CS 188 Fall 2024 | Introduction to Artificial Intelligence | Written HW1

- **Due:** Tuesday 9/10 at 11:59pm.
- **Policy:** Can be solved in groups (acknowledge collaborators) but must be submitted individually.
- **Make sure to show all your work and justify your answers**.
- **Note:** This is a typical exam-level question. On the exam, you would be under time pressure, and have to complete this question on your own. We strongly encourage you to first try this on your own to help you understand where you currently stand. Then feel free to have some discussion about the question with other students and/or staff, before independently writing up your solution.
- Your submission on Gradescope should be a PDF that matches this template. Each page of the PDF should align with the corresponding page of the template (page 1 has name/collaborators, question begins on page 2.). **Do not reorder, split, combine, or add extra pages**. The intention is that you print out the template, write on the page in pen/pencil, and then scan or take pictures of the pages to make your submission. You may also fill out this template digitally (e.g. using a tablet.)

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|---|---|
| First name | |
| Last name | |
| SID | |
| Collaborators | |

# Q1. [6 pts] Robot in a Factory

Suppose a factory floor has width $W$ and length $L$. There are $P$ packages on the factory floor at the start. The robot is able to move North, South, East, or West on the floor.

**(a)** [3 pts] For this subquestion only, the position of the robot is known, and it wants to pick up all $P$ packages in the factory. However, the robot can move North at most 2 times overall.

What is the minimal size of the state space for this problem? Write your answer in the box as a product of terms that reference problem quantities (such as, but not limited to, $W$, $L$, and $P$). You may also use constants as part of your expression. For each term in your expression, also state the information it encodes. For example, you might write "$4 \times WL$" and write "number of directions" under the first term and "robot's position" under the second term. You will receive partial credit for a complete but non-minimal state space.

$WL \times 2^P \times 3$.

Robot's position, a boolean vector representing whether a certain package has been picked up, and the number of times the robot has moved North (could be 0, 1, or 2).

**(b)** [3 pts] In this subquestion, the robot is lost on the factory floor and does not know its location. However, the robot wants to visit every single square (it does not care about collecting the packages anymore). The robot's task is to find a sequence of actions that guarantees it will visit every single square.

What is the size of a minimal state space for this problem? As in part **(a)**, give your answer as a product of terms along with the information encoded by each term. You will receive partial credit for a complete but non-minimal state space.

$WL \cdot 2^{WL}$

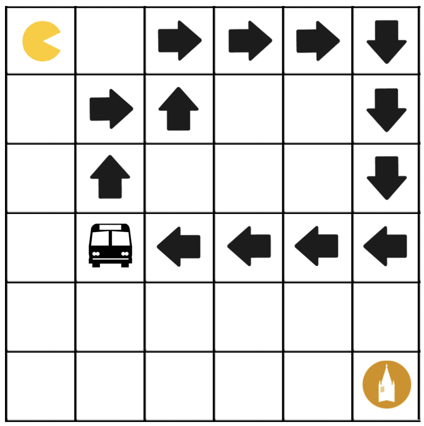
For every possible unknown starting location $p \in W \cdot L$, we need a boolean to keep track of all locations in $W \cdot L$ we've visited and haven't visited, given we started from $p$. In other words, we need $WL$ sets of $WL$ booleans, which results in $WL \cdot 2^{WL}$.

# Q2. [10 pts] Pacman Goes to School!

Pacman lives far from his university, so he decides to model his daily commute as a search problem. He imagines the city of Berkeley as an $M$ by $N$ square grid, where his apartment is the top left square; his goal is to reach Dwinelle Hall, located in the bottom right square in the fewest number of timesteps. He can move *left, right, up,* or *down*, as long as he stays within the grid.

There is a single fixed bus route on the grid, where a bus travels in a loop at a constant rate of three squares per timestep. Any square along this route is a valid bus stop. Pacman knows the bus route, and if he's on the same square as the bus, **he can hop on and travel at a rate of three squares per timestep along the bus route.** He can stay on the bus for any number of timesteps and get off at any square adjacent to the route. However, Pacman's Clipper card only allows one ride per commute, so he can only board and disembark from the bus route at most once during his trip.

Below is an example initial state on a 6 by 6 grid. The arrows represent the bus route. Note that this is just an example route, and the actual bus route may vary. For the following questions, consider the general case, **not** this specific example. **Additionally, consider each part separately (i.e., do not carry over assumptions).**



**(a)** [2 pts] Which of the following are admissible heuristics? Select all that apply.

- [ ] The Manhattan distance between Pacman and the university.
- [x] The Manhattan distance between Pacman and the university divided by 4.
- [ ] The Manhattan distance between Pacman and the bus.
- [ ] The Manhattan distance between the closest bus stop to Pacman and the university.
- [ ] None of the above.

A. Not admissible: Pacman can reach the university in fewer timesteps than the actual number of spaces between if he takes the bus.

B. Admissible: At best, Pacman could reach the university by moving 3 spaces per timestep if he rides the bus the whole way. Thus, this heuristic underestimates the true cost of reaching the university.

C. Not admissible: Consider the case where Pacman is already next to the university; the best path may not involve Pacman's distance to the bus.

D. Not admissible: Consider the case where Pacman is already next to the university; the best path may not involve Pacman's distance to any bus stop.

**(b)** [2 pts] Suppose Pacman knows there is at least one bus stop adjacent to the university. Which of the following are admissible heuristics? Select all that apply.

- [ ] The Manhattan distance between Pacman and the bus.
- [ ] The Manhattan distance between the bus and the stop next to the university divided by 3.
- [ ] $\frac{1}{3}$ for all states.
- [ ] The minimum of the above heuristics.
- [x] None of the above.

