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INTRODUCTION TO AI STRIPS PLANNING

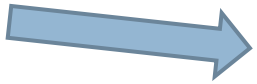
.. and Applications to Video-games!

Course overview

- Lecture 1: Game-inspired competitions for AI research, AI decision making for non-player characters in games
- Lecture 2: STRIPS planning, state-space search
- Lecture 3: Planning Domain Definition Language (PDDL), using an award winning planner to solve Sokoban
- Lecture 4: Planning graphs, domain independent heuristics for STRIPS planning
- Lecture 5: Employing STRIPS planning in games: SimpleFPS, iThinkUnity3D, SmartWorkersRTS
- Lecture 6: Planning beyond STRIPS

STRIPS planning

- Given:
  - Initial state

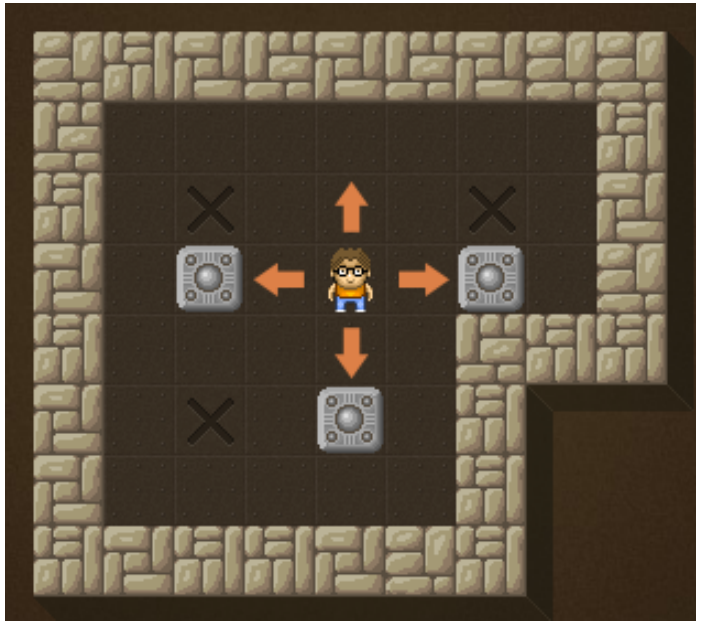


STRIPS planning

- Given:
  - Initial state
  - Goal

STRIPS planning

- Given:
  - Initial state
  - Goal
  - Available actions



STRIPS planning

- Given:
  - Initial state
  - Goal
  - Available actions

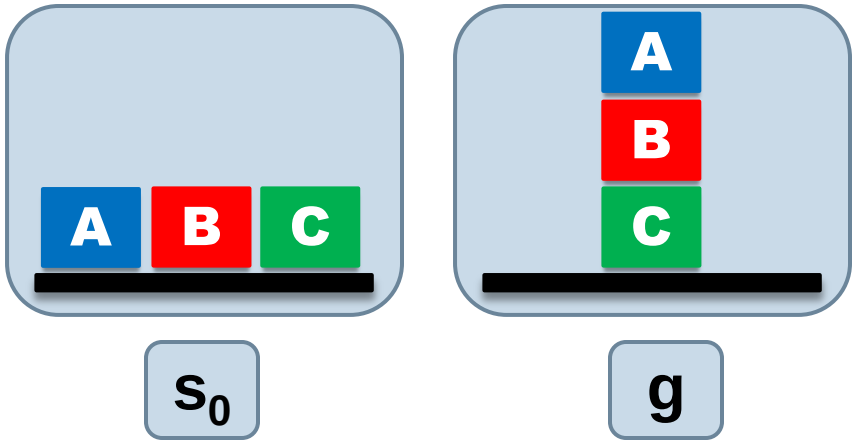
- Find:
  - A **sequence of actions** that achieves the goal
  - E.g.: **[Left, Down, Left, Up, …]**

Planning Domain Description Language

- Planning Domain Definition Language (PDDL)
  - Formal language for specifying **planning problems**
  - Formal syntax similar to a **programming language**
  - Includes **STRIPS** and ADL, and many more features
  - Provides the ground for performing a direct comparison between planning techniques and evaluating against classes of problems

Planning Domain Description Language

- Blocks world domain
  - Initial state: s_0
  - Goal: g



  - Available actions: moving a block
    - from the table to the top of another block
    - from the top of another block to the table
    - from the top of one block to the top of another block

Planning Domain Description Language

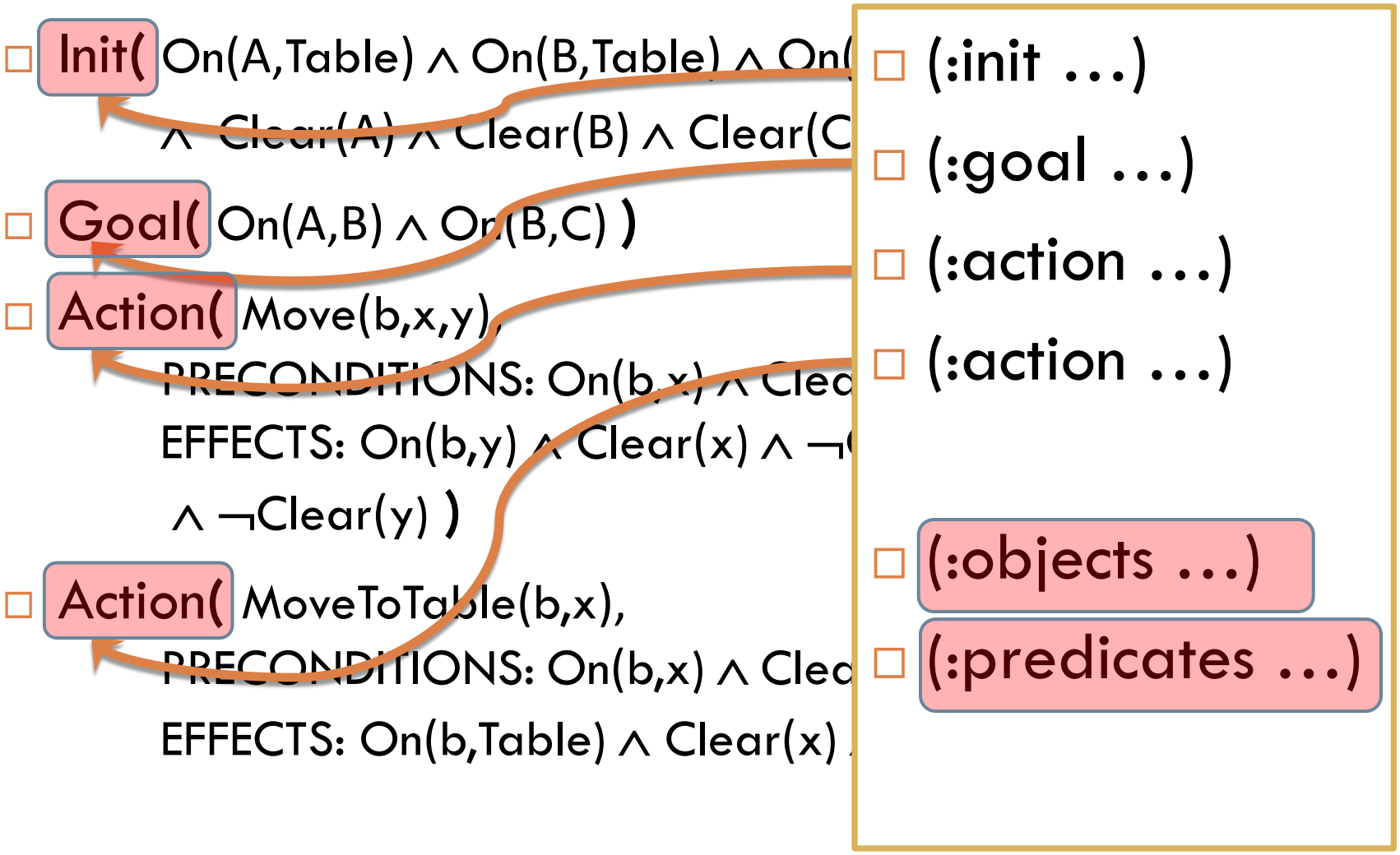
- Init(On(A,Table) ∧ On(B,Table) ∧ On(C,Table)
  ∧ Clear(A) ∧ Clear(B) ∧ Clear(C))
- Goal(On(A,B) ∧ On(B,C))
- Action(Move(b,x,y),
  PRECONDITIONS: On(b,x) ∧ Clear(b) ∧ Clear(y)
  EFFECTS: On(b,y) ∧ Clear(x) ∧ ¬On(b,x)
  ∧ ¬Clear(y))
- Action(MoveToTable(b,x),
  PRECONDITIONS: On(b,x) ∧ Clear(b)
  EFFECTS: On(b,Table) ∧ Clear(x) ∧ ¬On(b,x))

