## Artificial Intelligence

- Artificial intelligence is the study of how to make computers do things which, at moment people do better.
- Artificial intelligence can be viewed from a variety of perspectives.
- From the perspective of intelligence, artificial intelligence is making machines "intelligent" -- acting as we would expect people to act.
    - The inability to distinguish computer responses from human responses is called the Turing test.
    - Intelligence requires knowledge.
- From a business perspective AI is a set of very powerful tools, and methodologies for using those tools to solve business problems.
- From a programming perspective, AI includes the study of symbolic programming, problem solving, and search.
    - Typically AI programs focus on symbols rather than numeric processing.
    - Problem solving i.e. to achieve a specific goal.
    - Search - rarely access a solution directly. Search may include a variety of techniques.
- It is the science and engineering of making intelligent machines, especially intelligent computer programs.

## AI Problems

- Much of the early work in the field of AI focused on formal tasks, such as game playing and theorem proving.
- Game playing and theorem proving share the property that people who do them well are considered to be displaying *Intelligence*.
- Initially computers could perform well at those tasks simply by being fast at exploring a large number of solution paths and then selecting the best one.
- Humans learn mundane (ordinary) tasks since their birth. They learn by perception, speaking, using language, and training. They learn Formal Tasks and Expert Tasks later.
- Another early foray into AI focused on commonsense reasoning, which includes reasoning about physical objects and their relationship to each other, as well as reasoning about actions and their consequences.
- As AI research progressed, techniques for handling large amount of world knowledge were developed.
- New tasks reasonably attempted such as perception, natural language understanding and problem solving in specialized domains.
- Some of the task domains of artificial intelligence are presented in table I.
- Earlier, all work of AI was concentrated in the mundane task domain.

| Mundane tasks | Formal tasks | Expert tasks |
|---|---|---|
| Perception<br>– Computer Vision<br>– Speech, Voice | Games<br>– Go<br>– Chess (Deep Blue)<br>– Ckeckers | Engineering<br>– Design<br>– Fault Finding<br>– Manufacturing<br>– Monitoring |
| Natural Language Processing<br>– Understanding<br>– Language Generation<br>– Language Translation | Mathematics<br>– Geometry<br>– Logic<br>– Integration and Differentiation | Scientific Analysis |
| Common Sense Reasoning | Theorem Proving | Financial Analysis |
| Planning | | Medical Diagnosis |
| Robot Control | | |

Table I Task Domains of AI

- Later, it turned out that the machine requires more knowledge, complex knowledge representation, and complicated algorithms for handling mundane tasks.
- This is the reason why AI work is more flourishing in the Expert Tasks domain now, as the expert task domain needs expert knowledge without common sense, which can be easier to represent and handle.

## What is an AI technique?

- Artificial intelligence problems span a very broad spectrum. They appear to have very little in common except that they are hard.
- AI Research of earlier decades results into the fact that intelligence requires knowledge.
- Knowledge possess following properties:
    - It is voluminous.
    - It is not well-organized or well-formatted.
    - It is constantly changing.
    - It differs from data. And it is organized in a way that corresponds to its usage.
- AI technique is a method that exploits knowledge that should be represented in such a way that:
    - Knowledge captures generalization. Situations that share common properties are grouped together. Without this property, inordinate amount of memory and modifications will be required.
    - It can be understood by people who must provide it. Although bulk of data can be acquired automatically, in many AI domains most of the knowledge must ultimately be provided by people in terms they understand.

  - It can easily be modified to correct errors and to reflect changes in the world.
  - It can be used in many situations even though it may not be totally accurate or complete.
  - It can be used to reduce its own volume by narrowing range of possibilities.
- There are three important AI techniques:
  1. Search –
     a. Provides a way of solving problems for which no direct approach is available.
     b. It also provides a framework into which any direct techniques that are available can be embedded.
  2. Use of knowledge –
     a. Provides a way of solving complex problems by exploiting the structure of the objects that are involved.
  3. Abstraction –
     a. Provides a way of separating important features and variations from many unimportant ones that would otherwise overwhelm any process.

## Classification of AI

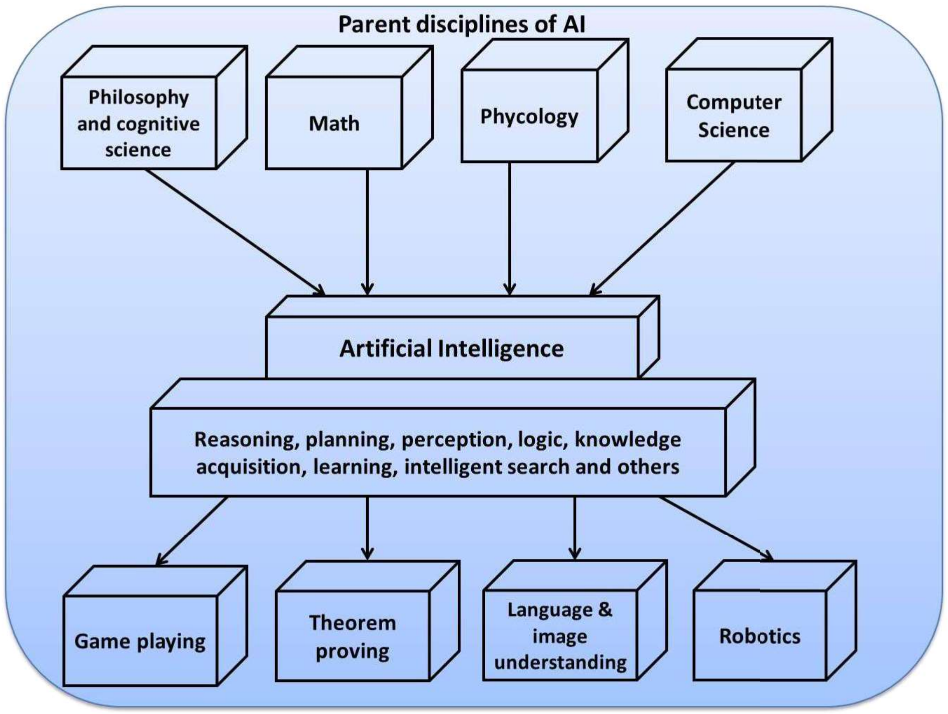
1. Weak AI: The study and design of machines that perform intelligent tasks.
   - Not concerned with how tasks are performed, mostly concerned with performance and efficiency, such as solutions that are reasonable for NP-Complete problems. E.g., to make a flying machine, use logic and physics, don't mimic a bird.
2. Strong AI: The study and design of machines that simulate the human mind to perform intelligent tasks.
   - Borrow many ideas from psychology, neuroscience. Goal is to perform tasks the way a human might do them – which makes sense, since we do have models of human thought and problem solving.
   - Includes psychological ideas in STM, LTM, forgetting, language, genetics, etc. Assumes that the physical symbol hypothesis holds.
3. Evolutionary AI. The study and design of machines that simulate simple creatures, and attempt to evolve and have higher level emergent behavior. For example, ants, bees, etc.

## Applications of AI

- AI has been dominant in various fields such as −
  1. Gaming − AI plays vital role in strategic games such as chess, poker, tic-tac-toe, etc., where machine can think of large number of possible positions based on heuristic knowledge.
  2. Natural Language Processing − It is possible to interact with the computer that

understands natural language spoken by humans.

3. Expert Systems − There are some applications which integrate machine, software, and special information to impart reasoning and advising. They provide explanation and advice to the users.
4. Computer Vision Systems − These systems understand, interpret, and comprehend visual input on the computer.
5. Speech Recognition − Some intelligent systems are capable of hearing and comprehending the language in terms of sentences and their meanings while a human talks to it. It can handle different accents, slang words, noise in the background, change in human's noise, etc.
6. Handwriting Recognition − The handwriting recognition software reads the text written on paper by a pen or on screen by a stylus. It can recognize the shapes of the letters and convert it into editable text.
7. Intelligent Robots − Robots are able to perform the tasks given by a human. They have sensors to detect physical data from the real world such as light, heat, temperature, movement, sound, bump, and pressure. They have efficient processors, multiple sensors and huge memory, to exhibit intelligence. In addition, they are capable of learning from their mistakes and they can adapt to the new environment.


Parent disciplines of AI
Philosophy and cognitive science
Math
Phycology
Computer Science
Artificial Intelligence
Reasoning, planning, perception, logic, knowledge acquisition, learning, intelligent search and others
Game playing
Theorem proving
Language & image understanding
Robotics

## Introduction

- Problem solving is the major area of concern in Artificial Intelligence.
- It is the process of generating solution from given observed data.
- To solve a particular problem, we need to build a system or a method which can generate required solution.
- Following four things are required for building such system.
    1. Define the problem precisely.
        - This definition must precisely specify the initial situation (input).
        - What final situation (output) will constitute the acceptable solution to the problem.
    2. Analyze the problem.
        - To identify those important features which can have an immense impact on the appropriateness of various possible techniques for solving the problem.
    3. Isolate and represent the task knowledge that is necessary to solve the problem.
    4. Choose the best problem solving technique and apply it to the particular problem.

## Defining the Problem as a State Space Search

### 1. Defining Problem & Search

- A problem is described formally as:
    1. Define a state space that contains all the possible configurations of relevant objects.
    2. 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.
    3. Specify one or more states that would be acceptable as solutions to the problem. These states are called goal states.
    4. Specify a set of rules that describe the actions available.
- The problem can then be solved by using the rules, in combination with an appropriate control strategy, to move through the problem space until a path from an initial state to a goal state is found.
- This process is known as search.
- Search is fundamental to the problem-solving process.
- Search is a general mechanism that can be used when more direct method is not known.
- Search also provides the framework into which more direct methods for solving subparts of a problem can be embedded.

### 2. Defining State & State Space

- A ***state*** is a representation of problem elements at a given moment.
- ***A State space is the set of all states reachable from the initial state.***

- A state space forms a graph in which the nodes are states and the arcs between nodes are actions.
- In state space, a path is a sequence of states connected by a sequence of actions.
- The solution of a problem is part of the graph formed by the state space.

- ***The state space representation forms the basis of most of the AI methods*.**
- Its structure corresponds to the structure of problem solving in two important ways:
  1. It allows for a formal definition of a problem as per the need to convert some given situation into some desired situation using a set of permissible operations.
  2. It permits the problem to be solved with the help of known techniques and control strategies to move through the problem space until goal state is found.

## 3. Define the Problem as State Space Search

**Ex.1:- Consider the problem of Playing Chess**

- To build a program that could play chess, we have to specify:
  - The starting position of the chess board,
  - The rules that define legal moves, and
  - The board position that represents a win.
- The starting position can be described by an 8 X 8 array square in which each element square (x, y), (x varying from 1 to 8 & y varying from 1 to 8) describes the board position of an appropriate piece in the official chess opening position.
- The goal is any board position in which the opponent does not have a legal move and his or her "king" is under attack.
- The legal moves provide the way of getting from initial state of final state.
- The legal moves can be described as a set of rules consisting of two parts: A left side that gives the current position and the right side that describes the change to be made to the board position.
- An example is shown in the following figure.

***Current Position***

*While pawn at square ( 5 , 2), AND Square ( 5 , 3 ) is empty, AND Square ( 5 , 4) is empty.*

***Changing Board Position***

*Move pawn from Square ( 5 , 2 ) to Square ( 5 , 4 ) .*

- The current position of a chess coin on the board is ***its state*** and the set of all possible states is ***state space***.
- One or more states where the problem terminates are goal states.
- Chess has approximately $10^{120}$ game paths. These positions comprise the problem search space.
- Using above formulation, the problem of playing chess is defined as a problem of moving around in a state space, where each state corresponds to a legal position of the

board.

- State space representation seems natural for play chess problem because the set of states, which corresponds to the set of board positions, is well organized.

**Ex.2:- Consider Water Jug problem**

- A Water Jug Problem: You are given two jugs, a 4-gallon one and a 3-gallon one, a pump which has unlimited water which you can use to fill the jug, and the ground on which water may be poured. Neither jug has any measuring markings on it. How can you get exactly 2 gallons of water in the 4-gallon jug?
- Here the initial state is (0, 0). The goal state is (2, n) for any value of n.
- **State Space Representation:** we will represent a state of the problem as a tuple (x, y) where x represents the amount of water in the 4-gallon jug and y represents the amount of water in the 3-gallon jug. Note that $0 \le x \le 4$, and $0 \le y \le 3$.
- To solve this we have to make some assumptions not mentioned in the problem. They are:
    - We can fill a jug from the pump.
    - We can pour water out of a jug to the ground.
    - We can pour water from one jug to another.
    - There is no measuring device available.
- Operators – we must define a set of operators that will take us from one state to another.

| Sr. | Current state | Next State | Descriptions |
|---|---|---|---|
| 1 | (x, y) if x < 4 | (4,y) | Fill the 4 gallon jug |
| 2 | (x, y) if y <3 | (x,3) | Fill the 3 gallon jug |
| 3 | (x, y) if x > 0 | (x-d, y) | Pour some water out of the 4 gallon jug |
| 4 | (x, y) if y > 0 | (x, y-d) | Pour some water out of the 3 gallon jug |
| 5 | (x, y) if x>0 | (0, y) | Empty the 4 gallon jug |
| 6 | (x, y) if y >0 | (x,0) | Empty the 3 gallon jug on the ground |
| 7 | (x, y) if x+y >= 4 and y > 0 | (4, y-(4-x)) | Pour water from the 3 gallon jug into the 4 gallon jug until the 4 gallon jug is full |
| 8 | (x, y) if x+y >= 3 and x>0 | (x-(3-y), 3) | Pour water from the 4 gallon jug into the 3-gallon jug until the 3 gallon jug is full |
| 9 | (x, y) if x+y <=4 and y>0 | (x+y, 0) | Pour all the water from the 3 gallon jug into the 4 gallon jug |

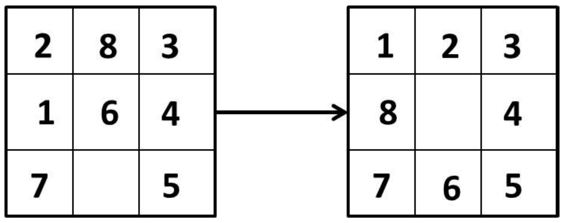
| | | | |
|---|---|---|---|
| 10 | (x, y) if x+y <= 3 and x>0 | (0, x+y) | Pour all the water from the 4 gallon jug into the 3 gallon jug |
| 11 | (0,2) | (2,0) | Pour the 2 gallons from 3 gallon jug into the 4 gallon jug |
| 12 | (2,y) | (0,y) | Empty the 2 gallons in the 4 gallon jug on the ground |

- There are several sequences of operators that will solve the problem.
- One of the possible solutions is given as:

| **Gallons in the 4-gallon jug** | **Gallons in the 3-gallon jug** | **Rule applied** |
|---|---|---|
| 0 | 0 | 2 |
| 0 | 3 | 9 |
| 3 | 0 | 2 |
| 3 | 3 | 7 |
| 4 | 2 | 5 or 12 |
| 0 | 2 | 9 0r 11 |
| 2 | 0 | -- |

**<u>Ex.3:- Consider 8 puzzle problem</u>**

- The 8 puzzle consists of eight numbered, movable tiles set in a 3x3 frame. One cell of the frame is always empty thus making it possible to move an adjacent numbered tile into the empty cell. Such a puzzle is illustrated in following diagram.



