CS 1571 Introduction to AI
Lecture 16

STRIPS planning

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Administration

- **Problem set 6 is out**
  - **due on Tuesday, October 28, 2003**
- **Midterm:**
  - **at the end of the lecture**

Planning

Planning problem:
- find a sequence of actions that lead to a goal
- is a special type of a **search problem**

Specifics of a planning problem:
- Very complex states
- Large number of actions
- Every action effects only a "small" subset of relations in the state
- Goal conditions are defined over a "small" set of relations

Planning

Ways to deal planning problems:
- **Open state, action and goal representations** to allow selection, reasoning. Expose the structure.
  - **Use FOL or its restricted subset to do the reasoning.**
- **Drop the need to construct solutions sequentially from the initial state.**
  - **Apply divide and conquer strategies to sub-goals.**

Challenges:
- Build a representation language for modeling action and change
- Design of special search algorithms for a given representation

Planning systems design.

Two planning systems designs:

- **Situation calculus**
  - based on first-order logic,
  - a situation variable models new states of the world
  - use inference methods developed for FOL to do the reasoning
- **STRIPS – like planners**
  - STRIPS – Stanford research institute problem solver
  - Restricted language as compared to the situation calculus
  - Allows for more efficient planning algorithms

Situation calculus

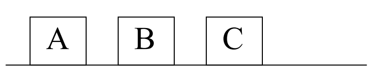
- Logic for reasoning about changes in the state of the world
- **The world is described by:**
  - Sequences of **situations** of the current state
  - Changes from one situation to another are caused by actions
- **The situation calculus allows us to:**
  - Describe the initial state and goal state
  - Build the KB that describes the effect of actions (operators)
  - Prove that the KB allows us to derive (prove) the goal state
    - and thereby allow us to extract a plan

Situation calculus

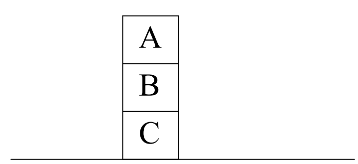
The language is based on First order logic plus:

- **Special variables:** *s,a* – objects of type situation and action
- **Action functions** that return actions.
  - E.g. *Move(A, TABLE, B)* represents a move action
  - *Move(x,y,z)* represents an action schema
- **Two special function symbols of type situation**
  - s_0 – initial situation
  - *DO(a,s)* – denotes the situation obtained after performing an action a in situation s
- **Situation-dependent functions and relations**
  (also called **fluents**)
  - **Relation:** *On(x,y,s)* – object x is on object y in situation s;
  - **Function:** Above(x,s) – object that is above x in situation s.

Situation calculus. Blocks world example.



Initial state



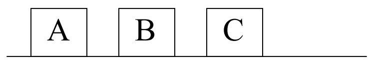
Goal

$On(A,Table, s_0)$
$On(B,Table, s_0)$
$On(C,Table, s_0)$
$Clear(A, s_0)$
$Clear(B, s_0)$
$Clear(C, s_0)$
$Clear(Table, s_0)$

Find a state (situation) s, such that

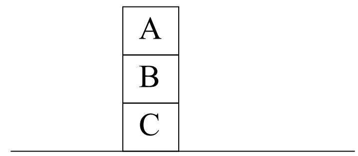
On(A,B, s)
On(B,C, s)
On(C,Table, s)

Blocks world example.



Initial state

On(A,Table, s_0*)*
On(B,Table, s_0*)*
On(C,Table, s_0*)*
Clear(A, s_0*)*
Clear(B, s_0*)*
Clear(C, s_0*)*
Clear(Table, s_0*)*



Goal

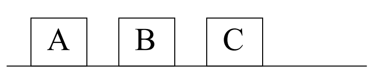
On(A,B, s)
On(B,C, s)
On(C,Table, s)

Note: It is not necessary that the goal describes all relations

Clear(A, s)

Blocks world example.

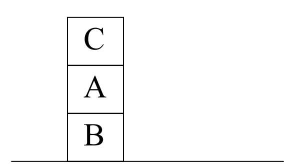
Assume a simpler goal *On(A,B, s)*

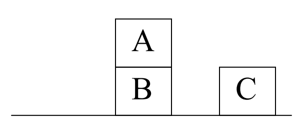


Initial state

On(A,Table, s_0*)*
On(B,Table, s_0*)*
On(C,Table, s_0*)*
Clear(A, s_0*)*
Clear(B, s_0*)*
Clear(C, s_0*)*
Clear(Table, s_0*)*

3 possible goal configurations





Goal *On(A,B, s)*

Knowledge about the world. Axioms.