Planning Domain Description Language

- Init(On(A,Table) ∧ On(B,Table) ∧ On(
  ∧ Clear(A) ∧ Clear(B) ∧ Clear(C
- Goal(On(A,B) ∧ On(B,C))
- Action(Move(b,x,y),
  PRECONDITIONS: On(b,x) ∧ Clea
  EFFECTS: On(b,y) ∧ Clear(x) ∧ ¬(
  ∧ ¬Clear(y))
- Action(MoveToTable(b,x),
  PRECONDITIONS: On(b,x) ∧ Clea
  EFFECTS: On(b,Table) ∧ Clear(x)

- (:init …)
- (:goal …)
- (:action …)
- (:action …)

Planning Domain Description Language



Planning Domain Description Language

- (:init …)
- (:goal …)
- (:action …)
- (:action …)

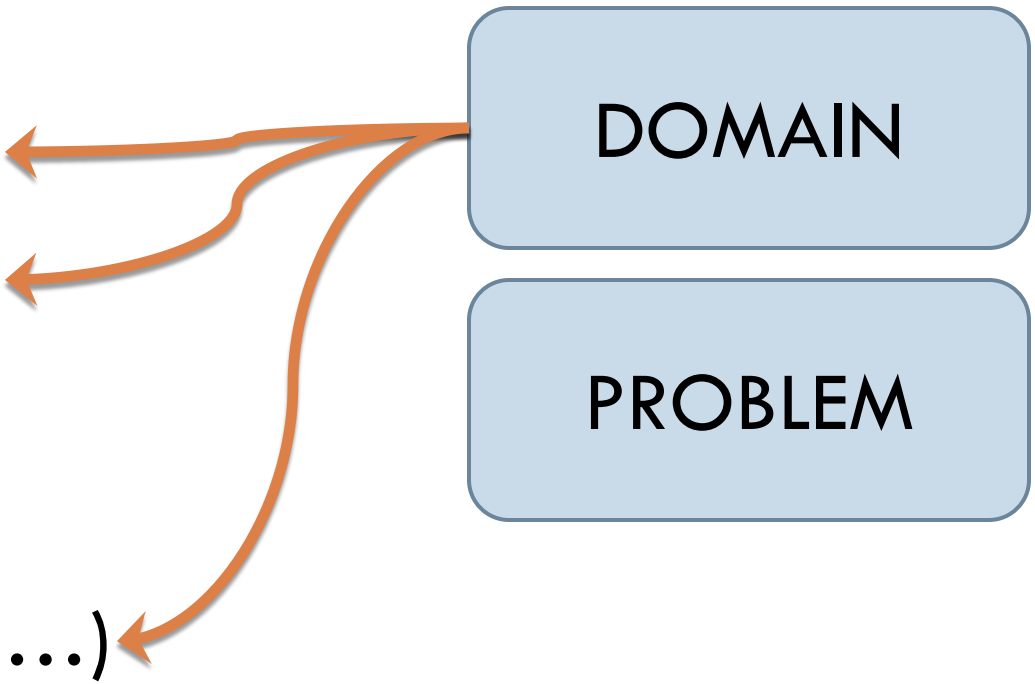
- (:objects …)
- (:predicates …)

DOMAIN

PROBLEM

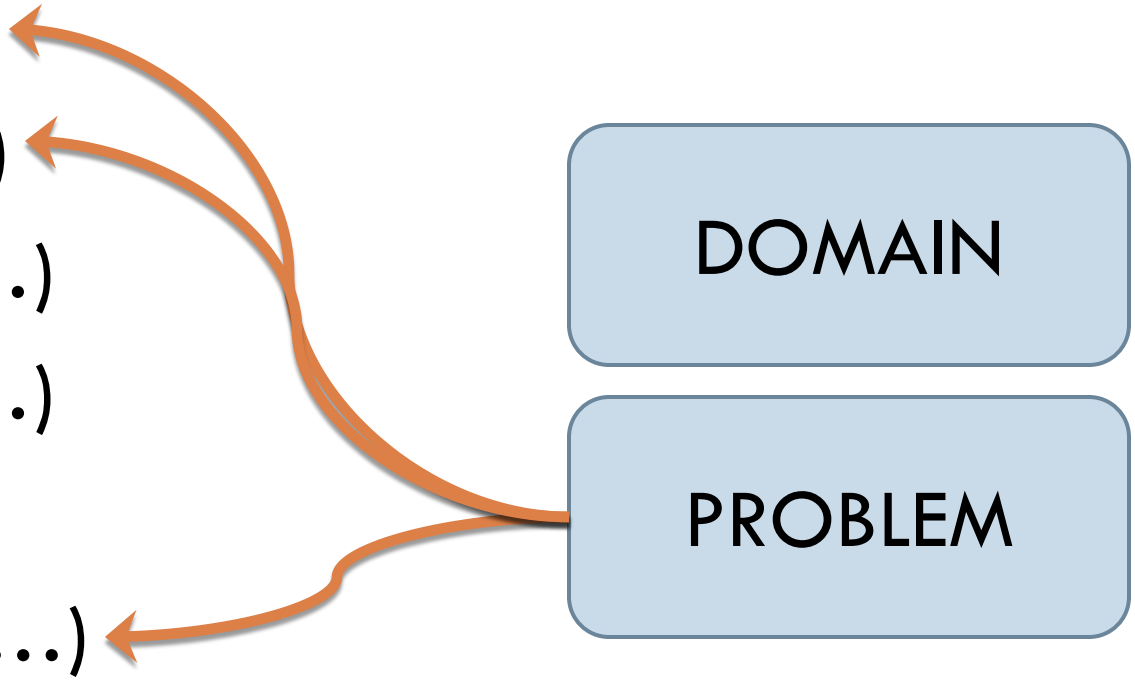
Planning Domain Description Language

- (:init …)
- (:goal …)
- (:action …)
- (:action …)
- (:objects …)
- (:predicates …)



Planning Domain Description Language

- (:init …)
- (:goal …)
- (:action …)
- (:action …)
- (:objects …)
- (:predicates …)



Planning Domain Description Language

- (:predicates …)
- (:action …)
- (:action …)

DOMAIN

- (:objects …)
- (:init …)
- (:goal …)

PROBLEM

Planning Domain Description Language

- On(A,B) → (on a b)
- ¬On(A,B) → (not (on a b))
- On(A,B) ∧ On(B,C) → (and (on a b) (on b c))
- On(x,y) → (on ?x ?y)

The blocks world example in PDDL

- Blocks world **domain**
  - Available predicates (:predicates …)
  - Available actions (:action …)

The blocks world example in PDDL

- Blocks world **domain**
  - Available predicates

```
(:predicates
        (on ?x ?y)  (clear ?x)
)
```

