

# Informatics 2D Coursework 2: Planning with PDDL

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Deadline : **3pm, Thursday 28th March 2019**

## Introduction

This assignment is about planning using the **Planning Domain Definition Language (PDDL)**. It consists of three parts:

- Part 1 - A written exercise in which you will formalize a planning problem using **PDDL** (worth 40%).
- Part 2 - Implementing and verifying the correctness of your written model using a browser-based PDDL planner (worth 25%).
- Part 3 - Extending the model to deal with additional features (and constraints) in the environment (worth 20%)
- Part 4 - A discussion of how one would address yet another, much more complex, theoretical extension to the planning problem, which we have deliberately designed to test the limit of what can be done in PDDL (worth 15%)

This assignment is marked out of 100, and it is worth 12.5% of your overall grade for Inf-2D.

The files you need are available from:

[https://www.inf.ed.ac.uk/teaching/courses/inf2d/coursework/inf2d\\_assignment2.tar.gz](https://www.inf.ed.ac.uk/teaching/courses/inf2d/coursework/inf2d_assignment2.tar.gz)

In this document, you will find two icons:



means that the following sentence describes how to answer the question/task.



means this is a task that contributes to your overall grade.

## Submission

Create a directory in which you keep the files you submit for this assignment. This directory should be called `Inf2d-ass2-s<matric>` where `<matric>` is your matriculation number (e.g 0929508).

In this directory, write your answers to part 1 and 4 in a file you call `answers.txt`. For the implementation in parts 2 and 3, copy and edit the corresponding `*-template.pl` files, available in the coursework archive.

Submit your assignment by creating a new archive file from your directory `Inf2d-ass2-s<matric>`. You do this using the following command in a DICE machine:

```
tar cvzf Inf2d-ass2-s<matric>.tar.gz Inf2d-ass2-s<matric>
```

**Submit** this archive file using the command:

```
submit inf2d cw2 Inf2d-ass2-s<matric>.tar.gz
```

The deadline for submission is **3pm, Thursday 28th March 2019**.

You can submit more than once up until the submission deadline. All submissions are timestamped automatically. Identically named files will overwrite earlier submitted versions, so we will mark the latest submission that comes in before the deadline.

If you submit anything before the deadline, you may not resubmit afterward. (This policy allows us to begin marking submissions immediately after the deadline, without having to worry that some may need to be re-marked).

If you do not submit anything before the deadline, you may submit *exactly once* after the deadline, and a late penalty will be applied to this submission, unless you have received an approved extension. Please be aware that late submissions may receive lower priority for marking, and marks may not be returned within the same timeframe as for on-time submissions.

**Warning:** Unfortunately the `submit` command will technically allow you to submit late even if you submitted before the deadline (i.e. it does not enforce the above policy). **Don't do this!** We will mark the version that we retrieve just after the deadline, and (even worse) you may still be penalized for submitting late because the timestamp will update.

For additional information about late penalties and extension requests, see the School web page below. Do **not** email any course staff directly about extension requests; you must follow the instructions on the web page.

<http://web.inf.ed.ac.uk/infweb/student-services/ito/admin/coursework-projects/late-coursework-extension-requests>

#### Good Scholarly Practice:

Please remember the University requirement as regards all assessed work for credit. Details about this can be found at:

<http://www.ed.ac.uk/schools-departments/academic-services/students/undergraduate/discipline/academic-misconduct>

and at:

<http://web.inf.ed.ac.uk/infweb/admin/policies/academic-misconduct>

Furthermore, you are required to take reasonable measures to protect your assessed work from unauthorised access. For example, if you put any such work on a public repository then you must set access permissions appropriately (generally permitting access only to yourself, or your group in the case of group practicals).

## Part 1 : Modelling The Planner (Total Marks: 40%)

For the first part of this assignment, you will develop a model for a planning problem. You will formalize the domain using the Planning Domain Definition Language (PDDL, see Lecture 16 or Russell & Norvig 3rd Edition, section 10.1 for a reminder). You will need to **define the predicates you use to describe the state of the world and the actions**. You will also need to **define the initial and goal states**. The actions will be available to the planner. You will then use your definitions to **infer a plan for an instance of the problem**.

Write your answers in the relevant sections of the `answers.txt` file found in the assignment archive.

### Problem Description

The all-you-can-eat buffet Bland British Buffet has decided to innovate on their service by employing robotic waiter to bring the food to the customers. These agents can plan and execute a sequence of actions to accomplish some goals.

