Planning Representations:
Symbolic Representation for Task Planning

Maxim Likhachev
Robotics Institute
Carnegie Mellon University
Planning to Construct a Birdcage

- Robot takes in a 3D model of a birdcage it needs to build
Planning to Construct a Birdcage

• Robot takes in a 3D model of a birdcage it needs to build

Planning the order in which to assemble pieces is an example of Task Planning.
Famous “Blocksworld” Example

- Planning to re-order the blocks

start state

goal state
Famous “Blocksworld” Example

• Planning to re-order the blocks

Assuming the arm can reach/move all the top blocks, the problem is in figuring out the order.

start state

goal state
Famous “Blocksworld” Example

• Planning to re-order the blocks

**Actions:**

- \( \text{Move}(b,x,y) \) – moves block \( b \) from \( x \) to \( y \)
- \( \text{MoveToTable}(b,x) \) – moves block \( b \) from \( x \) to table

\[
\begin{array}{c}
A \\
B \\
C \\
\end{array} \quad \rightarrow \quad \begin{array}{c}
B \\
C \\
A \\
\end{array}
\]

**start state** \rightarrow **goal state**
Famous “Blocksworld” Example

• Planning to re-order the blocks

*Actions*:

\[\text{Move}(b,x,y) \text{ – moves block } b \text{ from } x \text{ to } y\]
\[\text{MoveToTable}(b,x) \text{ – moves block } b \text{ from } x \text{ to table}\]

\[\begin{array}{c}
A \\
B \\
C
\end{array} \quad \begin{array}{c}
B \\
C \\
A
\end{array}\]

*start state* \quad *goal state*

*What is a plan that achieves the goal?*
Defining it as a Graph Search (State-space Search)

• Planning to re-order the blocks

Actions:

- Move($b,x,y$) – moves block $b$ from $x$ to $y$
- MoveToTable($b,x$) – moves block $b$ from $x$ to table

Any ideas for how to represent a state in a graph?
Defining it as a Graph Search (State-space Search)

• Planning to re-order the blocks

**Actions:**

- Move(b,x,y) – moves block b from x to y
- MoveToTable(b,x) – moves block b from x to table

**start state**

- A=on B
- B=on table
- C=on table

**goal state**

- A=on B
- B=on table
- C=on table
Defining it as a Graph Search (State-space Search)

- Planning to re-order the blocks

**Actions:**

\[
\text{Move}(b,x,y) \rightarrow \text{moves block } b \text{ from } x \text{ to } y
\]

\[
\text{MoveToTable}(b,x) \rightarrow \text{moves block } b \text{ from } x \text{ to table}
\]

\[
\begin{array}{c}
A \\
\hline
B \\
\hline
C
\end{array}
\quad \Rightarrow \quad
\begin{array}{c}
A=\text{on } B \\
B=\text{on table} \\
C=\text{on table}
\end{array}
\]

```
move(A,B,C)
```

\[
\begin{array}{c}
A=\text{on table} \\
B=\text{on table} \\
C=\text{on table}
\end{array}
\]

\[
\begin{array}{c}
B \\
\hline
C \\
\hline
A
\end{array}
\]

```
... move(A,B,C)
```

```
A=\text{on } B \\
B=\text{on table} \\
C=\text{on table}
```

\[
\begin{array}{c}
A=\text{on C} \\
B=\text{on table} \\
C=\text{on table}
\end{array}
\]
• Planning to re-order the blocks

**Actions:**

- Move\((b,x,y)\) – moves block \(b\) from \(x\) to \(y\)
- MoveToTable\((b,x)\) – moves block \(b\) from \(x\) to table

**start state**

\[
\begin{array}{c}
A \\
B \\
C
\end{array}
\]

**goal state**

\[
\begin{array}{c}
B \\
C \\
A
\end{array}
\]

Cost of each edge is often set to 1
(minimization of the total # of actions)
Defining it as a Graph Search (State-space Search)

• Planning to re-order the blocks

Actions:

\[ \text{Move}(b,x,y) \] – moves block \( b \) from \( x \) to \( y \)

\[ \text{MoveToTable}(b,x) \] – moves block \( b \) from \( x \) to table

![Start state diagram](image)

![Goal state diagram](image)

Any ideas for heuristics?
We would like to be able to represent ANY planning problem with a single representational language that allows for the definition of:

STATES, ACTIONS, GOAL
Generic Representation of Symbolic Planning Problems

- STRIPS (=Stanford Research Institute Problem Solver)

  *State Representation:*

  *Goal Representation:*

  *Action Representation:*
Generic Representation of Symbolic Planning Problems

• STRIPS (=Stanford Research Institute Problem Solver)

State Representation:

conjunction of positive(true) literals

(e.g. On(A,B)^On(B,Table)^On(C,Table)^Block(A)^Block(B)^Block(C)^Clear(A)^Clear(C))

Goal Representation:

Action Representation:
Generic Representation of Symbolic Planning Problems

- STRIPS (=Stanford Research Institute Problem Solver)