The blocks world example in PDDL

- Blocks world **domain**

  - Available action

```
(:action move
        :parameters (?b ?x ?y)
        :precondition (and
                (on ?b ?x) (clear ?b)
                (clear ?y))
        :effect (…)
)
```

The blocks world example in PDDL

- Blocks world **domain**

  - Available action

```
(:action move-to-table
        :parameters (?b ?x)
        :precondition (…)
        :effect (…)
)
```

The blocks world example in PDDL

- Blocks world **problem**
  - Available objects (:objects …)
  - Initial state (:init …)
  - Goal (:goal …)

The blocks world example in PDDL

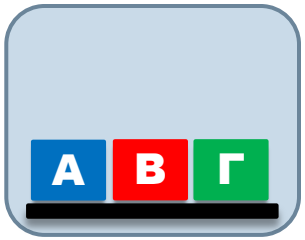
- Blocks world **domain**
  - Available objects

```
(:objects
        a b c table
)
```

The blocks world example in PDDL

- Blocks world **domain**

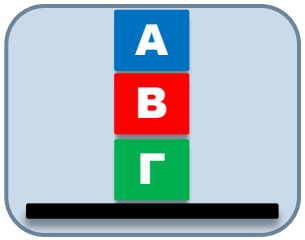
  - Initial state




```
(:init
        (on a table)  (clear a)
        (on b table)  (clear b)
        (on c table)   (clear c)
)
```

The blocks world example in PDDL

- Blocks world **domain**
  - Goal




```
(:goal
        (and (on a b) (on b c) )
)
```

The blocks world example in PDDL

blocks-domain.txt:

```
(define (domain gripper)
(:requirements :strips)
(:predicates (on ?x ?y)  (clear ?x))

(:action move
:parameters (?b ?x ?y)
:precondition (and (on ?b ?x) (clear ?b) (clear ?y))
:effect (and (not (on ?b ?x))
        (not (clear ?y))
        (on ?b ?y)
        (clear ?x)))
...
```

blocks-problem1.txt:

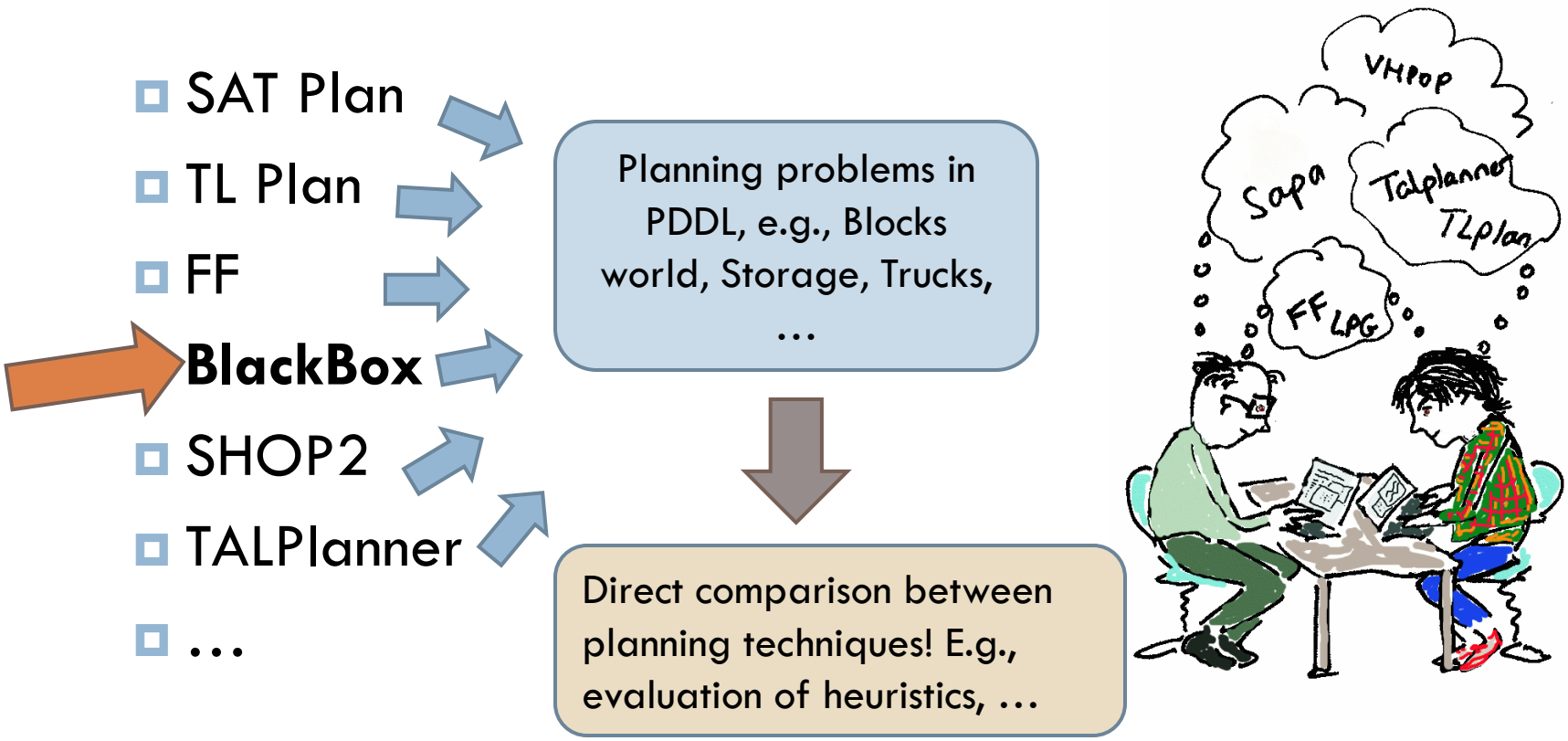
```
(define (problem gripper1)
(:domain gripper)
(:objects  a b c table)

(:init
  (on a table)   (on b table)  (on c table)
  (clear a)   (clear b)  (clear c)
)

(:goal (and (on a b) (on b c)))
)
```

Using PDDL planners

- Planning Domain Definition Language (PDDL)
  - International Planning Competition 1998 – today



Using PDDL planners: Blocks world

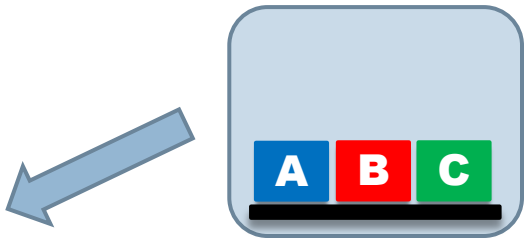
- blackbox –o blocks-domain.txt –f blocks-problem1.txt

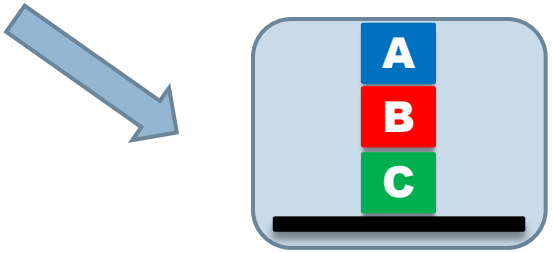
Begin plan

1 (move b table c)

2 (move a table b)

End plan





Using PDDL planners: Blocks world

- blackbox –o blocks-domain.txt –f blocks-problem2.txt

Begin plan

1 (move e b d)

2 (move b table e)

3 (move g f table)

4 (move f c g)

5 (move b e c)

6 (move e d f)

7 (move d a e)