**Initial State** **Goal State**

- The program is to change the initial configuration into the goal configuration.
- A solution to the problem is an appropriate sequence of moves, such as “move tiles 5 to the right, move tile 7 to the left ,move tile 6 to the down” etc…

- To solve a problem, we must specify the global database, the rules, and the control strategy.
- For the 8 puzzle problem that correspond to three components.
- These elements are the problem states, moves and goal.
- In this problem each tile configuration is a state.
- The set of all possible configuration in the problem space, consists of 3,62,880 different configurations of the 8 tiles and blank space.
- For the 8-puzzle, a straight forward description is a 3X3 array of matrix of numbers. Initial global database is this description of the initial problem state. Virtually any kind of data structure can be used to describe states.
- A move transforms one problem state into another state.

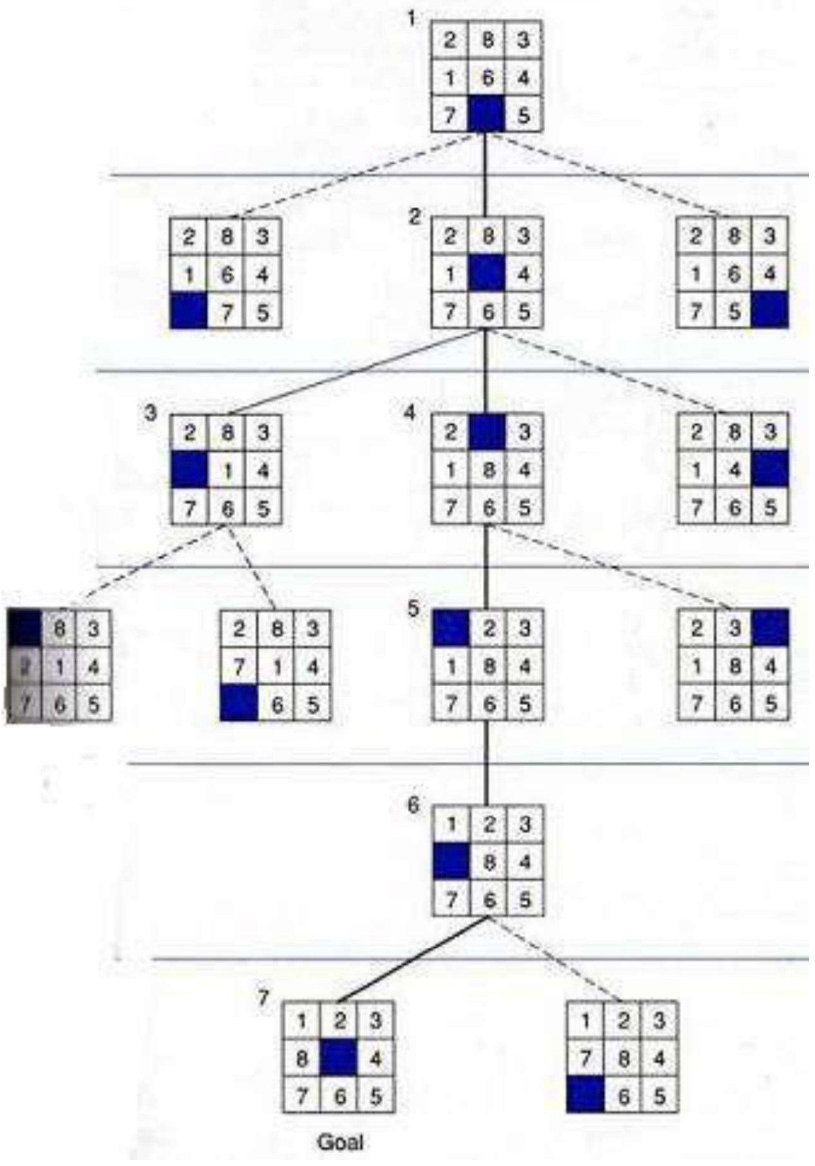


Figure 1: Solution of 8 Puzzle problem

- The 8-puzzle is conveniently interpreted as having the following for moves.

    - Move empty space (blank) to the left, move blank up, move blank to the right and move blank down.
    - These moves are modeled by production rules that operate on the state descriptions in the appropriate manner.
- The goal condition forms the basis for the termination.
- The control strategy repeatedly applies rules to state descriptions until a description of a goal state is produced.
- It also keeps track of rules that have been applied so that it can compose them into sequence representing the problem solution.
- A solution to the 8-puzzle problem is given in fig. 1.

## Production System

- Search process forms the core of many intelligence processes.
- So, it is useful to structure AI programs in a way that facilitates describing and performing the search process.
- Production system provides such structures.
- A production system consists of:
    1. **A set of rules**, each consisting of a left side that determines the applicability of the rule and a right side that describes the operation to be performed if that rule is applied.
    2. **One or more knowledge/databases** that contain whatever information is appropriate for the particular task. Some parts of the database may be permanent, while other parts of it may pertain only to the solution of the current problem.
    3. **A control strategy** that specifies the order in which the rules will be compared to the database and a way of resolving the conflicts that arise when several rules match at once.
    4. **A rule applier** which is the computational system that implements the control strategy and applies the rules.
- In order to solve a problem:
    - We must first reduce it to the form for which a precise statement can be given. This can be done by defining the problem's state space (start and goal states) and a set of operators for moving that space.
    - The problem can then be solved by searching for a path through the space from an initial state to a goal state.
    - The process of solving the problem can usefully be modeled as a production system.

**Benefits of Production System**

1. Production systems provide an excellent tool for structuring AI programs.
2. Production Systems are highly modular because the individual rules can be added, removed or modified independently.
3. The production rules are expressed in a natural form, so the statements contained in the

knowledge base should be easily understandable.

**Production System Characteristics**

1. Monotonic Production System: the application of a rule never prevents the later application of another rule that could also have been applied at the time the first rule was selected. i.e., rules are independent.
2. Non-Monotonic Production system is one in which this is not true.
3. Partially commutative Production system: a production system with the property that if application of a particular sequence of rules transforms state x to state y, then allowable permutation of those rules, also transforms state x into state y.
4. Commutative Production system: A Commutative production system is a production system that is both monotonic and partially commutative.

## Control Strategies

- Control strategies help us decide which rule to apply next during the process of searching for a solution to a problem.
- Good control strategy should:
    1. It should cause motion
    2. It should be Systematic
- Control strategies are classified as:
    1. Uninformed/blind search control strategy:
        - Do not have additional information about states beyond problem definition.
        - Total search space is looked for solution.
        - Example: Breadth First Search (BFS), Depth First Search (DFS), Depth Limited Search (DLS).
    2. Informed/Directed Search Control Strategy:
        - Some information about problem space is used to compute preference among the various possibilities for exploration and expansion.
        - Examples: Best First Search, Problem Decomposition, A*, Mean end Analysis

## Breadth-First Search Strategy (BFS)

- This is an exhaustive search technique.
- The search generates all nodes at a particular level before proceeding to the next level of the tree.
- ***The search systematically proceeds testing each node that is reachable from a parent node before it expands to any child of those nodes.***
- Search terminates when a solution is found and the test returns true.

**Algorithm:**

```
1. Create a variable called NODE-LIST and set it to initial state.
2. Until a goal state is found or NODE-LIST is empty do:
```

```
i.  Remove the first element from NODE-LIST and call it E. If NODE-LIST was empty, quit.
ii. For each way that each rule can match the state described in E do:
    a. Apply the rule to generate a new state.
    b. If the new state is a goal state, quit and return this state.
    c. Otherwise, add the new state to the end of NODE-LIST.
```

## Depth-First Search Strategy (DFS)

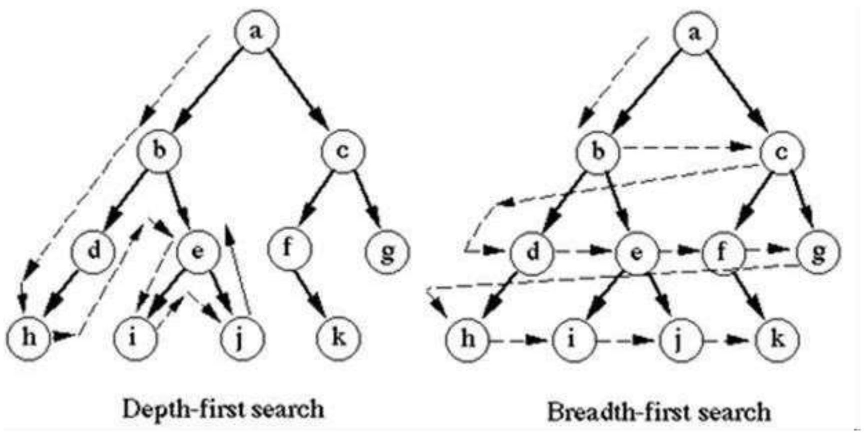
- Here, the search systematically proceeds to some depth *d*, before another path is considered.
- If the maximum depth of search tree is reached and if the solution has not been found, then the search backtracks to the previous level and explores any remaining alternatives at this level, and so on.

**Algorithm:**

```
1. If the initial state is a goal state, quit and return success
2. Otherwise, do the following until success or failure is signaled:
    a. Generate a successor, E, of initial state. If there are no more successors, signal failure.
    b. Call Depth-First Search, with E as the initial state
    c. If success is returned, signal success. Otherwise continue in this loop.
```

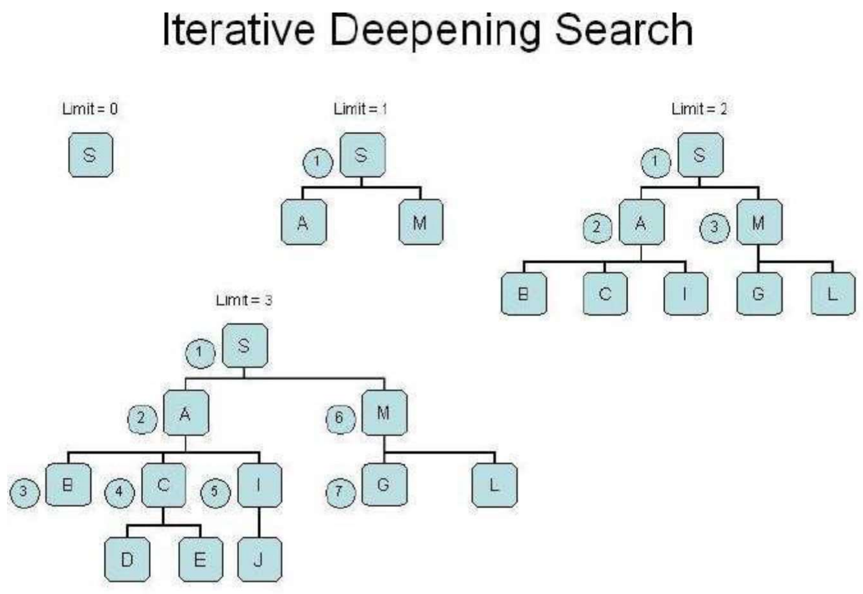
## Comparison: DFS & BFS

| Depth First Search | Breath First Search |
|---|---|
| DFS requires less memory since only the nodes on the current path are stored. | BFS guarantees that the space of possible moves is systematically examined; this search requires considerable memory resources. |
| By chance, DFS may find a solution without examining much of the search space at all. Then it finds solution faster. | The search systematically proceeds testing each node that is reachable from a parent node before it expands to any child of those nodes. |
| If the selected path does not reach to the solution node, DFS gets stuck into a blind alley. | BFS will not get trapped exploring a blind alley. |
| Does not guarantee to find solution. Backtracking is required if wrong path is selected. | If there is a solution, BFS is guaranteed to find it. |



## Iterative Deepening Search

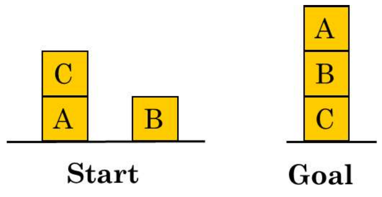
- Depth first search is incomplete if there is an infinite branch in the search tree.
- Infinite branches can happen if:
    - paths contain loops
    - infinite number of states and/or operators.
- For problems with infinite (or just very large) state spaces, several variants of depth-first search have been developed:
    - depth limited search
    - iterative deepening search
- Depth limited search (DLS) is a form of depth-first search.
- It expands the search tree depth-first up to a maximum depth $l$
- The nodes at depth $l$ are treated as if they had no successors
- If the search reaches a node at depth $l$ where the path is not a solution, we backtrack to the next choice point at $depth < l$
- Depth-first search can be viewed as a special case of DLS with $l = \infty$
- The depth bound can sometimes be chosen based on knowledge of the problem
- For e.g., in the route planning problem, the longest route has length $s - 1$, where $s$ is the number of cities (states), so we can set $l = s - 1$
- For the most problems, $d$ is unknown.
- Iterative deepening (depth-first) search (IDS) is a form of depth limited search which progressively increases the bound.
- It first tries $l = 1$, then $l = 2$, then $l = 3$, etc. until a solution is found
- Solution will be found when $l = d$
- IDDFS combines depth-first search's space-efficiency and breadth-first search's fast search (for nodes closer to root).
- IDDFS calls DFS for different depths starting from an initial value. In every call, DFS is restricted from going beyond given depth. So basically we do DFS in a BFS fashion.
- The example of Iterative-deepening depth-first search as given below, with the current depth-limit ($l$) starting at 1 and incrementing each time:



## Problem Characteristics

- In order to choose the most appropriate problem solving method, it is necessary to analyze the problem along various key dimensions.
- These dimensions are referred to as problem characteristics discussed below.

