Lab 1: Plan Synthesis

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ICAPS 2020 Online Summer School

Lab 1: Plan Synthesis

- PS-1: **Introductory Lecture**.
- PS-2: Hands-on session.
- PS-3: Hands-on Session and Solution Walk-through.

Lab 1: Plan Synthesis

Goals of this lab:

- Learn what domain-independent automated planning is.
- Gain hands-on experience modelling planning problems.

Outline:

- Domain-independent Automated Planning.
- Introduction to the Planning Domain Definition Language.
- Lab materials (inc. Online editor).
- PDDL2.1 Time and Numbers
- Lab materials (Exercise 4).

Domain-independent Automated Planning

What is Planning?

Short Definition: Planning is the act of thinking before acting.

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Longer Definition: Planning is the process of choosing and organising actions that lead towards a goal, based on a high-level description of the world.

Domain Specific vs. Domain-Independent Planning

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Domain-independent planning uses a general representation and technique that is applicable across different domains.

- *still many kinds of general planning:* online and offline; discrete and continuous; deterministic and non-deterministic; fully- and partially observable; sequential and temporal.

What is automated planning used for?

Introduction to Planning Domain Definition Language (PDDL)

Planning Domain Definition Language

The main components of a *planning problem* are:

- a description of how the world behaves and the capabilities of the agent (e.g. the action library).
- a description of the initial situation (the *initial state*).
- a description of the desired situation (the *goal*)

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- a description of the desired situation (the *goal*)

A basic planning formalism represents the state of the world and actions using propositional variables. Such a (classical) planning problem is a tuple: $< F, A, I, G >$, where:

- F is a set of (Boolean) *propositions*.
- A is a set of deterministic actions.
- The set of states S is the power set of F, $S = 2^F$.
- $s_o \in S$ is the initial state.
- $G : S \rightarrow \{\top, \bot\}$ is the goal function.

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Each action $a \in A$ consists of:

- $pre(a) \subseteq F$ (simple preconditions)
- $add(a) \subseteq F$ (add effects)
- $del(a) \subseteq F$ (delete effects)

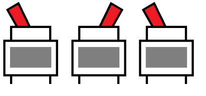
Planning Domain Definition Language

PDDL is a language for encoding classical planning tasks. Tasks are separated into two files:

1. **Domain File**, which contains:
    - **Predicates** that describe the properties of the world.
    - **Operators** that describe the way in which the state can change.
2. **Problem File**, which contains:
    - **Objects**: the things in the world.
    - The **initial state** of the world.
    - The **goal** specification.

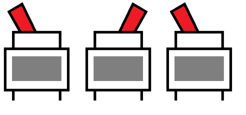
F and A are found by applying the object terms to the predicates and operators.

Example: Domain File



```
(define (domain simple_switches)
    (:requirements :typing)
    (:types switch)
    (:predicates
        (off ?s - switch) (on ?s - switch))
    (:action switch_on
        :parameters (?s - switch)
        :precondition (off ?s)
        :effect (and (not (off ?s)) (on ?s))
    )
```

Example: Problem File



```
(define (problem more_switches)
    (:domain simple_switches)
    (:objects s1 s2 s3 - switch)
    (:init (off s1) (off s2) (off s3))
    (:goal (and (on s1) (on s2) (on s3)))
)
```

Example: Plan

A **plan** for a classical planning problem is a sequence of actions that are applicable from the initial state and lead to a a state that satisfies the goal:

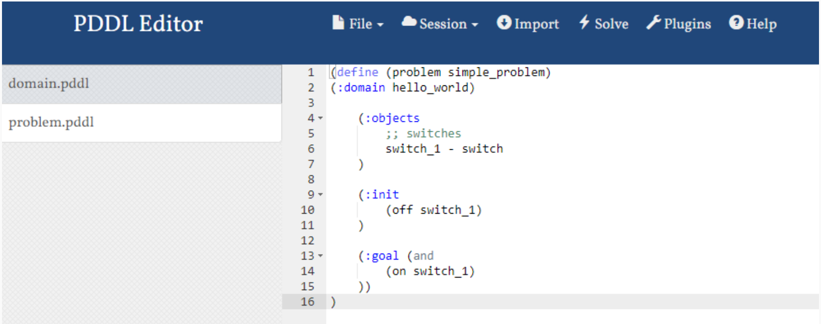
$$\langle a_0, \ldots, a_n \rangle$$

```
(switch_on s1)
(switch_on s2)
(switch_on s3)
```

