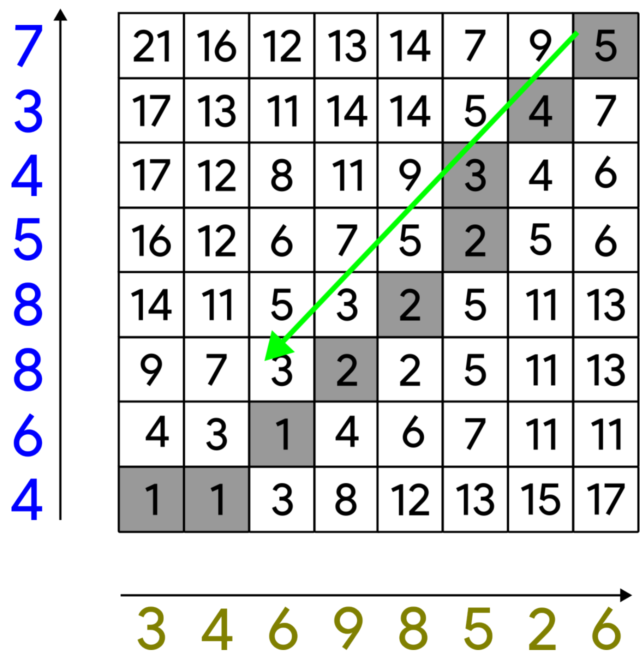

Figure 21: Path for DTW

and returns to her console to three different signals.

Signal_A = [3, 2, 0, 1, 4, 5, 6, 7, 2, 2, 1]
Signal_B = [4, 2, 1, 0, 5, 5, 7, 7, 3, 2, 1]
Signal_C = [5, 3, 1, 7, 8, 6, 9, 8, 6, 3, 2]

(a) (6 points) Perform DTW on the signals displayed on Dr. Wenjie's console. Enter the distance and path between the three pairs. Make sure you get full credit by writing your path with values separated by hyphens (e.g, 1-2-3-4-5-6). Grids are provided for your convenience and will not be graded.
Compute distance with the following formula,

$$Distance = \sqrt{\sum_{i=1}^{L-1}(v_i - v_{i+1})^2}$$

where v_i is an element in your path (e.g, $v = 1, 2, 3, 4, 5$), and L is the length of your path.

(Signal_A, Signal_B) Distance: 2.236068

(Signal_A, Signal_B) Path: 1-1-2-3-4-4-5-5-6-6-6

(Signal_B, Signal_C) Distance: 4.795832

(Signal_B, Signal_C) Path: 1-2-2-3-5-8-9-11-12-13-13-13-14

(Signal_C, Signal_A) Distance: 5.291503

(Signal_C, Signal_A) Path: 2-3-4-4-7-10-10-12-13-14-15-15-16

Optional Calculations for (Signal_A, Signal_B):

1	23	17	16	17	17	17	19	21	9	7	6
2	20	16	17	19	13	13	15	15	7	6	7
2	18	16	17	19	10	10	10	10	6	6	7
7	16	18	19	21	7	7	5	5	9	14	19
6	13	13	14	15	5	5	5	6	9	13	18
5	11	9	9	10	4	4	6	8	10	13	17
4	10	6	5	6	4	5	8	11	12	14	17
1	10	4	2	3	6	10	16	22	24	22	20
0	7	3	2	2	7	12	17	22	23	21	20
2	3	1	2	4	7	10	15	20	20	19	20
3	1	2	4	7	9	11	15	19	19	20	22
	4	2	1	0	5	5	7	7	3	2	1

Figure 22: (Optional) DTW Calculations for (Signal_A, Signal_B)

Optional Calculations for (B,C):

1	26	20	18	22	23	20	23	25	24	16	14
2	22	18	18	16	17	15	18	21	19	14	13
3	19	17	19	11	12	11	15	16	15	13	14
7	17	19	21	7	8	9	11	12	13	17	22
7	15	15	17	7	8	9	11	12	13	17	22
5	13	11	11	7	8	9	13	16	17	19	22
5	13	9	7	5	8	9	13	16	17	19	22
0	13	7	3	9	16	21	28	32	34	31	29
1	8	4	2	8	15	19	24	28	30	28	27
2	4	2	3	8	14	16	21	25	27	26	26
4	1	2	5	8	12	14	19	23	25	26	28
	5	3	1	7	8	6	9	8	6	3	2