**State Representation:**

conjunction of positive(true) literals

(e.g, On(A,B)^On(B,Table)^On(C,Table)^Block(A)^Block(B)^Block(C)^Clear(A)^Clear(C))

**Goal Representation:**

Closed-world assumption:
any conditions not mentioned in the state are assumed to be false

**Action Representation:**
Generic Representation of Symbolic Planning Problems

- STRIPS (=Stanford Research Institute Problem Solver)

State Representation:
conjunction of positive(true) literals
(e.g, On(A,B)^On(B,Table)^On(C,Table)^Block(A)^Block(B)^Block(C)^Clear(A)^Clear(C))

Goal Representation:
desired conjunction of positive(true) literals

Action Representation:
Generic Representation of Symbolic Planning Problems

- STRIPS (=Stanford Research Institute Problem Solver)

State Representation:

\[
\text{conjunction of positive(true) literals} \\
\text{(e.g, } \text{On}(A,B) \land \text{On}(B,\text{Table}) \land \text{On}(C,\text{Table}) \land \text{Block}(A) \land \text{Block}(B) \land \text{Block}(C) \land \text{Clear}(A) \land \text{Clear}(C)\text{)}
\]

Goal Representation:

\[
\text{desired conjunction of positive(true) literals}
\]

Action Representation:

What is it for this goal?
Generic Representation of Symbolic Planning Problems

- STRIPS (=Stanford Research Institute Problem Solver)

**State Representation:**

conjunction of positive(true) literals

(e.g, On(A,B)\(^\land\)On(B,Table)\(^\land\)On(C,Table)\(^\land\)Block(A)\(^\land\)Block(B)\(^\land\)Block(C)\(^\land\)Clear(A)\(^\land\)Clear(C))

**Goal Representation:**

desired conjunction of positive(true) literals

**Action Representation:**

*Could be partially-specified*

Goal: any state where A is directly on the table
Generic Representation of Symbolic Planning Problems

- STRIPS (=Stanford Research Institute Problem Solver)

**State Representation:**

\[ \text{conjunction of positive(true) literals} \]

\[ \text{(e.g, } \text{On}(A,B) \land \text{On}(B,\text{Table}) \land \text{On}(C,\text{Table}) \land \text{Block}(A) \land \text{Block}(B) \land \text{Block}(C) \land \text{Clear}(A) \land \text{Clear}(C)) \]

**Goal Representation:**

\[ \text{desired conjunction of positive(true) literals} \]

**Action Representation:**

Goal: any state where \( A \) is directly on the table

What is it for this goal?
Generic Representation of Symbolic Planning Problems

- STRIPS (= Stanford Research Institute Problem Solver)

**State Representation:**

conjunction of positive(true) literals

(e.g., \(\text{On}(A,B) \land \text{On}(B,\text{Table}) \land \text{On}(C,\text{Table}) \land \text{Block}(A) \land \text{Block}(B) \land \text{Block}(C) \land \text{Clear}(A) \land \text{Clear}(C)\))

**Goal Representation:**

desired conjunction of positive(true) literals

**Action Representation:**

**Preconditions:** conjunction of positive(true) literals that must held true in order for the action to be applicable

**Effect:** conjunction of positive(true) literals showing how the state will change (what should be deleted and added)
Generic Representation of Symbolic Planning Problems

- STRIPS (=Stanford Research Institute Problem Solver)

State Representation:

conjunction of positive (true) literals

(e.g., On(A,B)^On(B,Table)^On(C,Table)^Block(A)^Block(B)^Block(C)^Clear(A)^Clear(C))

Goal Representation:

desired conjunction of positive (true) literals

What are preconditions & effect for MoveToTable(b,x) action?

Action Representation:

**Preconditions:** conjunction of positive (true) literals that must be held true in order for the action to be applicable

**Effect:** conjunction of positive (true) literals showing how the state will change (what should be deleted and added)
Generic Representation of Symbolic Planning Problems

- STRIPS (=Stanford Research Institute Problem Solver)

**State Representation:**

conjunction of positive (true) literals

(e.g, On(A,B)^On(B,Table)^On(C,Table)^Block(A)^Block(B)^Block(C)^Clear(A)^Clear(C))

**Goal Representation:**

desired conjunction of positive (true) literals

**Action Representation:**

Preconditions: conjunction of positive (true) literals that must hold true in order for the action to be applicable

Effect: conjunction of positive (true) literals showing how the state will change (what should be deleted and added)

What are preconditions & effect for MoveToTable(b,x) action?

**MoveToTable(b,x)**

Precond: On(b,x)^Clear(b)^Block(b)

Effect: On(b,Table)^Clear(x)^~On(b,x)
Generic Representation of Symbolic Planning Problems

- STRIPS (=Stanford Research Institute Problem Solver)

**State Representation:**

\[ \text{conjunction of positive(true) literals} \]

(e.g. \(\text{On}(A,B) \land \text{On}(B,\text{Table}) \land \text{On}(C,\text{Table}) \land \text{Block}(A) \land \text{Block}(B) \land \text{Block}(C) \land \text{Clear}(A) \land \text{Clear}(C)\))

**Goal Representation:**

\[ \text{desired conjunction of positive(true) literals} \]

**Action Representation:**

- **Preconditions:** conjunction of positive(true) literals that must be held true in order for the action to be applicable
- **Effect:** conjunction of positive(true) literals showing how the state will change (what should be deleted and added)

What are preconditions & effect for the Move\((b,x,y)\) action?
• Representing it with STRIPS

Start state:
\(\text{On}(A,B) \land \text{On}(B,\text{Table}) \land \text{On}(C,\text{Table}) \land \text{Block}(A) \land \text{Block}(B) \land \text{Block}(C) \land \text{Clear}(A) \land \text{Clear}(C)\)

Goal state:
\(\text{On}(B,C) \land \text{On}(C,A) \land \text{On}(A,\text{Table})\)

Actions:

\text{MoveToTable}(b,x)

Precond: \(\text{On}(b,x) \land \text{Clear}(b) \land \text{Block}(b)\)

Effect: \(\text{On}(b,\text{Table}) \land \text{Clear}(x) \land \lnot \text{On}(b,x)\)

\text{Move}(b,x,y)

Precond: \(\text{On}(b,x) \land \text{Clear}(b) \land \text{Clear}(y) \land \text{Block}(b) \land \text{Block}(y) \land (b \neq y)\)

Effect: \(\text{On}(b,y) \land \text{Clear}(x) \land \lnot \text{On}(b,x) \land \lnot \text{Clear}(y)\)
• Representing it with STRIPS

**Start state:**
\[\text{On}(A,B)^\wedge \text{On}(B,\text{Table})^\wedge \text{On}(C,\text{Table})^\wedge \text{Block}(A)^\wedge \text{Block}(B)^\wedge \text{Block}(C)^\wedge \text{Clear}(A)^\wedge \text{Clear}(C)\]

**Goal state:**
\[\text{On}(B,C)^\wedge \text{On}(C,A)^\wedge \text{On}(A,\text{Table})\]

**Actions:**

- **MoveToTable**(b,x)
  
  **Precond:** \[\text{On}(b,x)^\wedge \text{Clear}(b)^\wedge \text{Block}(b)\]
  
  **Effect:** \[\text{On}(b,\text{Table})^\wedge \text{Clear}(x)^\wedge \neg \text{On}(b,x)\]

- **Move**(b,x,y)
  
  **Precond:** \[\text{On}(b,x)^\wedge \text{Clear}(b)^\wedge \text{Clear}(y)^\wedge \text{Block}(b)^\wedge \text{Block}(y)^\wedge (b\neq y)\]
  
  **Effect:** \[\text{On}(b,y)^\wedge \text{Clear}(x)^\wedge \neg \text{On}(b,x)^\wedge \neg \text{Clear}(y)\]
• Representing it with STRIPS

We can now write a (domain-independent) program that takes in such specifications and automatically provides a function GetSuccessors(state S, action A) required for implicit graph construction.

Start state:
On(A,B)\&On(B,Table)\&On(C,Table)\&Block(A)\&Block(B)\&Block(C)\&Clear(A)\&Clear(C)

Goal state:
On(B,C)\&On(C,A)\&On(A,Table)

Actions:

MoveToTable(b,x)
Precond: On(b,x)\&Clear(b)\&Block(b)
Effect: On(b,Table)\&Clear(x)\&\sim On(b,x)

Move(b,x,y)
Precond: On(b,x)\&Clear(b)\&Clear(y)\&Block(b)\&Block(y)\&(b\sim=y)
Effect: On(b,y)\&Clear(x)\&\sim On(b,x)\&\sim Clear(y)
We can now write a (domain-independent) program that takes in such specifications and automatically provides a function GetSuccessors(state S, action A) required for implicit graph construction.

**Start state:**

\[ \text{On}(A,B)^\land \text{On}(B,\text{Table})^\land \text{On}(C,\text{Table})^\land \text{Block}(A)^\land \text{Block}(B)^\land \text{Block}(C)^\land \text{Clear}(A)^\land \text{Clear}(C) \]

**Goal state:**

\[ \text{On}(B,C)^\land \text{On}(C,A)^\land \text{On}(A,\text{Table}) \]

**Actions:**

- **MoveToTable**(b,x)
  
  **Precond:** \( \text{On}(b,x)^\land \text{Clear}(b)^\land \text{Block}(b) \)
  
  **Effect:** \( \text{On}(b,\text{Table})^\land \text{Clear}(x)^\land \neg \text{On}(b,x) \)

- **Move**(b,x,y)
  
  **Precond:** \( \text{On}(b,x)^\land \text{Clear}(b)^\land \text{Clear}(y)^\land \text{Block}(b)^\land \text{Block}(y)^\land (b \neq y) \)
  
  **Effect:** \( \text{On}(b,y)^\land \text{Clear}(x)^\land \neg \text{On}(b,x)^\land \neg \text{Clear}(y) \)

This graph can be searched with A* or any other search.

This is often referred to as **domain-independent planning**.
What You Should Know…

• Task Planning vs. Motion Planning

• State-space representation for Task Planning

• STRIPS representation for Task Planning