Algorithms and Satisfiability

. Mini-Project: Planning

Solving Problems using Planning

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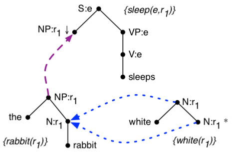
Thanks to Jörg Hoffmann for slide sources

Agenda

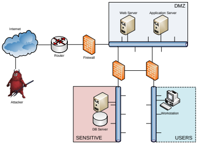
1. Introduction
2. The PDDL Language
3. Beyond Classical Planning
4. Conclusion

Agenda

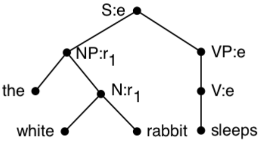
Planning

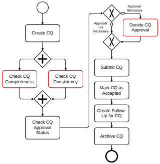


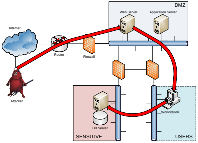
Action name	precondition	effect
Check CQ Completeness	CQ.archiving:notArchived	CQ.completeness:complete OR CQ.completeness:notComplete
Check CQ Consistency	CQ.archiving:notArchived	CQ.consistency:consistent OR CQ.consistency:notConsistent
Check CQ Approval Status	CQ.archiving:notArchived AND CQ.approval:notChecked AND CQ.completeness:complete AND CQ.consistency:consistent	CQ.approval:necessary OR CQ.approval:notNecessary
Decide CQ Approval	CQ.archiving:notArchived AND CQ.approval:necessary	CQ.approval:granted OR CQ.approval:notGranted
Submit CQ	CQ.archiving:notArchived AND (CQ.approval:notNecessary OR CQ.approval:granted)	CQ.submission:submitted
Mark CQ as Accepted	CQ.archiving:notArchived AND CQ.submission:submitted	CQ.acceptance:accepted
Create Follow-Up for CQ	CQ.archiving:notArchived AND CQ.acceptance:accepted	CQ.followUp:documentCreated
Archive CQ	CQ.archiving:notArchived	CQ.archiving:archived



Planning Domain Definition Language (PDDL) $\mapsto$ Planning System







STRIPS Planning: Syntax

Definition (STRIPS Planning Task). *A STRIPS planning task, short planning task, is a 4-tuple $\Pi = (P, A, I, G)$ where:*

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- *A is a finite set of actions; each $a \in A$ is a triple $a = (pre_a, add_a, del_a)$ of subsets of P referred to as the action's precondition, add list, and delete list respectively; we require that $add_a \cap del_a = \emptyset$.*
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Note: We assume unit costs for simplicity: every action has cost 1.

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PDDL History

Planning Domain Description Language:

- A description language for planning in the STRIPS formalism and various extensions.
- Used in the International Planning Competition (IPC).

- 1998: PDDL [McDermott *et al.* (1998)].
- 2000: "PDDL subset for the 2000 competition" [Bacchus (2000)].
- 2002: PDDL2.1, Levels 1-3 [Fox and Long (2003)].
- 2004: PDDL2.2 [Hoffmann and Edelkamp (2005)].
- 2006: PDDL3 [Gerevini *et al.* (2009)].

PDDL Quick Facts

PDDL is not a propositional language:

- Representation is lifted, using object variables to be instantiated from a finite set of objects. (Similar to predicate logic)
- Action schemas parameterized by objects.
- Predicates to be instantiated with objects.

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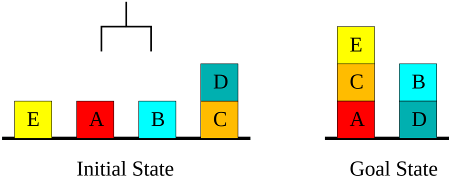
A PDDL planning task comes in two pieces:

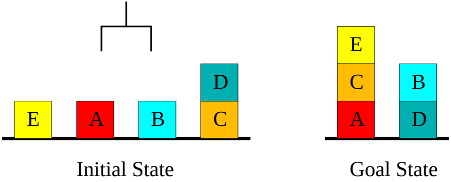
- The domain file and the problem file.
- The problem file gives the objects, the initial state, and the goal state.
- The domain file gives the predicates and the action schemas; each benchmark domain has *one* domain file.