Online Editor: planning.domains

planning.domains

http://editor.planning.domains/



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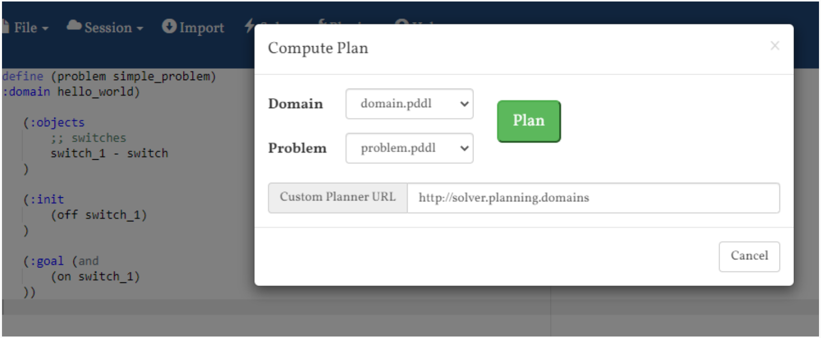

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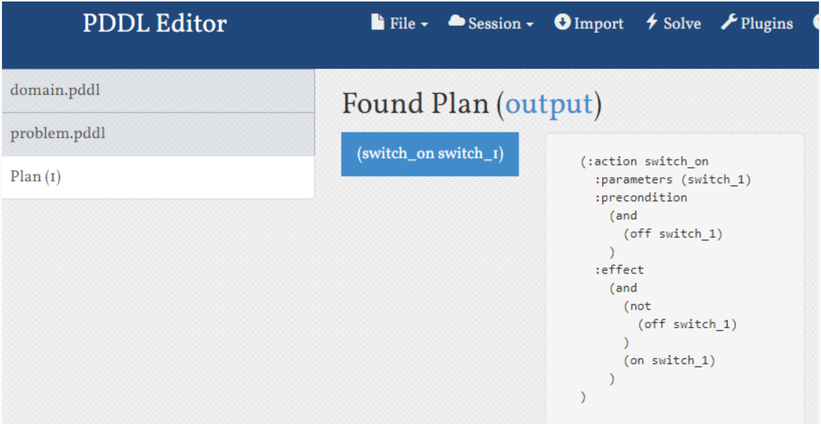

planning.domains

http://editor.planning.domains/

- Simple switches: http://editor.planning.domains/#read_session=jfespcjFc3
- More switches: http://editor.planning.domains/#read_session=iseLBtK6jo
- Tricky Switches: http://editor.planning.domains/#read_session=ob1iWAQRp

PDDL2.1: Temporal Planning

Temporal Planning

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- Literature: Haslum, P., Lipovetzky, N., Magazzeni, D., Muise, C. *An Introduction to the Planning Domain Definition Language*, 2019.
- Literature: Malik Ghallab, Dana Nau, and Paolo Traverso. *Automated Planning – Theory and Practice*, chapter 13-14. Elsevier/Morgan Kaufmann, 2004.

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- Literature: Malik Ghallab, Dana Nau, and Paolo Traverso. *Automated Planning – Theory and Practice*, chapter 13-14. Elsevier/Morgan Kaufmann, 2004.
- Resource: Planning wiki (https://planning.wiki/ref)
- Resource: Planning editor (planning.domains)

PDDL2.1

Fox and Long introduced PDDL2.1 (and PDDL+) to increase the expressiveness of PDDL to more realistic problems:

- Level 1: STRIPS and ADL.
- Level 2: **Numeric variables and optimisation metrics.**
- Level 3: **Durative Actions.**
- Level 4: Continuous Change.
- Level 5: Processes and Events.