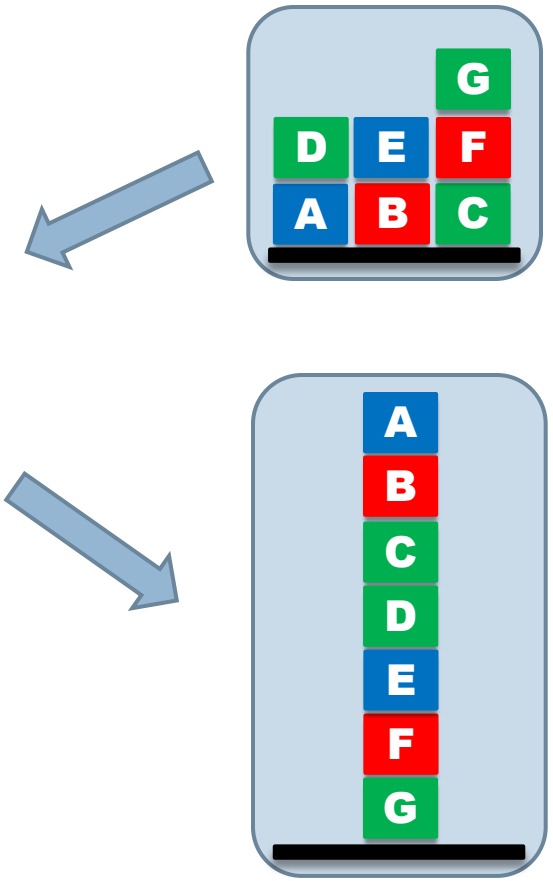
8 (move b c a)

9 (move c table d)

10 (move b a c)

11 (move a table b)

End plan

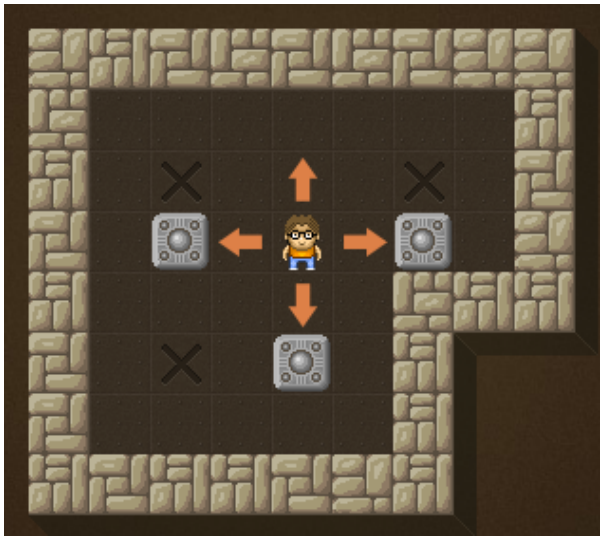


Using PDDL planners

- We can use blackbox (or any other off-the-self PDDL planner) for any problem we can write in PDDL!

Using PDDL planners: Sokoban

- We can use blackbox (or any other off-the-self PDDL planner) for any problem we can write in PDDL!


- Let's do this for Sokoban

Using PDDL planners: Sokoban

- Available predicates
- Available actions

- Available objects
- Initial state
- Goal

Using PDDL planners: Sokoban

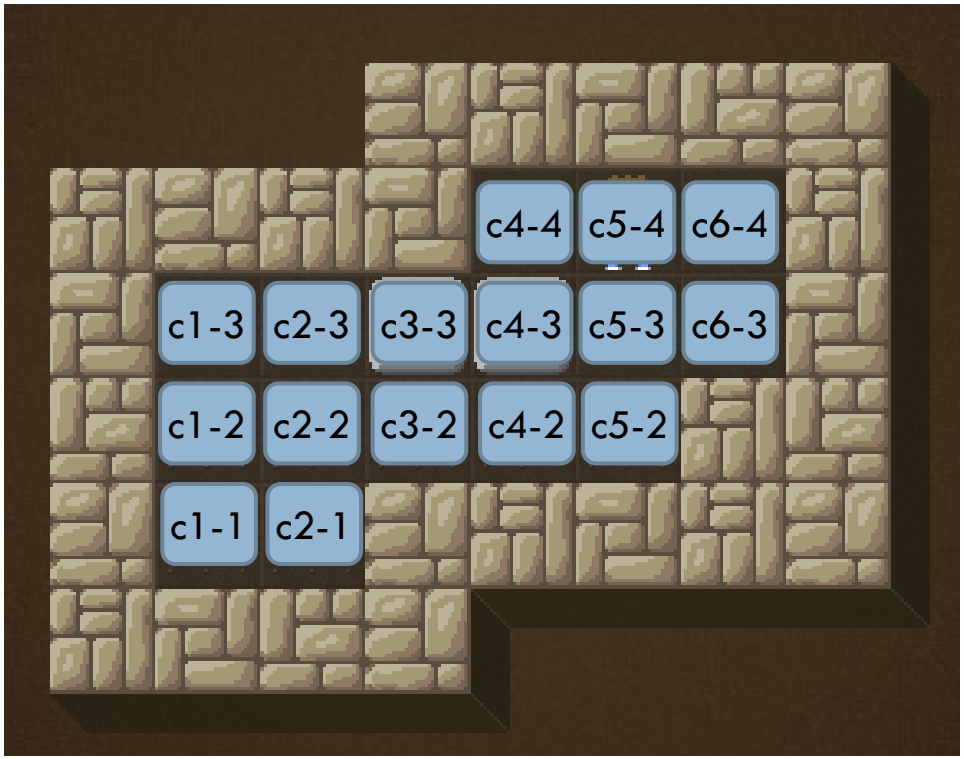
- Available predicates

Using PDDL planners: Sokoban

- Available predicates
  - (robot-at ?loc)
  - (object-at ?b ?loc)

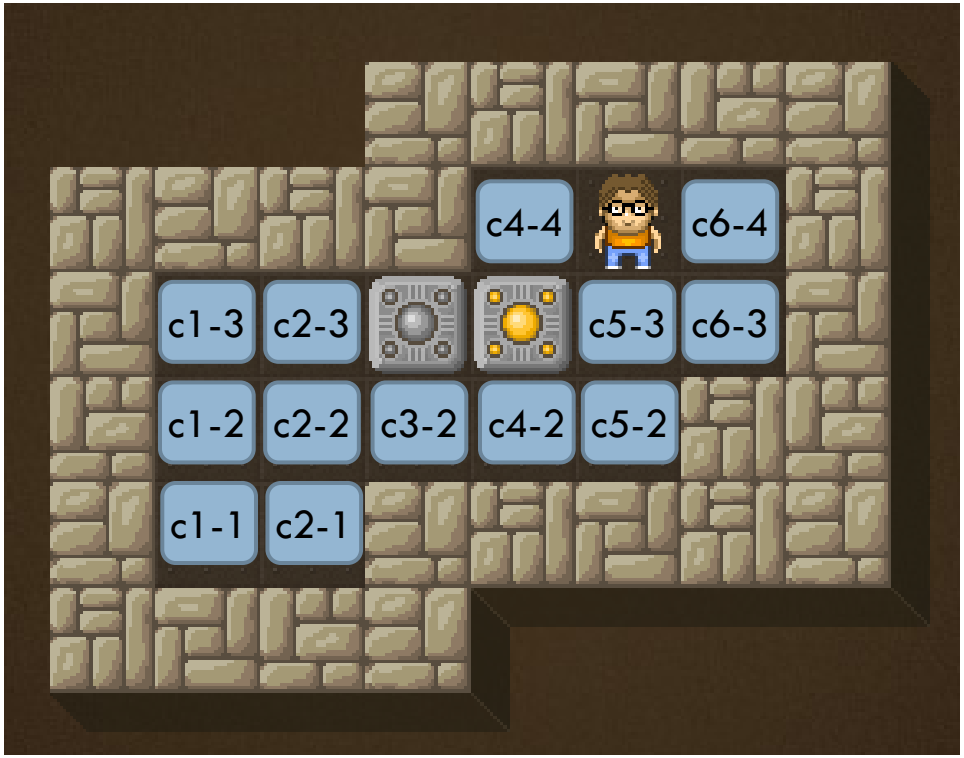
Using PDDL planners: Sokoban

- Available predicates
  - (robot-at ?loc)
  - (object-at ?b ?loc)
- Available objects
  - c1-1, c1-2, c2-1, …
  - box1, box2