1. **Is the problem decomposable into a set of independent smaller or easier sub-problems?**
   - A very large and composite problem can be easily solved if it can be broken into smaller problems and recursion could be used.
   - For example, we want to solve :- $\int\ x2\ +\ 3x +\ sin2x\ cos2x\ dx$
   - This can be done by breaking it into three smaller problems and solving each by applying specific rules. Adding the results we can find the complete solution.
   - But there are certain problems which cannot be decomposed into sub-problems.
   - For example Blocks world problem in which, start and goal state are given as,



   - Here, solution can be achieved be moving blocks in a sequence such that goal state can be derived.
   - Solution steps are interdependent and cannot be decomposed in sub problems.
   - These two examples, symbolic integration and the blocks world illustrate the difference between decomposable and non-decomposable problems.
2. **Can solution steps be ignored or at least undone if they prove unwise?**
   - Problem fall under three classes, (i) ignorable, (ii) recoverable and (iii) irrecoverable.

- This classification is with reference to the steps of the solution to a problem.
- Consider theorem proving. We may later find that it is of no use. We can still proceed further, since nothing is lost by this redundant step. This is an example of ignorable solutions steps.
- Now consider the 8 puzzle problem tray and arranged in specified order.
- While moving from the start state towards goal state, we may make some stupid move but we can backtrack and undo the unwanted move. This only involves additional steps and the solution steps are recoverable.
- Lastly consider the game of chess. If a wrong move is made, it can neither be ignored nor be recovered. The thing to do is to make the best use of current situation and proceed. This is an example of an irrecoverable solution steps.
- Knowledge of these will help in determining the control structure.
  - Ignorable problems can be solved using a simple control structure that never backtracks.
  - Recoverable problems can be solved by a slightly more complicated control strategy that allows backtracking.
  - Irrecoverable problems will need to be solved by a system that expends a great deal of effort making each decision since decision must be final.

3. **Is the problem's universe predictable?**
   - Problems can be classified into those with certain outcome (eight puzzle and water jug problems) and those with uncertain outcome (playing cards).
   - In certain – outcome problems, planning could be done to generate a sequence of operators that guarantees to lead to a solution.
   - Planning helps to avoid unwanted solution steps.
   - For uncertain outcome problems, planning can at best generate a sequence of operators that has a good probability of leading to a solution.
   - The uncertain outcome problems do not guarantee a solution and it is often very expensive since the number of solution paths to be explored increases exponentially with the number of points at which the outcome cannot be predicted.
   - Thus one of the hardest types of problems to solve is the irrecoverable, uncertain – outcome problems (Ex:- Playing cards).
4. **Is a good solution to the problem obvious without comparison to all other possible solutions?**
   - There are two categories of problems - Any path problem and Best path problem.
   - In any path problem, like the water jug and 8 puzzle problems, we are satisfied with the solution, irrespective of the solution path taken.
   - Whereas in the other category not just any solution is acceptable but we want the best path solution.
   - Like that of traveling sales man problem, which is the shortest path problem.
   - In any – path problems, by heuristic methods we obtain a solution and we do not

explore alternatives.

- Any path problems can often be solved in a reasonable amount of time by using heuristics that suggest good paths to explore.
- For the best-path problems all possible paths are explored using an exhaustive search until the best path is obtained.
- Best path problems are computationally harder.

5. **Is the desired solution a state of the world or a path to a state?**
   - Consider the problem of natural language processing.
   - Finding a consistent interpretation for the sentence "The bank president ate a dish of pasta salad with the fork".
   - We need to find the interpretation but not the record of the processing by which the interpretation is found.
   - Contrast this with the water jug problem.
   - In water jug problem, it is not sufficient to report that we have solved, but the path that we found to the state (2, 0). Thus the statement of a solution to this problem must be a sequence of operations that produces the final state.
6. **What is the role of knowledge?**
   - Though one could have unlimited computing power, the size of the knowledge base available for solving the problem does matter in arriving at a good solution.
   - Take for example the game of playing chess, just the rules for determining legal moves and some simple control mechanism is sufficient to arrive at a solution.
   - But additional knowledge about good strategy and tactics could help to constrain the search and speed up the execution of the program. The solution would then be realistic.
   - Consider the case of predicting the political trend. This would require an enormous amount of knowledge even to be able to recognize a solution, leave alone the best.
7. **Does the task require interaction with a person?**

   The problems can again be categorized under two heads.

   i. Solitary in which the computer will be given a problem description and will produce an answer, with no intermediate communication and with the demand for an explanation of the reasoning process. Simple theorem proving falls under this category. Given the basic rules and laws, the theorem could be proved, if one exists.
   ii. Conversational, in which there will be intermediate communication between a person and the computer, either to provide additional assistance to the computer or to provide additional information to the user, or both, such as medical diagnosis fall under this category, where people will be unwilling to accept the verdict of the program, if they cannot follow its reasoning.

**Problem Classification**

- Actual problems are examined from the point of view of all these questions; it becomes apparent that there are several broad classes into which the problems fall.

## Issues in the design of search programs

1. The direction in which to conduct the search (forward versus backward reasoning). If the search proceeds from start state towards a goal state, it is a forward search or we can also search from the goal.
2. How to select applicable rules (Matching). Production systems typically spend most of their time looking for rules to apply. So, it is critical to have efficient procedures for matching rules against states.
3. How to represent each node of the search process (knowledge representation problem).

## Heuristic Search Techniques

- In order to solve many hard problems efficiently, it is often necessary to compromise the requirements of mobility and systematicity and to construct a control structure that is no longer guaranteed to find the best answer but will always find a very good answer.
- Usually very hard problems tend to have very large search spaces. Heuristics can be used to limit search process.
- There are good general purpose heuristics that are useful in a wide variety of problem domains.
- Special purpose heuristics exploit domain specific knowledge.
- For example nearest neighbor heuristics for shortest path problem. It works by selecting locally superior alternative at each step.
- Applying nearest neighbor heuristics to Travelling Salesman Problem:
    1. Arbitrarily select a starting city
    2. To select the next city, look at all cities not yet visited and select the one closest to the current city. Go to next step.
    3. Repeat step 2 until all cities have been visited.
- This procedure executes in time proportional to $N^2$, where N is the number of cities to be visited.

## Heuristic Function

- ***Heuristic function maps from problem state descriptions to measures of desirability, usually represented as numbers.***
- Which aspects of the problem state are considered, how those aspects are evaluated, and the weights given to individual aspects are chosen in such a way that the value of the heuristic function at a given node in the search process gives as good an estimate as possible of whether that node is on the desired path to a solution.
- Well-designed heuristic functions can play an important part in efficiently guiding a search process toward a solution.
- Every search process can be viewed as a traversal of a directed graph, in which the nodes represent problem states and the arcs represent relationships between states.

- The search process must find a path through this graph, starting at an initial state and ending in one or more final states.
- Domain-specific knowledge must be added to improve search efficiency. Information about the problem includes the nature of states, cost of transforming from one state to another, and characteristics of the goals.
- This information can often be expressed in the form of heuristic evaluation function.
- In general, heuristic search improve the quality of the path that are exported.
- Using good heuristics we can hope to get good solutions to hard problems such as the traveling salesman problem in less than exponential time.

## Heuristic Search Techniques

### I. Generate-and-Test

- Generate-and-test search algorithm is a very simple algorithm that guarantees to find a solution if done systematically and there exists a solution.

**Algorithm:**

1. *Generate a possible solution. For some problems, this means generating a particular point in the problem space. For others it means generating a path from a start stat.*
2. *Test to see if this is actually a solution by comparing the chosen point or the endpoint of the chosen path to the set of acceptable goal states.*
3. *If a solution has been found, quit, Otherwise return to step 1.*

- It is a depth first search procedure since complete solutions must be generated before they can be tested.
- In its most systematic form, it is simply an exhaustive search of the problem space.
- It operates by generating solutions randomly.

### II. Simple Hill Climbing

- Hill climbing is a variant of generate-and test in which feedback from the test procedure is used to help the generator decide which direction to move in search space.
- The test function is augmented with a heuristic function that provides an estimate of how close a given state is to the goal state.
- Hill climbing is often used when a good heuristic function is available for evaluating states but when no other useful knowledge is available.
- ***The key difference between Simple Hill climbing and Generate-and-test is the use of evaluation function as a way to inject task specific knowledge into the control process.***

**Algorithm:**

1. *Evaluate the initial state. If it is also goal state, then return it and quit. Otherwise continue with the initial state as the current state.*
2. *Loop until a solution is found or until there are no new operators left to be applied in the current state:*
    a. *Select an operator that has not yet been applied to the current state and*

```
        apply it to produce a new state.
    b. Evaluate the new state
        i. If it is the goal state, then return it and quit.
        ii. If it is not a goal state but it is better than the current state, then make
            it the current state.
        iii. If it is not better than the current state, then continue in the loop.
```

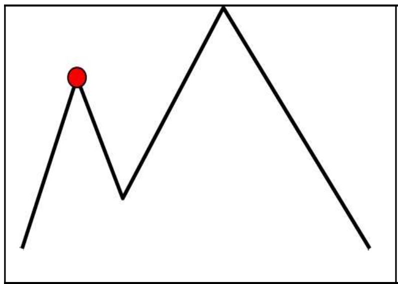
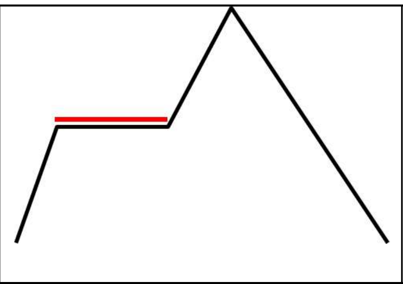
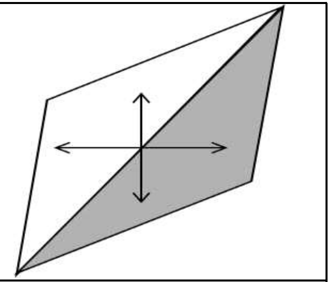
## III. Steepest-Ascent Hill Climbing

- This is a variation of simple hill climbing which considers all the moves from the current state and selects the best one as the next state.
- At each current state we select a transition, evaluate the resulting state, and if the resulting state is an improvement we move there, otherwise we try a new transition from where we were.
- We repeat this until we reach a goal state, or have no more transitions to try.
- The transitions explored can be selected at random, or according to some problem specific heuristics.

**Algorithm**

```
1. Evaluate the initial state. If it is also a goal state, then return it and quit. Otherwise,
   continue with the initial state as the current state.
2. Loop until a solution is found or until a complete iteration produces no change to current
   state:
    a. Let S be a state such that any possible successor of the current state will be better
       than S.
    b. For each operator that applies to the current state do:
        i. Apply the operator and generate a new state
        ii. Evaluate the new state. If is is a goal state, then return it and quit. If not,
            compare it to S. If it is better, then set S to this state. If it is not better,
            leave S alone.
    c. If the S is better than the current state, then set current state to S.
```

- Hill Climbing has three well-known drawbacks:
   i. **Local Maxima**: a local maximum is a state that is better than all its neighbors but is not better than some other states further away.
   ii. **Plateau**: a plateau is a flat area of the search space in which, a whole set of neighboring states have the same values.
   iii. **Ridge**: is a special kind of local maximum. It is an area of the search space that is higher than surrounding areas and that itself has slop.

| | | |
|---|---|---|
|  |  |  |
| **Local Maxima** | **Plateau** | **Ridge** |

- In each of the previous cases (local maxima, plateaus & ridge), the algorithm reaches a point at which no progress is being made.
- A solution is,
    - i. Backtrack to some earlier node and try going in a different direction.
    - ii. Make a big jump to try to get in a new section.
    - iii. Moving in several directions at once.

## IV. Simulated Annealing (SA)

- Motivated by the physical annealing process.
- Material is heated and slowly cooled into a uniform structure. Simulated annealing mimics this process.
- Compared to hill climbing the main difference is that SA allows downwards steps.
- Simulated annealing also differs from hill climbing in that a move is selected at random and then decides whether to accept it.
- *To accept or not to accept?*
    - The law of thermodynamics states that at temperature, t, the probability of an increase in energy of magnitude, $\delta E$, is given by,

$$P(\delta E) = exp(-\delta E / kt)$$

    - Where k is a constant known as Boltzmann's constant and it is incorporated into T.
    - So the revised probability formula is,

$$P'(\delta E) = exp(-\delta E / T)$$

    - $\delta E$ is the positive change in the objective function and T is the current temperature.
    - The probability of accepting a worse state is a function of both the temperature of the system and the change in the cost function.
    - As the temperature decreases, the probability of accepting worse moves decreases.
    - If t=0, no worse moves are accepted (i.e. hill climbing).

**Algorithm**

1. *Evaluate the initial state. If it is also a goal state, then return it and quit. Otherwise, continue with the initial state as the current state.*
2. Initialize BEST-SO-FAR to the current state.
3. Initialize T according to the annealing schedule.
4. Loop until a solution is found or until there are no new operators left to be applied in the

current state.

a. Select an operator that has not yet been applied to the current state and apply it to produce a new state.
b. Evaluate the new state. Compute

$$\delta E = \text{(value of current)} - \text{(value of new state)}$$

  - If the new state is a goal state, then return it and quit.
  - If it is not a goal state but is better than the current state, then make it the current state. Also set BEST-SO-FAR to this new state.
  - If it is not better than the current state, then make it the current state with probability $P'$ as defined above. This step is usually implemented by generating a random number between [0, 1]. If the number is less than $P'$, then the move is accepted otherwise do nothing.

c. Revise T as necessary according to the annealing schedule.