The Blocksworld in PDDL (STRIPS): Domain File




```
(define (domain blocksworld)
(:predicates (clear ?x) (holding ?x) (on ?x ?y)
             (on-table ?x) (arm-empty))
(:action stack
 :parameters (?x ?y)
 :precondition (and (clear ?y) (holding ?x))
 :effect (and (arm-empty) (on ?x ?y)
              (not (clear ?y)) (not (holding ?x)))
)
...
```

The Blocksworld in PDDL (STRIPS): Problem File




```
(define (problem bw-abcde)
(:domain blocksworld)
(:objects a b c d e)
(:init (on-table a) (clear a)
       (on-table b) (clear b)
       (on-table e) (clear e)
       (on-table c) (on d c) (clear d)
       (arm-empty))
(:goal (and (on e c) (on c a) (on b d))))
```

Fast Downward

Fast Downward is a planning system featuring a lot of algorithms. When you run it you need to select which configuration to use:

```
./fast-downward.py (<domain>) <instance> --search "config"
```

```
./fast-downward.py --alias "config-alias" (<domain>) <instance>
```

There are A LOT of configurations. Here I list a few convenient ones:

Satisficing Planning:

- What we see in the lecture:
  `--evaluator "hff=ff(transform=adapt_costs(one))" --search "eager_greedy([hff], preferred=[hff], cost_type=one)"`
- `--alias lama-first`: Good configuration
- `--alias lama`: Good configuration (anytime)

Optimal Planning:

- `--search "astar(blind)"`: Dijkstra search
- `--search "astar(lmcut)"`: Ok configuration (though not best)

Action Description Language (ADL)

STRIPS + ADL (Action Description Language):

- Arbitrary first-order logic formulas in action preconditions and the goal: forall, exists, or, imply, not
- Conditional effects, i.e., effects that occur only if their separate effect condition holds: when

→A useful construct is effects of the form forall-when:

```
(forall (?x) (when (condition) (effect))
```

ADL is a real headache to implement:

- Most planners that do handle ADL *compile* it down [Gazen and Knoblock (1997)]
- Example FF: 7000 C lines for compilation, 2000 lines core planner.

Action Costs

`(:requirements :action-costs)`

Domain file:

- Declare cost function

```
(:functions
    (road-length ?l1 ?l2 - location) - number ; optional
    (total-cost) - number ; The cost function must have this name
)
```

- Declare action cost as effect:

  `(increase (total-cost) (road-length ?l1 ?l2))`

Problem file:

- (optional) Declare costs in the initial state:

  `(= (total-cost) 0)`

  `(= (road-length city-3-loc-2 city-2-loc-3) 186)`

- Optimization criteria: `(:metric minimize (total-cost))`

PDDL Extensions

- PDDL 2.1: numeric and temporal planning
- PDDL 2.2: derived predicates (e.g., flow of current in an electricity network) and timed initial literals (e.g., sunrise and sunset, shop closing times).
- PDDL 3: soft goals (e.g.goals that have a reward) and preferences (e.g.temporal goals)

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In practice, most planners only support a subset of PDDL. In this project, you should consider:

- STRIPS
- Negative Preconditions
- Forall-when effects
- Action costs

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(C): Those AI planning guys.

(D): Being lazy at work.

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→ (C): Yep. (When I started in this area, every system had its own language, so running experiments felt a lot like "Lost in Translation".)

→ (D): Yep. You can be a busy bee, programming a solver yourself. Or you can be lazy and just write the PDDL. (I think I said that before . . .)

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There are many extensions that go beyond this:

- **Planning with Uncertainty:** partially-observable environments.
- **Non-deterministic Planning:** non-deterministic environments.
- **Numeric Planning:** continous environments.
- **Multi-agent Planning:** environments where several agents cooperate.
- **Temporal Planning:** actions whose effects take some time.
- And more...

Planning with Uncertainty

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We have only partial knowledge about the initial state.
How to represent our knowledge?

