Artificial Intelligence for Robotics II
Assignment 1 report

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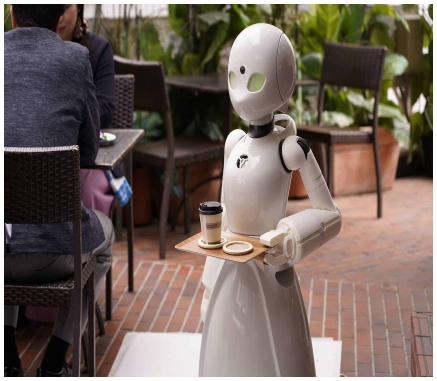
1 Introduction

The project consists of modeling a robotic coffee shop using an Artificial Intelligence approach. The goal is to find a sequence of instructions (i.e. a plan) to synchronize the actions of two types of robots, a barista and a waiter. The first one needs to prepare the drinks ordered by the customers, and the latter is in charge of serving the drinks and cleaning the table when the customers leave the table.
For our implementation of the model, the waiter is equipped with only one gripper so that it can take only one object at a time.

(a) Barman



(b) Waiter

The environment is organized into two main sections:

- The **bar:**

  where the barman will prepare the drinks and, when ready, put them on the bar counter so the waiter can pick them up in order to serve them to the customers.

- The **Tables:**

  where all the tables of the restaurant are set at given distances from the bar and from other tables. the waiter will serve the drinks (and eventually the biscuits) to the customers seated at the tables. An image of the coffee shop can be seen in Figure 2.

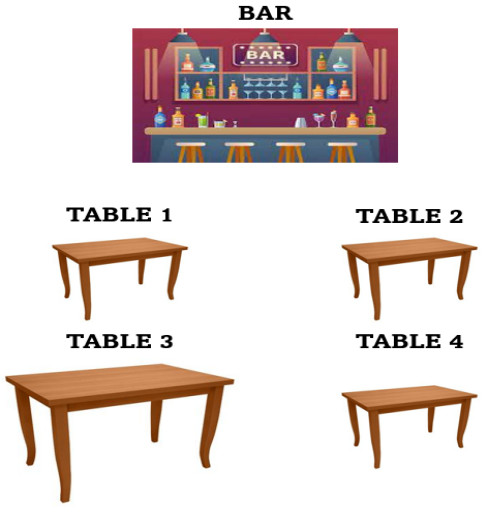


Figure 2: Illustration of the coffee shop

The cafeteria offers two types of drinks: *cold* and *warm*.
Warm drinks need 5 time units (tu) to prepare, while cold drinks need only 3 tu.
Moreover, according to the optional extension, warm drinks have to be served before they get too cold.

To recap the basic features of the two robots:

- the **barista:**
  1. is always located at the bar;
  2. prepares cold and warm drinks;
  3. puts the ready drinks on the bar counter.
- the **waiter:**
  1. is initially located at the bar;
  2. has only one gripper that can grasp objects;
  3. can only bring one drink at a time;
  4. moves at 2 meters per time unit ($2m/tu$);
  5. it takes 2 time units per square meter ($2tu/m^2$) to clean a table.

In addition to these base features, there are some optional extensions that may lead to a better but also more complex solution.

In particular, 3 additional properties have been implemented:

1. **"Warm drinks cool down"**: A warm drink takes 4 time units to become cold. A customer will not accept a warm drink delivered more than 4 time units after it was put on the bar by the barista.
2. **"Finish your drink"**: After receiving the drink, a customer will finish it in 4 time units, and will leave the table. When all the customers of a table have left, the waiter robot can clean it. The waiter robot is required to clean all the tables to complete the problem.
3. **"Serve food"**: The coffee shop is also serving biscuits. They need no preparation and can be picked up by the waiter at the bar counter. All the customers with cold drinks will also receive a biscuit after having received their drink. The waiter can not bring at the same time the drink and the biscuit but must deliver the drink, and then go back to the counter to take a biscuit for the customer.