## V. Best First Search

- DFS is good because it allows a solution to be found without expanding all competing branches. BFS is good because it does not get trapped on dead end paths.
- Best first search combines the advantages of both DFS and BFS into a single method.
- One way of combining BFS and DFS is to follow a single path at a time, but switch paths whenever some competing path looks more promising than the current one does.
- At each step of the Best First Search process; we select the most promising of the nodes we have generated so far.
- This is done by applying an appropriate heuristic function to each of them.
- We then expand the chosen node by using the rules to generate its successors.
- If one of them is a solution, we can quit. If not, all those new nodes are added to the set of nodes generated so far.

**OR Graphs**

- It is sometimes important to search graphs so that duplicate paths will not be pursued.
- An algorithm to do this will operate by searching a directed graph in which each node represents a point in problem space.
- Each node will contain:
  - Description of problem state it represents
  - Indication of how promising it is
  - Parent link that points back to the best node from which it came
  - List of nodes that were generated from it
- Parent link will make it possible to recover the path to the goal, once the goal is found.
- The list of successors will make it possible, if a better path is found to an already existing node, to propagate the improvement down to its successors.
- This is called OR-graph, since each of its branches represents an alternative problem solving

path.

**Implementation of OR graphs**

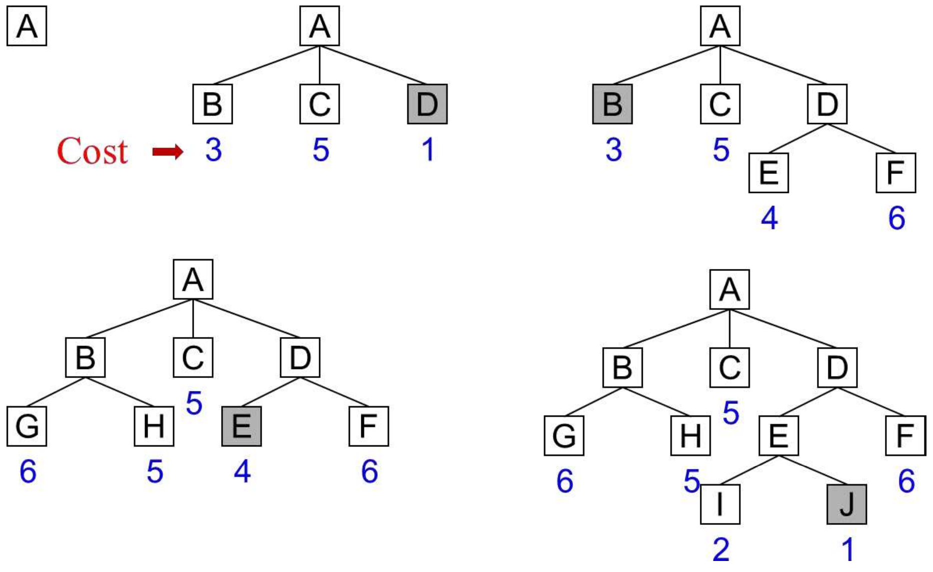
We need two lists of nodes:

- OPEN – nodes that have been generated and have had the heuristic function applied to them but which have not yet been examined. OPEN is actually a priority queue in which the elements with the highest priority are those with the most promising value of the heuristic function.
- CLOSED- nodes that have already been examined. We need to keep these nodes in memory if we want to search a graph rather than a tree, since whenever a new node is generated; we need to check whether it has been generated before.

**Algorithm: Best First Search**

```
1. Start with OPEN containing just the initial state
2. Until a goal is found or there are no nodes left on OPEN do:
    a. Pick the best node on OPEN
    b. Generate its successors
    c. For each successor do:
        i. If it has not been generated before, evaluate it, add it to OPEN, and record
           its parent.
        ii. If it has been generated before, change the parent if this new path is
            better than the previous one. In that case, update the cost of getting to
            this node and to any successors that this node may already have.
```

**Best First Search example**



**The A* Algorithm**

- Best First Search is a simplification of A* Algorithm.
- This algorithm uses following functions:

1. ***f'*:** Heuristic function that estimates the merits of each node we generate. ***f'*** = *g* + *h'*. ***f'*** represents an estimate of the cost of getting from the initial state to a goal state along with the path that generated the current node.
2. ***g*:** The function *g* is a measure of the cost of getting from initial state to the current node.
3. ***h'*:** The function *h'* is an estimate of the additional cost of getting from the current node to a goal state.

- The algorithm also uses the lists: OPEN and CLOSED

**Algorithm: A***

1. *Start with OPEN containing only initial node. Set that node's g value to 0, its h' value to whatever it is, and its f' value to h'+0 or h'. Set CLOSED to empty list.*
2. *Until a goal node is found, repeat the following procedure: If there are no nodes on OPEN, report failure. Otherwise select the node on OPEN with the lowest f' value. Call it BESTNODE. Remove it from OPEN. Place it in CLOSED. See if the BESTNODE is a goal state. If so exit and report a solution. Otherwise, generate the successors of BESTNODE but do not set the BESTNODE to point to them yet. For each of the SUCCESSOR, do the following:*
    a. *Set SUCCESSOR to point back to BESTNODE. These backwards links will make it possible to recover the path once a solution is found.*
    b. *Compute g(SUCCESSOR) = g(BESTNODE) + the cost of getting from BESTNODE to SUCCESSOR*
    c. *See if SUCCESSOR is the same as any node on OPEN. If so call the node OLD.*
        i. *Check whether it is cheaper to get to OLD via its current parent or to SUCESSOR via BESTNODE by comparing their g values.*
        ii. *If OLD is cheaper, then do nothing. If SUCCESSOR is cheaper then reset OLD's parent link to point to BESTNODE.*
        iii. *Record the new cheaper path in g(OLD) and update f '(OLD).*
    d. *If SUCCESSOR was not on OPEN, see if it is on CLOSED. If so, call the node on CLOSED OLD and add OLD to the list of BESTNODE's successors.*
    e. *If SUCCESSOR was not already on either OPEN or CLOSED, then put it on OPEN and add it to the list of BESTNODE's successors. Compute f'(SUCCESSOR) = g(SUCCESSOR) + h'(SUCCESSOR).*

**Observations about A***

- Role of g function: This lets us choose which node to expand next on the basis of not only of how good the node itself looks, but also on the basis of how good the path to the node was.
- h', the distance of a node to the goal. If h' is a perfect estimator of h, then A* will converge immediately to the goal with no search.

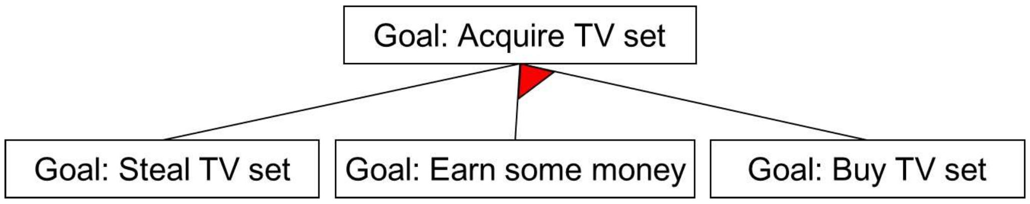
**Admissibility of A***

- A heuristic function h'(n) is said to be admissible if it never overestimates the cost of getting to a goal state.
- i.e. if the true minimum cost of getting from node n to a goal state is C then h must satisfy: $h'(n) \le C$
- If h' is a perfect estimator of h, then A* will converge immediately to the goal state with no search.
- If h' never overestimates h, then A* algorithm is guaranteed to find an optimal path if one exists.

## VI. Problem Reduction

**AND-OR graphs**

- AND-OR graph (or tree) is useful for representing the solution of problems that can be solved by decomposing them into a set of smaller problems, all of which must then be solved.
- This decomposition or reduction generates arcs that we call AND arcs.
- One AND arc may point to any numbers of successor nodes. All of which must then be solved in order for the arc to point solution.
- In order to find solution in an AND-OR graph we need an algorithm similar to best –first search but with the ability to handle the AND arcs appropriately.
- ***We define FUTILITY, if the estimated cost of solution becomes greater than the value of FUTILITY then we abandon the search, FUTILITY should be chosen to correspond to a threshold***.
- In following figure AND arcs are indicated with a line connecting all the components.



**The AO* Algorithm**

- Rather than the two lists, OPEN and CLOSED, that were used in the A* algorithm, the AO* algorithm will use a single structure GRAPH, representing the part of the search graph that has been explicitly generated so far.
- Each node in the graph will point both down to its immediate successors and up to its immediate predecessors.
- Each node in the graph will also have associated with it an *h'* value, an estimate of the cost of a path from itself to a set of solution nodes.
- We will not store *g* (the cost of getting from the start node to the current node) as we did in the A* algorithm.
- And such a value is not necessary because of the top-down traversing of the edge

which guarantees that only nodes that are on the best path will ever be considered for expansion.

**Algorithm: AO***

1. Let GRAPH consist only of the node representing the initial state. Call this node INIT, Compute VINIT.
2. Until INIT is labeled SOLVED or until INIT's h' value becomes greater than FUTILITY, repeat the following procedure:
    a. Trace the labeled arcs from INIT and select for expansion one of the as yet unexpanded nodes that occurs on this path. Call the selected node NODE.
    b. Generate the successors of NODE. If there are none, then assign FUTILITY as the h' value of NODE. This is equivalent to saying that NODE is not solvable. If there are successors, then for each one (called SUCCESSOR) that is not also an ancestor of NODE do the following:
        i. Add SUCCESSOR to GRAPH
        ii. If SUCCESSOR is a terminal node, label it SOLVED and assign it an h' value of 0
        iii. If SUCCESSOR is not a terminal node, compute its h' value
    c. Propagate the newly discovered information up the graph by doing the following: Let S be a set of nodes that have been labeled SOLVED or whose h' values have been changed and so need to have values propagated back to their parents. Initialize S to NODE. Until S is empty, repeat the, following procedure:
        i. If possible, select from S a node none of whose descendants in GRAPH occurs in S. If there is no such node, select any node from S. Call this node CURRENT, and remove it from S.
        ii. Compute the cost of each of the arcs emerging from CURRENT. The cost of each arc is equal to the sum of the h' values of each of the nodes at the end of the arc plus whatever the cost of the arc itself is. Assign as CURRENT'S new h' value the minimum of the costs just computed for the arcs emerging from it.
        iii. Mark the best path out of CURRENT by marking the arc that had the minimum cost as computed in the previous step.
        iv. Mark CURRENT SOLVED if all of the nodes connected to it through the new labeled arc have been labeled SOLVED.
        v. If CURRENT has been labeled SOLVED or if the cost of CURRENT was just changed, then its new status must be propagated back up the graph. So add all of the ancestors of CURRENT to S.

## VII. Constraint Satisfaction

- Constraint satisfaction is a search procedure that operates in a space of constraint sets. The initial state contains the constraints that are originally given in the problem description.

- A goal state is any state that has been constrained "enough" where "enough" must be defined for each problem.
- For example, in cryptarithmetic problems, enough means that each letter has been assigned a unique numeric value.
- Constraint Satisfaction problems in AI have goal of discovering some problem state that satisfies a given set of constraints.
- Design tasks can be viewed as constraint satisfaction problems in which a design must be created within fixed limits on time, cost, and materials.
- Constraint Satisfaction is a two-step process:
    1. First constraints are discovered and propagated as far as possible throughout the system.
    2. Then if there is still not a solution, search begins. A guess about something is made and added as a new constraint.

**<u>Example: Cryptarithmetic Problem</u>**

Constraints:

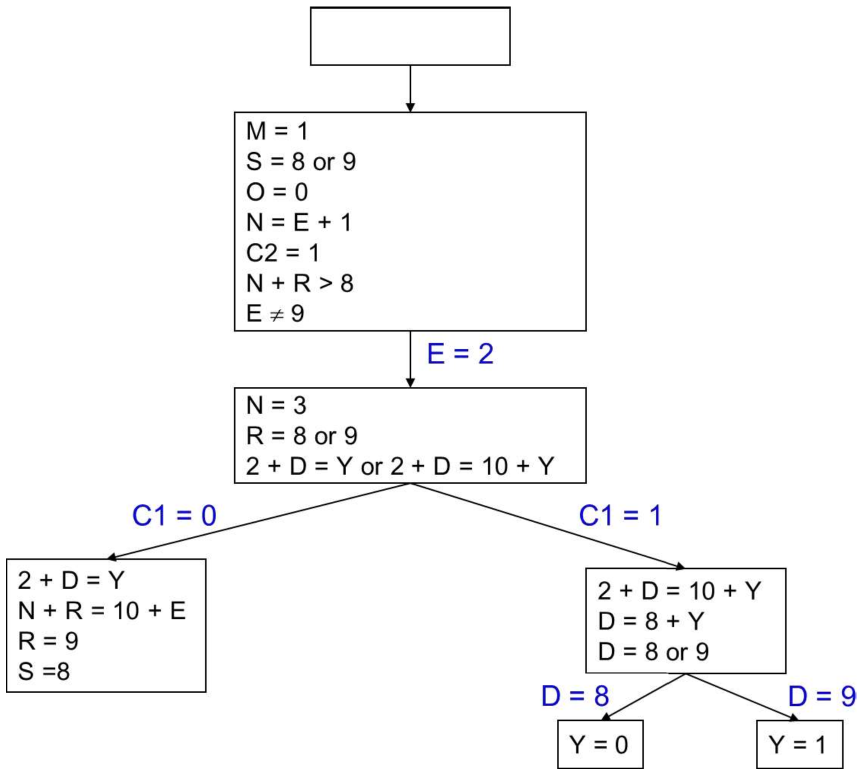
- No two letters have the same value
- The sums of the digits must be as shown in the problem

Goal State:

- All letters have been assigned a digit in such a way that all the initial constraints are satisfied

**Input State**

$$\begin{array}{r} \text{SEND} \\ +\ \text{MORE} \\ \hline \text{MONEY} \end{array}$$



- The solution process proceeds in cycles. At each cycle, two significant things are done:
    1. Constraints are propagated by using rules that correspond to the properties of arithmetic.
    2. A value is guessed for some letter whose value is not yet determined.