Figure 1 shows a map of the restaurant divided into 7 discrete areas: The buffet table itself (BUFF), the upper front area (UF), middle front (MF), lower front (LF), lower back (LB), middle back (MB), and upper back (UB). The agent can step directly between two adjacent areas (e.g UF and MF), but cannot move directly between areas blocked by grey dividers (e.g It cannot step directly from MB to MF).

For simplicity, lets assume :

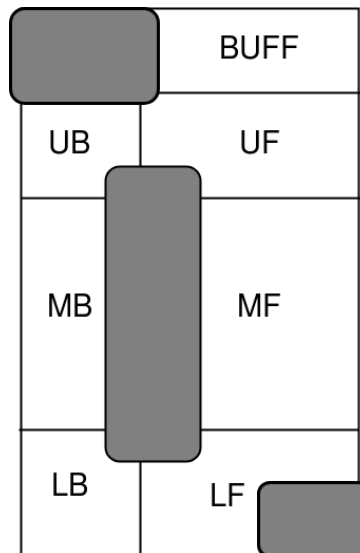


Figure 1: Map of the Restaurant

- Customers place orders using a mobile app so they do not have to go anywhere to place or accept the order.
- Each order consists simply of a request for a plate of food, not specifying specific items from the buffet.
- The agent's **movement** within the building is **discrete**

The setup is then as follows: The agent receives a list of customer orders, which give their name and location in the restaurant. For each order, the agent must fill plate with food from the buffet-table, then deliver the food directly to the customer's table.

## Describing World State (10%)

The first step in the creation of a model to design the structures that will hold information about the environment. Then planner can access these structures to construct a plan.

You should define a minimal set of predicates that can encode every state of the problem.

The initial model should include information about the 7 areas and their connections, the locations of the agent, customers and plates, and the current state of both the agent and plates.

📁 Fill in the first section in the `answers.txt` file:

- 📎 [1.1] Define the predicates you will use to describe the map. Specifically, how will you establish that one location is **Adjacent** to another?
- 📎 [1.2] Define how you will keep track of the **Location** that an agent, plate or customer is **At**.
- 📎 [1.3] Define the predicates you will need to model a **Plate** and, in particular, whether or not it **Has Food**.
- 📎 [1.4] Define the predicates you will need to model a **Customer**, and whether or not that customer has been **Served**
- 📎 [1.5] Using the symbols you just defined and the map as depicted in Figure 1, describe the following *initial state* of the problem:
  - The map is as depicted in Figure 1
  - The agent starts off at BUFF
  - There is a plate at BUFF

- There is a single customer at LB

## Actions (15%)

In the `answers.txt` file, formalize the following actions in terms of the PDDL action schemata. That is, in terms of *Preconditions* and *Effects*:

- ⇒ [1.6 (4%)] The agent can **Pick up** a plate. Note, an agent can only hold one plate at a time, so if it is currently **Holding** a plate, it will be unable to pick up another.
- ⇒ [1.7 (4%)] The agent can **Hand over** a plate of food to a customer that is in the same location as the agent, after which a customer should be said to be **Served**
- ⇒ [1.8 (3%)] At the BUFF, the agent can **Fill** a plate with food that it is **Holding** if the plate does not already **Have Food**.
- ⇒ [1.9 (4%)] The agent can **Move** from its current location to an **Adjacent** one.

Take particular care when defining these actions to consider what happens to the location of items that the agent is holding when she is moving. (*Hint*: Do we even need to explicitly know the location of a plate if we know the agent is holding it? At what point does its location become important? See Example 10.1.1 from Russel & Norvig 3rd Edition for additional hints).

## Backward State Space Search (15 %)

Using the definitions you developed in the first part of this assignment, you should be able to construct a **plan** for a given initial/goal state. Remember, a plan is a sequence of actions that leads from the initial state to a state which satisfies the goal.

One way of finding such a plan is by using **Backwards State-Space search** (See Lecture 17 or Russell & Norvig 3rd Edition Section 10.2.2). Here, we start at the goal state and work backwards towards the initial state by considering only *relevant actions* at each step. That is, actions which could be the last step in a plan leading up to the current step's goal.

⇒ [1.10 (15%)] Formalize the following initial and goal states using the predicates you developed in the previous sections:

- **Initial State** - The agent is at BUFF, there is one empty plate P at the BUFF, and there is a customer C who hasn't yet been served at UF.
- **Goal State** - The customer C has been served

Then, using **Backwards State-Space Search**, provide a plan which works backwards from the goal state towards the initial state. Show in your working:

- The **relevant** (as opposed to applicable in Forward State-Space Search) actions available at each step
- The current updated goal state at each stage of the search
- The final plan executed

In your working, you **do not** have to enumerate the entire search space and show every possible dead-end. Just assume at each step that the agent manages to choose the “correct” action and avoids backtracking.