Literature: Maria Fox and Derek Long. *PDDL2.1 : An Extension to PDDL for Expressing Temporal Planning Domains*, Journal of Artificial Intelligence Research, 2003.

Formally a **Temporal Planning Problem** is a tuple:

$\Pi =< F, V, A, I, G >$,

where:

- F is a set of (Boolean) *propositions*.
- V is a set of (Real) *primitive numeric expressions* (PNEs/functions).
- A is a set of deterministic actions.
- I is the initial state.
- $G : S \rightarrow \{\top, \bot\}$ is the goal function.

PDDL2.1 State

A state is now a combination of time and both Boolean and numeric variables: S is a tuple $(time, s_{logical}, s_{numeric})$.

- $time \in \mathbb{R}$ is the time of the state.
- $s_{logical} \subseteq F$ is the logical state.
- $s_{numeric} : V \rightarrow \mathbb{R}_{\perp}$ the assignment to the numeric expressions, where $\perp$ denotes an undefined value.

For example: $(0, I_{logical}, \mathbf{x})$ is the initial state, where $\mathbf{x}$ assigns each numeric function $v \in V$ to a value in $\mathbb{R}_{\perp}$ (the initial numeric assignments).

PDDL2.1 State Example

Below is an example initial state (with $time = 0$)

```
(:init
  (at truck Rome)
  (at car Paris)
  (= (fuel-level truck) 100)
  (= (fuel-level car) 100)
)
```

PDDL2.1 Durative Actions

An action consists of:

- an action name,
- (typed) parameters,
- a duration constraint,
- *at start*, *over all*, and *at end* conditions,
- *at start*, *over all*, and *at end* effects.

PDDL2.1 Comparisons and Effects

- **Comparisons** between **numeric expressions** can be used as logical axioms:
  $(>=$ (*fuel*) $($* (*distance* ?*from* ?*to*) (*fuel_consumption*)))

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- **Effects can modify functions** by numeric expressions:
  (*decrease* (*fuel*) ($*$ (*distance* ?*from* ?*to*) (*fuel_consumption*)))

PDDL2.1 Comparisons and Effects

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  (>= (*fuel*) (* (*distance* ?*from* ?*to*) (*fuel_consumption*)))
- **Effects can modify functions** by numeric expressions:
  (*decrease* (*fuel*) (* (*distance* ?*from* ?*to*) (*fuel_consumption*)))
- **Actions take an amount of time** given by the value of the numeric expression *?duration*, which is constrained by a comparison: (= ?*duration* (/ (*distance* ?*from* ?*to*) (?*speed*)))

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- **Actions take an amount of time** given by the value of the numeric expression *?duration*, which is constrained by a comparison: $(= \ ?\textit{duration} \ (/ \ (\textit{distance} \ ?\textit{from} \ ?\textit{to}) \ (?\textit{speed})))$

Let's look at an example of the syntax...

PDDL2.1 Durative Action Syntax

```
(:durative-action attend_lecture
:parameters (?s - student ?l - lecturer ?r - room)
:duration (<= ?duration 120)
:condition (and
  (at start (awake ?s))
  (at start (in ?l ?r))
  (at start (in ?s ?r))
  (over all (awake ?l)))
:effect (and
  (at end (not (awake ?s)))))
```

PDDL2.1 Durative Action Syntax

```
(:durative-action attend_lecture
```

A durative action is defined differently from an instantaneous action (use *durative-action* instead). You can include both types of action in the domain.

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```

The parameters of an action can be *typed*.

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:parameters (?s - student ?l - lecturer ?r - room)

The parameters of an action can be *typed*.
Types can be compiled away using *unary type predicates*. For example:

```
(:objects student01)
(:init (is_a_student student01))
```

PDDL2.1 Durative Action Syntax

:duration (<= ?duration 120)

Duration constraints are expressed as a comparison with the special numeric expression *?duration*.

- Comparison operators: $<, >, <=, >=, =$.

PDDL2.1 Durative Action Syntax

Numeric expressions are either:

- A constant value, e.g. 120,
- a PDDL function, e.g. (*distance* ?*road*),
- the unary operator ($-$ *expression*)
- or a binary operation with operators: $+, -, *, /$.