Figure 23: (Optional) DTW Calculations for (Signal_B, Signal_C)

Optional Calculations for (A,C):

1	31	30	32	33	27	24	22	23	15	15	16
2	30	31	34	36	25	21	18	18	15	16	18
2	30	31	34	36	24	19	15	14	17	21	26
7	27	28	31	33	22	18	15	13	18	24	29
6	22	23	26	28	18	15	13	12	18	22	27
5	16	17	20	21	13	11	10	11	15	19	24
4	13	14	16	17	11	10	11	11	16	21	27
1	8	8	10	10	7	9	10	10	15	20	26
0	4	3	4	4	7	11	16	20	19	20	20
2	2	3	6	8	9	11	14	18	19	20	22
3	2	5	10	14	15	15	16	18	21	24	28
	5	3	1	7	8	6	9	8	6	3	2

Figure 24: (Optional) DTW Calculations for (Signal_C, Signal_A)

(b) (1 point) From these results, which signal is most likely an anomaly (farthest from the other signals)?

Signal A ☐ Signal B ☐ Signal C ★

Dr. Wenjie wants to confirm her findings but has a limited amount of compute credits remaining. She decides to apply a Sakoe-Chiba Band with her DTW as shown in Figure 25.

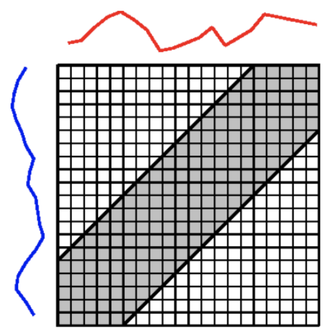

Figure 25: Sakoe-Chiba Bands

(c) (3 points) Suppose our band has a bound (cell from the center diagonal) of 0. What is the path and distance between Signal A and Signal C? Make sure you get full credit by writing your path with values separated by hyphens (e.g, 1-2-3-4-5-6).

(Signal_A, Signal_C) Distance: 9.110434

(Signal_A, Signal_C) Path: 2-3-4-10-14-15-18-19-23-24-25

(d) (3 points) Suppose our band has a bound (cell from the center diagonal) of 1. What is the path and distance between Signal A and Signal C? Make sure you get full credit by writing your path with values separated by hyphens (e.g, 1-2-3-4-5-6).

(Signal_A, Signal_C) Distance: 5.291503

(Signal_A, Signal_C) Path: 2-3-4-4-7-10-10-12-13-14-15-15-16

Optional Calculations for (Signal_A, Signal_C):