## Part 2: Implementation (Total Marks: 25%)

In this second part of the assignment, you will implement the model you developed in Part 1. We will be using the online PDDL editor provided by the *Planning.Domains* toolbox. It is available at:

<http://editor.planning.domains>

## Writing PDDL using the online planner

Translating the PDDL statements written in the previous section into code that `editor.planning.domains` understands requires a little work. The notation used by the online editor is slightly different from the one used in the lectures and Russel & Norvig. It more closely resembles a Lisp-like language.<sup>1</sup>

To see an example of the difference, click **File -> Load** in the online editor, and load up `blocks-world-domain.pddl` and `blocks-world-problem.pddl` from the assignment folder. These files give an implementation of the well known “Blocks World” problem (See Russel & Norvig 3rd Edition Section 10.1.3). To run the planner, click **Solve**, set the domain to `blocks-world-domain.pddl` and the problem to `blocks-world-problem.pddl`, then click **Plan**.

As you will see, the main differences are in the syntax:

- Brackets are placed around the *outside* of predicates rather than after them, and list items are separated by *whitespace* rather than commas. For example, `On(B1, B2)` becomes `(On B1 B2)`
- Arguments in action schemata definitions must start with a “?”.
- Instead of using the  $\wedge$  operator, conjunctions are bundled together using the `and` predicate. For example `Clear(a)  $\wedge$  Clear(b)` becomes `(and (Clear a) (Clear b))`

The other big difference is the use of *types*. In previous exercises and lectures, you may be used to seeing single-argument, atemporal predicates which simply describe the type of thing an object is. For example, `Cup(X)`, `Dog(D1)`, or `TeaBag(T1)`. In the online editor, we replicate this behaviour by defining **types** in the domain definition. For example: `(:types cup dog teabag)`. We then explicitly annotate our definitions of predicate and action arguments with the type of object they accept using a dash (-).

For example, consider the blocks-world action `Move`. In our standard notation, we would write:

```
Action(Move(b, x, y)) :  
  PRECOND : On(b, x)  $\wedge$  Clear(b)  $\wedge$  Clear(y)  $\wedge$  Block(b)  $\wedge$  Block(y)  $\wedge$   
    (b  $\neq$  x)  $\wedge$  (b  $\neq$  y)  $\wedge$  (x  $\neq$  y)  
  EFFECT : On(b, y)  $\wedge$  Clear(x)  $\wedge$   $\neg$ On(b, x)  $\wedge$   $\neg$ Clear(y)
```

However, using the Lisp-like notation of the online editor, we would write:

```
(:action MOVE  
  :parameters (?b - block ?x - object ?y - block)  
  :precondition (and  
    (On ?b ?x)  
    (Clear ?b)  
    (Clear ?y)  
    (not (= ?b ?x)) (not (= ?b ?y)) (not (= ?x ?y))  
  )  
  :effect (and  
    (On ?b ?y) (Clear ?x) (not (On ?b ?x)) (not (Clear ?y))  
  )  
)
```

Notice here that we can use the built-in `object` type if we wish to allow an action to accept an object of any type. We can also express inheritance via types. For example:

```
(:types cup flask teapot - container teabag)
```

Expresses that `cup`, `flask` and `teapot` are all sub-types of `container`, while `teabag` is only a sub-type of the top-level type `object`

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<sup>1</sup>For those interested, the official language specification for PDDL can be found at: <http://icaps-conference.org/ipc2008/deterministic/data/mcdermott-et-al-tr-1998.pdf>

## Task 2.1 : Translate to Official PDDL (15%)

After reading the sample files,

👉 Make a copy of the `domain-template.pddl` file and rename it as `domain-task-21.pddl`.

📁 [2.1 (15%)] Translate the predicates/actions of your model and save them in this file.

## Simple experiments

The next two exercises are minimal experiments to learn the language accepted by the planner, and for you to test the correctness of the model. Each task has at least one solution, so if the planner fails to find a plan, there might be something wrong with your PDDL definitions.

👉 For each task, make a new copy of the file `problem-template.pddl` and rename it `problem-task-<#>.pddl` (replace `<#>` with 22 or 23 respectively). Any comment or description can go inside the `.pddl` source file (Comment lines in PDDL start with a semi-colon `;`).