**Solution:**

```
  9567
+ 1085
--------
 10652
```

**Algorithm: Constraint Satisfaction**

1. *Propagate available constraints. To do this first set OPEN to set of all objects that must have values assigned to them in a complete solution. Then do until an inconsistency is detected or until OPEN is empty:*
    a. *Select an object OB from OPEN. Strengthen as much as possible the set of constraints that apply to OB.*
    b. *If this set is different from the set that was assigned the last time OB was examined or if this is the first time OB has been examined, then add to OPEN all objects that share any constraints with OB.*
    c. *Remove OB from OPEN.*
2. *If the union of the constraints discovered above defines a solution, then quit and report the solution.*
3. *If the union of the constraints discovered above defines a contradiction, then return the*

*failure.*

4. *If neither of the above occurs, then it is necessary to make a guess at something in order to proceed. To do this loop until a solution is found or all possible solutions have been eliminated:*
    a. *Select an object whose value is not yet determined and select a way of strengthening the constraints on that object.*
    b. *Recursively invoke constraint satisfaction with the current set of constraints augmented by strengthening constraint just selected.*

## VIII. Means-Ends Analysis

- Collection of strategies presented so far can reason either forward or backward, but for a given problem, one direction or the other must be chosen.
- A mixture of the two directions is appropriate. Such a mixed strategy would make it possible to solve the major parts of a problem first and then go back and solve the small problems that arise in "gluing" the big pieces together.
- The technique of Means-Ends Analysis (MEA) allows us to do that.
- MEA process centers around the detection of differences between the current state and the goal state.
- Once such a difference is isolated, an operator that can reduce the difference must be found.
- If the operator cannot be applied to the current state, we set up a sub-problem of getting to a state in which it can be applied.
- The kind of backward chaining in which operators are selected and then sub-goals are set up to establish the preconditions of the operators is called operator sub-goaling

**Algorithm: Means-Ends Analysis**

```
1. Compare CURRENT to GOAL. If there are no differences between them then return.
2. Otherwise, select the most important difference and reduce it by doing the following
   until success or failure is signaled:
    a. Select an as yet untried operator O that is applicable to the current difference.
       If there are no such operators, then signal failure.
    b. Attempt to apply O to CURRENT. Generate descriptions of two states: O-
       START, a state in which O's preconditions are satisfied and O-RESULT, the
       state that would result if O were applied in O-START.
    c. If
             (FIRST-PART ← MEA( CURRENT, O-START))
       and
             (LAST-PART ← MEA(O-RESULT, GOAL))
       are successful, then signal success and return the result of concatenating
       FIRST-PART, O, and LAST-PART.
```

## Representations and Mappings

- In order to solve complex problems encountered in artificial intelligence, one needs both a large amount of knowledge and some mechanism for manipulating that knowledge to create solutions.
- Knowledge and Representation are two distinct entities. They play central but distinguishable roles in intelligent system.
- ***Knowledge is a description of the world. It determines a system's competence by what it knows.***
- ***Representation is the way knowledge is encoded. It defines a system's performance in doing something.***
- Different types of knowledge require different kinds of representation.
- The Knowledge Representation models/mechanisms are often based on:
    - Logic
    - Rules
    - Frames
    - Semantic Net
- Knowledge is categorized into two major types:
    1. Tacit corresponds to "informal"  or "implicit“
        - Exists within a human being;
        - It is embodied.
        - Difficult to articulate formally.
        - Difficult to communicate or share.
        - Hard to steal or copy.
        - Drawn from experience, action, subjective insight
    2. Explicit formal type of knowledge, Explicit
        - Explicit knowledge
        - Exists outside a human being;
        - It is embedded.
        - Can be articulated formally.
        - Can be shared, copied, processed and stored.
        - Easy to steal or copy
        - Drawn from artifact of some type as principle, procedure, process, concepts.
- A variety of ways of representing knowledge have been exploited in AI programs.
- There are two different kinds of entities, we are dealing with.
    1. Facts: Truth in some relevant world. Things we want to represent.
    2. Representation of facts in some chosen formalism. Things we will actually be able to manipulate.
- These entities are structured at two levels:
    1. The knowledge level, at which facts are described.

2. The symbol level, at which representation of objects are defined in terms of symbols that can be manipulated by programs

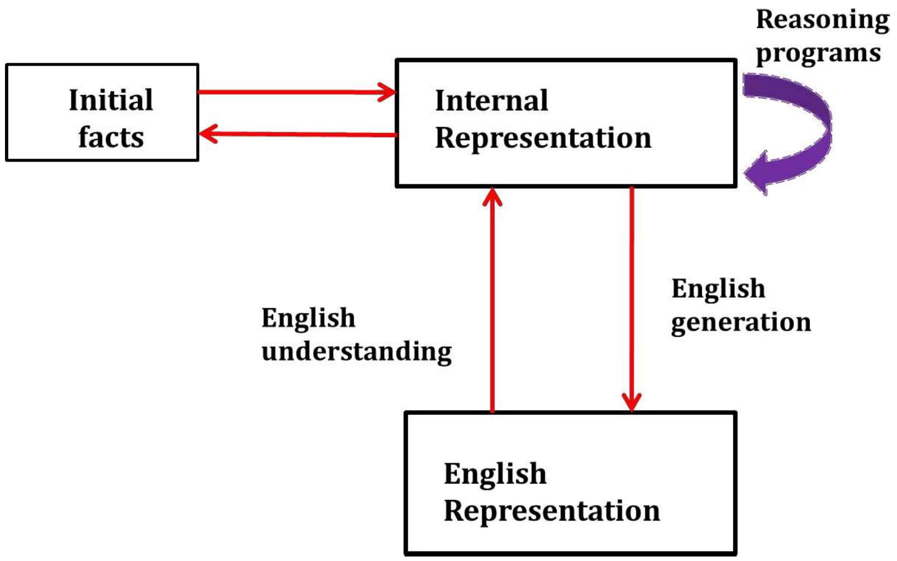


**Fig. 3.1 Mapping between Facts and Representations**

## Framework of Knowledge Representation

- Computer requires a well-defined problem description to process and provide well-defined acceptable solution.
- To collect fragments of knowledge we need first to formulate a description in our spoken language and then represent it in formal language so that computer can understand.
- The computer can then use an algorithm to compute an answer. This process is illustrated as,

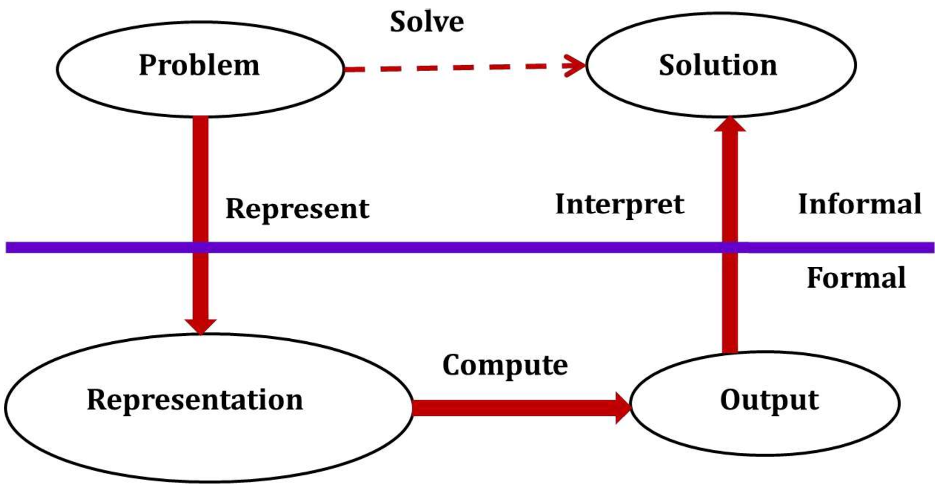


**Fig. 3.2 Knowledge Representation Framework**

- The steps are:
    - The informal formalism of the problem takes place first.
    - It is then represented formally and the computer produces an output.

  - This output can then be represented in an informally described solution that user understands or checks for consistency.
- The Problem solving requires,
  - Formal knowledge representation, and
  - Conversion of informal knowledge to formal knowledge that is conversion of implicit knowledge to explicit knowledge.

**Mapping between Facts and Representation**

- Knowledge is a collection of facts from some domain.
- We need a representation of "facts" that can be manipulated by a program.
- Normal English is insufficient, too hard currently for a computer program to draw inferences in natural languages.
- Thus some symbolic representation is necessary.

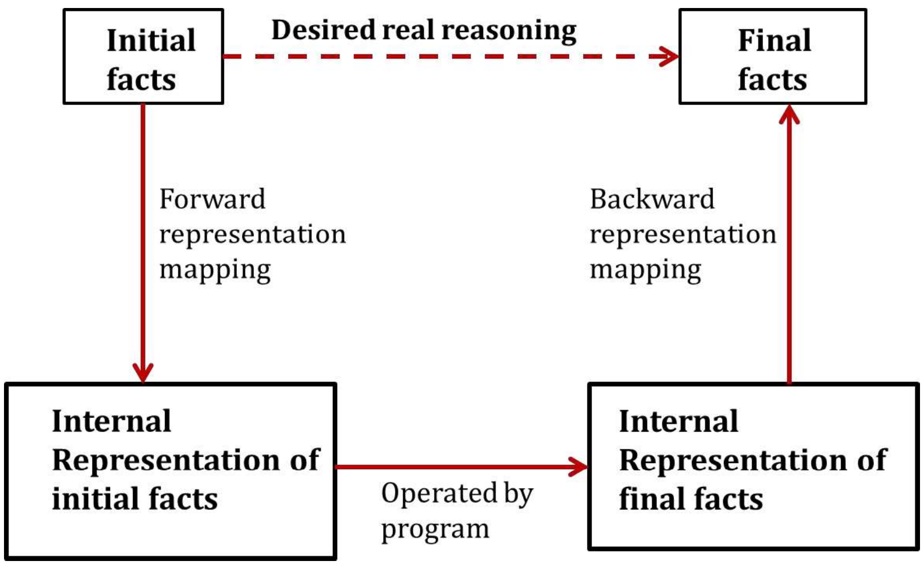

Initial facts
Desired real reasoning
Final facts
Forward representation mapping
Backward representation mapping
Internal Representation of initial facts
Operated by program
Internal Representation of final facts

**Fig. 3.3 Representation of Facts**

## Approaches to knowledge Representation

- A good knowledge representation enables fast and accurate access to knowledge and understanding of the content.
- A knowledge representation system should have following properties.
  1. Representational Adequacy
     - The ability to represent all kinds of knowledge that are needed in that domain.
  2. Inferential Adequacy
     - The ability to manipulate the representational structures to derive new structures corresponding to new knowledge inferred from old.
  3. Inferential Efficiency
     - The ability to incorporate additional information into the knowledge structure that can be used to focus the attention of the inference mechanisms in the most

promising direction.

4. Acquisitional Efficiency
   - The ability to acquire new knowledge using automatic methods wherever possible rather than reliance on human intervention.

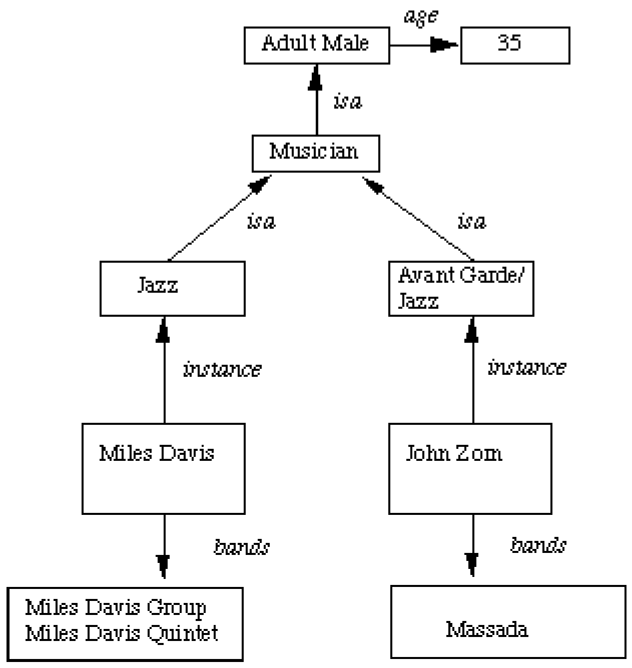
**Knowledge Representation Schemes**

1. **Relational Knowledge :**
   - The simplest way to represent declarative facts is as a set of relations of the same sort used in the database system.
   - Provides a framework to compare two objects based on equivalent attributes.
   - Any instance in which two different objects are compared is a relational type of knowledge.
   - The table below shows a simple way to store facts.
     - The facts about a set of objects are put systematically in columns.
     - This representation provides little opportunity for inference.

| **Player** | **Height** | **Weight** | **Bats - Throws** |
|---|---|---|---|
| **Aaron** | **6-0** | **180** | **Right - Right** |
| **Mays** | **5-10** | **170** | **Right - Right** |
| **Ruth** | **6-2** | **215** | **Left - Left** |
| **Williams** | **6-3** | **205** | **Left - Right** |

     - Given the facts it is not possible to answer simple question such as :
       "Who is the heaviest player?"
     - But if a procedure for finding heaviest player is provided, then these facts will enable that procedure to compute an answer.
     - We can ask things like who "bats – left" and "throws – right".

2. **Inheritable Knowledge**
   - Here the knowledge elements inherit attributes from their parents.
   - The knowledge is embodied in the design hierarchies found in the functional, physical and process domains.
   - Within the hierarchy, elements inherit attributes from their parents, but in many cases not all attributes of the parent elements be prescribed to the child elements.
   - The inheritance is a powerful form of inference, but not adequate.
   - The basic KR (Knowledge Representation) needs to be augmented with inference mechanism.
   - Property inheritance: The objects or elements of specific classes inherit attributes and values from more general classes.
   - The classes are organized in a generalized hierarchy.



- Boxed nodes -- objects and values of attributes of objects.
- Arrows -- point from object to its value.
- This structure is known as a slot and filler structure, semantic network or a collection of frames.