A. Not admissible: The bus could be far from Pacman, while Pacman could be right next to the university.

B. Not admissible: The bus travels a fixed route, and its distance from the university does not represent how close Pacman is to his goal.

C. Not admissible: The heuristic's value at the goal state must be 0 for admissibility, even though it underestimates everywhere else.

D. Not admissible: The minimum would be admissible if one of the heuristics reached 0 at the goal state, because the third heuristic underestimates everywhere except the goal state; however, since none of them do, the minimum is still not admissible.

**(c)** [2 pts] Suppose that there are $B$ different buses with their own routes. Pacman can now ride the bus multiple times, but he must also ride a bus at least once. Which of the following are admissible heuristics? Select all that apply.

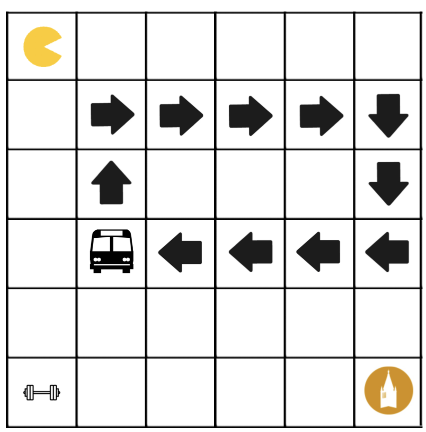
- [x] The minimum of the Manhattan distances between every bus stop and the university, and Pacman and the university.
- [ ] The number of times Pacman has ridden the bus so far.
- [ ] The Manhattan distance from Pacman to the closest bus stop plus the distance from that bus stop to the university divided by three.
- [ ] None of the above.

A. Admissible: Because Pacman must now ride a bus at least once, he must at least travel the Manhattan distance from the closest bus stop to the university at some point. After arriving at the bus stop, the Manhattan distance between Pacman and the university becomes the minimum number of steps necessary to reach the goal. The combination of these two is an admissible heuristic.

B. Not admissible: The number of times Pacman has ridden the bus is not indicative of how close Pacman is to reaching the goal state.

C. Not admissible: Once Pacman has already ridden the bus to the university, this is an overestimate because it recalculates the distance from Pacman to the closest bus stop even when he could go straight to the university.

**(d)** [2 pts] Suppose Pacman now wants to work out at the RSF (the campus gym), located in the bottom left square of the grid. It doesn't matter if he goes before or after reaching the university, but he must visit both locations. Below is an example initial state with the RSF represented by a dumbbell in the bottom left corner:



Which of the following are admissible heuristics? Select all that apply.

- [x] The minimum of the Manhattan distances between Pacman and the RSF, the RSF and the university, and Pacman and the university, divided by 3.
- [ ] The sum of the Manhattan distances between Pacman and the RSF, the RSF and the university, and Pacman and the university, divided by 3.
- [ ] The maximum of the above heuristics.
- [ ] None of the above.

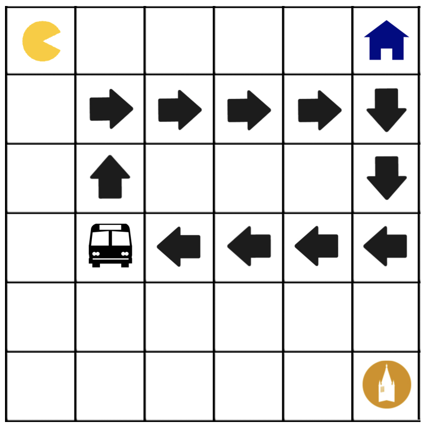
A. Admissible: From any space, Pacman is heading to either the RSF or the university, so the minimal Manhattan distance between him and either (divided by 3 assuming he could take the bus the whole way) is less than or equal to the timesteps necessary to reach a goal state.

B. Not admissible: Since Pacman only needs to reach either the RSF or the university before going to the other, summing the distance between Pacman and the RSF with the distance between Pacman and the university overcounts by a factor.

C. Not admissible: Generally, the maximum of admissible heuristics would be admissible, but since one of them is not, the maximum isn't.

**(e)** [2 pts] Suppose Pacman and his friend Xavier want to go to the university together today. Xavier lives in an apartment in the top right corner of the grid and wants to meet up with Pacman somewhere before they move together to the university. Assume that Xavier moves independently from Pacman, one space per timestep, and that they must meet in another square before either of them can go to the university. Xavier cannot take the bus, with or without Pacman (although Pacman can still take it alone). In this updated search problem, you can control both Pacman and Xavier.

Below is an example initial state with Xavier's apartment in the top right corner. Xavier is currently in his apartment:



Which of the following are admissible heuristics? Select all that apply.

- [ ] The Manhattan distance between Pacman and Xavier divided by 2.
- [x] The Manhattan distance from Xavier to the university.
- [x] The Manhattan distance from Pacman to the university divided by 3.
- [ ] None of the above.

A. Not admissible: Pacman traveling by bus could move toward Xavier faster than Xavier can move toward Pacman, making this an overestimate, since it assumes they move towards each other at the same rate.

B. Admissible: Because Xavier can't take the bus, he must at minimum move exactly the number of spaces between himself and the university at a rate of 1 space per timestep to reach the university.

C. Admissible: Wherever Pacman is in the grid, he must at minimum reach the university to end the search, so this is a relaxation of the problem where he just goes straight to the university via bus and ignores ever meeting Xavier. The solution to a relaxed problem is admissible.