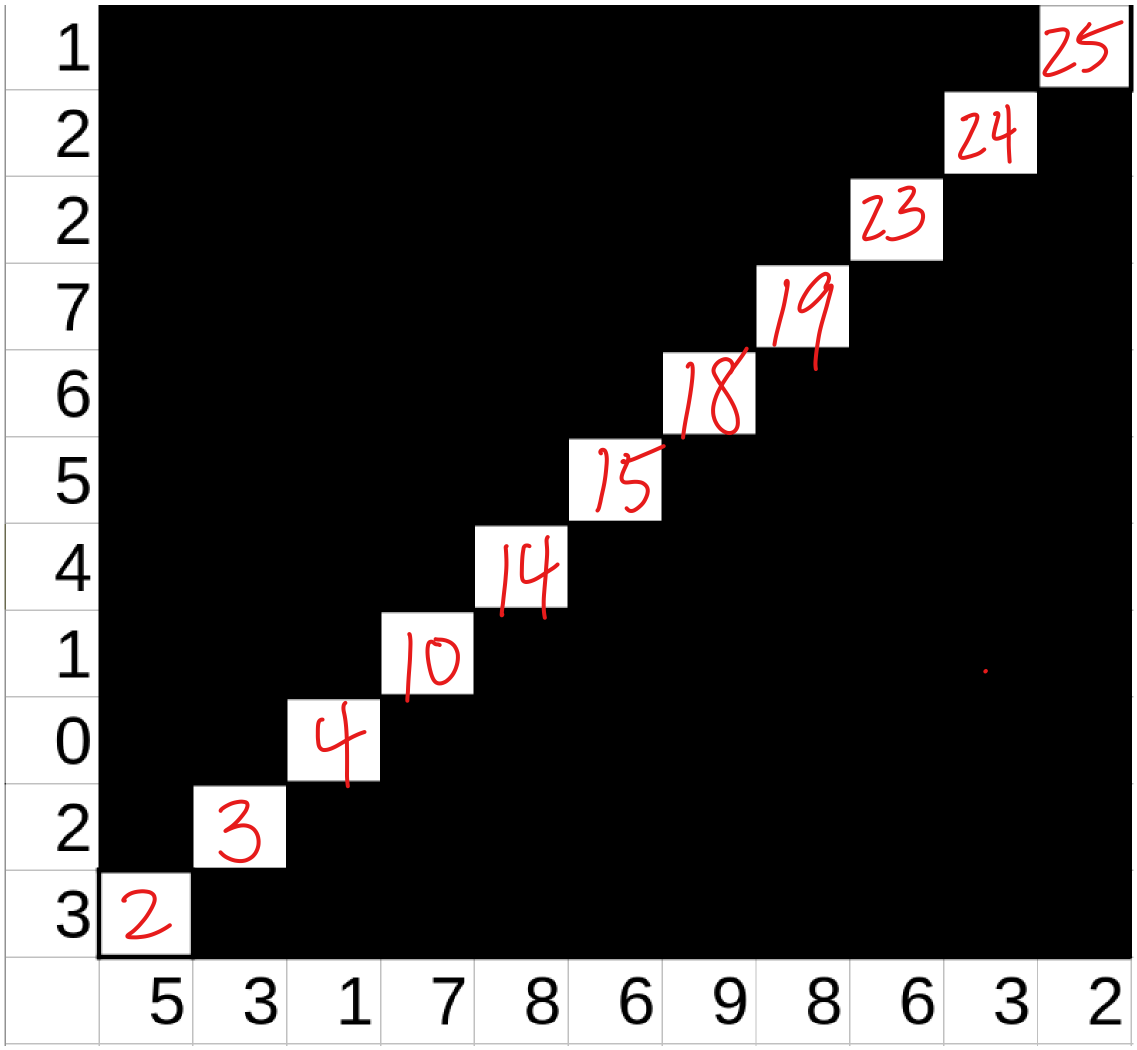

Figure 26: (Optional) DTW Calculations for (Signal_A, Signal_C) with Sakoe-Chiba Bounds with Margin 0

Optional Calculations for (Signal_A, Signal_C):

1										18	16
2									21	16	15
2								18	17	15	
7							12	13	14		
6						10	13	15			
5					10	11	15				
4				7	11	13					
1			4	10	17						
0		6	4	10							
2	5	3	3								
3	2	2									
	5	3	1	7	8	6	9	8	6	3	2

Figure 27: (Optional) DTW Calculations for (Signal_A, Signal_C) with Sakoe-Chiba bounds with Margin 1

You can add your notes on this page (if any)

Problem 9: Logic & Planning [11 points]

Being part of Netflix's creative development team, you and your friend are tasked with generating a script for a new Netflix original film.

Task 1: Picking a story

Despite being a prolific scriptwriter, your friend is finding it difficult to pick between two story ideas for the script of a new Netflix original. Being stuck for a couple of days, they approach you for help. Having taken Artificial Intelligence at Georgia Tech, you decide to take a data-driven approach, putting what you have learned to use. Your friend has conducted a study that involved several stakeholders including creative executives, directors, audience, and screenwriters. From the study, it was found that the following factors are extremely important in determining the success of a Netflix original film:

1. *HasTexture (HT)* - Whether or not characters introduced in the story are relatable.
2. *isFastPaced (FP)* - Whether or not the story has suspenseful action sequences.
3. *IsOriginal (IO)* - Although it depends on the viewers' knowledge, culture, and preferences, it is important to measure whether a story is original given the viewers' background.
4. *HasHeroArc (HA)* - Whether or not the story contains the Hero Arc

By analyzing the data collected during the study, your friend tells you that the success of a chosen story (*isSuccessful*) is dictated by the following logic shown in Figure 28:

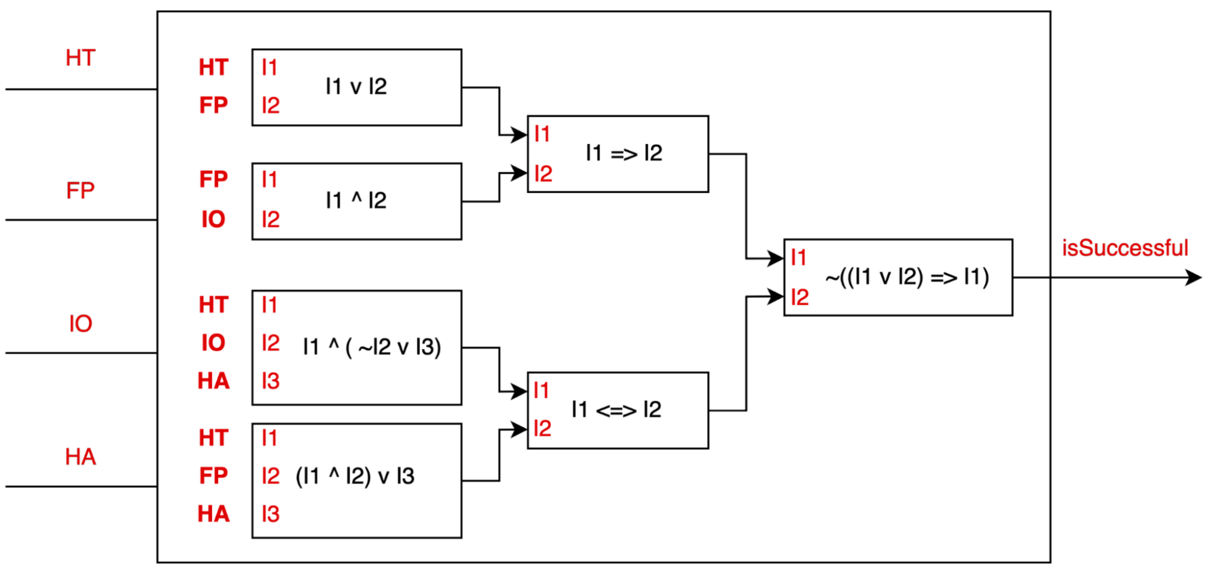

Figure 28: Logic dictating whether a film is successful or not based on the four aforementioned factors

Given your background in computer science, you decide to pick the story that will be successful based on historical data which is encoded by the following truth table. Suppose T = True and F = False. Inputs HT, GP, IO, and HA are either T or F inputs. '~' is equivalent to 'not.' Each of the inputs can be mapped to the factors discussed earlier as shown in Figure 29:

Factor	Symbol in Figure 1
hasTexture	HT
isFastPaced	FP
isOriginal	IO
hasHeroArc	HA

Figure 29: Factor-Symbol Table

hasTexture	isFastPaced	isOriginal	hasHeroArc	isSuccessful
F	F	F	F	A
F	F	F	T	B
F	F	T	F	C
F	F	T	T	D
F	T	F	F	E
F	T	F	T	F
F	T	T	F	G
F	T	T	T	H
T	F	F	F	I
T	F	F	T	J
T	F	T	F	K
T	F	T	T	L
T	T	F	F	M
T	T	F	T	N
T	T	T	F	O
T	T	T	T	P

Figure 30: Truth Table

(a) (4 points) Fill out the output values in Figure 30 for all possible inputs. (Write T for True and F for False)

Enter the value of "A" here: F

Enter the value of "B" here: F

Enter the value of "C" here: F

Enter the value of "D" here: F

Enter the value of "E" here: T

Enter the value of "F" here: F

Enter the value of "G" here: F

Enter the value of "H" here: F

Enter the value of "I" here: F

Enter the value of "J" here: T

Enter the value of "K" here: T

Enter the value of "L" here: T

Enter the value of "M" here: T

Enter the value of "N" here: T

Enter the value of "O" here: F

Enter the value of "P" here: F

(b) (1 point) Your friend tells you a bit more about each of the two stories they are deciding between.

1. The first, dubbed Mostly Famous, is a fast-paced action narrative with no Hero Arc and unrelatable characters but a rather original plot.
2. The second story is dubbed The Dinner Club; It is a slow-paced film with a very typical narrative centered around a hero's journey that almost anyone can connect with.

Refer to the truth table you have filled in above and determine which of the two stories the team should go with to make a successful film.