Using PDDL planners: Sokoban

- Initial state
  - (robot-at c5-4)
  - (object-at box1 c3-3)
  - (object-at box2 c4-3)



Using PDDL planners: Sokoban

- Available actions
  - move(?from ?to ?dir)

  :precondition (

)

Using PDDL planners: Sokoban

- Available actions
  - move(?from ?to ?dir)

```
:precondition (and
   (robot-at ?from)
   (adjacent ?from ?to ?dir)
   (empty ?to)
)
```

Using PDDL planners: Sokoban

- Available actions
  - move(?from ?to ?dir)

:effect (and

)

Using PDDL planners: Sokoban

- Available actions
  - move(?from ?to ?dir)

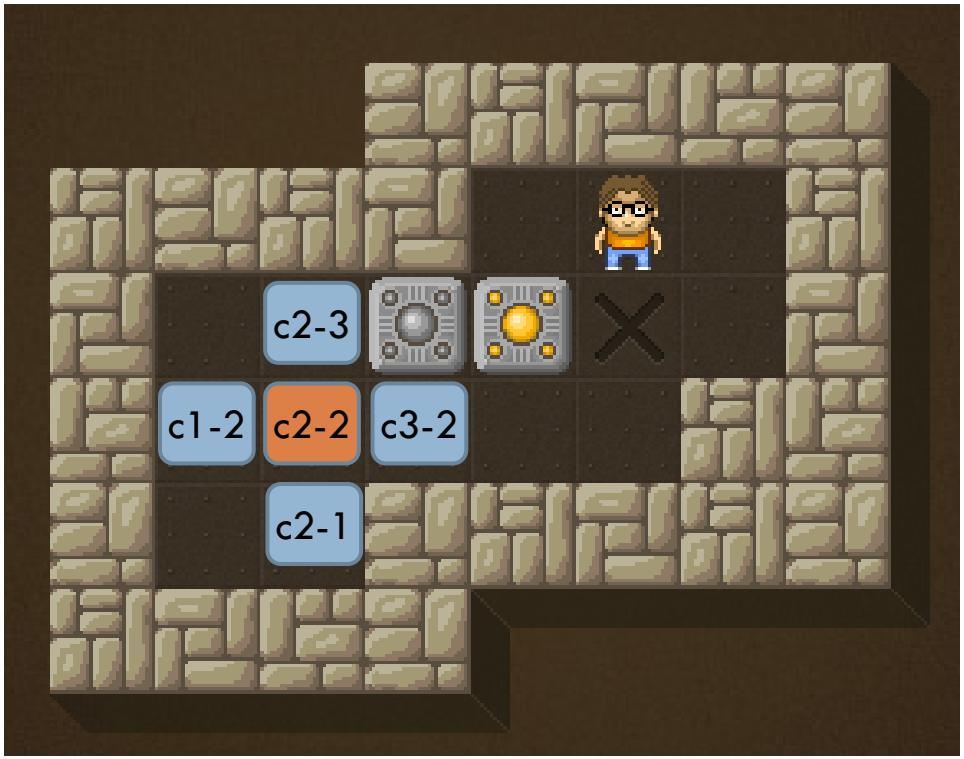
```
:effect (and
   (empty ?from)
   (robot-at ?to)
   (not (empty ?to))
   (not (robot-at ?from))
)
```

Using PDDL planners: Sokoban

- Available predicates
  - (robot-at ?loc)
  - (object-at ?b ?loc)
  - (adjacent ?from ?to ?dir)
  - (empty ?to)

Using PDDL planners: Sokoban

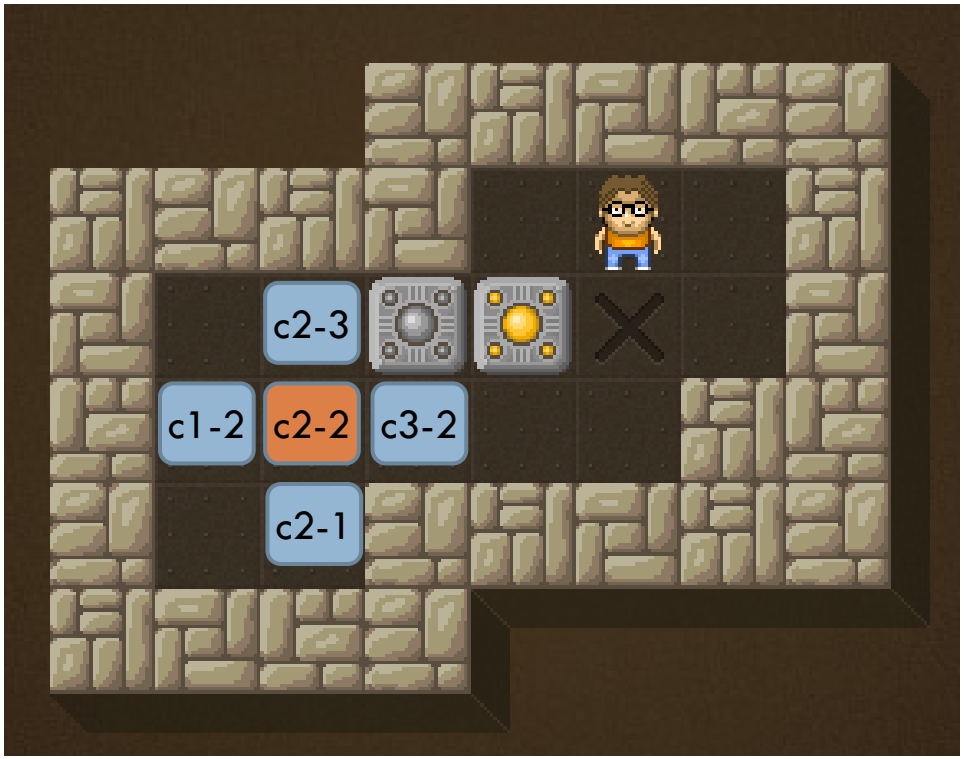
- Initial state
  - (robot-at c5-4)
  - (object-at box1 c3-3)
  - (object-at box2 c4-3)
  - (empty c1-1)
  - (empty c2-1)
  - (empty c1-2)
  - (empty c2-2)
  - …



Using PDDL planners: Sokoban

- Initial state
  - (robot-at c5-4)
  - (object-at box1 c3-3)
  - (object-at box2 c4-3)

  - (adjacent c2-2 c3-2 right)
  - (adjacent c2-2 c1-2 left)
  - (adjacent c2-2 c2-3 up)
  - (adjacent c2-2 c2-1 down)
  - …



Using PDDL planners: Sokoban

- Available actions
  - push(?rloc ?bloc ?floc ?dir ?b)

Using PDDL planners: Sokoban

- Available actions
  - push(?rloc ?bloc ?floc ?dir ?b)

```
:precondition (and
   (robot-at ?rloc)
   (object-at ?b ?bloc)
   (adjacent ?rloc ?bloc ?dir)
   (adjacent ?bloc ?floc ?dir)
   (empty ?floc)
)
```