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1,4	2,4	3,4	4,4
1,3	2,3	3,3	4,3
1,2 OK	2,2	3,2	4,2
1,1 $\boxed{A}$ OK	2,1 OK	3,1	4,1

Initial knowledge:

- You're in cell [1,1]. $P_{1,1}$
- There's a Wumpus $(W_{1,1} \vee W_{1,2} \vee W_{1,3} \vee \dots)$
- There's gold $(G_{1,1} \vee G_{1,2} \vee G_{1,3} \vee \dots)$
- There's no stench in position [1, 1]: $\neg S_{1,1}$
- General knowledge:
  $\neg S_{1,1} \rightarrow \neg W_{1,1} \wedge \neg W_{1,2} \wedge \neg W_{2,1}$

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Definition (Belief State). *Let φ be a propositional formula that describes our knowledge about the current state. Then, the belief state B is the set of states that correspond to satisfying assignments of φ.*

$\rightarrow$The set of states that are consistent with our belief.

Partially-Observable Planning

A planning task with uncertainty in the initial state, is a 4-tuple $\Pi = (P, A, \varphi_I, G)$ *where:*

- P is a finite set of facts.
- A is a finite set of actions; each $a \in A$ is a tuple (pre, add, del, obs). $\rightarrow$The value of facts in **obs** set after executing the action.
- φ_I is the initial belief state.
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$\rightarrow$**Contingent Planning:** Find a tree of actions that transform the initial belief state φ_I into $\varphi_G \models G$. We may need different plans for every result of the observation actions! [2EXPSPACE-hard]

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Extensions of PDDL:

- PPDDL
- RDDL

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Offline Planning: Plan ahead for every possibility.

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1. Drop probabilities away (assume that you get to choose the outcome)
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$\rightarrow$Very effective online probabilistic planner, specially in tasks where probabilities model that actions have a (low) probability of failure.

Numeric Planning

In the real world: We have numbers!

Numeric STRIPS Planning: Extends STRIPS by introducing numeric variables V_n with rational values in $\mathbb{Q}$.

- Numeric expressions: We can do simple arithmetic $(+, -, \times, \div)$ with the values of variables and/or constants.

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Example: drive (x,y):

$pre : \{at(x), fuel > 0\}, add : \{at(y)\} del : \{at(x)\},$
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[Undecidable]

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→Agents must communicate during the planning process to share information about how they will achieve the goal

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- preconditions at-end
- effects at-end
- over-all: during the execution of the action

Planning in the Real World

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- Oftentimes, reasoning with a simplified model can still lead to intelligent decisions and solutions are easier to compute than with more complex models.
- Classical planning is a relaxation of the problem so it can be used in heuristics for more complex types of planning.

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- Classical planning is a relaxation of the problem so it can be used in heuristics for more complex types of planning.

My two cents: Ideally, we should always provide an accurate description of the environment so that the AI simplifies it when necessary. However, automatic simplification methods are not powerful enough in all cases yet.

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Summary

- You can use planning tools to solve your problems:
  →Encode them in PDDL and use any planner
- Classical planning is very effective at solving large problems
- Non-classical planning models reason about more complex environments such as non-deterministic, partially-observable, continuous, temporal, etc.
- Solving these problems by computing a complete offline policy is hard (though many non-classical planners are able to do this satisfactorily in some domains). Many approaches are online, planning to decide the next action by looking into the future but without considering all alternatives.
- Classical planning and heuristic search techniques are still an important ingredient of many approaches that deal with complex environments.

Additional Resources

- Editor: `http://editor.planning.domains/`
- VS Extension: https://marketplace.visualstudio.com/items?itemName=jan-dolejsi.pddl
- Wiki: `https://planning.wiki/`
- Benchmarks: `https://github.com/aibasel/downward-benchmarks`
- Planners:
  - Fast Downward: `http://www.fast-downward.org/`
  - IPC-18: `https://ipc2018-classical.bitbucket.io/#planners`
- Domains as examples:
  - STRIPS: FD'All → Blocksworld, Logistics
  - Action costs: IPC'11 → Woodworking, Transport
  - Discretized numbers: IPC'11 → Nomystery (fuel consumption)
  - Forall-when: IPC'18 → Nurikabe
  - Complex ADL: FD'All → Miconic-ADL (ID114)

References I

Fahiem Bacchus. *Subset of PDDL for the AIPS2000 Planning Competition*. The AIPS-00 Planning Competition Comitee, 2000.

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