2 Folder Organization

The project's folder is organized with the following subfolders:

- *ENHSP*: which contains the planner along with some examples on how to use it;
- *results*: which contains the plans corresponding to each problem file;
- *src*: this folder contains the source files for the implementation of the model, in particular:
  - *simple_model*: provides the base implementation of the assignment without any extensions;
  - *extended_model*: hold the implementation of the assignment with the extensions explained in the previous section.

3 Implementation

The code is written in *PDDL+*, so the best fit is to use the *ENHSP* planning engine, which stands for Expressive Numeric Heuristic Planner. It supports *PDDL+* along with numeric planning.
The implementation of the model is divided into:

- a *domain* file: defines the "universal" aspects of a problem;
- the *problem* files: each problem expresses the specific situations, given an initial state, for which the planner has to find a solution (reach the goal state).

3.1 Domain

The domain is divided into:

- *requirements*: the section that allows the inclusion of needed extensions;
  types: definition of the object types used in the problem;
- *predicates*: definition of predicated (which can be interpreted as boolean variables);
- *functions*: definition of fluents (which can be interpreted as numeric variables);
- *actions*: transformations of the state of the world that the planner can exploit to find a plan;
- *processes*: directly correspond to a durative action and last for as long as their pre-condition is met;
- *events*: directly correspond to instantaneous actions, and happen the instant their preconditions are met.

3.1.1 Types

In the domain, 4 different types have been used to define 6 different objects:

- **robot**: barman or waiter
- **location**: table or bar
- **drink**
- **biscuit**

3.1.2 Actions

This section describes in detail the development of each functionality of the model. Each one of them is composed of a sequence of action-process-event (with some exceptions):

- ***Move***: abilities the waiter to move around the environment, both if it's carrying or not a drink/biscuit. This action starts only if $steps \geq 0$, and this can happen only if the waiter has already picked up a drink or a biscuit. The *steps* predicate serves as a "robot's action counter" to prevent the robot to move randomly.

  In the *move_start* action, the robot is assigned the moving time with the following formula:

$$moving\_time = \frac{distance}{2}$$

Since the waiter moves at 2 meters per time unit. The *distance* function represents the distance between two locations and is defined in the problem.

Afterward, the robot begins the *move process*, which decreases the function associated with the robot moving time by one unit. This process will stop thanks to the *move_end* event when the moving time is exhausted, which allows the waiter to arrive at the destination. When this event occurs also the number of steps the waiter can do decreases by one unit.

The *steps* function has been introduced because we encountered a problem in the planning: without this function, the waiter was moving when not required. After the waiter performs an action (serve drink, serve biscuit, and clean a table), its value is reset to 2. This value has been chosen due to the particular architecture used: to go from the bar to the furthest tables (tables 3 and 4) the waiter has to pass by the intermediate tables (tables 1 and 2).

This was introduced supposing that the waiter has knowledge only of the distances given and can't perform sum operations.

- ***Prepare cold/warm drink***: with these actions the barman, if is *free*, i.e. when it is not already making another drink, can start preparing a drink. In this action the *preparing time* for the drink is assigned according to whether it is cold or warm: 3 time units for cold drinks and 5 time units for warm drinks.

  Then the barman can start the *prepare drink* process, which is the same for both types of drinks: it simply decreases the *preparing time* function.

  Finally, the process will stop when the event *drink_prep_end* is triggered. The predicate *ready drink* activates so the waiter can now pick it and serve it. In the case of a warm drink, it must be served to the customer within 4 time units. To make this happen, the predicate *priority_warm* is used to allow only the activation of the actions necessary to serve the drink. When the drink has been served the priority is deactivated and the waiter can perform other actions.

- ***Cooling***: this operation is used to keep track of the time that has passed since the end of the preparation of a warm drink. This action will be triggered only when the *priority_warm* predicate is activated by the *drink_prep_end* event if the drink is warm.