Mostly Famous ☐ The Dinner Club ★

Task 2: Automated story generation

Now that you have both decided which story idea to go with, you embark on writing the full script with the assistance of an automatic story generator. Automated story generators are intelligent systems that produce fictional stories from a minimal set of inputs. There are multiple ways to use systems to generate stories. With the recent advances in deep learning, especially in natural language processing, deep learning-based approaches leveraging Generative Pre-trained Transformer (GPT) have become extremely popular. This was not always the case. Prior to the proliferation of deep learning, non-learning story generation approaches such as those leveraging story grammars and story planners were extremely popular.

While many of the engineers at Netflix research have been exploring end-to-end deep learning-based approaches, your friend and you are not sure if relying solely on deep language models is the best way forward. Hence, you decide to stick with a hybrid approach where you write part of the story and an automated system generates some missing parts. This can be achieved using planners, which leverage PDDL (Planning Domain Definition Language) to complete partially written stories.

The story you have so far: (**Optional, but fun to read**)

On Jan 13, 2006, officers rush to establish a perimeter around a branch of Peace Bank, Italy's prominent financial institution, as a single security guard walked out of the bank, with his gun disassembled.

The thieves disassembled and emptied the weapon before permitting the guard to leave. Inside the bank, mayhem. There are four thieves in the bank, costumed in various disguises, and now they are trapped, along with 15 other hostages. The streets are swarming with police, who soon established radio contact with one of the robbers, who calls himself, Walt. The thieves knew they were surrounded, Walt said, but they weren't yet ready to give up. And until they were, the police had better stay back. Nobody wanted to see another Milano.

The heist in the town of Milano was infamous. Six years earlier, four armed men had burst into another bank, not far from this one. On this day, the thieves held hostages and, during an attempted escape, used them as human shields. That's when things got out of control. The police opened fire, killing a robber and several hostages. Milano was a national scandal, but what made it especially terrible is that the fiasco played out on live television.

Now, in Verona, the news cameras had arrived again, training their lenses on the scene as several hundred cops surrounded the bank and cordoned the nearby streets. Every available perch that afforded a view of the bank was occupied by snipers and photographers.

For more than six hours, the country was transfixed. The police had nicknamed Walt "the Gray Goose." He was instantly famous. Walt kept claiming that the hostages were treated well. The mood inside seemed eerily ebullient: At one point, Walt and another robber were heard singing "Happy Birthday" to one of the bank employees whose phone had been buzzing with birthday messages from family members. At 3 pm in the afternoon, Walt asked for pizzas; the hostages were extremely hungry, he claimed. A couple of minutes later, Walt goes silent.

For several hours, the police and city officials fretted over what to do as further attempts to reach Walt were to no avail. The special forces finally take up position outside the bank and at 8 pm they burst inside. To the surprise of the special forces, there was no shootout. In fact, there was no commotion and no sign of the thieves anywhere. The hostages were dispersed on four floors—the lobby level, a mezzanine space, the manager's office, and down in a basement conference room. None of the hostages were harmed.

The police swept every inch of the bank's four floors but failed to locate a single member of the crew.

The bank had only two exits—both of which had been covered by police since the siege began. All of the building's windows were intact. And the robbers were not hiding among the hostages. They'd simply vanished, with contents from over half of all 1000 safety deposit boxes that lined the basement walls of the bank. In an affluent place like Verona in 2006 where the richest of the Italians kept their valuables, no one knew what was grabbed or where the bandits had gone with all the valuables. It was as though hundreds of millions of dollars just disappeared into thin air.

To be continued...

Your task is to continue the story by designing some aspects of the planner using PDDL. What happened to the robbers?

1. Walt drills a hole and hands the valuables to his crew in the underground tunnels.
2. The bandits pass the police in the underground tunnels without getting noticed by the police, and then
3. the bandits transfer the loot into a parked getaway van and escape.