- The steps to retrieve a value for an attribute of an instance object:
    i. Find the object in the knowledge base
    ii. If there is a value for the attribute report it
    iii. Otherwise look for a value of an instance, if none fail
    iv. Otherwise go to that node and find a value for the attribute and then report it
    v. Otherwise search through using isa until a value is found for the attribute.

3. **Inferential Knowledge**
    - This knowledge generates new information from the given information.
    - This new information does not require further data gathering form source, but does require analysis of the given information to generate new knowledge.
    - Example: given a set of relations and values, one may infer other values or relations. A predicate logic (a mathematical deduction) is used to infer from a set of attributes. Inference through predicate logic uses a set of logical operations to relate individual data.
    - Represent knowledge as formal logic:

      **All dogs have tails** $\forall x$***: dog(x) → hastail(x)***
    - Advantages:
        - A set of strict rules.
        - Can be used to derive more facts.
        - Truths of new statements can be verified.
        - Guaranteed correctness.
    - Many inference procedures available to implement standard rules of logic popular in AI

systems. e.g Automated theorem proving.

4. **Procedural Knowledge**
   - A representation in which the control information, to use the knowledge, is embedded in the knowledge itself. For example, computer programs, directions, and recipes; these indicate specific use or implementation;
   - Knowledge is encoded in some procedures, small programs that know how to do specific things, how to proceed.
   - Advantages:
     - Heuristic or domain specific knowledge can be represented.
     - Extended logical inferences, such as default reasoning facilitated.
     - Side effects of actions may be modeled. Some rules may become false in time. Keeping track of this in large systems may be tricky.
   - Disadvantages:
     - Completeness -- not all cases may be represented.
     - Consistency -- not all deductions may be correct. e.g If we know that Fred is a bird we might deduce that Fred can fly. Later we might discover that Fred is an emu.
     - Modularity is sacrificed. Changes in knowledge base might have far-reaching effects.
     - Cumbersome control information.

## Issues in Knowledge Representation

- The fundamental goal of Knowledge Representation is to facilitate inference (conclusions) from knowledge.
- The issues that arise while using KR techniques are many. Some of these are explained below.
  1. **Important Attributes :**
     - Any attribute of objects so basic that they occur in almost every problem domain?
     - There are two attributes "instance" and "isa", that are of general significance. These attributes are important because they support property inheritance.
  2. **Relationship among attributes:**
     - Any important relationship that exists among object attributes?
     - The attributes we use to describe objects are themselves entities that we represent.
     - The relationship between the attributes of an object, independent of specific knowledge they encode, may hold properties like:
       i. Inverses - This is about consistency check, while a value is added to one attribute. The entities are related to each other in many different ways.
       ii. Existence in an *isa* hierarchy - This is about generalization-specialization, like, classes of objects and specialized subsets of those classes, there are attributes and specialization of attributes. For example, the attribute height is a specialization of general attribute physical-size which is, in turn, a specialization of physical-attribute. These generalization-specialization relationships are

important for attributes because they support inheritance.

iii. Techniques for reasoning about values - This is about reasoning values of attributes not given explicitly. Several kinds of information are used in reasoning, like,

height : must be in a unit of length,

Age: of person cannot be greater than the age of person's parents.

The values are often specified when a knowledge base is created.

iv. Single valued attributes - This is about a specific attribute that is guaranteed to take a unique value. For example, a baseball player can at time have only a single height and be a member of only one team. KR systems take different approaches to provide support for single valued attributes.

**3. Choosing Granularity :**

- At what level of detail should the knowledge be represented?
- Regardless of the KR formalism, it is necessary to know :
  - At what level should the knowledge be represented and what are the primitives?"
  - Should there be a small number or should there be a large number of low-level primitives or High-level facts.
  - High-level facts may not be adequate for inference while Low-level primitives may require a lot of storage.
- Example of Granularity :
  - Suppose we are interested in following facts:

    John spotted Sue.

    This could be represented as

    **Spotted (agent(John), object (Sue))**

    − Such a representation would make it easy to answer questions such are :

    ▪ Who spotted Sue?

    Suppose we want to know :

    ▪ Did John see Sue?

    − Given only one fact, we cannot discover that answer.

    − We can add other facts, such as

    **Spotted (x , y) → saw (x , y)**

    − We can now infer the answer to the question.

**4. Set of objects :**

- How should sets of objects be represented?
- There are certain properties of objects that are true as member of a set but not as individual;
  - Example : Consider the assertion made in the sentences :

    "there are more sheep than people in Australia", and

    "English speakers can be found all over the world."

   - To describe these facts, the only way is to attach assertion to the sets representing people, sheep, and English.
   - The reason to represent sets of objects is: If a property is true for all or most elements of a set, then it is more efficient to associate it once with the set rather than to associate it explicitly with every elements of the set .
   - This is done,
     - in logical representation through the use of universal quantifier, and
     - in hierarchical structure where node represent sets and inheritance propagate set level assertion down to individual.

5. **Finding Right structure :**
   - Given a large amount of knowledge stored in a database, how can relevant parts are accessed when they are needed?
   - This is about access to right structure for describing a particular situation.
   - This requires, selecting an initial structure and then revising the choice.
   - While doing so, it is necessary to solve following problems :
     - how to perform an initial selection of the most appropriate structure.
     - how to fill in appropriate details from the current situations.
     - how to find a better structure if the one chosen initially turns out not to be appropriate.
     - what to do if none of the available structures is appropriate.
     - when to create and remember a new structure.
   - There is no good, general purpose method for solving all these problems. Some knowledge representation techniques solve some of these issues.

## Logic

- The logical formalism of a language is useful because it immediately suggests a powerful way of deriving new knowledge from old using mathematical deduction.
- In this formalism, we can conclude that a new statement is true by proving that it follows from the statements that are already known.

**Proposition**

- A proposition is a statement, or a simple declarative sentence.
- For example, "the book is expensive" is a proposition.
- A proposition can be either true or false.

**Propositional logic**

- Logical constants: true, false
- Propositional symbols: P, Q, S,... (atomic sentences)
- Propositions are combined by connectives:

| | |
|---|---|
| $\wedge$ | *and* [conjunction] |
| $\vee$ | *or* [disjunction] |
| $\Rightarrow$ | *implies* [implication] |
| $\neg$ | *not* [negation] |
| $\forall$ | *For all* |
| $\exists$ | *There exists* |

- Propositional logic is a simple language useful for showing key ideas and definitions.
- User defines a set of propositional symbols, like P and Q.
- User defines the semantics of each propositional symbol:
  - P means "It is hot"
  - Q means "It is humid"
  - R means "It is raining"
- A sentence (well-formed formula) is defined as follows:
  - A symbol is a sentence.
  - If S is a sentence, then $\neg$ S is a sentence.
  - If S is a sentence, then (S) is a sentence.
  - If S and T are sentences, then (S $\vee$ T), (S $\wedge$ T), (S $\rightarrow$ T), and (S $\leftrightarrow$ T) are sentences
  - A sentence results from a finite number of applications of the above rules.
- ***Real world facts can be represented by well-formed formulas (wffs) in propositional logic.***

## Representation of Simple Facts in Logic

- Propositional logic is useful because it is simple to deal with and a decision procedure for it exists.
- In order to draw conclusions, facts are represented in a more convenient way as,
    1. Marcus is a man.
       man(Marcus)
    2. Plato is a man.
       man(Plato)
    3. All men are mortal.
       mortal(men)
- But propositional logic fails to capture the relationship between any individual being a man and that individual being a mortal.
- How can these sentences be represented so that we can infer the third sentence from the first two?
- Propositional logic commits only to the existence of facts that may or may not be the case in the world being represented.
- It has a simple syntax and simple semantics. It suffices to illustrate the process of inference.
- Propositional logic quickly becomes impractical, even for very small worlds.

**Predicate logic**

- First-order Predicate logic (FOPL) models the world in terms of
    - Objects, which are things with individual identities
    - Properties of objects that distinguish them from other objects
    - Relations that hold among sets of objects
    - Functions, which are a subset of relations where there is only one “value” for any given “input”
- First-order Predicate logic (FOPL) provides
    - Constants: a, b, dog33. Name a specific object.
    - Variables: X, Y. Refer to an object without naming it.
    - Functions: Mapping from objects to objects.
    - Terms: Refer to objects
    - Atomic Sentences: in(dad-of(X), food6) Can be true or false, Correspond to propositional symbols P, Q.

- A well-formed formula (*wff*) is a sentence containing no “free” variables. That is, all variables are “bound” by universal or existential quantifiers.
  (∀x)P(x, y) has x bound as a universally quantified variable, but y is free.

**Quantifiers**

- Universal quantification
  (∀x)P(x) means that P holds for all values of x in the domain associated with that

variable

E.g., $(\forall x)$ dolphin(x) $\rightarrow$ mammal(x)

- Existential quantification

  $(\exists x)P(x)$ means that P holds for some value of x in the domain associated with that variable

  E.g., $(\exists x)$ mammal(x) $\wedge$ lays-eggs(x)

- Consider the following example that shows the use of predicate logic as a way of representing knowledge.
  1. Marcus was a man.
  2. Marcus was a Pompeian.
  3. All Pompeians were Romans.
  4. Caesar was a ruler.
  5. All Pompeians were either loyal to Caesar or hated him.
  6. Everyone is loyal to someone.
  7. People only try to assassinate rulers they are not loyal to.
  8. Marcus tried to assassinate Caesar.
- The facts described by these sentences can be represented as a set of well-formed formulas (*wffs*) as follows:
  1. Marcus was a man.

     man(Marcus)
  2. Marcus was a Pompeian.

     Pompeian(Marcus)
  3. All Pompeians were Romans.

     $\forall$x: Pompeian(x) $\rightarrow$ Roman(x)
  4. Caesar was a ruler.

     ruler(Caesar)
  5. All Pompeians were either loyal to Caesar or hated him.

     *inclusive-or*

     $\forall$x: Roman(x) $\rightarrow$ loyalto(x, Caesar) $\vee$ hate(x, Caesar)

     *exclusive-or*

     $\forall$x: Roman(x) $\rightarrow$ (loyalto(x, Caesar) $\wedge \neg$hate(x, Caesar)) $\vee$
     ($\neg$loyalto(x, Caesar) $\wedge$ hate(x, Caesar))
  6. Every-one is loyal to someone.

     $\forall$x: $\exists$y: loyalto(x, y)
  7. People only try to assassinate rulers they are not loyal to.

     $\forall$x: $\forall$y: person(x) $\wedge$ ruler(y) $\wedge$ tryassassinate(x, y)
     $\rightarrow \neg$loyalto(x, y)
  8. Marcus tried to assassinate Caesar.

     tryassassinate(Marcus, Caesar)

- Now suppose if we want to use these statements to answer the question
  ***Was Marcus loyal to Caesar?***
- Now let's try to produce a formal proof, reasoning backward from the desired goal:
  ¬ loyalto(Marcus, Caesar)
- In order to prove the goal, we need to use the rules of inference to transform it into another goal (or possibly a set of goals) that can in turn be transformed, and so on, until there are no unsatisfied goals remaining.

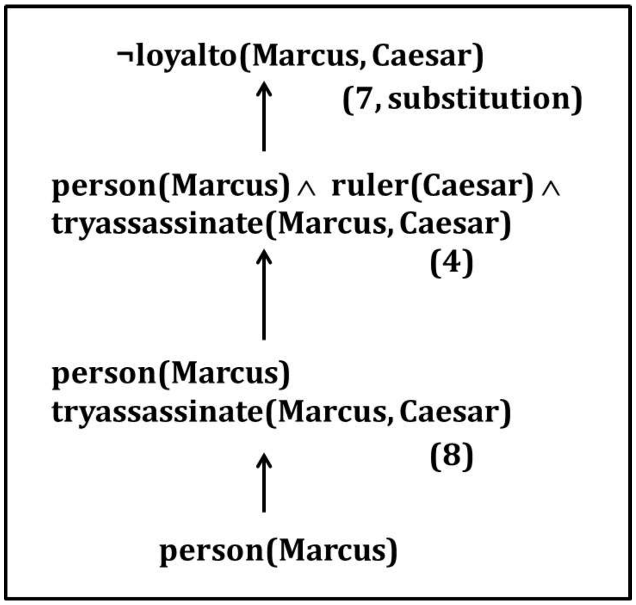

¬loyalto(Marcus, Caesar)
(7, substitution)
person(Marcus) ∧ ruler(Caesar) ∧ tryassassinate(Marcus, Caesar)
(4)
person(Marcus)
tryassassinate(Marcus, Caesar)
(8)
person(Marcus)

**Figure 4.1 An attempt to prove ¬loyalto(Marcus, Caesar).**

- The problem is that, although we know that Marcus was a man, we do not have any way to conclude from that that Marcus was a person. We need to add the representation of another fact to our system, namely:
  $\forall$ ***: man(x) → person(x)***
- Now we can satisfy the last goal and produce a proof that Marcus was not loyal to Caesar.
- From this simple example, we see that three important issues must be addressed in the process of converting English sentences into logical statements and then using those statements to deduce new ones:
  1. Many English sentences are ambiguous (for example, 5, 6, and 7 above). Choosing the correct interpretation may be difficult.
  2. There is often a choice of how to represent the knowledge. Simple representations are desirable, but they may exclude certain kinds of reasoning.
  3. Even in very simple situations, a set of sentences is unlikely to contain all the information necessary to reason about the topic at hand. In order to be able to use a set of statements effectively, it is usually necessary to have access to another set of statements that represent facts that people consider too obvious to mention.

## Representing INSTANCE and *ISA* Relationships

- Specific attributes ***instance*** and ***isa*** play important role particularly in a useful form of reasoning called property inheritance.
- ***The predicates instance and isa explicitly captured the relationships they are used to express, namely class membership and class inclusion.***
- Fig. 4.2 shows the first five sentences of the last section represented in logic in three different ways.
- The first part of the figure contains the representations we have already discussed. In these representations, class membership is represented with unary predicates (such as Roman), each of which corresponds to a class.
- Asserting that P(x) is true is equivalent to asserting that x is an instance (or element) of P.
- The second part of the figure contains representations that use the ***instance*** predicate explicitly.