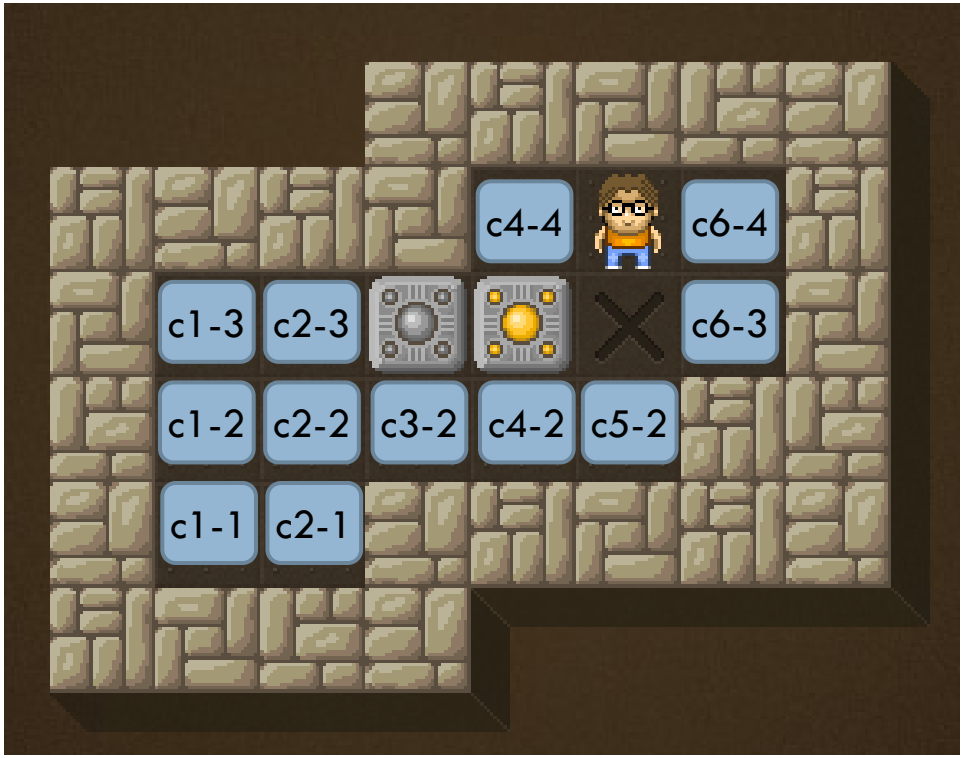
Using PDDL planners: Sokoban

- Available actions
  - push(?rloc ?bloc ?floc ?dir ?b)

```
:effect (and
   (robot-at ?bloc)
   (object-at ?b ?floc)
   (empty ?rloc)
   (not (robot-at ?rloc))
   (not (object-at ?b ?bloc))
   (not (empty ?floc))
)
```

Using PDDL planners: Sokoban

- Goal
  - (object-at box1 c4-3)
  - (object-at box2 c5-3)



Using PDDL planners: Sokoban

- blackbox –o sokoban-domain.txt –f sokoban-problem.txt

Begin plan

1 (push c4-4 c4-3 c4-2 down box1)

2 (push c4-3 c3-3 c2-3 left box2)

3 (move c3-3 c3-2 down)

4 (move c3-2 c2-2 left)

5 (move c2-2 c1-2 left)

…

27 (move c2-2 c1-2 left)

28 (move c1-2 c1-3 up)

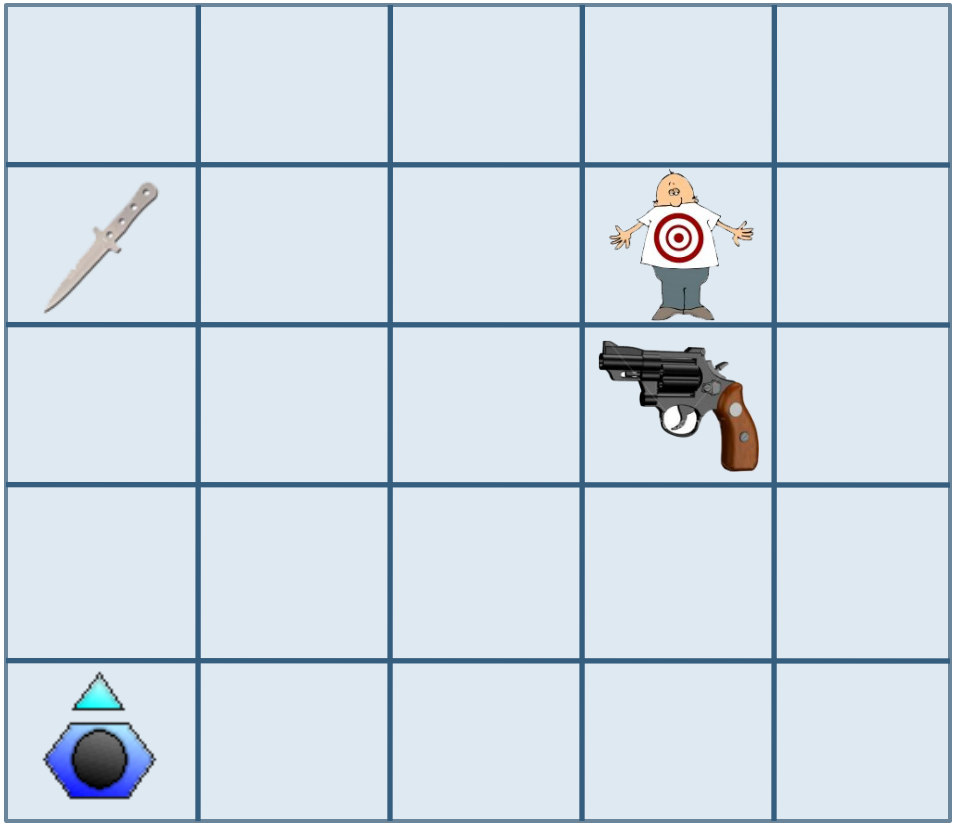
29 (push c1-3 c2-3 c3-3 right box1)

30 (push c2-3 c3-3 c4-3 right box1)

End plan

Using PDDL planners: SimpleGame

- SimpleGame domain



- turn(?fromd ?tod)
- move(?froml ?tol ?dir)
- pickup(?o ?l)
- stab(?l ?knife)
- shoot(?locn ?locp ?dir ?gun)

Building your own PDDL planner

- Pyperplan
  - Lightweight STRIPS planner written in Python. Developed during the planning course at Albert-Ludwigs-Universität Freiburg 2010/2011, GNU General Public License 3
  - https://bitbucket.org/malte/pyperplan
- Source code of academic planners
  - BlackBox: http://www.cs.rochester.edu/u/kautz/satplan/blackbox/
  - FastForward: http://www.loria.fr/~hoffmanj/ff.html
  - FastDownward: http://www.fast-downward.org/
- ANTLR Parser Generator
  - http://www.antlr.org/
  - http://www.antlr.org/grammar/1222962012944/Pddl.g

Building your own PDDL planner

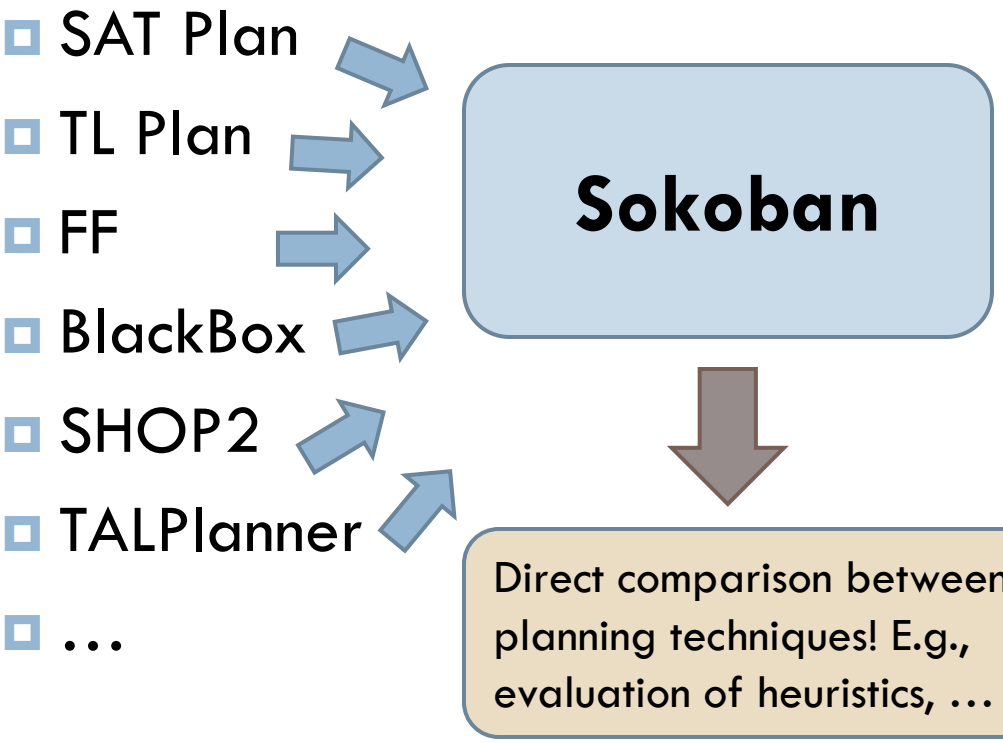
- Quick overview of the provided PROLOG code
- Good for quick prototyping ;-)