PDDL2.1 Durative Action Syntax

```
:condition (and
    (at start (awake ?s))
    ...)
```

- *at start* conditions must be true in the state that the action is applied.
- *at end* conditions must be true in the state that the actions is completed.
- *over all* conditions must be true throughout the duration of the action.

Note that the value of a function must be made true at least a little time (ϵ) before it is used to satisfy a condition. This is called *epsilon separation*.

PDDL2.1 Durative Action Syntax

```
:effect (and
    (at end (not (awake ?s))))
```

- Effects can be *at start* or *at end*.
- Numeric Effects can *increase*, *decrease*, or *assign* the values of primitive numeric assignments. Example: (*assign* (?*fuel*) (?*max_fuel_capacity*))

Temporal Planning Example

```
(define (domain matchcellar)
  (:requirements :typing :durative-actions)
  (:types match fuse)
  (:predicates
    (light ?m - match)
    (handfree)
    (unused ?m - match)
    (mended ?f - fuse)
  )

  (:durative-action light_match
    :parameters (?m - match)
    :duration (= ?duration 8)
    :condition (and
      (at start (unused ?m)))
    :effect (and
      (at start (not (unused ?m)))
      (at start (light ?m))
      (at end (not (light ?m)))))
```

```
(:durative-action mend_fuse
  :parameters (
    ?f - fuse
    ?m - match)
  :duration (= ?duration 5)
  :condition (and
    (at start (handfree))
    (over all (light ?m)))
  :effect (and
    (at start (not (handfree)))
    (at end (mended ?f))
    (at end (handfree)))))
```

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    ?f - fuse
    ?m - match)
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  :condition (and
    (at start (handfree))
    (over all (light ?m)))
  :effect (and
    (at start (not (handfree)))
    (at end (mended ?f))
    (at end (handfree)))))
```

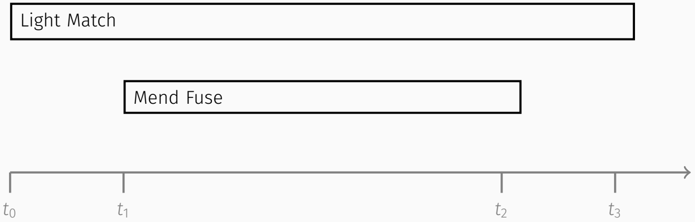
Temporal Planning Example

```
(define (problem fixfuse)
  (:domain matchcellar)
  (:objects
    match1 match2 - match
    fuse1 fuse2 - fuse)
  (:init
    (unused match1)
    (unused match2)
    (handfree))
  (:goal (and
    (mended fuse1))
)
```

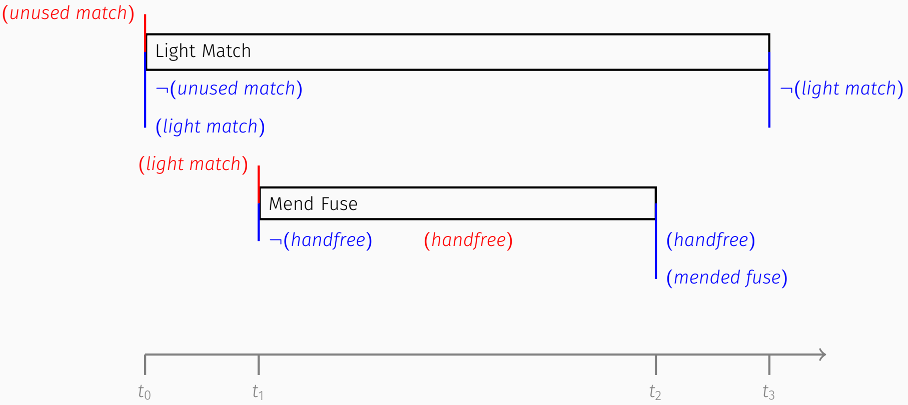
Plan Timeline

```
0.00: light_match match1 [8.00]
0.01: fix_fuse fuse1 match1 [5.00]
```

Plan Timeline



Plan Timeline



- Conditions are above the action and red.
- *Over all* conditions are below the middle of the action in red.
- Effects are below the action and in blue.

Timed Initial Literals

Timed initial literals are defined in the initial state:

```
(:init
  (at 20 (available match1))
  (at 40 (not (available match1)))
)
```

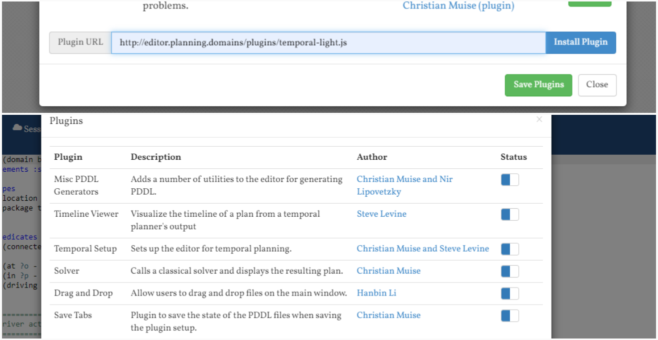
leads to a time window in which *match*1 can be used.

Timed Initial Literals

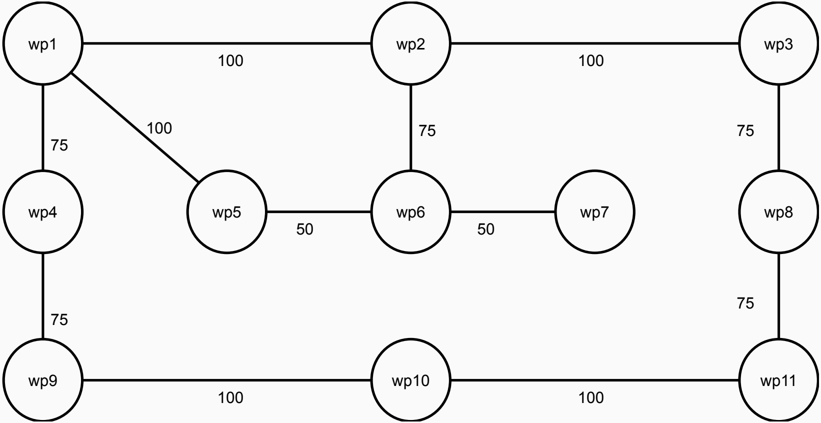
```
40.01: light_match match1 [8.00]
40.02: fix_fuse fuse1 match1 [5.00]
```

Online Editor: Temporal Planning

Use the following plugins to enable a temporal solver and timeline view:



The following link already has these enabled:
http://editor.planning.domains/#read_session=EWjbgnhuUd


wp1
wp2
wp3
100
100
100
75
75
75
wp4
wp5
wp6
wp7
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50
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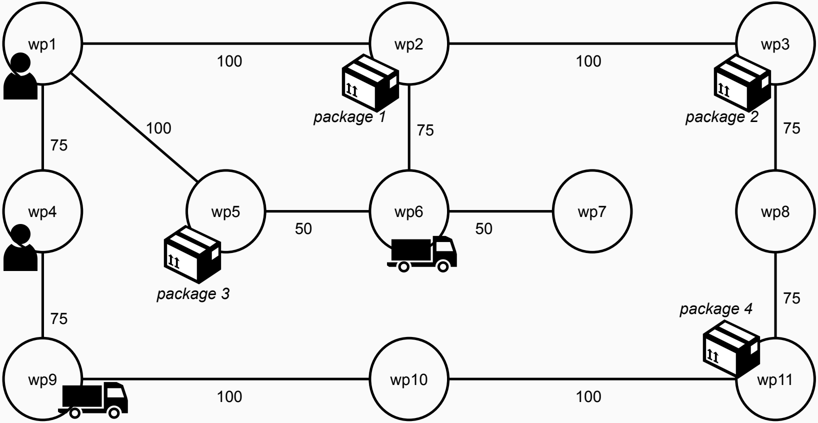
wp9
wp10
wp11
100
100

Temporal Logistics



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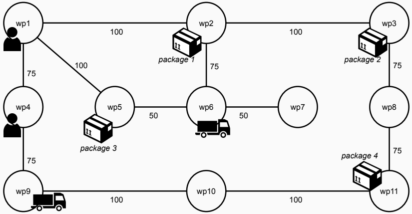
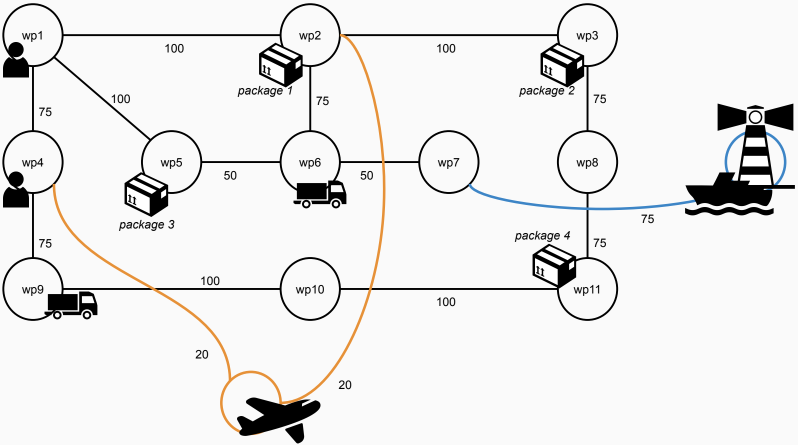


- Packages can be loaded into and unloaded from trucks (10 time units).
- Drivers can walk between connected waypoints at a speed of 0.5.
- Drivers can get into and out of trucks (10 time units).
- Trucks with drivers can drive between connected waypoints at a speed of 1.