1. Man(Marcus).
2. Pompeian(Marcus).
3. $\forall x$: Pompeian(x) $\rightarrow$ Roman(x).
4. ruler(Caesar).
5. $\forall x$: Roman(x) $\rightarrow$ loyalto(x, Caesar) $\vee$ hate(x, Caesar).

1. instance(Marcus, man).
2. instance(Marcus, Pompeian).
3. $\forall x$: instance(x, Pompeian) $\rightarrow$ instance(x, Roman).
4. instance(Caesar, ruler).
5. $\forall x$: instance(x, Roman). $\rightarrow$ loyalto(x, Caesar) $\vee$ hate(x, Caesar).

1. instance(Marcus, man).
2. instance(Marcus, Pompeian).
3. isa(Pompeian, Roman)
4. instance(Caesar, ruler).
5. $\forall x$: instance(x, Roman). $\rightarrow$ loyalto(x, Caesar) $\vee$ hate(x, Caesar).
6. $\forall x$: $\forall y$: $\forall z$: instance(x, y) $\wedge$ isa(y, z) $\rightarrow$ instance(x, z).

**Figure 4.2 Three ways of representing class membership**

- The predicate ***instance*** is a binary one, whose first argument is an object and whose second argument is a class to which the object belongs.

- But these representations do not use an explicit ***isa*** predicate.
- Instead, subclass relationships, such as that between Pompeians and Romans, are described as shown in sentence 3.
- The implication rule states that if an object is an instance of the subclass Pompeian then it is an instance of the superclass Roman.
- Note that this rule is equivalent to the standard set-theoretic definition of the subclass-superclass relationship.
- The third part contains representations that use both the ***instance*** and ***isa*** predicates explicitly.
- The use of the ***isa*** predicate simplifies the representation of sentence 3, but it requires that one additional axiom (shown here as number 6) be provided.

## Computable Functions and Predicates

- To express simple facts, such as the following greater-than and less-than relationships:

| | |
|---|---|
| gt(1,O) | It(0,1) |
| gt(2,1) | It(1,2) |
| gt(3,2) | It( 2,3) |

- It is often also useful to have computable functions as well as computable predicates. Thus we might want to be able to evaluate the truth of

  gt(2 + 3,1)
- To do so requires that we first compute the value of the plus function given the arguments 2 and 3, and then send the arguments 5 and 1 to gt.
- Consider the following set of facts, again involving Marcus:

1. Marcus was a man.

   man(Marcus)
2. Marcus was a Pompeian.

   Pompeian(Marcus)
3. Marcus was born in 40 A.D.

   born(Marcus, 40)
4. All men are mortal.

   ∀x: man(x) → mortal(x)
5. All Pompeians died when the volcano erupted in 79 A.D.

   erupted(volcano, 79) A ∀ x : [Pompeian(x) → died(x, 79)]
6. No mortal lives longer than 150 years.

   ∀x: ∀t1: At2: *mortal(x)* A *born(x, t1)* A *gt(t2 - t1,150)* → *died(x, t2)*

7. It is now 1991.

   *now* = 1991

- Above example shows how these ideas of computable functions and predicates can be useful.

- It also makes use of the notion of equality and allows equal objects to be substituted for each other whenever it appears helpful to do so during a proof.
- Now suppose we want to answer the question "Is Marcus alive?”
- The statements suggested here, there may be two ways of deducing an answer.
- Either we can show that Marcus is dead because he was killed by the volcano or we can show that he must be dead because he would otherwise be more than 150 years old, which we know is not possible.
- As soon as we attempt to follow either of those paths rigorously, however, we discover, just as we did in the last example, that we need some additional knowledge. For example, our statements talk about dying, but they say nothing that relates to being alive, which is what the question is asking.
- So we add the following facts:

  8. Alive means not dead.

     ∀x: ∀t: [alive(x, t) → ¬ dead(x, t)] A [¬ dead(x, t) → alive(x, t)]

  9. If someone dies, then he is dead at all later times.

     ∀x: ∀t1: At2*: died(x, t1)* A *gt(t2, t1)* → *dead(x, t2)*

- Now let's attempt to answer the question "Is Marcus alive?" by proving:

  ***¬ alive(Marcus, now)***

$$\begin{tikzcd}
\neg \text{alive}(\text{Marcus}, \text{now}) \\
\text{dead}(\text{Marcus}, \text{now}) \arrow[u, "(9, \text{substitution})"'] \\
\text{died}(\text{Marcus}, t_1) \wedge \text{gt}(\text{now}, t_1) \arrow[u, "(10, \text{substitution})"'] \\
\text{Pompeian}(\text{Marcus}) \wedge \text{gt}(\text{now}, 79) \arrow[u, "(5, \text{substitution})"'] \\
\text{gt}(\text{now}, 79) \arrow[u, "(2)"'] \\
\text{gt}(1991, 79) \arrow[u, "(8, \text{substitute equal})"'] \\
\text{nil} \arrow[u, "(\text{compute gt})"']
\end{tikzcd}$$

## Resolution

- Resolution is a procedure, which gains its efficiency from the fact that it operates on statements that have been converted to a very convenient standard form.

- Resolution produces proofs by refutation.
- In other words, ***to prove a statement (i.e., to show that it is valid), resolution attempts to show that the negation of the statement produces a contradiction with the known statements (i.e., that it is unsatisfiable).***
- The resolution procedure is a simple iterative process: at each step, two clauses, called the parent clauses, are compared (resolved), resulting into a new clause that has been inferred from them. The new clause represents ways that the two parent clauses interact with each other. Suppose that there are two clauses in the system:

  ***winter*** V ***summer***

  ¬ ***winter*** V ***cold***

  - Now we observe that precisely one of winter and ¬ winter will be true at any point.
  - If winter is true, then cold must be true to guarantee the truth of the second clause. If ¬ winter is true, then summer must be true to guarantee the truth of the first clause.
  - Thus we see that from these two clauses we can deduce

    ***summer V cold***
  - This is the deduction that the resolution procedure will make.
  - Resolution operates by taking two clauses that each contains the same literal, in this example, ***winter***.
  - The literal must occur in positive form in one clause and in negative form in the other. The resolvent is obtained by combining all of the literals of the two parent clauses except the ones that cancel.
  - If the clause that is produced is the empty clause, then a contradiction has been found.
    *For example, the two clauses*

    *winter*

    *¬ winter*

    *will produce the empty clause.*

**Conversion to Clause form**

- To apply resolution, we need to reduce a set of *wff's* to a set of clauses, where a clause is defined to be a *wff* in conjunctive normal form but with no instances of the connector A.
- We can do this by first converting each wff into conjunctive normal form and then breaking apart each such expression into clauses, one for each conjunct.
- All the conjuncts will be considered to be conjoined together as the proof procedure operates. To convert a *wff* into clause form, perform the following sequence of steps.

***<u>Algorithm: Convert to Clause Form</u>***

1. Eliminate →, using the fact that a → b is equivalent to ¬ a V b. Performing this transformation on the wff given above becomes

   **∀x: ¬ [Roman(x)** A **know(x, Marcus)] V**

   **[hate(x, Caesar) V (∀y : ¬(∃z : hate(y, z)) V thinkcrazy(x, y))]**

2. Reduce the scope of each ¬ to a single term, using the fact that ¬ (¬ p) = p, Performing this transformation on the wff from step 1 becomes

   **∀x: [¬ Roman(x) V ¬ know(x, Marcus)] V**
   **[hate(x, Caesar) V (∀y: ∀z: ¬ hate(y, z) V thinkcrazy(x, y))]**

3. Standardize variables so that each quantifier binds a unique variable. Since variables are just dummy names, this process cannot affect the truth value of the wff.

   **For example, the formula ∀x: P(x) V ∀x: Q(x)**
   **would be converted to ∀x: P(x) V ∀y: Q(y)**

4. Move all quantifiers to the left of the formula without changing their relative order. This is possible since there is no conflict among variable names. Performing this operation on the formula of step 2, we get

   **∀x: ∀y: Az: [¬ Roman(x) V ¬ know(x, Marcus)] V**
   **[hate(x, Caesar) V (¬ hale(y, z) V thinkcrazy(x, y))]**

5. Eliminate existential quantifiers. So, for example, the formula

   **∃y : President(y)**

   can be transformed into the formula

   **President(S1)**

   For example, in the formula

   **∀x: ∃y: father-of(y, x)**

   would be transformed into

   **∀x: father-of(S2(x), x)**

   These generated functions are called Skolem functions. Sometimes ones with no arguments are called Skolem constants.

6. Drop the prefix. At this point, all remaining variables are universally quantified, so the prefix can just be dropped and any proof procedure we use can simply assume that any variable it sees is universally quantified. Now the formula produced in step 4 appears as

   **[¬ Roman(x) V ¬ know(x, Marcus)] V**
   **[hate(x, Caesar) V (¬ hate(y, z) V thinkcrazy(x, y))]**

7. Convert the matrix into a conjunction of disjuncts. In the case or our example, since there are no and's, it is only necessary to exploit the associative property of or [ i.e., (a A b) V c = (a V c) A (b A c)] and simply remove the parentheses, giving

   **¬ Roman(x) V ¬ know(x, Marcus) V**
   **hate(x, Caesar) V ¬ hate(y, z) V thinkcrazy(x, y)**

8. Create a separate clause corresponding to each conjunct. In order for a wff to be true, all the clauses that are generated from it must be true.

9. Standardize apart the variables in the set of clauses generated in step 8. By this we mean rename the variables so that no two clauses make reference to the same variable. In making this transformation, we rely on the fact that

   **(∀x: P(x) A Q(x)) = ∀x: P(x) A ∀x: Q(x)**

Thus since each clause is a separate conjunct and since all the variables are universally quantified, there need be no relationship between the variables of two clauses, even if they were generated from the same wff.

***<u>Algorithm: Propositional Resolution</u>***

1. Convert all the propositions of F to clause form.
2. Negate P and convert the result to clause form. Add it to the set of clauses obtained in step 1.
3. Repeat until either a contradiction is found or no progress can be made:
    a. Select two clauses. Call these the parent clauses.
    b. Resolve them together. The resulting clause, called the resolvent, will be the disjunction of all of the literals of both of the parent clauses with the following exception: If there are any pairs of literals L and ¬ *L* such that one of the parent clauses contains *L* and the other contains ¬*L,* then select one such pair and eliminate both *L* and ¬ *L* from the resolvent.
    c. If the resolvent is the empty clause, then a contradiction has been found. If it is not, then add it to the set of clauses available to the procedure.

***<u>The Unification Algorithm</u>***

- In propositional logic, it is easy to determine that two literals cannot both be true at the same time.
- Simply look for L and ¬L in predicate logic, this matching process is more complicated since the arguments of the predicates must be considered.
- For example, man(John) and ¬man(John) is a contradiction, while man(John) and ¬man(Spot) is not.
- Thus, in order to determine contradictions, we need a matching procedure that compares two literals and discovers whether there exists a set of substitutions that makes them identical.
- There is a straightforward recursive procedure, called the unification algorithm, that does it.

***<u>Algorithm: Unify(L1, L2)</u>***

```
1. If L1 or L2 are both variables or constants, then:
     a. If L1 and L2 are identical, then return NIL.
     b. Else if L1 is a variable, then if L1 occurs in L2 then return {FAIL}, else return (L2/L1).
     c. Else if L2 is a variable, then if L2 occurs in L1 then return {FAIL}, else return (L1/L2).
     d. Else return {FAIL}.
2. If the initial predicate symbols in L1 and L2 are not identical, then return {FAIL}.
3. If LI and L2 have a different number of arguments, then return {FAIL}.
4. Set SUBST to NIL. (At the end of this procedure, SUBST will contain all the substitutions used
   to unify L1 and L2.)
5. For i ← 1 to number of arguments in L1 :
     a. Call Unify with the ith argument of L1 and the ith argument of L2, putting result in S.
     b. If S contains FAIL then return {FAIL}.
     c. If S is not equal to NIL then:
         i. Apply S to the remainder of both L1 and L2.
         ii. SUBST: = APPEND(S, SUBST).
6. Return SUBST.
```

***Resolution in Predicate Logic***

- We can now state the resolution algorithm for predicate logic as follows, assuming a set of given statements F and a statement to be proved P:

***Algorithm: Resolution***

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1. Convert all the statements of F to clause form.
2. Negate P and convert the result to clause form. Add it to the set of clauses obtained in 1.
3. Repeat until a contradiction is found, no progress can be made, or a predetermined
   amount of effort has been expended.
    a. Select two clauses. Call these the parent clauses.
    b. Resolve them together. The resolvent will be the disjunction of all the literals of
       both parent clauses with appropriate substitutions performed and with the
       following exception: If there is one pair of literals T1 and ¬T2 such that one of the
       parent clauses contains T2 and the other contains T1 and if T1 and T2 are
       unifiable, then neither T1 nor T2 should appear in the resolvent. We call T1 and
       T2 Complementary literals. Use the substitution produced by the unification to
       create the resolvent. If there is more than one pair of complementary literals,
       only one pair should be omitted from the resolvent.
    c. If the resolvent is an empty clause, then a contradiction has been found. If it is
       not, then add it to the set of clauses available to the procedure.
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**Example: Consider the following facts. Translate given sentences into formulas in predicate logic. Prove by resolution the given fact.**

1. Marcus was a man.
2. Marcus was a Pompeian.
3. All pompeians were Romans.
4. Caesar was a ruler.
5. All Romans were either loyal to Caesar or hated him.
6. Everyone is loyal to someone.
7. People only try to assassinate rulers they are not loyal to.
8. Marcus tried to assassinate Caesar.

**Prove: hate (Marcus, Caesar)**

**Solution:**

Predicate logic statements.