Notations:
Walt - character (c1)
Walt's bandit crew - character (c2)
Police - character (c3)
Getaway driver - character (c4)
Valuables - v
Place1, Place2, Place3 - p1,p2,p3

Actions:
1. MoveValuables(c1,v,p1,c2)
2. PassPolice(c1,c2,v,p2,p3,c3)
3. GetAway(c1,c2,v,c4,p3)

Types: <Subtype - Supertype> (a type with no Superclass is the Superclass of all types)
Object
Location - Object
Place - Location
Character - Object
Valuables - Object

Predicates:
Object(o) - returns true if **o** is an object.
Valuables(v) - returns true if **v** is valuables.
Place(p) - returns true if **p** is a planet.
Character(c) - returns true if **c** is a character.
MeetCrew(c,f) - returns true if a character **c** meets a character **f**, and **f** is a friend of **c**.
SeePolice(c, a) - returns true if a character **a** is the authorities, and character **c** gets noticed by the authorities **a**.
Hold(v,c) - returns true if **v** is valuables, **c** is a character and character **c** is holding the valuables **v**.
At(c,p) - returns true if **p** is a place, **c** is a character, and character **c** is on the place **p**.
Pass(v,c1, c2) - returns true if **v** is valuables, **c1**, and **c2** are characters and valuables **v** are being passed to character **c2** from **c1**.

Escape(v, c1, c2, c3) - returns true if **v** is valuables, **c1**, **c2**, **c3** are characters, and valuables **v** are with all three characters and everyone escapes.

Initializations:
init(character(c1) ∧ character(c2) ∧ character(c3) ∧ character(c4) ∧ valuables(v) ∧ place(p1) ∧ place(p2) ∧ place(p3))

(c) (2 points) You want to add the action MoveValuables(c1,v,p1,c2), this action will cause Walt (c1) to pass the valuables (v) to his crew (c2) in Place1 (p1) after he has drilled a hole. Given the Preconditions, you have to select the effects from the options below.
Preconditions: At(c1,p1) ∧ Hold(v, c1) ∧ At(c2,p1) ∧ MeetCrew(c1,c2)

Select the applicable clauses for the effect (Postconditions) from the below options.

- [ ] ~At(c2,p1)
- [x] Pass(v, c1, c2)
- [ ] SeePolice(c1,c3)
- [x] Hold(v, c2)
- [ ] Pass(v, c1, c3)
- [ ] Hold(v,c1)

(d) (2 points) You want to add the action PassPolice(c1,c2,v,p2,p3,c3), this action will cause Walt (c1) and his crew (c2) to pass the police barricades (p2) without getting noticed by the police (c3), and finally reach the beach (p3) to getaway while holding the valuables (v). Given the Preconditions, you have to select the effects.
Preconditions: Hold(v,c1) ∧ Hold(v,c2)

Select the applicable clauses for the effect (Postconditions) from the below options.

- [ ] Hold(v, c1)
- [ ] Hold(v, c2)
- [ ] ~Hold(v,c2)
- [ ] SeePolice(c2,c3)
- [ ] At(c3,p2)
- [x] At(c1,p3)
- [x] At(c2,p3)

(e) (2 points) you want to add the action GetAway(c1,c2,v,c4,p3), which will cause Walt (c1) and the rest of his bandit crew (c2) to pass the valuables (v) to the getaway driver (c4) in the van at the beach (p3). Given the effects, you have to select Preconditions.

Effect (Postcondition): Hold(v,c1) Λ Hold(v,c2) Λ Pass(v, c4) Λ Hold(v,c4)

Select the applicable clauses for the Preconditions from the below options.

- ☐ Escape(v, c1,c2, c4)
- ✔ At(c2,p3)
- ✔ At(c1,p3)
- ☐ Hold(v,c3)
- ☐ Hold(v,c4)
- ☐ SeePolice(c1,c3)

You can add your notes on this page (if any)

Problem 10: Planning under Uncertainty [15.5 points]

Note: please review chapter 17 of AIMA

Each quarter the marketing manager of a retail store divides customers into three classes based on their purchase behavior in the previous quarter. Denote the classes as L for low, M for medium and H for high. The manager wishes to determine to which classes of customers he/she/they should send quarterly printed catalogs. The cost of sending a catalog is $15 per customer and the expected purchase depends on the customer's class and the manager's action.

If a customer is in class L and receives a catalog, then the expected purchase in the current quarter is $20, and if a class-L customer does not receive a catalog the expected purchase is $10. If a customer is in class M and receives a catalog, then the expected purchase is $30, and if a class M customer does not receive a catalog the expected purchase is $20. If a customer is in class H and receives a catalog, then the expected purchase is $50, and if a class H customer does not receive a catalog the expected purchase is $25.