## Task 2.2: Hello PDDL

In this instance of the problem:

- The agent starts at BUFF
- There is an empty plate at BUFF
- There is an unserved customer at LB
- The **goal** is for the customer to be served.

📁 [2.2 (5%)] Implement and test.

## Task 2.3: A More Complex Problem

In this instance of the problem:

- The agent starts at MF
- There is one empty plate at MB and another at LB
- There are two customers—One at UB and one at LF
- The **goal** is that both customers are served, and the agent is at BUFF.

📁 [2.3 (5%)] Implement and test.

## Part 3: Extending the Domain (Total Marks: 20 %)

In this section you will implement the following extension to the original problem:

The agent is additionally in charge of keeping the restaurant clean. There are two main ways that it can become dirty. Some customers drop plates on the floor which means there are sharp shards that must be cleaned up. The agent can not move into a location which has broken porcelain. Sometimes some food is also spilled on the ground. This food doesn't endanger the agent as it can move through these spaces, but it does need to be cleaned up. The agent can clean up this rubbish if the agent has a broom and is adjacent to the rubbish. The agent cannot hold the broom and a plate at the same time.


For this extension task, you may find the PDDL extension module `:quantified-preconditions` useful (The templates in the assignment folder all import the `adl` module, which automatically bundles


:quantified-preconditions as a dependency). This extension allows you to avoid cumbersome book-keeping predicates by allowing existential and universal quantification (using **exists** and **forall** respectively) in action pre-conditions and goal states.

To see how this works, let's return to the **MOVE** action from the blocks-world example. Instead of having an extra **Clear** predicate to mark that nothing is on top of a block, we can define a block as being clear if there are no other blocks on top of it:

```
(:action MOVE
:parameters (?b - block ?x - block ?y - object)
:precondition (and
  (On ?b ?x)
  (not (= ?b ?x)) (not (= ?b ?y)) (not (= ?x ?y))
  (not (exists (?z - block) (On ?z ?b)))
  (not (exists (?z - block) (On ?z ?y)))
)
:effect (and
  (On ?b ?y) (not (On ?b ?x)))
)
)
```

Note, it is entirely possible to complete the entire assignment *without* using quantified pre-conditions, but using them might result in shorter, more elegant solutions.

 For this task, make a copy of the file **domain-template.pddl** and rename it **domain-task-31.pddl**. Similarly, make a copy of **problem-template.pddl** and rename it **problem-task-32.pddl**. We'd recommend you paste in your implementation from task 2 first, then make the appropriate modifications to extend it to task 3.

 **[3.1 (15%)]** Modify your existing implementation such that:

- The agent cannot **Move** into an area if it contains **Broken Plate**.
- The agent can remove broken plates and dropped food from an area by **Sweeping it Up**. To sweep up, the agent must be **At** an adjacent location to the rubbish, and must be **Holding** a **Broom**
- The agent cannot hold a plate and the broom at the same time, so must **Put Down** one item to **Pick Up** the other.

 **[3.2 (5%)]** Implement an initial state where:

- The agent starts at BUFF
- There is an unserved customer at LB
- There is an empty plate at BUFF
- There is a broom at UB
- There is broken plate at MF and MB
- There is dropped food at UF

And a goal of:

- All customers are served
- The agent is at BUFF
- There is not any rubbish on any part of the floor


Then test that your model generates a valid plan.

## Part 4: Theoretical Extension (Total Marks: 15%)


In this final section we would like you to explore the potential limitations of PDDL and symbolic planning.

For this question, imagine that the restaurant starts making food to order from a limited menu. They do hot tea and coffee, a dessert with ice-cream, and sushi. Now the agent must not only ensure that all customers are served, but must also ensure that these items are served in a timely fashion. In particular, if left too long the tea and coffee will go cold and the ice-cream will melt. The sushi is largely unaffected by time.

 Fill in sections 4 in `answers.txt`

 **[4.1] (5%)** How would the goals and actions need to be updated to deal with these new constraints? You do not need to implement your suggestions.

In this planning problem the robot has to meet the needs of multiple customers. In reality this would create a number of social expectations, for example, customers expect to be served on a first-come first-served basis. Ideally our robot waiter would be able to deal with these expectations.

 **[4.2] (10%)** How would the additional consideration of meeting social expectations change your answer to [4.1]? How might you go about implementing a system which could deal with this problem? Think in particular about what actions would be required, what the planner would need to keep track of, and how you would evaluate how well the agent is doing.