Temporal Logistics



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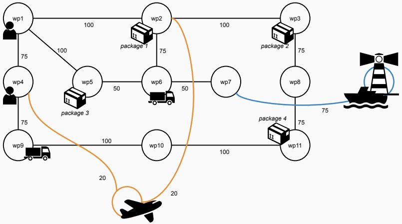
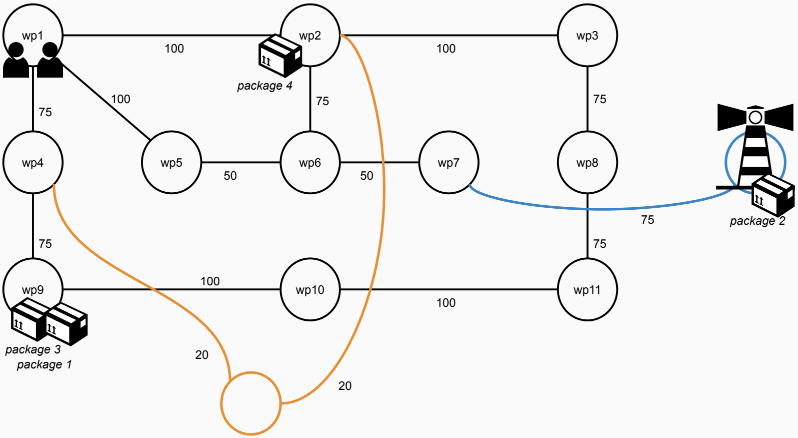


- The plane starts in the sky waypoint, the boat starts in the lighthouse waypoint.
- The boat and the plane don't need drivers to move.
- They can only travel over the blue and yellow edges (connected to the lighthouse and the sky).
- The boat travels at a speed of 1.5.
- The plane travels at a speed of 2.

Temporal Logistics

Goal:



Extra Challenges

- Each truck can only make a maximum of 7 trips.
- The plane must wait a minimum of 20 time units between trips.
- Each driver must return to waypoint 1 and disembark at least once within each 400 time unit interval. This can be at the start or end of the time interval, for example at: $399, 401, 850, \ldots$.
- Trucks can make any number of trips, but consume 1 unit of fuel for each time unit they are travelling. Trucks can be refuelled at stations in waypoints 3 and 9.
- Trucks also consume 0.1 fuel per time unit when they are not driving.

Note: these extra challenges may create a problem that is too difficult to solve within the time limit given to the online solver.