The decision whether or not to send a catalog to a customer also affects the customer's classification in the subsequent quarter. If a customer is class L at the start of the present quarter and receives a catalog, then the probability the customer is in class L at the subsequent quarter is 0.3, and in class M 0.5. If the customer does not receive the catalog, the probability that the customer stays in class L is 0.5, and in class M 0.3.

If a customer is in class M in the current period, then the probability that the customer remains in class M in the subsequent quarter is 0.6 if they receive a catalog, and the probability of the customer being in class L is 0.1. If the customer does not receive the catalog, then there is a probability of 0.4 that the customer remains in class M and 0.3 in class L.

If a customer is class H in the current period, then the probability that they remain in class H in the subsequent period is 0.8 if the customer receives a catalog and 0.2 being in class M. Finally, with a probability of 0.4 the customer remains in class H if does not receive the catalog, and 0.3 in class M. Assume a discount rate of 0.9.

Suppose you are the manager and want to maximize the long-run expected total discounted reward. You formulated this problem as an infinite-horizon discounted Markov decision problem and attempted to solve it.

Throughout this question, let's denote the states of the problem as L, M, H, and denote the actions for each state by C (sending the catalog), and N (not sending). Additionally, denote the policy as π, and the utility function for each state as $U(\cdot)$, as the expected total sum of discounted rewards, where reward function denoted as $r(\cdot,\cdot)$, and denote the probability transition function as $p(s'|s,a)$, the probability transitioning to state s' given current state s and action a.

(a) (1 point) Compute the reward function (revenue you earn from each of the designated customer in each quarter)

Enter the value of $r(L,C)$ here: 5

Enter the value of $r(M,N)$ here: 20

(b) (1 point) Compute the transition probability

Enter the value of $p(M|L,N)$ here: 0.3

Enter the value of $p(H|H, C)$ here: 0.8

(c) (4.5 points) Policy Evaluation

Suppose that your current policy is $\pi(L) = N$, $\pi(M) = N$, $\pi(H) = C$. You wish to use policy evaluation to determine the utility of the current policy. So you perform **TWO** iterations of policy evaluation with the following initial values: $U_0(L) = 5$, $U_0(M) = 5$, $U_0(H) = 5$.

Fill up the table shown in Figure 31.

$U'(L)$	A
$U'(M)$	B
$U'(H)$	C

Figure 31: Table 1

Enter the value of A here: 30.25

Enter the value of B here: 43.4

Enter the value of C here: 67.85

(d) (3 points) Policy Improvement

Suppose that at some iteration, the current utility functions are given as $U(L) = 25$, $U(M) = 34$, $U(H) = 58$. Compute the current policy based on these utility functions to fill up the table shown in Figure 32.

$\pi(L)$	A
$\pi(M)$	B
$\pi(H)$	C

Figure 32: Table 2

Enter the value of A here: N

Enter the value of B here: N

Enter the value of C here: C

(e) (3 points) Value Iteration

Suppose that you start value iteration with the following initial values: $U_0(L) = 5$, $U_0(M) = 7$, $U_0(H) = 12$. Perform **ONE** iteration of Value Iteration and fill in the table shown in Figure 33.

$U_1(L)$	A
$U_1(M)$	B
$U_1(H)$	C

Figure 33: Table 3

Enter the value of A here: 16.3

Enter the value of B here: 27.11

Enter the value of C here: 44.9

(f) (3 points) Determine the current policy using the utility function you just computed in (e). Fill in the table shown in Figure 34.

$\pi(L)$	A
$\pi(M)$	B
$\pi(H)$	C

Figure 34: Table 4

Enter the value of A here: N

Enter the value of B here: N

Enter the value of C here: C

If you wish to learn more about Markov Decision Processes and Reinforcement Learning, please check out the following references (**Note that this resource is not a requirement to solve this question**)

References:

Markov decision process by Puterman

Reinforcement Learning: an introduction by Sutton and Barto

You can add your notes on this page (if any)

Problem 11: Extra Credits: Bonus Question [3 points]

SURPRISE!

This is another opportunity to gain extra credits in this course. Although the first page of this PDF mentions total marks as 103, the last 3 points will be considered as bonus points and your exam grade will be considered out of 100. (If you solve the following question correctly, 3 points will be added to your total grade. So, the maximum you can score in this exam is 103 out of 100)

Here is the bonus question:

Solving the following 8-puzzle from start state to goal state, the order of moving tiles is "left, right, top, down" when breaking ties ('Moving' means swapping the empty spot with the tile next to it). For example, if state (a) and state(c) were tied, explore state (a) first, since tile 1 is on the left side and tile 8 is on top of the empty spot of start state. Once explored, the state could not be revisited.