Building your own PDDL planner

- Quick overview of the provided PROLOG code
- Works with SWI Prolog 6.x (tested with 6.0.2)
- Predicates provided
  - parsePDDL(+DomainFile, +ProblemFile)
  - get_init(-InitialState)
  - get_goal(-Goal)
  - satisfies_goal(+State)
  - progress(+State, -Action, -NextState)
  - h(+State, -Value)
- {dfs,astar}planner(+DomainFile, +ProblemFile)

Planning Domain Description Language

- Planning Domain Definition Language (PDDL)
  - International Planning Competition 1998 – today



Using PDDL planners

- FastDownward [Helmert 2006]
  - Introduced a new type of heuristic that is not based on an empty list of negative actions
  - Efficient implementation of all notable forward search methods and heuristics (including the more recent ones)
  - Requires a number of preprocessing steps that transforms the STRIPS planning problem…

Using PDDL planners

- FastDownward [Helmert 2006]
  - Introduced a new type of heuristic that is not based on an empty list of negative actions
  - **Efficient implementation** of all notable **forward search** methods and **heuristics** (including the more recent ones)
  - Requires a number of preprocessing steps that transforms the STRIPS planning problem…
  - **Can be used as a framework to evaluate forward search planning methods**

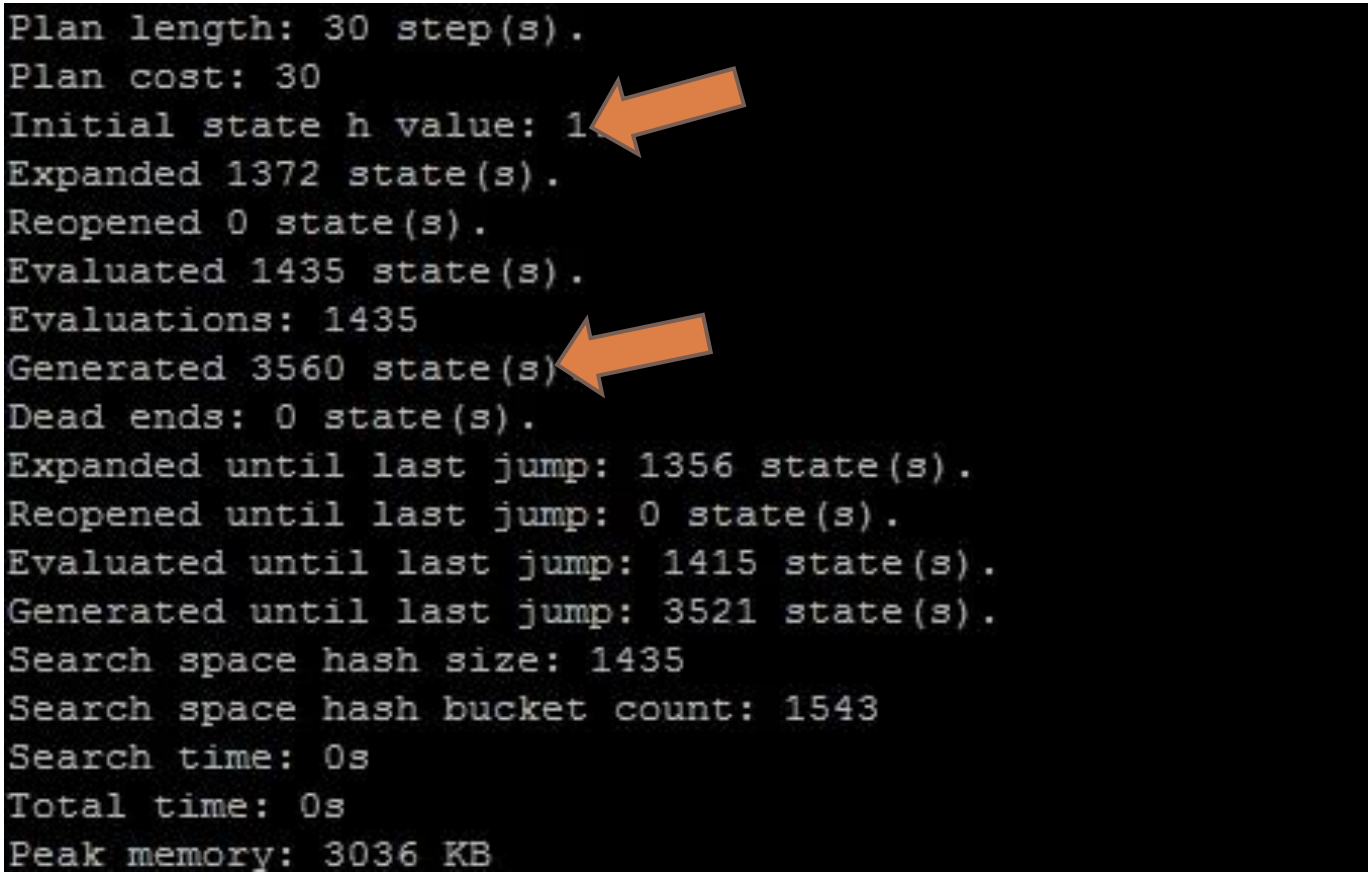
Using PDDL planners

- FastDownward [Helmert 2006]
  - translate/translate.py sokoban-domain.txt \
    sokoban.problem.txt
  - preprocess/preprocess < output.sas
  - search/downward --search SearchConfiguration < output

- http://www.fast-downward.org

Using PDDL planners: Sokoban

- search/downward --search "astar(blind())" <output



Using PDDL planners: Sokoban

- search/downward --search "astar(goalcount())"

```
Plan length: 30 step(s).
Plan cost: 30
Initial state h value: 1.
Expanded 1298 state(s).
Reopened 0 state(s).
Evaluated 1365 state(s).
Evaluations: 1365
Generated 3370 state(s).
Dead ends: 0 state(s).
Expanded until last jump: 1295 state(s).
Reopened until last jump: 0 state(s).
Evaluated until last jump: 1361 state(s).
Generated until last jump: 3365 state(s).
Search space hash size: 1365
Search space hash bucket count: 1543
Search time: 0s
Total time: 0s
Peak memory: 3040 KB
```

