Problem Solving – State-Space Search and Control Strategies

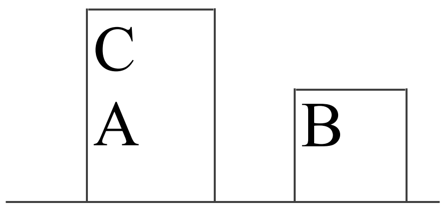
Problem Characteristics

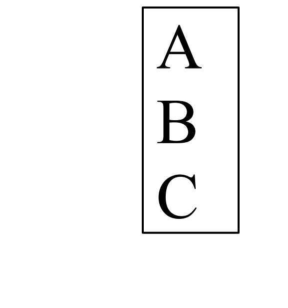
- Heuristic search is a very general method applicable to a large class of problem.
- In order to choose the most appropriate method (or combination of methods) for a particular problem it is necessary to analyze the problem along several key dimensions.
  - Is the problem decomposable into a set of independent smaller sub problems?

Contd..

- Decomposable problems can be solved by the **divide-and-conquer** technique.
  - Each sub-problem is simpler to solve.
  - Each sub-problem can be handed over to a different processor. Thus can be solved in parallel processing environment.
- Is problem non decomposable? Need different strategies
  - For example, Block world problem is non decomposable.

Initial State (State0) Goal State





Start: ON(C, A) ….

Goal: ON(B, C) Λ ON(A, B)

Contd..

- Can solution steps be ignored or at least undone if they prove to be unwise?
  - In real life, there are three types of problems:
    - Ignorable,
    - Recoverable and
    - Irrecoverable.

Example - Ignorable

- **(Ignorable)**: **In theorem proving -** (solution steps can be ignored)
  - Suppose we have proved some lemma in order to prove a theorem and eventually realized that lemma is no help at all, then ignore it and prove another lemma.
  - Can be solved by using simple **control strategy**?

Example - Recoverable

- **8 puzzle game** - (solution steps can be undone)
  - Objective of 8 puzzle game is to rearrange a given initial configuration of eight numbered tiles on 3 X 3 board (one place is empty) into a given final configuration (goal state).
    - Rearrangement is done by sliding one of the tiles into empty square.
  - Steps can be undone if they are not leading to solution.
  - Solved by backtracking, so control strategy must be implemented using a **push down stack**.

Example - Irrecoverable

- **Chess** (solution steps cannot be undone)
  - A stupid move cannot be undone.
  - Can be solved by **planning process.**

Contd..

- What is the Role of knowledge?
  - In Chess game, knowledge is important to constrain the search
  - Newspapers scanning to decide some facts, a lot of knowledge is required even to be able to recognize a solution.
- Is the knowledge Base consistent?
  - Should not have contradiction

Contd…

- Is a good solution Absolute or Relative ?
  - In water jug problem there are two ways to solve a problem.
    - If we follow one path successfully to the solution, there is no reason to go back and see if some other path might also lead to a solution.
    - Here a solution is **absolute**.
  - In travelling salesman problem, our goal is to find the shortest route/path. Unless all routes are known, the shortest is difficult to know.
    - This is a best-path problem whereas water jug is any-path problem.

Contd…

- Any path problem can often be solved in reasonable amount of time using heuristics that suggest good paths to explore.
- Best path problems are in general computationally harder than any-path.

Problem Solving

- AI programs have a clean separation of
  - computational components of data,
  - operations & control.
- Search forms the core of many intelligent processes.
- It is useful to structure AI programs in a way that facilitates describing the search process.

Production System - PS

- PS is a formation for structuring AI programs which facilitates describing search process.
- It consists of
  - Initial or start state of the problem
  - Final or goal state of the problem
  - It consists of one or more databases containing information appropriate for the particular task.
- The information in databases may be structured
  - using knowledge representation schemes.

Production Rules

- PS contains set of production rules,
  - each consisting of a left side that determines the applicability of the rule and
  - a right side that describes the action to be performed if the rule is applied.
  - These rules operate on the databases.
  - Application of rules change the database.
- A control strategy that specifies the order in which the rules will be applied when several rules match at once.
- One of the examples of Production Systems is an Expert System.

Advantages of PS

- In addition to its usefulness as a way to describe search, the production model has other advantages as a formalism in AI.
  - It is a good way to model the strong state driven nature of intelligent action.
  - As new inputs enter the database, the behavior of the system changes.
  - New rules can easily be added to account for new situations without disturbing the rest of the system, which is quite important in real-time environment.

Example : Water Jug Problem

- **Problem statement**:
  - Given two jugs, a 4-gallon and 3-gallon having no measuring markers on them. There is a pump that can be used to fill the jugs with water. How can you get exactly 2 gallons of water into 4-gallon jug.
- **Solution**:
  - State for this problem can be described as the set of ordered pairs of integers (X, Y) such that
    - X represents the number of gallons of water in 4-gallon jug and
    - Y for 3-gallon jug.
  - Start state is (0,0)
  - Goal state is (2, N) for any value of N.

Production Rules

- Following are the production rules for this problem.

$R1{:}(X, Y \mid X < 4) \quad \square \quad (4, Y)$

{Fill 4-gallon jug}

$R2{:}(X, Y \mid Y < 3) \quad \square \quad (X, 3)$

{Fill 3-gallon jug}

$R3{:}(X, Y \mid X > 0) \quad \square \quad (0, Y)$

{Empty 4-gallon jug}

$R4{:}(X, Y \mid Y > 0) \quad \square \quad (X, 0)$

{Empty 3-gallon jug}

$R5{:}(X, Y \mid X+Y >= 4 \land Y > 0) \quad \square(4,\ Y - (4 - X))$

{Pour water from 3- gallon jug into 4-gallon jug until 4-gallon jug is full}

Contd..

R6: (X, Y | X+Y >= 3 Λ X > 0) □ (X – (3 – Y), 3)

{ Pour water from 4-gallon jug into 3-gallon jug until 3-gallon jug is full}

R7: (X, Y | X+Y <= 4 Λ Y > 0) □ (X+Y, 0)

{ Pour all water from 3-gallon jug into 4-gallon jug }

R8: (X, Y | X+Y <= 3 Λ X > 0) □ (0, X+Y)

{ Pour all water from 4-gallon jug into 3-gallon jug }

Superficial Rules: {May not be used in this problem}

R9: (X, Y | X > 0) □ (X – D, Y)

{ Pour some water D out from 4-gallon jug}

R10: (X, Y | Y > 0) □ (X, Y - D)

{ Pour some water D out from 3- gallon jug}

Trace of steps involved in solving the water jug problem - First solution

Number of Steps	*Rules applied*	*4-g jug*	*3-g jug*	
1.	**Initial State**	0	0	
2.	R2 {Fill 3-g jug}	0	3	
3.	R7 {Pour all water from 3 to 4-g jug }	3	0	
4.	R2 {Fill 3-g jug}	3	3	
5.	R5 {Pour from 3 to 4-g jug until it is full}	4	2	
6.	R3 {Empty 4-gallon jug}	0	2	
7.	R7 {Pour all water from 3 to 4-g jug}	2	0	**Goal State**

Trace of steps involved in solving the water jug problem - Second solution

- Note that there may be more than one solutions.

Number of steps	*Rules applied*		*4-g jug*	*3-g jug*	
1	**Initial State**		0	0	
2	R1	{Fill 4-gallon jug}	4	0	
3	R6	{Pour from 4 to 3-g jug until it is full }	1	3	
4	R4	{Empty 3-gallon jug}	1	0	
5	R8	{Pour all water from 4 to 3-gallon jug}	0	1	
6	R1	{Fill 4-gallon jug}	4	1	
7	R6	{Pour from 4 to 3-g jug until it is full}	2	3	
8	R4	{Empty 3-gallon jug}	2	0	**Goal State**

Important Points

- For each problem
  - there is an initial description of the problem.
  - final description of the problem.
  - more than one ways of solving the problem.
  - a path between various solution paths based on some criteria of goodness or on some heuristic function is chosen.
  - there are set of rules that describe the actions called production rules.
    - Left side of the rules is current state and right side describes new state that results from applying the rule.

- Summary: In order to provide a formal description of a problem, it is necessary to do the following things:
  - Define a state space that contains all the possible configurations of the relevant objects.
  - Specify one or more states within that space that describe possible situations from which the problem solving process may start. These states are called **initial states.**
  - Specify one or more states that would be acceptable as solutions to the problem called **goal states.**
  - Specify a set of rules that describe the actions. Order of application of the rules is called control strategy.
  - Control strategy should cause motion towards a solution.