Two heuristic functions were available: $h1(n)$ = the number of misplaced tiles and $h2(n)$ = the sum of the Manhattan Distance between each misplaced tile and their destination. For example, $h1(n)$ of start state is 3 because three tiles (1, 2 and 8) are misplaced when compared with goal state, $h2(n)$ of start state is 4, because the Manhattan Distance of misplaced tiles (1,2 and 8) to their spots in goal state is 1, 1 and 2 respectively.

Now using A^* search to solve the puzzle: the total cost is defined as $f(n) = g(n) + h(n)$. Here, $g(n)$ is defined as the steps from the start to reach the state. For example, $g(n)$ is 0 for the start state and $g(n)$ is 1 for state (a) and (b). Check this link to see how the 8-puzzle is solved if it is still not clear. Apply A^* search using $h1$ or $h2$ and answer the following questions:

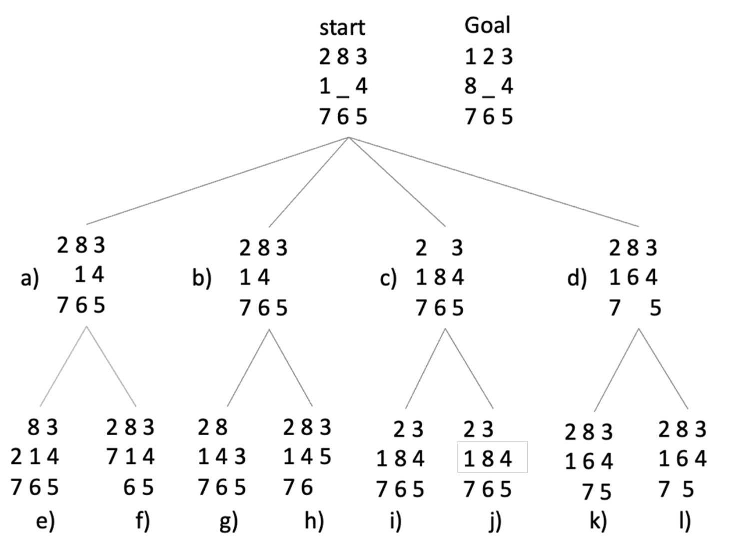

Figure 35: 8-puzzle

(a) (0.5 points) What is the total cost for state a ($f(n)$ of state a), if $h1(n)$ was used as heuristic?

Type Your Answer Here: 4

(b) (0.5 points) What is the total cost for state f ($f(n)$ of state f), if $h2(n)$ was used as heuristic?

Type Your Answer Here: 8

(c) (1 point) Which state is the closest to the goal state (fewest steps needed to reach the goal state)?

- ☐ e
- ☐ f
- ☐ g
- ☐ h
- ☑ i
- ☐ j
- ☐ k
- ☐ l

(d) (1 point) Which heuristic performs better in solving this puzzle (reaches goal first)?

$h1(n)$ ☐ $h2(n)$ ★

You can add your notes on this page (if any)

Checklist

Mark all the boxes from the checklist below to make sure you have taken care of each of the points listed:

1. I have read the pinned Ed post with the title "Final Exam Clarifications Thread" and I am familiar with all of the clarifications made by the Teaching staff.

   I Confirm ✔

2. All answers with more than 6 digits after the decimal point have been rounded to 6 decimal places.

   I Confirm ✔

3. All the pages in my submission PDF are in the correct order in which they were presented to me and none of the pages are missing/removed.

   I Confirm ✔

4. Any extra pages (excluding the pages provided after each question) are only attached at the END of this exam, after page number 60, with clear pointers to wherever the actual answer is in the PDF (references are made properly).

   I Confirm ✔

5. I am submitting only one PDF and nothing else (no docx, doc, etc.).

   I Confirm ✔

6. The PDF that I am submitting is not blank (unless I want it to be blank).

   I Confirm ✔

7. I will go over the uploaded PDF on the 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 Confirm ✔

8. I have submitted a copy of my submission PDF to the Canvas.

   I Confirm ✔