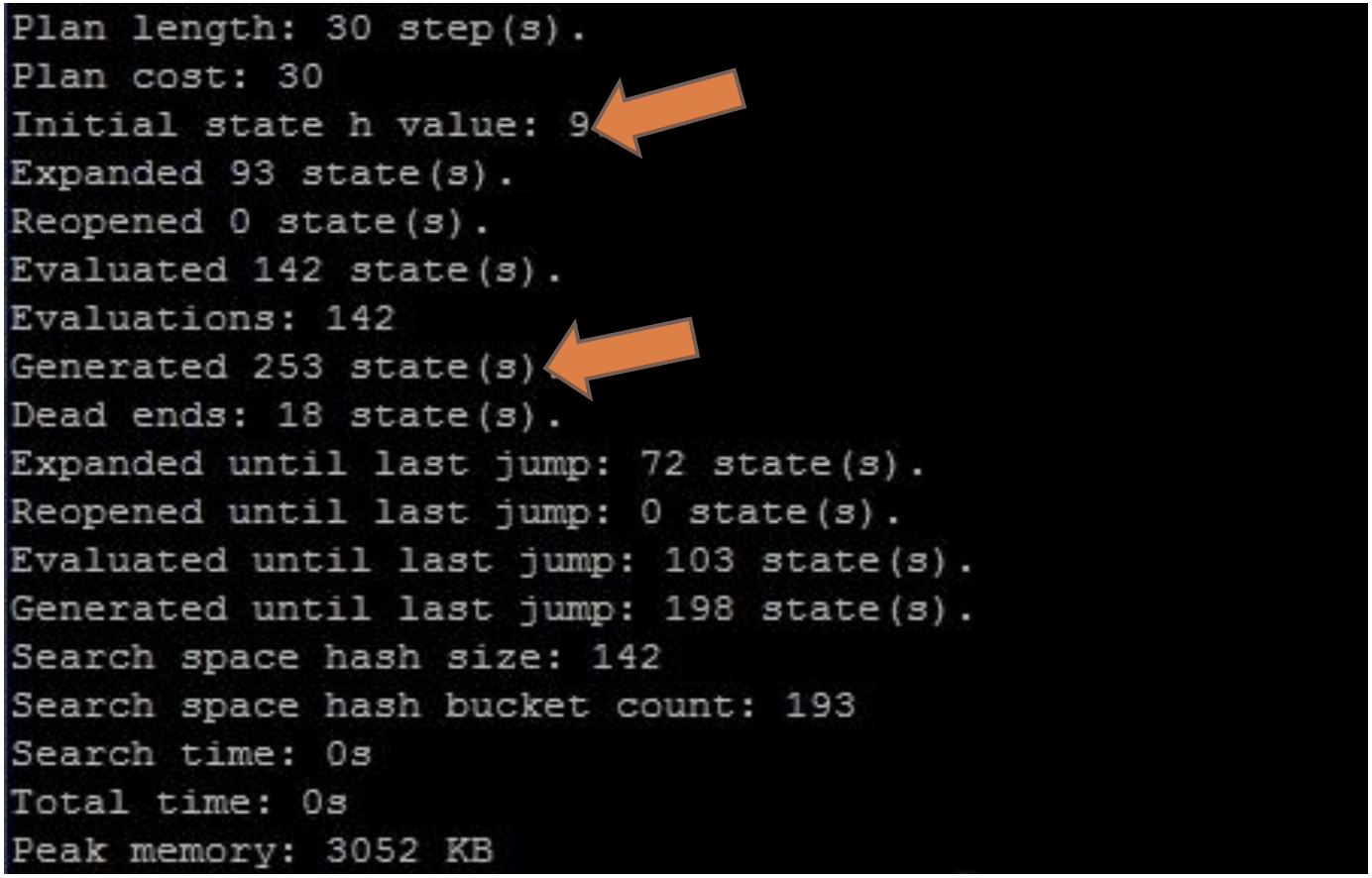
Using PDDL planners: Sokoban

- search/downward --search "astar(hmax())" <output

```
Plan length: 30 step(s).
Plan cost: 30
Initial state h value: 5
Expanded 139 state(s).
Reopened 0 state(s).
Evaluated 176 state(s).
Evaluations: 176
Generated 364 state(s).
Dead ends: 21 state(s).
Expanded until last jump: 133 state(s).
Reopened until last jump: 0 state(s).
Evaluated until last jump: 166 state(s).
Generated until last jump: 351 state(s).
Search space hash size: 176
Search space hash bucket count: 193
Search time: 0s
Total time: 0s
Peak memory: 3052 KB
```

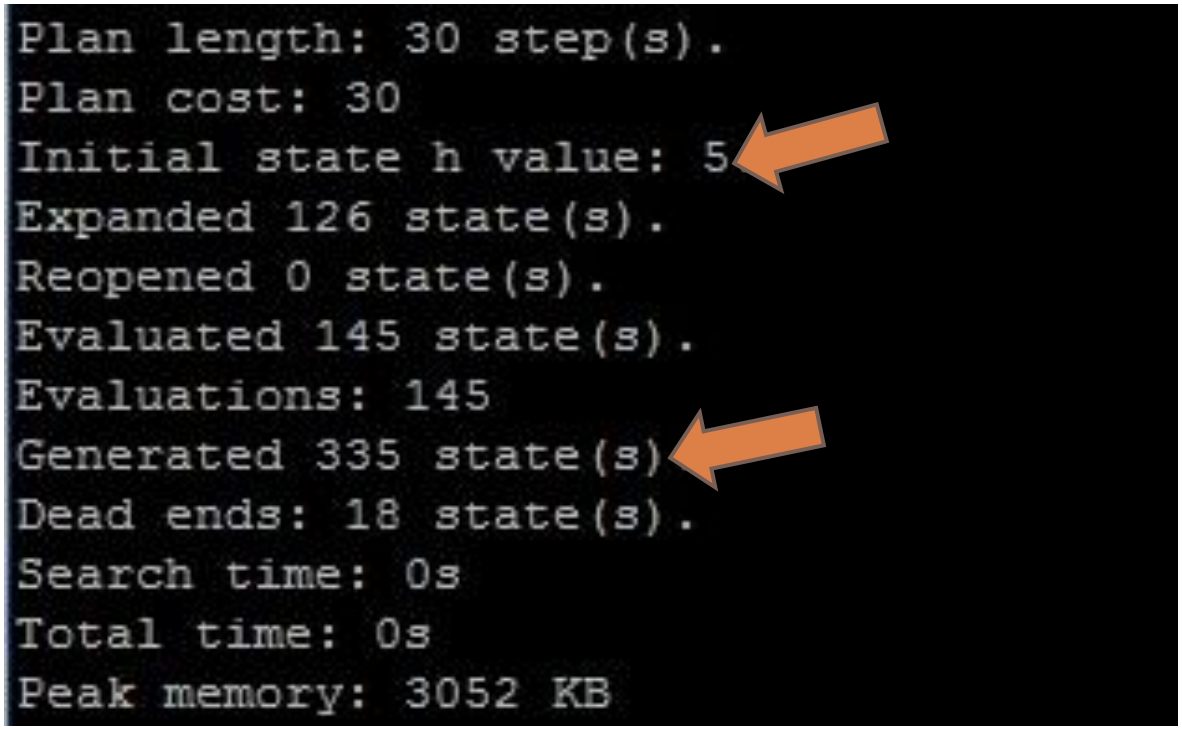
Using PDDL planners: Sokoban

- search/downward --search "astar(add())" <output



Using PDDL planners: Sokoban

- search/downward --search "lazy_greedy(ff())" <output



Using PDDL planners: Sokoban

- Notice that the planner does not know anything about the planning problem we are solving
- The heuristics we tried are **domain independent**
  - goal count
  - h_{max}
  - h_{add}
  - FF
- We will see how each one works in Lecture 4 (after we first go over planning graphs that are needed)

Next lecture

- Lecture 1: Game-inspired competitions for AI research, AI decision making for non-player characters in games
- Lecture 2: STRIPS planning, state-space search
- Lecture 3: Planning Domain Definition Language (PDDL), using an award winning planner to solve Sokoban
- Lecture 4: Planning graphs, domain independent heuristics for STRIPS planning
- Lecture 5: Employing STRIPS planning in games: SimpleFPS, iThinkUnity3D, SmartWorkersRTS
- Lecture 6: Planning beyond STRIPS

Bibliography

- Material
  - Artificial Intelligence: A Modern Approach 2nd Ed. Stuart Russell, Peter Norvig. Prentice Hall, 2003 Section 11.4

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