Knowledge base we need to built to support the reasoning:

- Must represent changes in the world due to actions.

Two types of axioms:

- **Effect axioms**
  - changes in situations that result from actions
- **Frame axioms**
  - things preserved from the previous situation

Blocks world example. Effect axioms.

Effect axioms:

Moving x from y to z. $MOVE(x, y, z)$

Effect of move changes on **On** relations

$$On(x, y, s) \wedge Clear(x, s) \wedge Clear(z, s) \rightarrow On(x, z, DO(MOVE(x, y, z), s))$$

$$On(x, y, s) \wedge Clear(x, s) \wedge Clear(z, s) \rightarrow \neg On(x, y, DO(MOVE(x, y, z), s))$$

Effect of move changes on **Clear** relations

$$On(x, y, s) \wedge Clear(x, s) \wedge Clear(z, s) \rightarrow Clear(y, DO(MOVE(x, y, z), s))$$

$$On(x, y, s) \wedge Clear(x, s) \wedge Clear(z, s) \wedge (z \neq Table) \rightarrow \neg Clear(z, DO(MOVE(x, y, z), s))$$

Blocks world example. Frame axioms.

- **Frame axioms.**
  - Represent things that remain unchanged after an action.

On relations:

$$On(u,v,s) \wedge (u \neq x) \wedge (v \neq y) \rightarrow On(u,v,DO(MOVE(x,y,z),s))$$

Clear relations:

$$Clear(u,s) \wedge (u \neq z) \rightarrow Clear(u,DO(MOVE(x,y,z),s))$$

Planning in situation calculus.

Planning problem:

- find a sequence of actions that lead to a goal

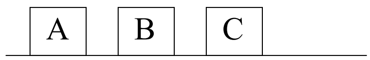
Planning in situation calculus is converted to theorem proving.

Goal state:

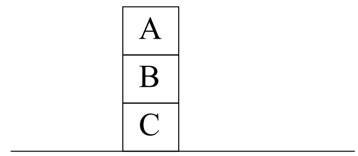
$$\exists s\ On(A,B,s) \wedge On(B,C,s) \wedge On(C,Table,s)$$

- Possible inference approaches:
  - **Inference rule approach**
  - **Conversion to SAT**
- **Plan** (solution) is a byproduct of theorem proving.
- **Example:** blocks world

Planning in a blocks world.



Initial state

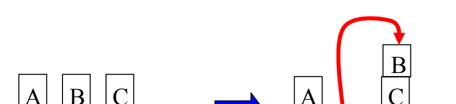


Goal

On(A,Table, s_0)
On(B,Table, s_0)
On(C,Table, s_0)
Clear(A, s_0)
Clear(B, s_0)
Clear(C, s_0)
Clear(Table, s_0)

On(A,B, s)
On(B,C, s)
On(C,Table, s)

Planning in the blocks world.



Initial state (s0) **s1**

$s_0 =$

$On(A, Table, s_0)$ $Clear(A, s_0)$ $Clear(Table, s_0)$

$On(B, Table, s_0)$ $Clear(B, s_0)$

$On(C, Table, s_0)$ $Clear(C, s_0)$

Action: $MOVE(B, Table, C)$

$s_1 = DO(MOVE(B, Table, C), s_0)$

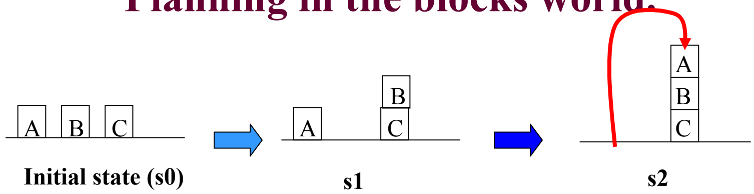
$On(A, Table, s_1)$ $Clear(A, s_1)$ $Clear(Table, s_1)$

$On(B, C, s_1)$ $Clear(B, s_1)$

$\neg On(B, Table, s_1)$ $\neg Clear(C, s_1)$

$On(C, Table, s_1)$

Planning in the blocks world.



