Planning

- **Propositional and first-order logic**
  - formalism for representing the knowledge about the world and ways of reasoning
  - Statements about the world are true or false
- **The real-world:**
  - is dynamic; can change over time
  - an agent can actively change the world through its actions
- **Planning problem:** find sequence of actions that lead to a goal
- **Challenges:**
  - Build a representation language for modeling action and change
  - Design of special search algorithms for a given representation

Planning and search

Planning – a special type of a search problem

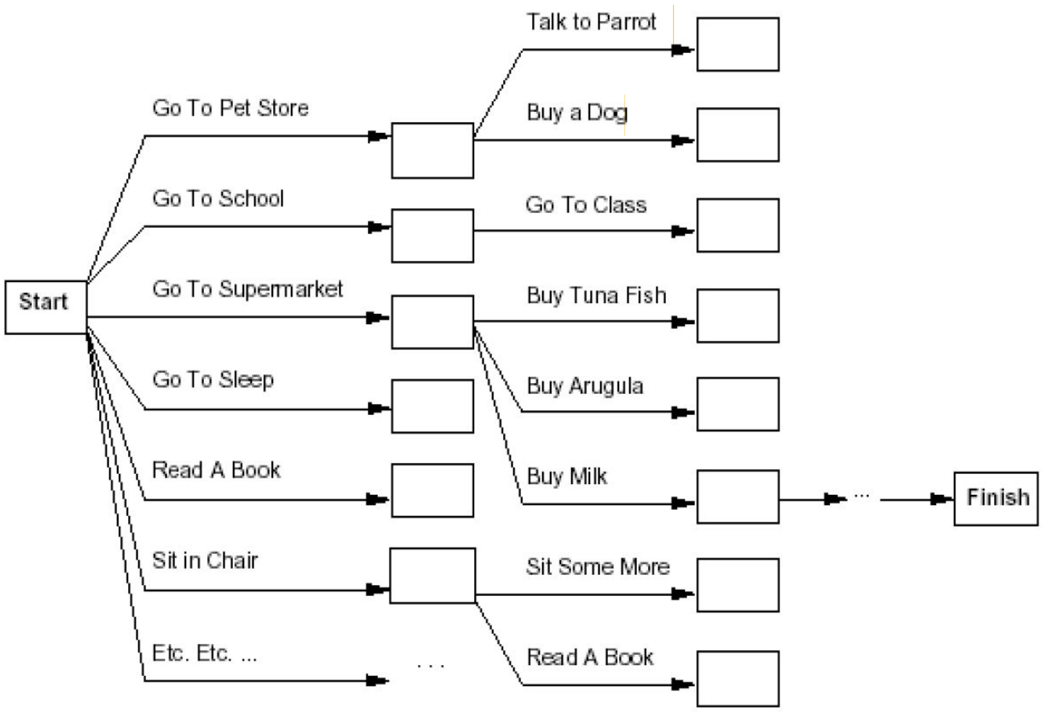
What if we use a standard search formulation?

Search problem:

- State space – a set of states of the world among which we search for the solution.
- Initial state. A state we start from.
- Operators. Map states to new states.
- Goal condition. Test whether the goal is satisfied.

- Assume a simple problem of buying things:
  – Get a quarter of milk, bananas, cordless drill

Planning search - Example



A huge branch factor !!! Goals can take multiple steps to reach!!!

Planning systems. Representation.

Design of planning systems:

- **Situation calculus**
  - based on FOL,
  - a situation variable models new states of the world
- **STRIPS – like planners**
  - STRIPS – STanford Research Institute Problem Solver
  - Restricted language as compared to situation calculus
  - Allows for more efficient planning algorithms

Situation calculus

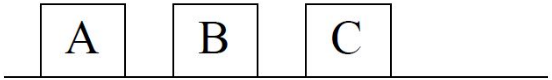
- Logic for reasoning about changes in the state of the world
- **The world is described by:**
  - Sequences of situations of the current state
  - Changes from one situation to another are caused by actions
- **The situation calculus allows us to:**
  - Describe the initial state and goal state
  -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