  Each warm drink will be served with the required priority and will respect the *cooling_time* so it will not be rejected by the customer. If this were not the case and the *cooling time* reaches value 0 before the drink has been served, then the *cooling_end* event would happen and the plan will be invalid. This will never happen thanks to the priority mentioned before. When a warm drink is served within the time limit the *cooling_cancel* event will flush the remaining cooling time and remove the cooling state.

- ***Pick/Serve drink***: these actions will make the waiter grasp the drink and serve it to the table that has ordered it.

  To keep count of the drinks to be served at a given table, the *drinks_to_serve_at_table* function will be decreased by one unit every time a drink is served at that table. This function counts how many drinks still need to be served at the table.

  When the drink is served, the barman becomes *free*: in this way, each drink will be prepared and served sequentially to prevent any drink to stay too long on the bar counter.

- ***Pick/Serve drink***: these actions will work in a similar way of the *pick and serve drink* actions. They simply grab the biscuit paired with the corresponding drink and serve it to the table where the paired drink is.

- ***Clean table***: this action is used to make the waiter clean a table, considering the area of the table that has to be cleaned.

  The tables that have to be cleaned are specified by the predicate *to_clean*. When this predicate is true because it is set in the initial conditions or because all the drinks at a table have been consumed, the action *clean_table_start* can begin and the *cleaning_time* function can be assigned according to the following formula:

  $$cleaning\_time = table\_area \times 2$$

  With the cleaning velocity of the waiter set to *2*.

  The *clean_process* will decrease the *cleaning_time* function every unit time. Finally, when the cleaning time runs out, the *clean_table_end* event occurs and the process will stop and mark the table as *cleaned*.

- ***Drinking***: this procedure will be triggered only for the last drink served at a table (just to reduce the number of calls to the drinking state).

  When the function *drinks_to_serve_at_table* reaches zero, we will know that all the customers at that table have received their drinks and, only at this point, we can start the *drinking_process*.

  The latter will decrease the *drinking_time* until it reaches zero and the *drinking_end* event occurs. When this event triggers, we subsequently activate the *clean_request* event that marks the table to be cleaned. Notice that this event will be triggered only after all drinks have been served and consumed, and after all biscuits have been served.

4 Results

4.1 Observations

As can be seen from the generated results, the more the problem is complicated, the greater the time to find a plan will be necessary. This is actually critical for the optional extensions which make the problems much more complicated to be solved.
To give a general overview of the results we decided to run the problems with two different algorithms, Greedy Best First Search (GBFS) and weighted A star (wA*). The timing results of the plans can be found in the next subsection.

4.2 Comparison

In the following section, we provided the comparisons between the different solutions found for each problem. The metrics used for the comparison are:

- **elapsed time**: time spent for the simulation;
- **search time**: time the planner spent to find the solution;
- **search time**: search time plus time to get to the solution;
- **search time**: time spent by the heuristic;
- **expanded nodes**: number of nodes actually expanded during the plan search;
- **evaluated states**: number of nodes predicted to be expanded during the plan search.

4.2.1 Extensions

Problem 1

- **Greedy Best First Search**: we obtained a solution with an expansion of 262 nodes (and 598 evaluated states) within the time indicated in Table 1:

Elapsed Time	26.5 ms
Search Time	201 ms
Planning Time	1619 ms
Heuristic Time	96 ms

Table 1: Problem 1 - GBFS

- **wA***: we obtained a solution with an expansion of 924 nodes (and 2322 evaluated states) within the time indicated in Table 2:

Elapsed Time	26.5 ms
Search Time	334 ms
Planning Time	2037 ms
Heuristic Time	198 ms

Table 2: Problem 1 - wA*

Problem 2

- **Greedy Best First Search**: we obtained a solution with an expansion of 1893 nodes (and 5625 evaluated states) within the time indicated in Table 3:

Elapsed Time	43.0 ms
Search Time	591 ms
Planning Time	2329 ms
Heuristic Time	426 ms

Table 3: Problem 2 - GBFS

- **wA***: we obtained a solution with an expansion of 7689 nodes (and 19017 evaluated states) within the time indicated in Table 4:

Elapsed Time	40.0 ms
Search Time	1344 ms
Planning Time	3278 ms
Heuristic Time	1004 ms

Table 4: Problem 2 - wA*

Problem 3

- **Greedy Best First Search**: we obtained a solution with an expansion of 38425 nodes (and 121900 evaluated states) within the time indicated in Table 5:

Elapsed Time	48.5 ms
Search Time	7087 ms
Planning Time	8888 ms
Heuristic Time	5926 ms

Table 5: Problem 3 - GBFS

- **wA***: we obtained a solution with an expansion of 21057 nodes (and 68106 evaluated states) within the time indicated in Table 6:

Elapsed Time	41.5 ms
Search Time	3822 ms
Planning Time	5706 ms
Heuristic Time	3186 ms

Table 6: Problem 3 - wA*

Problem 4

- **Greedy Best First Search**: we obtained a solution with an expansion of 48437 nodes (and 238426 evaluated states) within the time indicated in Table 7:

Elapsed Time	77.5 ms
Search Time	20656 ms
Planning Time	22286 ms
Heuristic Time	18738 ms

Table 7: Problem 4 - GBFS

- **wA***: we obtained a solution with an expansion of 194325 nodes (and 992826 evaluated states) within the time indicated in Table 8:

Elapsed Time	72.5 ms
Search Time	103705 ms
Planning Time	106026 ms
Heuristic Time	94970 ms

Table 8: Problem 4 - wA*

4.2.2 No extensions

Problem 1

- **Greedy Best First Search**: we obtained a solution with an expansion of 62 nodes (and 148 evaluated states) within the time indicated in Table 9:

Elapsed Time	16.5 ms
Search Time	182 ms
Planning Time	1783 ms
Heuristic Time	60 ms

Table 9: Problem 1 - GBFS

- **wA***: we obtained a solution with an expansion of 215 nodes (and 653 evaluated states) within the time indicated in Table 10:

Elapsed Time	15.5 ms
Search Time	342 ms
Planning Time	1931 ms
Heuristic Time	148 ms

Table 10: Problem 1 - wA*

Problem 2

- **Greedy Best First Search**: we obtained a solution with an expansion of 639 nodes (and 2199 evaluated states) within the time indicated in Table 11:

Elapsed Time	27.5 ms
Search Time	409 ms
Planning Time	1892 ms
Heuristic Time	209 ms

Table 11: Problem 2 - GBFS

- **wA***: we obtained a solution with an expansion of 2615 nodes (and 9202 evaluated states) within the time indicated in Table 12:

Elapsed Time	28.0 ms
Search Time	604 ms
Planning Time	1980 ms
Heuristic Time	386 ms

Table 12: Problem 2 - wA*

Problem 3

- **Greedy Best First Search**: we obtained a solution with an expansion of 515 nodes (and 1876 evaluated states) within the time indicated in Table 13:

Elapsed Time	33.5 ms
Search Time	262 ms
Planning Time	1400 ms
Heuristic Time	152 ms

Table 13: Problem 3 - GBFS

- **wA***: we obtained a solution with an expansion of 1549 nodes (and 5445 evaluated states) within the time indicated in Table 14:

Elapsed Time	32.5 ms
Search Time	487 ms
Planning Time	1911 ms
Heuristic Time	316 ms

Table 14: Problem 3 - wA*

Problem 4

- **Greedy Best First Search**: we obtained a solution with an expansion of 1880 nodes (and 9823 evaluated states) within the time indicated in Table 15:

Elapsed Time	54.5 ms
Search Time	1022 ms
Planning Time	2900 ms
Heuristic Time	771 ms

Table 15: Problem 4 - GBFS

- **wA***: we obtained a solution with an expansion of 78943 nodes (and 391390 evaluated states) within the time indicated in Table 16:

Elapsed Time	50.5 ms
Search Time	17570 ms
Planning Time	18876 ms
Heuristic Time	15741 ms

Table 16: Problem 4 - wA*