$s_1 = DO(MOVE(B, Table, C), s_0)$

$On(A, Table, s_1)$
$On(B, C, s_1)$
$\neg On(B, Table, s_1)$
$On(C, Table, s_1)$

$Clear(A, s_1)$
$Clear(B, s_1)$
$\neg Clear(C, s_1)$

$Clear(Table, s_1)$

Action: $MOVE(A, Table, B)$

$s_2 = DO(MOVE(A, Table, B), s_1)$
$= DO(MOVE(A, Table, B), DO(MOVE(B, Table, C), s_0))$

$On(A, B, s_2)$
$On(B, C, s_2)$
$On(C, Table, s_2)$

$\neg On(A, Table, s_2)$
$\neg On(B, Table, s_2)$
$Clear(A, s_2)$

$\neg Clear(B, s_2)$
$\neg Clear(C, s_2)$
$Clear(Table, s_2)$

Planning in situation calculus.

Planning problem:

- Find a sequence of actions that lead to a goal
- Is a special type of a search problem
- Planning in situation calculus is converted to theorem proving.

- **Problems:**
  - Large search space
  - Large number of axioms to be defined for one action
  - Proof may not lead to the best (shortest) plan.

STRIPS representation.

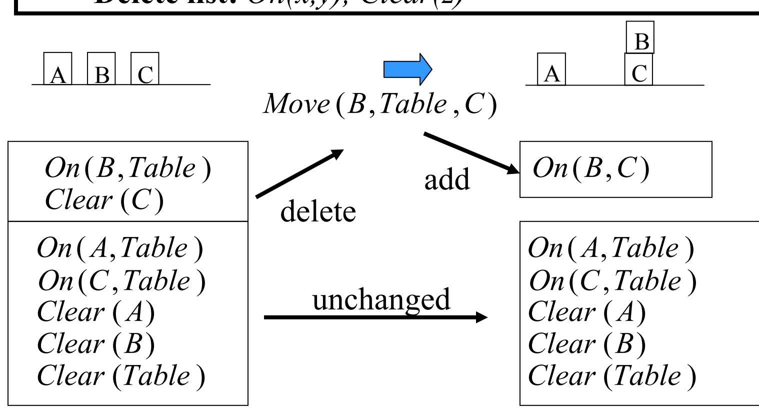
- More restricted representation language as compared to the situation calculus
- **States:**
  - represent facts that are true at a specific point in time conjunction of literals, e.g. *On(A,B), On(B,Table), Clear(A)*
- **Actions (represented by operators):**

Operator: *Move (x,y,z)*
- **Preconditions:** *On(x,y), Clear(x), Clear(z)*
- **Effect lists:**
  - **Add list:** *On(x,z), Clear(y)*
  - **Delete list:** *On(x,y), Clear(z)*
    (Everything else is unaffected)

- **Goals:** conjunctions of literals, e.g. *On(A,B), On(B,C),*

STRIPS operators

Operator: *Move (x,y,z)*
- **Preconditions:** *On(x,y), Clear(x), Clear(z)*
- **Add list:** *On(x,z), Clear(y)*
- **Delete list:** *On(x,y), Clear(z)*



STRIPS representation. Benefits.

Benefits:

- States, actions and goals have structure
- **Action representation**:
  - Leads to more intuitive and compact description of actions (no need to write many axioms !!!)
  - Avoids the frame problem
- Restrictions lead to more efficient planning algorithms.

STRIPS planning:

- find a sequence of operators from the initial state to the goal
- Search problem definition in STRIPS looks much like the standard search problem definition

STRIPS planning.

STRIPS planning problem:

- Find a sequence of actions that lead to a goal
- States and goals are defined by a conjunctions of literals

Two basic search methods:

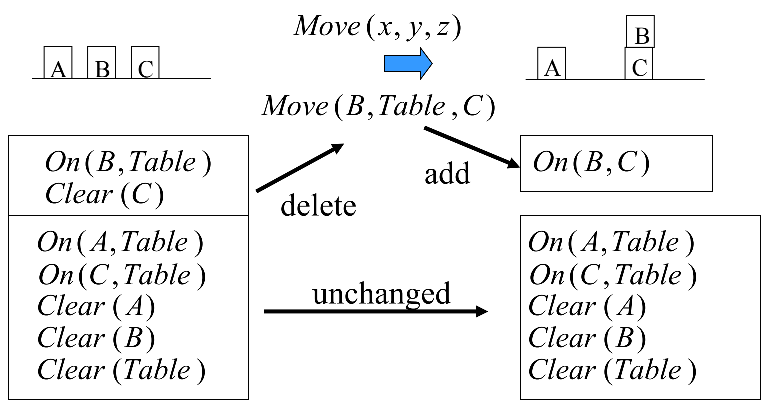
- **Forward search** (goal progression)
  - From the initial state try to reach the goal
- **Backward search** (goal regression)
  - Start from the goal and try to project it to the initial state