Situation calculus

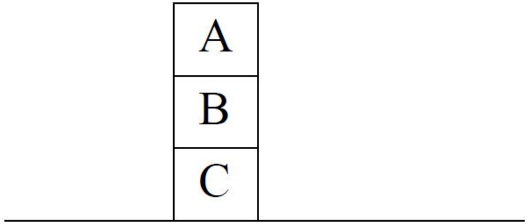
Language:

- **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

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

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

Blocks world example - Axioms

Knowledge in the KB - Two types of axioms:

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

Blocks world - 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 - Frame axioms

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

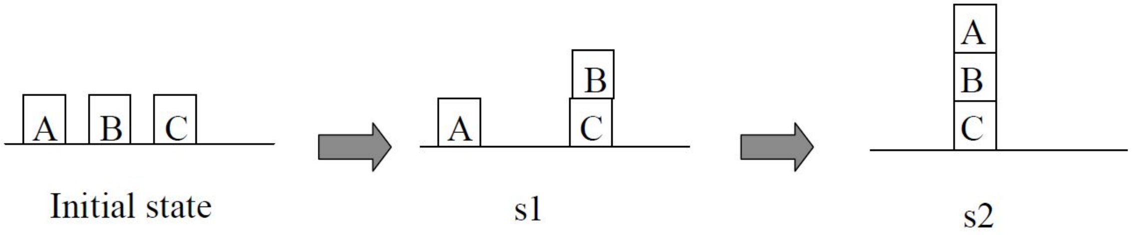
On relations:

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

Clear relations:

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

Inference - Plan derivation



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

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

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

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

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

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

$$\begin{aligned} s_2 &= DO(MOVE\,(A, Table, B), s_1) \\ &= DO(MOVE\,(A, Table, B), DO(MOVE\,(B, Table, C), s_0)) \end{aligned}$$

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

$On(B, C, s_2)$ $\quad$ $\neg Clear\,(B, s_2)$

$On(C, Table, s_2)$ $\quad$ $\neg Clear\,(C, s_2)$

STRIPS planner

- Restricted representation language as compared to the situation calculus
- Leads to more efficient planning algorithms:
  - State-space search with structured representations of states, actions and goals
  - Action representation avoids the frame problem

- STRIPS planning problem
  - much like a standard search problem;

Objective: find a sequence of operators from the initial state to the goal

STRIPS planner

- **States:**
  - conjunction of literals

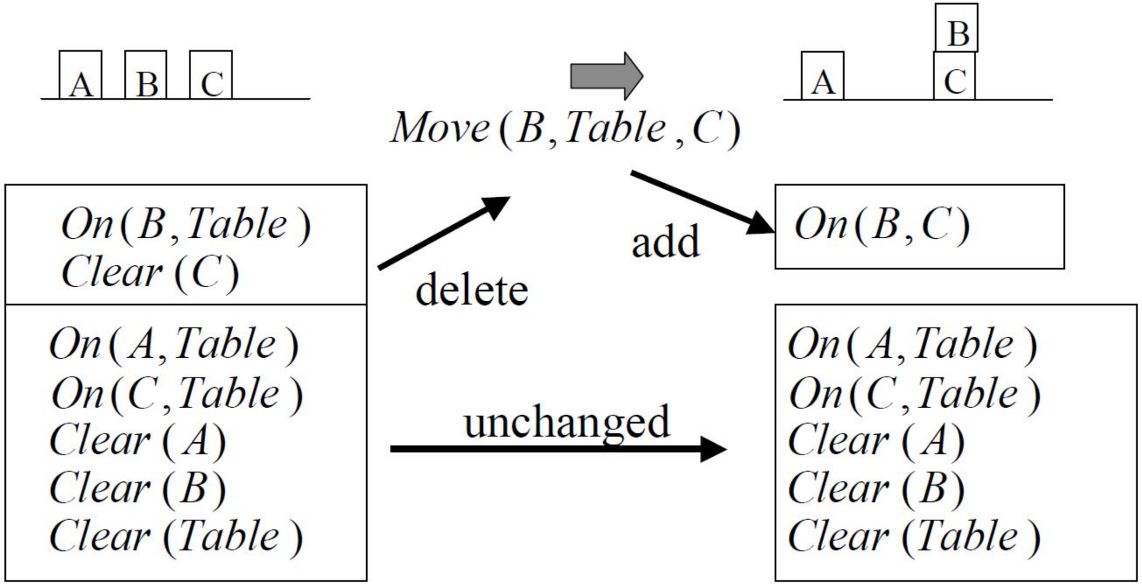
    On(A,B), On(B,Table), Clear(A)

    represent facts that are true at a specific point in time
- **Actions:**
  - **Action**: *Move (x,y,z)*
  - **Preconditions:** conjunctions of literals with variables

    On(x,y), Clear(x), Clear(z)
  - **Effects.** Two lists:
    - **Add list:** *On(x,z), Clear(y)*
    - **Delete list:** *On(x,y), Clear(z)*

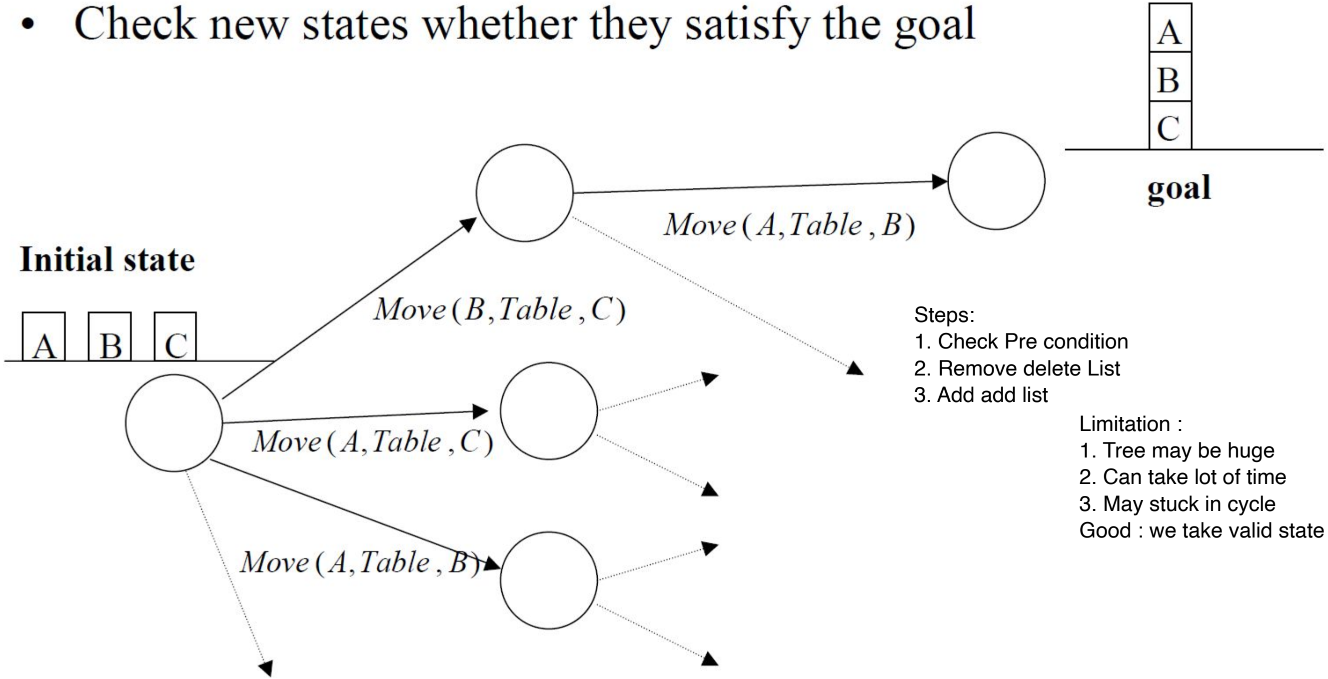
Forward search (goal progression)

- Main 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 (can be repeated)



Forward search (goal progression)

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



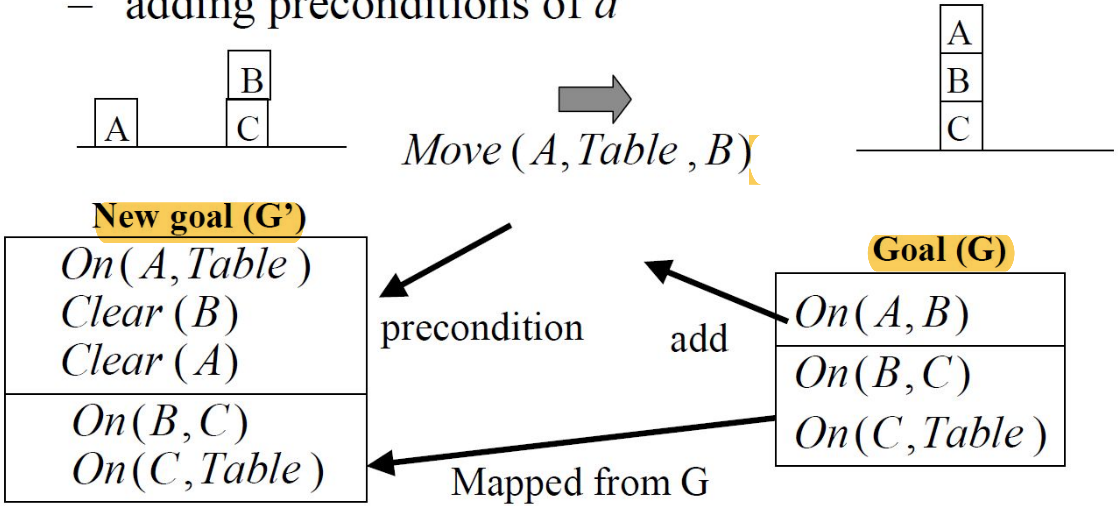
Steps:
1. Check Pre condition
2. Remove delete List
3. Add add list

Limitation :
1. Tree may be huge
2. Can take lot of time
3. May stuck in cycle
Good : we take valid state

Backward search (goal regression)

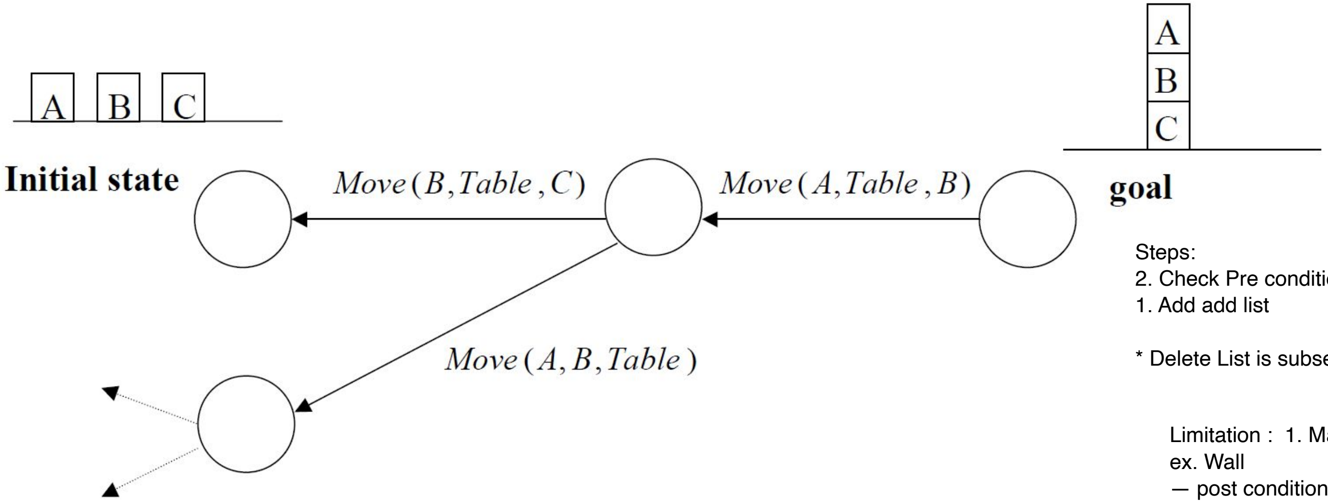
Main idea: Given a goal *G*

- Unify the addition list of some operator *a* with a subset of *G*
- If the delete list of *a* does not removes 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 goals
- Check whether the initial state satisfies the goal



Steps:
2. Check Pre condition
1. Add add list

* Delete List is subset of precondition

Limitation : 1. May be reach to invalid state
ex. Wall
— post condition