Advanced Problem Solving Systems

Planning

Objective

- Advanced Problem Solving Approaches
- Components of a Planning System
- Block World Problem
- STRIPS Mechanism
- Simple planning using a Goal Stack
- Sussman anomaly problem

Advanced Problem Solving Approaches

- In order to solve nontrivial problems, it is necessary to combine
  - Basic problem solving strategies
  - Knowledge representation mechanisms
  - Partial solutions and at the end combine into complete problem solution (decomposition)
- Planning refers to the process of computing several steps of a problem solving before executing any of them.
- Planning is useful as a problem solving technique for non decomposable problem.

Components of a Planning System

- In any general problem solving systems, elementary techniques to perform following functions are required
  - Choose the best rule (based on heuristics) to be applied
  - Apply the chosen rule to get new problem state
  - Detect when a solution has been found
  - Detect dead ends so that new directions are explored.

Choose Rules to apply

- Most widely used technique for selecting appropriate rules is to
  - first isolate a set of differences between the desired goal state and current state,
  - identify those rules that are relevant to reducing these difference,
  - if more rules are found then apply heuristic information to choose out of them.

Apply Rules

- In simple problem solving system,
  - applying rules was easy as each rule specifies the problem state that would result from its application.
  - In complex problem we deal with rules that specify only a small part of the complete problem state.

Example: Block World Problem

- Block world problem assumptions
  - Square blocks of same size
  - Blocks can be stacked one upon another.
  - Flat surface (table) on which blocks can be placed.
  - Robot arm that can manipulate the blocks. It can hold only one block at a time.
- In block world problem, the state is described by a set of predicates representing the facts that were true in that state.
- One must describe for every action, each of the changes it makes to the state description.
- In addition, some statements that everything else remains unchanged is also necessary.

Actions (Operations) done by Robot

- UNSTACK (X, Y) : **[US (X, Y)]**
  - Pick up X from its current position on block Y. The arm must be empty and X has no block on top of it.
- STACK (X, Y): **[S (X, Y)]**
  - Place block X on block Y. Arm must holding X and the top of Y is clear.
- PICKUP (X): **[PU (X)]**
  - Pick up X from the table and hold it. Initially the arm must be empty and top of X is clear.
- PUTDOWN (X): **[PD (X)]**
  - Put block X down on the table. The arm must have been holding block X.

Contd..

- Predicates used to describe the state
  - ON(X, Y) - Block X on block Y.
  - ONT(X) - Block X on the table.
  - CL(X) - Top of X clear.
  - HOLD(X) - Robot-Arm holding X.
  - AE - Robot-arm empty.
- Logical statements true in this block world.
  - Holding X means, arm is not empty

    $(\exists X)\ HOLD\ (X) \rightarrow \sim AE$
  - X is on a table means that X is not on the top of any block

    $(\forall X)\ ONT\ (X) \rightarrow \sim\ (\exists Y)\ ON\ (X, Y)$
  - Any block with no block on has clear top

    $(\forall X)\ (\sim\ (\exists Y)\ ON\ (Y,X)) \rightarrow\ CL\ (X)$

Effect of Unstack operation

- The effect of US(X, Y) is described by the following axiom

  [CL(X, State) Λ ON(X, Y, State)] $\rightarrow$
  [HOLD(X, DO(US (X, Y), State)) Λ
  CL(Y, DO(US(X, Y), State))]

  - DO is a function that generates a new state as a result of given action and a state.
- For each operator, set of rules (called frame axioms) are defined where the components of the state are
  - affected by an operator
    - If US(A, B) is executed in state S0, then we can infer that HOLD (A, S1) Λ CLEAR (B, S1) holds true, where S1 is new state after Unstack operation is executed.
  - not affected by an operator
    - If US(A, B) is executed in state S0, B in S1 is still on the table but we can't derive it. So frame rule stating this fact is defined as ONT(Z, S) $\rightarrow$ ONT(Z, DO(US (A, B), S))

Contd..

- Advantage of this approach is that
  - simple mechanism of resolution can perform all the operations that are required on the state descriptions.
- Disadvantage is that
  - number of axioms becomes very large for complex problem such as COLOR of block also does not change.
  - So we have to specify rule for each attribute.

COLOR(X, red, S) $\rightarrow$

COLOR(X, red, DO(US(Y, Z), s))

- To handle complex problem domain, there is a need of mechanism that does not require large number of explicit frame axioms.

STRIPS Mechanism

- One such mechanism was used in early robot problem solving system named STRIPS (developed by Fikes, 1971).
- In this approach, each operation is described by three lists.
  - Pre_Cond list contains predicates which have to be true before operation.
  - ADD list contains those predicates which will be true after operation
  - DELETE list contain those predicates which are no longer true after operation
- Predicates not included on either of these lists are assumed to be unaffected by the operation.
- Frame axioms are specified implicitly in STRIPS which greatly reduces amount of information stored.

STRIPS – Style Operators

- S (X, Y)
  - Pre: CL (Y) Λ HOLD (X)
  - Del: CL (Y) Λ HOLD (X)
  - Add: AE Λ ON (X, Y)
- US (X, Y)
  - Pre: ON (X, Y) Λ CL (X) Λ AE
  - Del: ON (X, Y) Λ AE
  - Add: HOLD (X) Λ CL (Y)
- PU (X)
  - Pre: ONT (X) Λ CL (X) Λ AE
  - Del: ONT (X) Λ AE
  - Add: HOLD (X)
- PD (X)
  - Pre: HOLD (X)
  - Del: HOLD (X)
  - Add: ONT (X) Λ AE

Simple Planning using a Goal Stack

- One of the earliest techniques is planning using goal stack.
- Problem solver uses single stack that contains
  - sub goals and operators both
  - sub goals are solved linearly and then finally the conjoined sub goal is solved.
- Plans generated by this method will contain
  - complete sequence of operations for solving one goal followed by complete sequence of operations for the next etc.
- Problem solver also relies on
  - A database that describes the current situation.
  - Set of operators with precondition, add and delete lists.

Algorithm

- Let us assume that the goal to be satisfied is:

$$GOAL = G1 \wedge G2 \wedge \ldots \wedge Gn$$

- Sub-goals G1, G2, … Gn are stacked with compound goal $G1 \wedge G2 \wedge \ldots \wedge Gn$ at the bottom.

Top → G1

G2

:

Gn

Bottom → $G1 \wedge G2 \wedge \ldots \wedge G4$

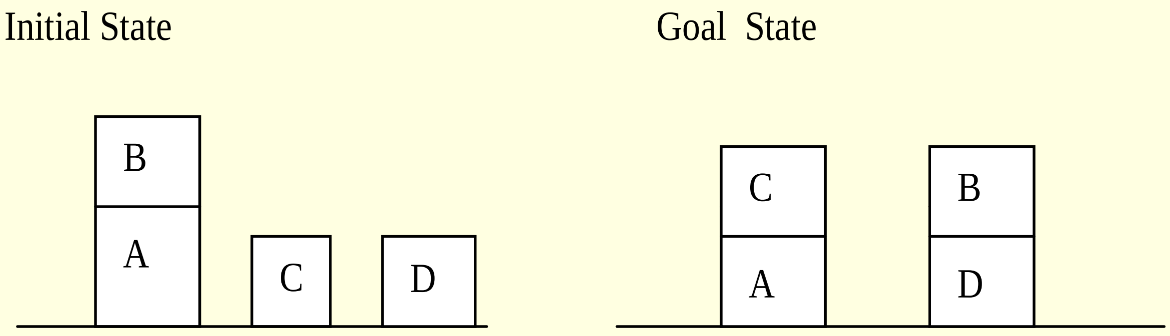
- At each step of problem solving process, the top goal on the stack is pursued.

Algorithm - Contd…

- Find an operator that satisfies sub goal G1 (makes it true) and replace G1 by the operator.
  - If more than one operator satisfies the sub goal then apply some heuristic to choose one.
- In order to execute the top most operation, its preconditions are added onto the stack.
  - Once preconditions of an operator are satisfied, then we are guaranteed that operator can be applied to produce a new state.
  - New state is obtained by using ADD and DELETE lists of an operator to the existing database.
- Problem solver keeps tract of operators applied.
  - This process is continued till the goal stack is empty and problem solver returns the plan of the problem.

Goal stack method - Example

- Logical representation of Initial and Goal states:
  - Initial State: ON(B, A) Λ ONT(C) Λ ONT(A) Λ ONT(D) Λ CL(B) ΛCL(C) Λ CL(D) Λ AE
  - Goal State: ON(C, A) Λ ON(B, D) Λ ONT(A) Λ ONT(D) Λ CL(C) Λ CL(B) Λ AE



Cont..

- We notice that following sub-goals in goal state are also true in initial state.

  $$ONT(A) \land ONT(D) \land CL(C) \land CL(B) \land AE$$

- Represent for the sake of simplicity - **TSUBG**.
- Only sub-goals ON(C, A) & ON(B, D) are to be satisfied and finally make sure that TSUBG remains true.
- Either start solving first ON(C, A) or ON(B, D). Let us solve first ON(C, A).

Goal Stack:

ON(C, A)
ON(B, D)
ON(C, A) Λ ON(B, D) Λ TSUBG

Cont...

- To solve ON(C, A), operation S(C, A) could only be applied.
- So replace ON(C, A) with S(C, A) in goal stack.

Goal Stack:

S (C, A)
ON(B, D)
ON(C, A) Λ ON(B, D) Λ TSUBG

- S(C, A) can be applied if its preconditions are true. So add its preconditions on the stack.

Goal Stack:

CL(A)	
HOLD(C)	Preconditions of STACK
CL(A) Λ HOLD(C)	
S (C, A)	Operator
ON(B, D)	
ON(C, A) Λ ON(B, D) Λ TSUBG	

Cont…

- Next check if CL(A) is true in State_0.
- Since it is not true in State_0, only operator that could make it true is US(B, A).
- So replace CL(A) with US(B, A) and add its preconditions.

Goal Stack: ON(B, A)

CL(B)	Preconditions of UNSTACK
AE	
ON(B, A) Λ CL(B) Λ AE	
US(B, A)	Operator
HOLD(C)	
CL(A)) Λ HOLD(C)	
S (C, A)	Operator
ON(B, D)	
ON(C, A) Λ ON(B, D) Λ TSUBG	

Contd…

- ON(B, A), CL(B) and AE are all true in initial state, so pop these along with its compound goal.
- Next pop top operator US(B, A) and produce new state by using its ADD and DELETE lists.
- Add US(B, A) in a queue of sequence ofoperators.

SQUEUE = US (B, A)

State_1:

ONT(A) Λ ONT(C) Λ ONT(D) Λ HOLD(B) Λ CL(A) Λ CL(C) Λ CL(D)

Goal Stack:

HOLD(C)	
CL(A)) Λ HOLD(C)	
S (C, A)	Operator
ON(B, D)	
ON(C, A) Λ ON(B, D) Λ TSUBG	

Cont…

- To satisfy the goal HOLD(C), two operators can be used e.g., PU(C) or US(C, X), where X could be any block. Let us choose PU(C) and proceed further.
- Repeat the process. Change in states is shown below.

State_1:

ONT(A) Λ ONT(C) Λ ONT(D) Λ HOLD(B) Λ CL(A) Λ CL(C) Λ CL(D)

SQUEUE = US (B, A)

- Next operator to be popped of is S(B, D). So

State_2:

ONT(A) Λ ONT(C) Λ ONT(D) Λ ON(B, D) Λ CL(A) Λ CL(C) Λ CL(B) Λ AE

SQUEUE = US (B, A), S(B, D)

State_3:

ONT(A) Λ HOLD(C) Λ ONT(D) Λ ON(B, D) Λ CL(A) Λ CL(B)

SQUEUE = US (B, A), S(B, D), PU(C)

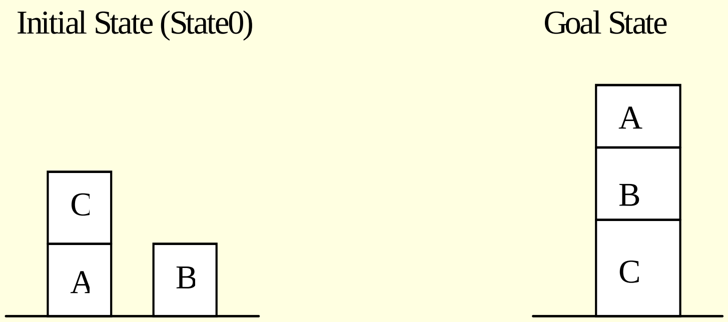
State_4:

ONT(A) Λ ON(C, A) Λ ONT(D) Λ ON(B, D) Λ CL(C) Λ CL(B) Λ AE

SQUEUE = US (B, A), S(B, D), PU(C), S(C, A)

Difficult Problem

- The Goal stack method is not efficient for difficult problems such as Sussman anomaly problem.
- It fails to find good solution.
- Let us consider the Sussman anomaly problem



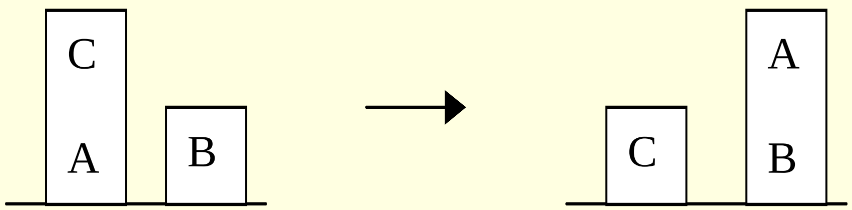
Cont…

Initial State: ON(C, A) Λ ONT(A) Λ ONT(B)

Goal State: ON(A, B) Λ ON(B, C)

- Remove CL and AE predicates for the sake of simplicity.
- To satisfy ON(A, B), following operators are applied

  US(C, A) , PD(C), PU(A) and S(A, B))



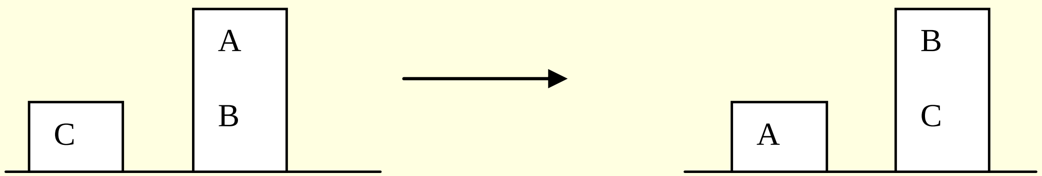
Cont…

State_1: ON(B, A) Λ ONT(C)

- To satisfy ON(B, C), following operators are applied

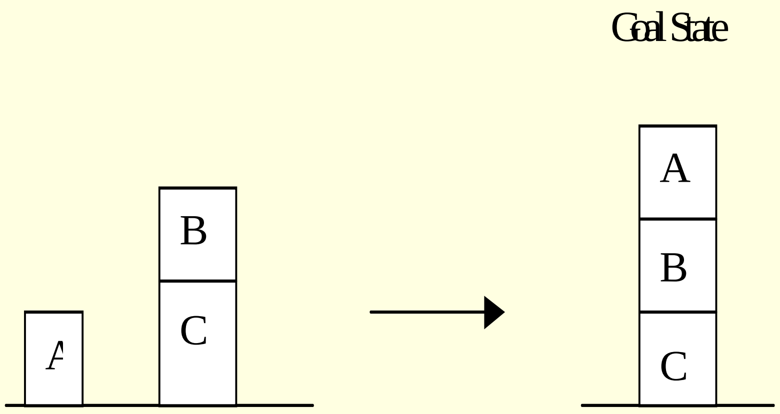
  US(A, B) , PD(A), PU(B) and S(B, C)

State_2: ON(B, C) Λ ONT(A)



Cont…

- Finally satisfy combined goal ON(A, B) Λ ON(B, C).
- Combined goal fails as while satisfying ON(B, C), we have undone ON(A, B).
- Difference in goal and current state is ON(A, B).
- Operations required are PU(A) and S(A, B)



Final Solution

- The complete plan for solution is as follows:
  1. US(C, A)
  2. PD (C)
  3. **PU(A)**
  4. **S(A, B)**
  5. **US(A, B)**
  6. **PD(A)**
  7. PU(B)
  8. S(B, C)
  9. PU(A)
  10. S(A, B)
- Although this plan will achieve the desired goal, but it is not efficient.

Cont…

- In order to get efficient plan, either repair this plan or use some other method.
- Repairing is done by looking at places where operations are done and undone immediately, such as S(A, B) and US(A, B).
- By removing them, we get
    1. US(C, A)
    2. PD (C)
    3. PU(B)
    4. S(B, C)
    5. PU(A)
    6. S(A, B)