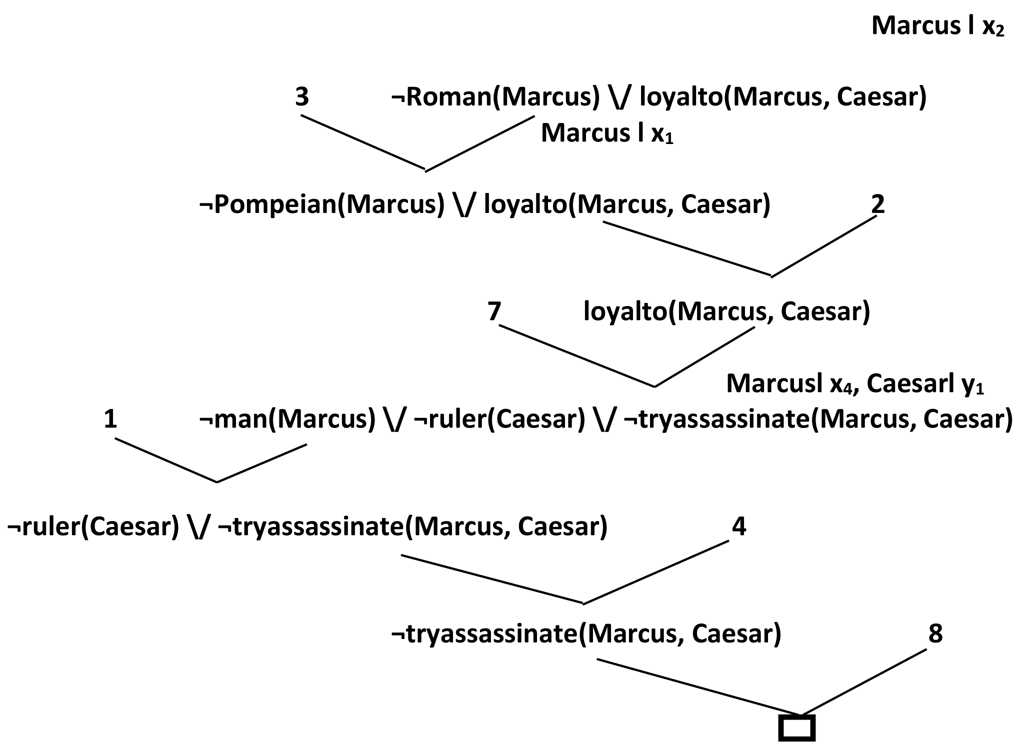
1. Marcus was a man.
   man(Marcus)
2. Marcus was a Pompeian.
   Pompeian(Marcus)
3. All Pompeians were Romans.
   $\forall$x: Pompeian(x) $\rightarrow$ Roman(x)
4. Caesar was a ruler.
   ruler(Caesar)
5. All Pompeians were either loyal to Caesar or hated him.
   $\forall$x: Roman(x) $\rightarrow$ loyalto(x, Caesar) $\vee$ hate(x, Caesar)
6. Every-one is loyal to someone.
   $\forall$x: $\exists$y: loyalto(x, y)
7. People only try to assassinate rulers they are not loyal to.
   $\forall$x: $\forall$y: person(x) $\wedge$ ruler(y) $\wedge$ tryassassinate(x, y)
   $\rightarrow$ $\neg$loyalto(x, y)
8. Marcus tried to assassinate Caesar.
   tryassassinate(Marcus, Caesar)

Axioms in clause form –

1. man(Marcus)
2. Pompeian(Marcus)
3. ¬Pompeian(x1) \/ Roman(x1)
4. ruler(Caesar)
5. ¬Roman(x2) \/ loyalto(x2, Caesar) \/ hate(x2, Caesar)
6. loyalto(x3,fl(x3))
7. ¬man(x4) \/ ¬ruler(y1) \/ ¬tryassassinate(x4,y1) \/ loyalto(x4,y1)
8. trayassassinate(Marcus,Caesar)

- **To prove hate (Marcus, Caesar) we start with a negation of it as ¬hate (Marcus, Caesar).**

**Prove: hate (Marcus, Caesar)** **¬hate (Marcus, Caesar)** **5**


Marcus l x₂
3
¬Roman(Marcus) \/ loyalto(Marcus, Caesar)
Marcus l x₁
¬Pompeian(Marcus) \/ loyalto(Marcus, Caesar)
2
7
loyalto(Marcus, Caesar)
Marcusl x₄, Caesarl y₁
1
¬man(Marcus) \/ ¬ruler(Caesar) \/ ¬tryassassinate(Marcus, Caesar)
¬ruler(Caesar) \/ ¬tryassassinate(Marcus, Caesar)
4
¬tryassassinate(Marcus, Caesar)
8

- **Final resolvent is an empty clause means that a contradiction is found in the initial assumption so, proved hate (Marcus, Caesar).**

## Introduction

- We have discussed various search techniques in previous units. Now we would consider a set of rules that represents,
  i. Knowledge about relationships in the world and
  ii. Knowledge about how to solve problem using the content of the rules.

## Procedural versus Declarative Knowledge

**Procedural Knowledge**

- A representation in which the control information that is necessary to use the knowledge is embedded in the knowledge itself for e.g. computer programs, directions, and recipes; these indicate specific use or implementation;
- The real difference between declarative and procedural views of knowledge lies in where control information reside.
- For example, consider the following

  *Man (Marcus)*

  *Man (Caesar)*

  *Person (Cleopatra)*

  $\forall$ *x: Man(x)* $\rightarrow$ *Person(x)*

  *Now, try to answer the question. ?Person(y)*

  The knowledge base justifies any of the following answers.

  *Y=Marcus*

  *Y=Caesar*

  *Y=Cleopatra*
- We get more than one value that satisfies the predicate.
- If only one value is needed, then the answer to the question will depend on the order in which the assertions are examined during the search for a response.
- If the assertions are declarative then they do not themselves say anything about how they will be examined. In case of procedural representation, they say how they will be examined.

**Declarative Knowledge**

- A statement in which knowledge is specified, but the use to which that knowledge is to be put is not given.
- For example, laws, people's name; these are the facts which can stand alone, not dependent on other knowledge;
- So to use declarative representation, we must have a program that explains what is to be done to the knowledge and how.
- For example, a set of logical assertions can be combined with a resolution theorem prover to give a complete program for solving problems but in some cases the logical assertions can be viewed as a program rather than data to a program.
- Hence the implication statements define the legitimate reasoning paths and automatic

assertions provide the starting points of those paths.

- These paths define the execution paths which is similar to the 'if then else "in traditional programming.
- So logical assertions can be viewed as a procedural representation of knowledge.

**Differences Between Declarative knowledge and procedural knowledge**

| Procedural knowledge | Declarative knowledge |
|---|---|
| High efficiency | Higher level of abstraction |
| Low modifiability | Good modifiability and good readability |
| Low perceptive adequacy (better for knowledge engineers) | Suitable for independent facts |
| Produces creative, reflective thought and promoters critical thinking and independent decision making | Good cognitive matching (better for domain experts and end-users) and low computational efficiency. |

## Logic Programming

- Logic programming is a programming paradigm in which logical assertions are viewed as programs.
- These are several logic programming systems, PROLOG is one of them.
- ***A PROLOG program consists of several logical assertions where each is a horn clause i.e. a clause with at most one positive literal.***

  Ex : P, P V Q, P $\rightarrow$ Q
- The facts are represented on Horn Clause for two reasons.
  - i. Because of a uniform representation, a simple and efficient interpreter can be written.
  - ii. The logic of Horn Clause is decidable.
- The first two differences are from the fact that PROLOG programs are actually sets of Horn clause that have been transformed as follows:-
  1. If the Horn Clause contains no negative literal then leave it as it is.
  2. Otherwise rewrite the Horn clauses as an implication, combining all of the negative literals in to the antecedent of the implications and the single positive literal into the consequent.
- This procedure causes a clause which originally consisted of a disjunction of literals (one of them was positive) to be transformed into a single implication whose antecedent is a conjunction universally quantified.
- But when we apply this transformation, any variables that occurred in negative literals and so now occur in the antecedent become existentially quantified, while the variables in the consequent are still universally quantified.

- For example the PROLOG clause P(x): - Q(x, y) is equal to logical expression ∀x: ∃y: Q (x, y) → P(x).
- The difference between the logic and PROLOG representation is that the PROLOG interpretation has a fixed control strategy and so the assertions in the PROLOG program define a particular search path to answer to any question.
- But, the logical assertions define only the set of answers but not about how to choose among those answers if there is more than one.
- Consider the following example:

  A. Logical representation

  *∀x : pet(x) ∧ small (x) → apartmentpet(x)*
  *∀ x : cat(x) ∨ dog(x) → pet(x)*
  *∀x : poodle (x) → dog (x) ∧ small (x)*
  *poodle (fluffy)*

  B. Prolog representation

  *apartmentpet (x) : -- pet(x), small (x)*
  *pet (x): -- cat (x)*
  *pet (x) :-- dog(x)*
  *dog(x) :-- poodle (x)*
  *small (x) :-- poodle(x)*
  *poodle (fluffy)*

## Forward versus Backward Reasoning

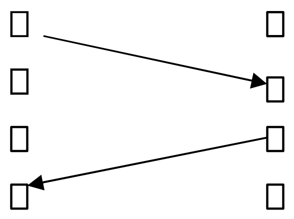
- A search procedure must find a path between initial and goal states.
- There are two directions in which a search process could proceed.
- The two types of search are:
  1. Forward search which starts from the start state
  2. Backward search that starts from the goal state
- The production system views the forward and backward as symmetric processes.
- Consider a game of playing 8 puzzles. The rules defined are
  - *Square 1 empty and square 2 contains tile n.* →
    - *Square 2 empty and square 1 contains the tile n.*
  - *Square 1 empty Square 4 contains tile n.* →
    - *Square 4 empty and Square 1 contains tile n.*
- We can solve the problem in 2 ways:
  1. Reason forward from the initial state
     - Step 1. Begin building a tree of move sequences by starting with the initial configuration at the root of the tree.
     - Step 2. Generate the next level of tree by finding all rules ***whose left hand side matches*** against the root node. The right hand side is used to create new

    configurations.
    - Step 3. Generate the next level by considering the nodes in the previous level and applying it to all rules whose left hand side match.
  2. Reasoning backward from the goal states:
    - Step 1. Begin building a tree of move sequences by starting with the goal node configuration at the root of the tree.
    - Step 2. Generate the next level of tree by finding all rules ***whose right hand side matches*** against the root node. The left hand side is used to create new configurations.
    - Step 3. Generate the next level by considering the nodes in the previous level and applying it to all rules whose right hand side match.
- The same rules can be used in both cases.
- In forward reasoning the left hand sides of the rules are matched against the current state and right sides are used to generate the new state.
- In backward reasoning the right hand sides of the rules are matched against the current state and left sides are used to generate the new state.
- There are four factors influencing the type of reasoning. They are,
  1. Are there more possible start or goal state? We move from smaller set of sets to the longer.
  2. In what direction is the branching factor greater? We proceed in the direction with the lower branching factor.
  3. Will the program be asked to justify its reasoning process to a user? If, so then it is selected since it is very close to the way in which the user thinks.
  4. What kind of event is going to trigger a problem-solving episode? If it is the arrival of a new factor, forward reasoning makes sense. If it is a query to which a response is desired, backward reasoning is more natural.
- Example 1: It is easier to drive from an unfamiliar place from home, rather than from home to an unfamiliar place. If you consider a home as starting place an unfamiliar place as a goal then we have to back track from unfamiliar place to home.
- Example 2: Consider a problem of symbolic integration. The problem space is a set of formulas, which contains integral expressions. Here START is equal to the given formula with some integrals. GOAL is equivalent to the expression of the formula without any integral. Here we start from the formula with some integrals and proceed to an integral free expression rather than starting from an integral free expression.
- Example 3: The third factor is nothing but deciding whether the reasoning process can justify its reasoning. If it justifies then it can be applied. For example, doctors are usually unwilling to accept any advice from diagnostics process because it cannot explain its reasoning.
- Example 4: Prolog is an example of backward chaining rule system. In Prolog rules are restricted to Horn clauses. This allows for rapid indexing because all the rules for deducing a

given fact share the same rule head. Rules are matched with unification procedure. Unification tries to find a set of bindings for variables to equate a sub-goal with the head of some rule. Rules in the Prolog program are matched in the order in which they appear.

**Combining Forward and Backward Reasoning**

- Instead of searching either forward or backward, you can search both simultaneously.
- That is, start forward from a stating state and backward from a goal state simultaneously until the paths meet.
- This strategy is called Bi-directional search. The following figure shows the reason for Bi-directional search to be ineffective.



- The two searches may pass each other resulting in more work.
- Based on the form of the rules one can decide whether the same rules can be applied for both forward and backward reasoning.
- If left hand side and right of the rule contain pure assertions then the rule can be reversed. And so the same rule can be applied for both types of reasoning.
- If the right side of the rule contains an arbitrary procedure then the rule cannot be reversed.
- In this case while writing the rule the commitment to direction of reasoning must be made.
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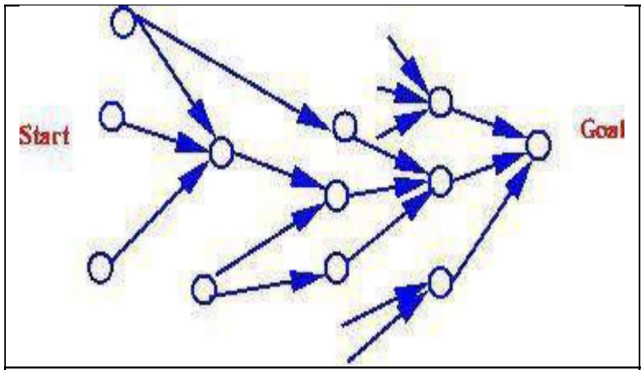
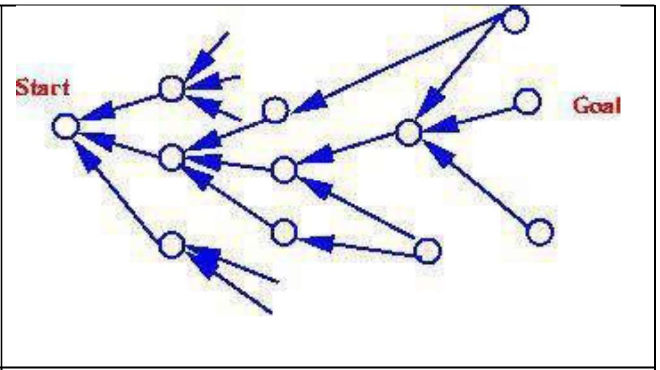
|  |  |
| **Forward Reasoning (goal driven)** | **Backward Reasoning (data driven)** |