More complex planning method:

- **Partial-order planning (POP)**
  - Search the space of partially build plans

Forward search (goal progression)

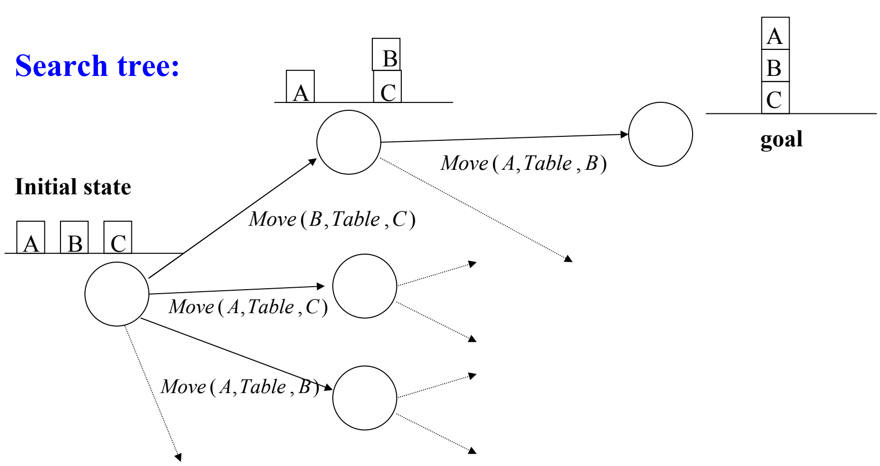
- **Idea:** Given a state *s*
  - Unify the preconditions of some operator *a* with *s*
  - Add and delete sentences from the add and delete list of an operator *a* from *s* to get a new state



Forward search (goal progression)

- Use operators to generate new states to explore
- Check new states whether they satisfy the goal

Search tree:

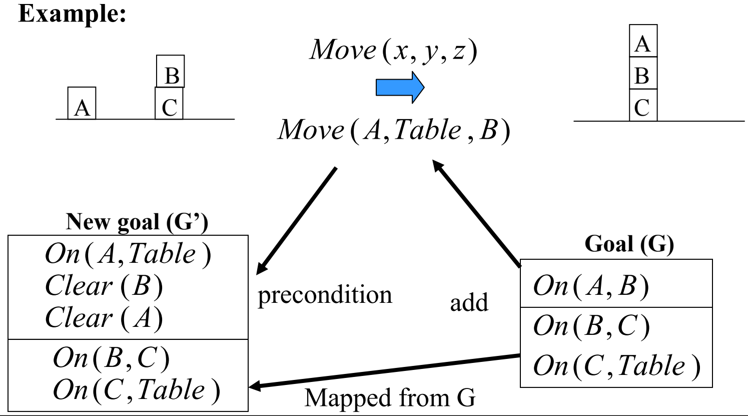


Backward search (goal regression)

Idea: Given a goal on a goal list *G*,

- find an operator that satisfies it (it is on its add list)
- Add its preconditions to the goal list G

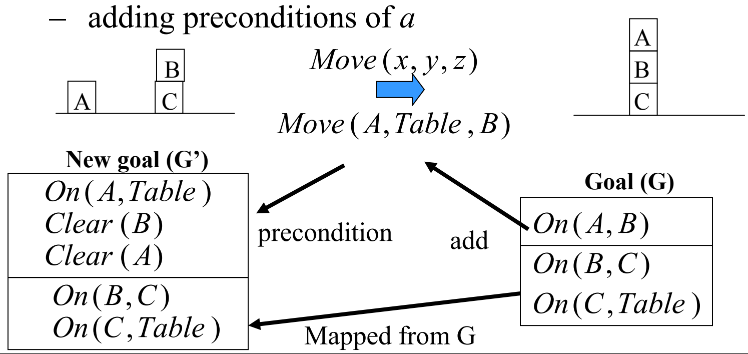
Example:



Backward search (goal regression)

More detailed description: Given a goal *G*

- Unify the add list of some operator *a* with a subset of *G*
- If the delete list of *a* does not remove elements of *G*, then the goal regresses to a new goal *G'* that is obtained from *G* by:
  - deleting add list of *a*
  - adding preconditions of *a*



Backward search (goal regression)

- Use operators to generate new goal conditions
- Check whether the initial state satisfies the current goal

Search tree: