

**Jaipur Engineering College & Research Centre, Jaipur**  
**Department of Computer Science and Engineering**



**Lecture Notes**  
**Artificial Intelligence [6CS4-05]**  
**Unit 1**

## **Vision of the Department:**

To become renowned Centre of excellence in computer science and engineering and make competent engineers & professionals with high ethical values prepared for lifelong learning.

## **Mission of the Department:**

**M1:** To impart outcome based education for emerging technologies in the field of computer science and engineering.

**M2:** To provide opportunities for interaction between academia and industry.

**M3:** To provide platform for lifelong learning by accepting the change in technologies.

**M4:** To develop aptitude of fulfilling social responsibilities.

## **Program Outcomes (PO):**

1. **Engineering knowledge:** Apply the knowledge of mathematics, science, engineering fundamentals, and Computer Science & Engineering specialization to the solution of complex Computer Science & Engineering problems.

2. **Problem analysis:** Identify, formulate, research literature, and analyze complex Computer Science and Engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

3. **Design/development of solutions:** Design solutions for complex Computer Science and Engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

4. **Conduct investigations of complex problems:** Use research-based knowledge and research methods including design of Computer Science and Engineering experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

5. **Modern tool usage:** Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex Computer Science Engineering activities with an understanding of the limitations.

6. **The engineer and society:** Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional Computer Science and Engineering practice.

7. **Environment and sustainability:** Understand the impact of the professional Computer Science and Engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

8. **Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of the Computer Science and Engineering practice.

9. **Individual and team work:** Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings in Computer Science and Engineering.

10. **Communication:** Communicate effectively on complex Computer Science and Engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

11. **Project management and finance:** Demonstrate knowledge and understanding of the Computer Science and Engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

12. **Life-long learning:** Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change in Computer Science and Engineering.

### **Program Educational Objectives (PEO):**

**PEO1:** To provide students with the fundamentals of Engineering Sciences with more emphasis in Computer Science & Engineering by way of analyzing and exploiting engineering challenges.

**PEO2:** To train students with good scientific and engineering knowledge so as to comprehend, analyze, design, and create novel products and solutions for the real life problems in Computer Science and Engineering

**PEO3:** To inculcate professional and ethical attitude, effective communication skills, teamwork skills, multidisciplinary approach, entrepreneurial thinking and an ability to relate engineering issues with social issues for Computer Science & Engineering.

**PEO4:** To provide students with an academic environment aware of excellence, leadership, written ethical codes and guidelines, and the self-motivated life-long learning needed for a successful professional career in Computer Science & Engineering.

**PEO5:** To prepare students to excel in Industry and Higher education by Educating Students along with High moral values and Knowledge in Computer Science & Engineering.

### **Course Outcomes (COs):**

**CO1:** Understand the concept of Artificial Intelligence and apply various Searching techniques.

**CO2:** Illustrate various Game Playing in Artificial Intelligence system.

**CO3:** Analyze different Knowledge Representation Techniques, Neural Network, Planning, Uncertain Knowledge and Reasoning.

**CO4:** Apply basic concepts of Learning, Natural Language Processing, Robotics and Expert Systems in AI.

## Syllabus:



RAJASTHAN TECHNICAL UNIVERSITY, KOTA

### Syllabus

III Year-VI Semester: B.Tech. Computer Science and Engineering

#### 6CS4-05: Artificial Intelligence

**Credit: 2**

**Max. Marks: 100(IA:20, ETE:80)**

**2L+0T+0P**

**End Term Exam: 2 Hours**

SN	Contents	Hours
1	<b>Introduction:</b> Objective, scope and outcome of the course.	01
2	<b>Introduction to AI and Intelligent agent:</b> Different Approach of AI, Problem Solving : Solving Problems by Searching, Uninformed search, BFS, DFS, Iterative deepening, Bi directional search, Hill climbing, Informed search techniques: heuristic, Greedy search, A* search, AO* search, constraint satisfaction problems.	03
3	<b>Game Playing:</b> Minimax, alpha-beta pruning, jug problem, chess problem, tiles problem	06
4	<b>Knowledge and Reasoning:</b> Building a Knowledge Base: Propositional logic, first order logic, situation calculus. Theorem Proving in First Order Logic. Planning, partial order planning. Uncertain Knowledge and Reasoning, Probabilities, Bayesian Networks.	06
5	<b>Learning:</b> Overview of different forms of learning, Supervised base learning: Learning Decision Trees, SVM, Unsupervised based learning, Market Basket Analysis, Neural Networks.	07
6	<b>Introduction to Natural Language Processing:</b> Different issue involved in NLP, Expert System, Robotics.	05
	<b>Total</b>	<b>28</b>

# Introduction to Artificial Intelligence

## What is Artificial Intelligence?

According to the father of Artificial Intelligence, John McCarthy, it is “The science and engineering of making intelligent machines, especially intelligent computer programs”.

Artificial Intelligence is a way of **making a computer, a computer-controlled robot, or a software think intelligently**, in the similar manner the intelligent humans think.

AI is accomplished by studying how human brain thinks, and how humans learn, decide, and work while trying to solve a problem, and then using the outcomes of this study as a basis of developing intelligent software and systems.

## Philosophy of AI

While exploiting the power of the computer systems, the curiosity of human, lead him to wonder, “*Can a machine think and behave like humans do?*”

Thus, the development of AI started with the intention of creating similar intelligence in machines that we find and regard high in humans.

## Goals of AI

- **To Create Expert Systems** – The systems which exhibit intelligent behavior, learn, demonstrate, explain, and advice its users.
- **To Implement Human Intelligence in Machines** – Creating systems that understand, think, learn, and behave like humans.
- Replicate human intelligence
- Solve Knowledge-intensive tasks
- An intelligent connection of perception and action
- Building a machine which can perform tasks that requires human intelligence such as:
  - Proving a theorem
  - Playing chess
  - Plan some surgical operation
  - Driving a car in traffic
- Creating some system which can exhibit intelligent behavior, learn new things by itself, demonstrate, explain, and can advise to its user.

Artificial Intelligence is composed of two words **Artificial** and **Intelligence**, where Artificial defines "*man-made*," and intelligence defines "*thinking power*", hence AI means "*a man-made thinking power*."

So, we can define AI as:

"It is a branch of computer science by which we can create intelligent machines which can behave like a human, think like humans, and able to make decisions."

Artificial Intelligence exists when a machine can have human based skills such as learning, reasoning, and solving problems

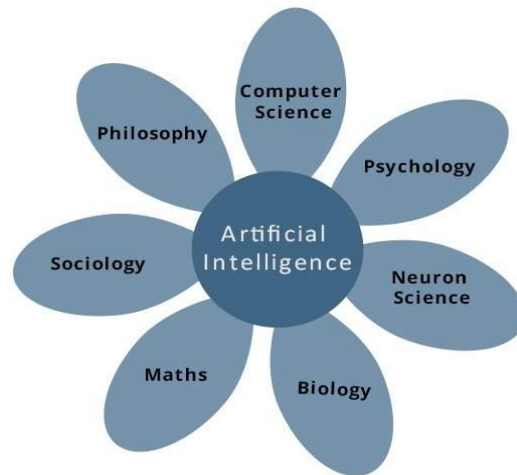
With Artificial Intelligence you do not need to preprogram a machine to do some work, despite that you can create a machine with programmed algorithms which can work with own intelligence, and that is the awesomeness of AI.

It is believed that AI is not a new technology, and some people says that as per Greek myth, there were Mechanical men in early days which can work and behave like humans.

## **Why Artificial Intelligence?**

Before Learning about Artificial Intelligence, we should know that what is the importance of AI and why should we learn it. Following are some main reasons to learn about AI:

- With the help of AI, you can create such software or devices which can solve real-world problems very easily and with accuracy such as health issues, marketing, traffic issues, etc.
- With the help of AI, you can create your personal virtual Assistant, such as Cortana, Google Assistant, Siri, etc.
- With the help of AI, you can build such Robots which can work in an environment where survival of humans can be at risk.
- AI opens a path for other new technologies, new devices, and new Opportunities.



## What Contributes to AI?

Artificial intelligence is a science and technology based on disciplines such as Computer Science, Biology, Psychology, Linguistics, Mathematics, and Engineering. A major thrust of AI is in the development of computer functions associated with human intelligence, such as reasoning, learning, and problem solving.

Out of the following areas, one or multiple areas can contribute to build an intelligent system.

## Programming Without and With AI

The programming without and with AI is different in following ways –

Programming Without AI	Programming With AI
A computer program without AI can answer the <b>specific</b> questions it is meant to solve.	A computer program with AI can answer the <b>generic</b> questions it is meant to solve.
Modification in the program leads to change in its structure.	AI programs can absorb new modifications by putting highly independent pieces of information together. Hence you can modify even a minute piece of information of program without affecting its structure.
Modification is not quick and easy. It may lead to affecting the program adversely.	Quick and Easy program modification.

## What is AI Technique?

In the real world, the knowledge has some unwelcomed properties –

- Its volume is huge, next to unimaginable.
- It is not well-organized or well-formatted.
- It keeps changing constantly.

AI Technique is a manner to organize and use the knowledge efficiently in such a way that –

- It should be perceivable by the people who provide it.
- It should be easily modifiable to correct errors.
- It should be useful in many situations though it is incomplete or inaccurate.

AI techniques elevate the speed of execution of the complex program it is equipped with.

## Applications of AI

AI has been dominant in various fields such as –

- **Gaming** – AI plays crucial 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.
- **Natural Language Processing** – It is possible to interact with the computer that understands natural language spoken by humans.
- **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.
- **Vision Systems** – These systems understand, interpret, and comprehend visual input on the computer. For example,
  - A spying aeroplane takes photographs, which are used to figure out spatial information or map of the areas.
  - Doctors use clinical expert system to diagnose the patient.
  - Police use computer software that can recognize the face of criminal with the stored portrait made by forensic artist.
- **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 due to cold, etc.
- **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.
- **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.

## History of AI

Here is the history of AI during 20th century –

Year	Milestone / Innovation
1923	Karel Čapek play named “Rossum's Universal Robots” (RUR) opens in London, first use of the word "robot" in English.
1943	Foundations for neural networks laid.
1945	Isaac Asimov, a Columbia University alumni, coined the term <i>Robotics</i> .
1950	Alan Turing introduced Turing Test for evaluation of intelligence and published <i>Computing Machinery and Intelligence</i> . Claude Shannon published <i>Detailed Analysis of Chess Playing</i> as a search.
1956	John McCarthy coined the term <i>Artificial Intelligence</i> . Demonstration of the first running AI program at Carnegie Mellon University.
1958	John McCarthy invents LISP programming language for AI.
1964	Danny Bobrow's dissertation at MIT showed that computers can understand natural language well enough to solve algebra word problems correctly.
1965	Joseph Weizenbaum at MIT built <i>ELIZA</i> , an interactive program that carries on a dialogue in English.
1969	Scientists at Stanford Research Institute Developed <i>Shakey</i> , a robot, equipped with locomotion, perception, and problem solving.
1973	The Assembly Robotics group at Edinburgh University built <i>Freddy</i> , the Famous Scottish Robot, capable of using vision to locate and assemble models.

1979	The first computer-controlled autonomous vehicle, Stanford Cart, was built.
1985	Harold Cohen created and demonstrated the drawing program, <i>Aaron</i> .
1990	Major advances in all areas of AI – <ul style="list-style-type: none"> <li>• Significant demonstrations in machine learning</li> <li>• Case-based reasoning</li> <li>• Multi-agent planning</li> <li>• Scheduling</li> <li>• Data mining, Web Crawler</li> <li>• natural language understanding and translation</li> <li>• Vision, Virtual Reality</li> <li>• Games</li> </ul>
1997	The Deep Blue Chess Program beats the then world chess champion, Garry Kasparov.
2000	Interactive robot pets become commercially available. MIT displays <i>Kismet</i> , a robot with a face that expresses emotions. The robot <i>Nomad</i> explores remote regions of Antarctica and locates meteorites.

## Advantages of Artificial Intelligence

Following are some main advantages of Artificial Intelligence:

- **High Accuracy with less errors:** AI machines or systems are prone to less errors and high accuracy as it takes decisions as per pre-experience or information.
- **High-Speed:** AI systems can be of very high-speed and fast-decision making, because of that AI systems can beat a chess champion in the Chess game.
- **High reliability:** AI machines are highly reliable and can perform the same action multiple times with high accuracy.
- **Useful for risky areas:** AI machines can be helpful in situations such as defusing a bomb, exploring the ocean floor, where to employ a human can be risky.
- **Digital Assistant:** AI can be very useful to provide digital assistant to the users such as AI technology is currently used by various E-commerce websites to show the products as per customer requirement.

- **Useful as a public utility:** AI can be very useful for public utilities such as a self-driving car which can make our journey safer and hassle-free, facial recognition for security purpose, Natural language processing to communicate with the human in human-language, etc.

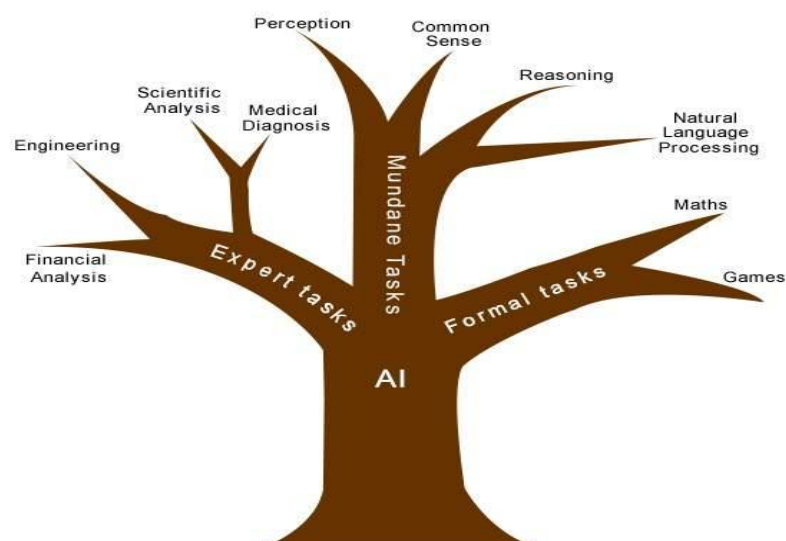
## Disadvantages of Artificial Intelligence

Every technology has some disadvantages, and the same goes for Artificial intelligence. Being so advantageous technology still, it has some disadvantages which we need to keep in our mind while creating an AI system. Following are the disadvantages of AI:

- **High Cost:** The hardware and software requirement of AI is very costly as it requires lots of maintenance to meet current world requirements.
- **Can't think out of the box:** Even we are making smarter machines with AI, but still they cannot work out of the box, as the robot will only do that work for which they are trained, or programmed.
- **No feelings and emotions:** AI machines can be an outstanding performer, but still it does not have the feeling so it cannot make any kind of emotional attachment with human, and may sometime be harmful for users if the proper care is not taken.
- **Increase dependency on machines:** With the increment of technology, people are getting more dependent on devices and hence they are losing their mental capabilities.
- **No Original Creativity:** As humans are so creative and can imagine some new ideas but still AI machines cannot beat this power of human intelligence and cannot be creative and imaginative.
- 

## Task Classification of AI

The domain of AI is classified into **Formal tasks**, **Mundane tasks**, and **Expert tasks**.



Task Domains of Artificial Intelligence		
Mundane (Ordinary) Tasks	Formal Tasks	Expert Tasks
Perception <ul style="list-style-type: none"> <li>• Computer Vision</li> <li>• Speech, Voice</li> </ul>	<ul style="list-style-type: none"> <li>• Mathematics</li> <li>• Geometry</li> <li>• Logic</li> <li>• Integration and Differentiation</li> </ul>	<ul style="list-style-type: none"> <li>• Engineering</li> <li>• Fault Finding</li> <li>• Manufacturing</li> <li>• Monitoring</li> </ul>
Natural Language Processing <ul style="list-style-type: none"> <li>• Understanding</li> <li>• Language Generation</li> <li>• Language Translation</li> </ul>	Games <ul style="list-style-type: none"> <li>• Go</li> <li>• Chess (Deep Blue)</li> <li>• Ckeckers</li> </ul>	Scientific Analysis
Common Sense	Verification	Financial Analysis
Reasoning	Theorem Proving	Medical Diagnosis
Planing		Creativity
Robotics <ul style="list-style-type: none"> <li>• Locomotive</li> </ul>		

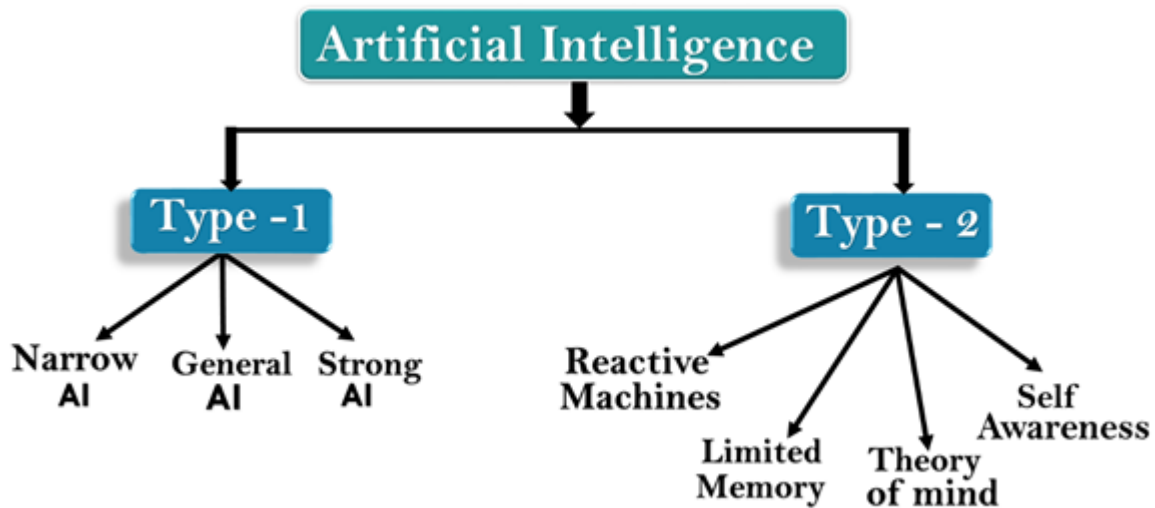
Humans learn **mundane (ordinary) tasks** since their birth. They learn by perception, speaking, using language, and locomotives. They learn Formal Tasks and Expert Tasks later, in that order.

For humans, the mundane tasks are easiest to learn. The same was considered true before trying to implement mundane tasks in machines. Earlier, all work of AI was concentrated in the mundane task domain.

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 prospering 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.

## Types of Artificial Intelligence:

Artificial Intelligence can be divided in various types, there are mainly two types of main categorization which are based on capabilities and based on functionality of AI. Following is flow diagram which explain the types of AI.



### AI type-1: Based on Capabilities

#### 1. Weak AI or Narrow AI:

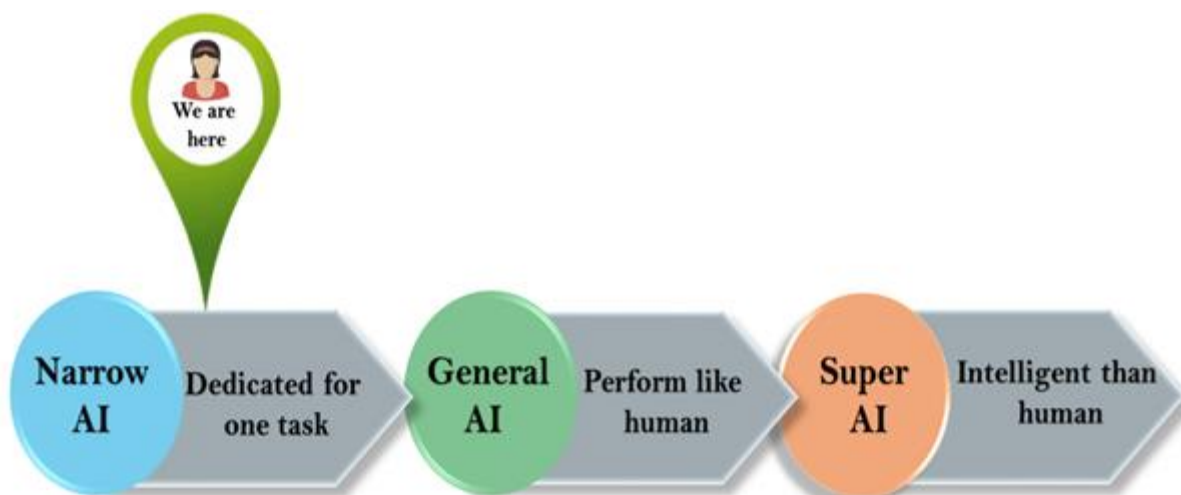
- Narrow AI is a type of AI which is able to perform a dedicated task with intelligence. The most common and currently available AI is Narrow AI in the world of Artificial Intelligence.
- Narrow AI cannot perform beyond its field or limitations, as it is only trained for one specific task. Hence it is also termed as weak AI. Narrow AI can fail in unpredictable ways if it goes beyond its limits.
- Apple Siri is a good example of Narrow AI, but it operates with a limited pre-defined range of functions.
- IBM's Watson supercomputer also comes under Narrow AI, as it uses an Expert system approach combined with Machine learning and natural language processing.
- Some Examples of Narrow AI are playing chess, purchasing suggestions on e-commerce site, self-driving cars, speech recognition, and image recognition.

## 2. General AI:

- General AI is a type of intelligence which could perform any intellectual task with efficiency like a human.
- The idea behind the general AI to make such a system which could be smarter and think like a human by its own.
- Currently, there is no such system exist which could come under general AI and can perform any task as perfect as a human.
- The worldwide researchers are now focused on developing machines with General AI.
- As systems with general AI are still under research, and it will take lots of efforts and time to develop such systems.

## 3. Super AI:

- Super AI is a level of Intelligence of Systems at which machines could surpass human intelligence, and can perform any task better than human with cognitive properties. It is an outcome of general AI.
- Some key characteristics of strong AI include capability include the ability to think, to reason, solve the puzzle, make judgments, plan, learn, and communicate by its own.
- Super AI is still a hypothetical concept of Artificial Intelligence. Development of such systems in real is still world changing task.



## Artificial Intelligence type-2: Based on functionality

## 1. Reactive Machines

- Purely reactive machines are the most basic types of Artificial Intelligence.
- Such AI systems do not store memories or past experiences for future actions.
- These machines only focus on current scenarios and react on it as per possible best action.
- IBM's Deep Blue system is an example of reactive machines.
- Google's AlphaGo is also an example of reactive machines.

## 2. Limited Memory

- Limited memory machines can store past experiences or some data for a short period of time.
- These machines can use stored data for a limited time period only.
- Self-driving cars are one of the best examples of Limited Memory systems. These cars can store recent speed of nearby cars, the distance of other cars, speed limit, and other information to navigate the road.

## 3. Theory of Mind

- Theory of Mind AI should understand the human emotions, people, beliefs, and be able to interact socially like humans.
- This type of AI machines are still not developed, but researchers are making lots of efforts and improvement for developing such AI machines.

## 4. Self-Awareness

- Self-awareness AI is the future of Artificial Intelligence. These machines will be super intelligent, and will have their own consciousness, sentiments, and self-awareness.
- These machines will be smarter than human mind.
- Self-Awareness AI does not exist in reality still and it is a hypothetical concept.

# AI: Agents and Environment

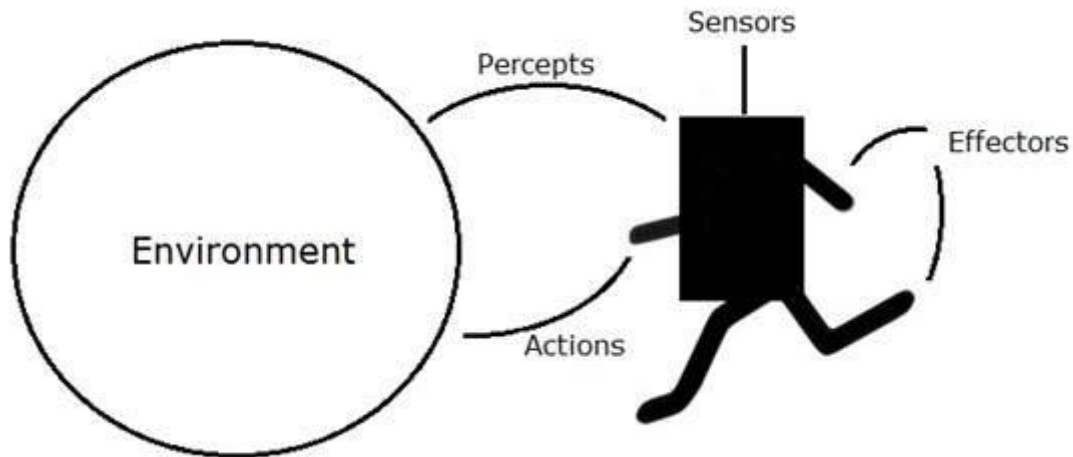
An AI system is composed of an agent and its environment. The agents act in their environment. The environment may contain other agents.

## What are Agent and Environment?

An **agent** is anything that can perceive its environment through **sensors** and acts upon that environment through **effectors**.

- A **human agent** has sensory organs such as eyes, ears, nose, tongue and skin parallel to the sensors, and other organs such as hands, legs, mouth, for effectors.

- A **robotic agent** replaces cameras and infrared range finders for the sensors, and various motors and actuators for effectors.
- A **software agent** has encoded bit strings as its programs and actions.



## Agent Terminology

- **Performance Measure of Agent** – It is the criteria, which determines how successful an agent is.
- **Behavior of Agent** – It is the action that agent performs after any given sequence of percepts.
- **Percept** – It is agent's perceptual inputs at a given instance.
- **Percept Sequence** – It is the history of all that an agent has perceived till date.
- **Agent Function** – It is a map from the precept sequence to an action.

## Rationality

Rationality is nothing but status of being reasonable, sensible, and having good sense of judgment.

Rationality is concerned with expected actions and results depending upon what the agent has perceived. Performing actions with the aim of obtaining useful information is an important part of rationality.

## What is Ideal Rational Agent?

An ideal rational agent is the one, which is capable of doing expected actions to maximize its performance measure, on the basis of –

- Its percept sequence
- Its built-in knowledge base

Rationality of an agent depends on the following –

- The **performance measures**, which determine the degree of success.
- Agent's **Percept Sequence** till now.



- The agent's **prior knowledge about the environment**.
- The **actions** that the agent can carry out.

A rational agent always performs right action, where the right action means the action that causes the agent to be most successful in the given percept sequence. The problem the agent solves is characterized by Performance Measure, Environment, Actuators, and Sensors (PEAS).

## The Structure of Intelligent Agents

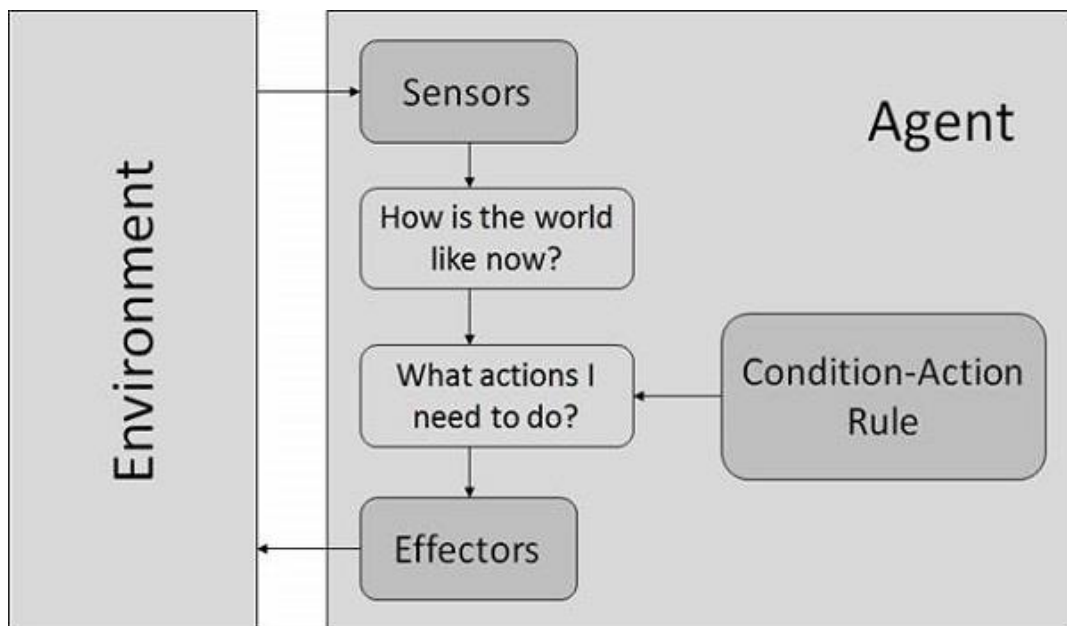
Agent's structure can be viewed as –

- Agent = Architecture + Agent Program
- Architecture = the machinery that an agent executes on.
- Agent Program = an implementation of an agent function.

### Simple Reflex Agents

- They choose actions only based on the current percept.
- They are rational only if a correct decision is made only on the basis of current percept.
- Their environment is completely observable.

**Condition-Action Rule** – It is a rule that maps a state (condition) to an action.



### Model Based Reflex Agents

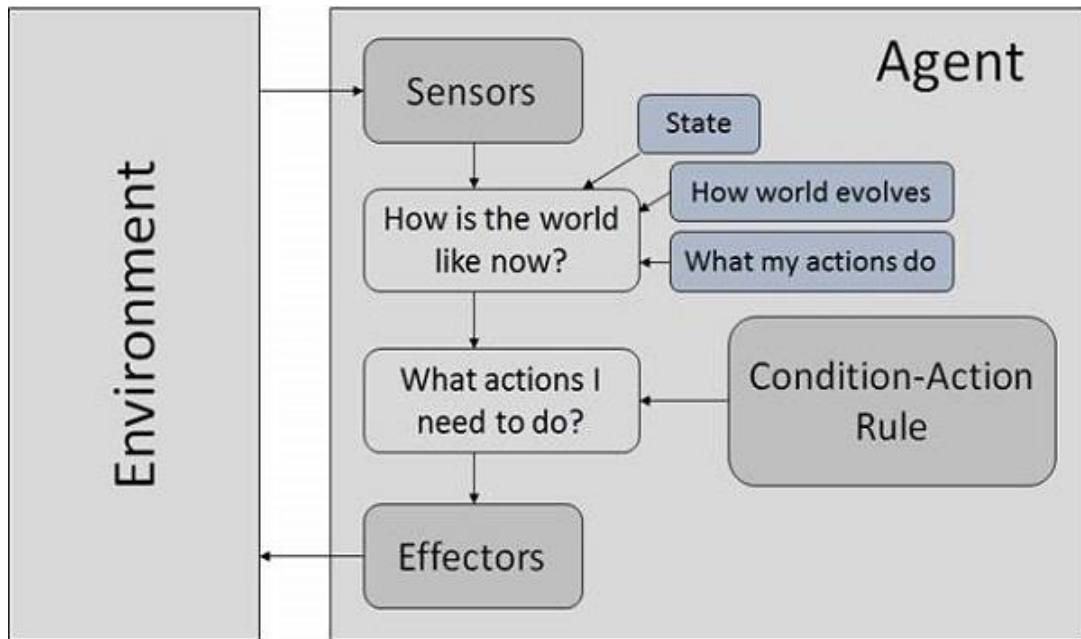
They use a model of the world to choose their actions. They maintain an internal state.

**Model** – knowledge about “how the things happen in the world”.

**Internal State** – It is a representation of unobserved aspects of current state depending on percept history.

**Updating the state requires the information about** –

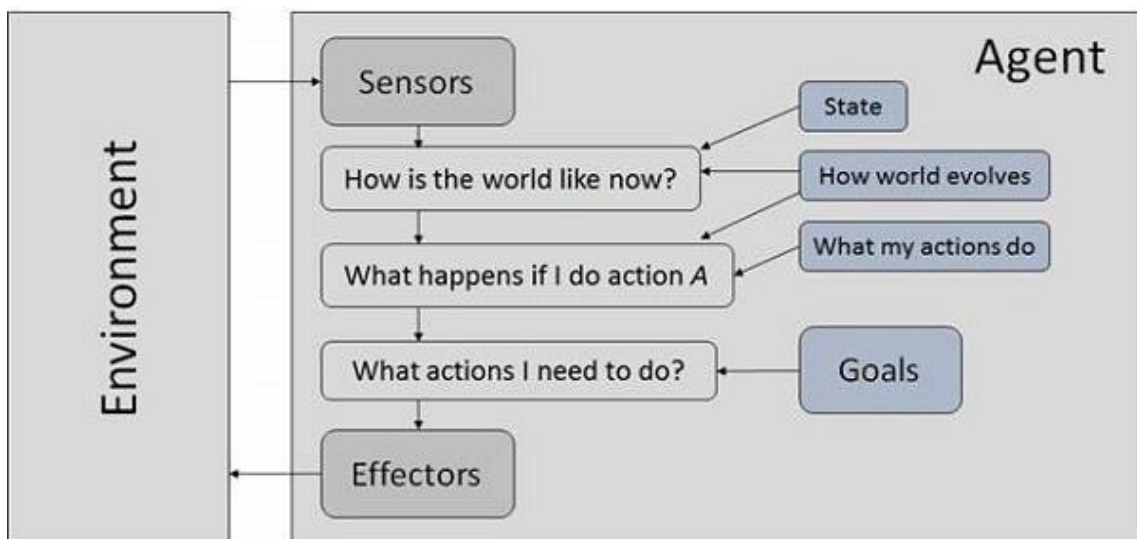
- How the world evolves.
- How the agent's actions affect the world.



### Goal Based Agents

They choose their actions in order to achieve goals. Goal-based approach is more flexible than reflex agent since the knowledge supporting a decision is explicitly modeled, thereby allowing for modifications.

**Goal** – It is the description of desirable situations.



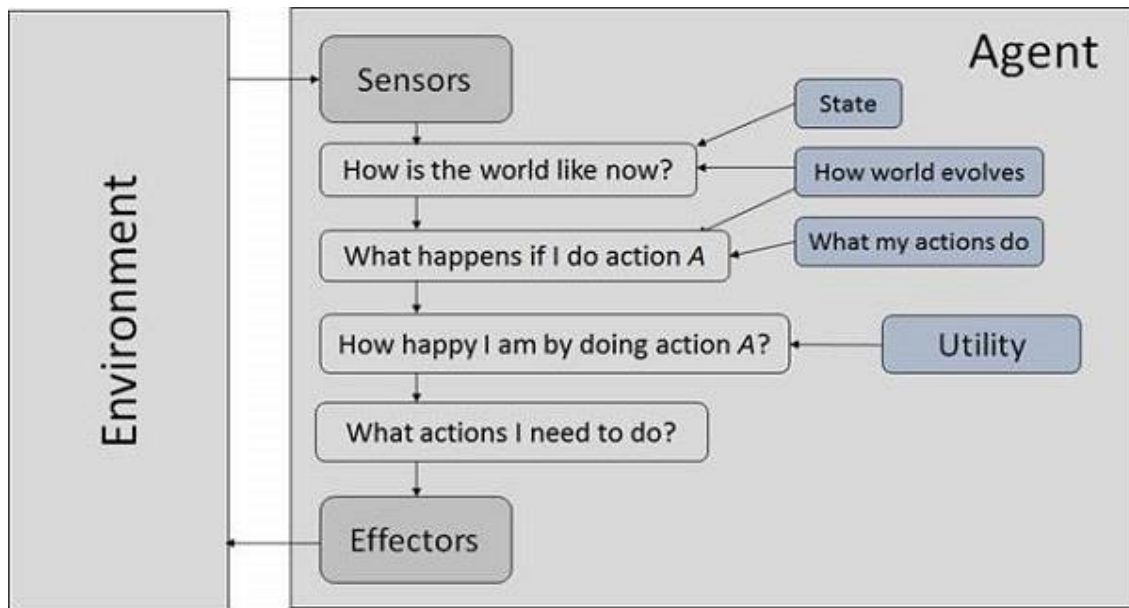
### Utility Based Agents

They choose actions based on a preference (utility) for each state.

Goals are inadequate when –

- There are conflicting goals, out of which only few can be achieved.

- Goals have some uncertainty of being achieved and you need to weigh likelihood of success against the importance of a goal.



## The Nature of Environments

Some programs operate in the entirely **artificial environment** confined to keyboard input, database, computer file systems and character output on a screen.

In contrast, some software agents (software robots or softbots) exist in rich, unlimited softbots domains. The simulator has a **very detailed, complex environment**. The software agent needs to choose from a long array of actions in real time. A softbot designed to scan the online preferences of the customer and show interesting items to the customer works in the **real** as well as an **artificial** environment.

The most famous **artificial environment** is the **Turing Test environment**, in which one real and other artificial agents are tested on equal ground. This is a very challenging environment as it is highly difficult for a software agent to perform as well as a human.

## Turing Test

The success of an intelligent behavior of a system can be measured with Turing Test.

Two persons and a machine to be evaluated participate in the test. Out of the two persons, one plays the role of the tester. Each of them sits in different rooms. The tester is unaware of who is machine and who is a human. He interrogates the questions by typing and sending them to both intelligences, to which he receives typed responses.

This test aims at fooling the tester. If the tester fails to determine machine's response from the human response, then the machine is said to be intelligent.

## Properties of Environment

The environment has multifold properties –

- **Discrete / Continuous** – If there are a limited number of distinct, clearly defined, states of the environment, the environment is discrete (For example, chess); otherwise it is continuous (For example, driving).
- **Observable / Partially Observable** – If it is possible to determine the complete state of the environment at each time point from the percepts it is observable; otherwise it is only partially observable.
- **Static / Dynamic** – If the environment does not change while an agent is acting, then it is static; otherwise it is dynamic.
- **Single agent / Multiple agents** – The environment may contain other agents which may be of the same or different kind as that of the agent.
- **Accessible / Inaccessible** – If the agent’s sensory apparatus can have access to the complete state of the environment, then the environment is accessible to that agent.
- **Deterministic / Non-deterministic** – If the next state of the environment is completely determined by the current state and the actions of the agent, then the environment is deterministic; otherwise it is non-deterministic.
- **Episodic / Non-episodic** – In an episodic environment, each episode consists of the agent perceiving and then acting. The quality of its action depends just on the episode itself. Subsequent episodes do not depend on the actions in the previous episodes. Episodic environments are much simpler because the agent does not need to think ahead.

## Problem Solving

### Problem:

A problem, which can be caused for different reasons, and, if solvable, can usually be solved in a number of different ways, is defined in a number of different ways.

To build a system or to solve a particular problem we need to do four things:

- Define the problem precisely. This definition must include precise specification of what the initial situation will be as well as what final situations constitute acceptable solutions to the problem
- Analyze the problem
- Isolate and represent the task knowledge that is necessary to solve the problem
- Choose the best solving technique and apply it to the particular problem.

Defining the Problem as a State Space Search

*Problem solving = Searching for a goal state*

It is a structured method for solving an unstructured problem. This approach consists of number of states. The starting of the problem is “Initial State” of the problem. The last point in the problem is called a “Goal State” or “Final State” of the problem.

*State space is a set of legal positions, starting at the initial state, using the set of rules to move from one state to another and attempting to end up in a goal state.*

## Searching Algorithm

### Search Algorithm Terminologies:

- **Search:** Searching is a step by step procedure to solve a search-problem in a given search space. A search problem can have three main factors:
  - a. **Search Space:** Search space represents a set of possible solutions, which a system may have.
  - b. **Start State:** It is a state from where agent begins **the search**.
  - c. **Goal test:** It is a function which observe the current state and returns whether the goal state is achieved or not.
- **Search tree:** A tree representation of search problem is called Search tree. The root of the search tree is the root node which is corresponding to the initial state.
- **Actions:** It gives the description of all the available actions to the agent.
- **Transition model:** A description of what each action do, can be represented as a transition model.
- **Path Cost:** It is a function which assigns a numeric cost to each path.
- **Solution:** It is an action sequence which leads from the start node to the goal node.
- **Optimal Solution:** If a solution has the lowest cost among all solutions.

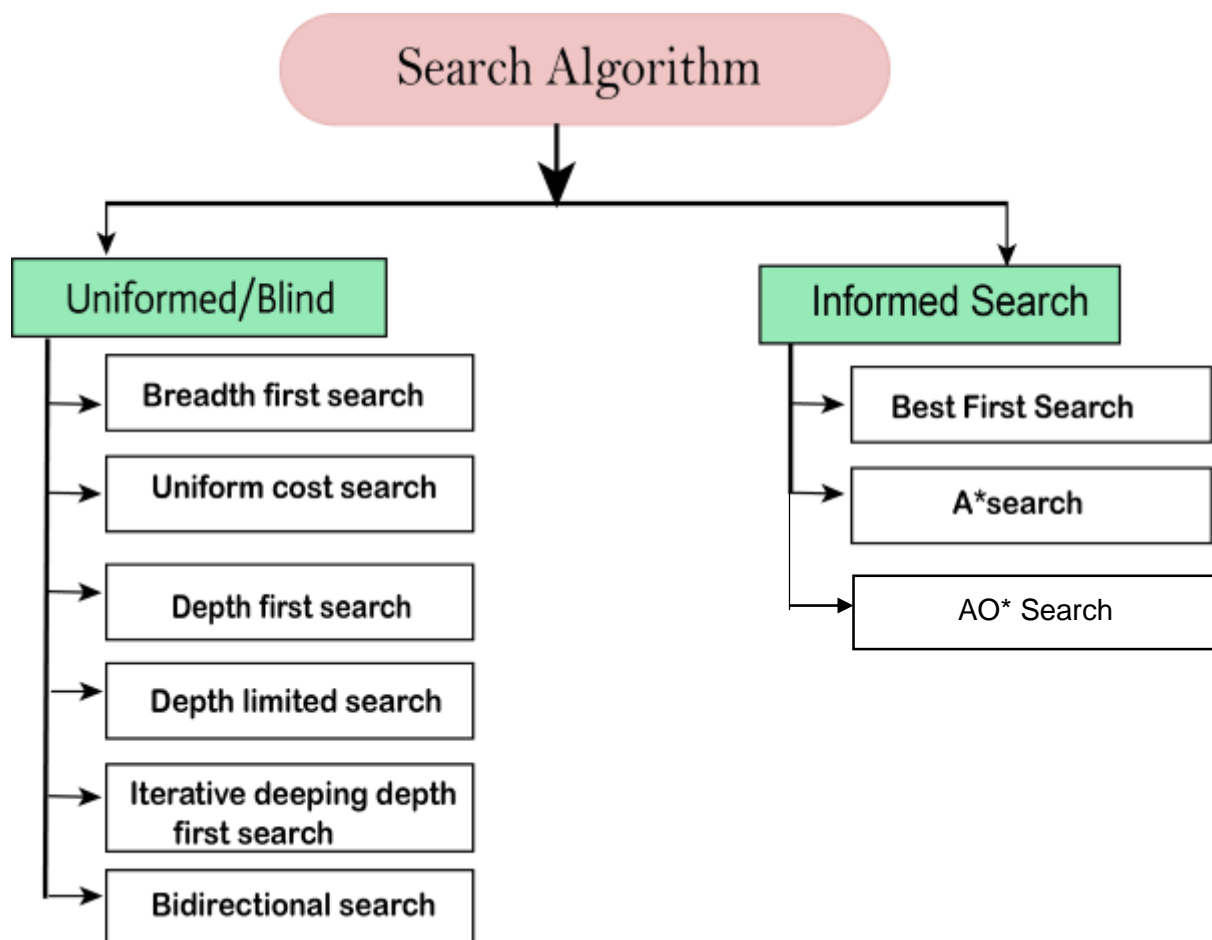
### Properties of Search Algorithms:

- **Completeness:** A search algorithm is said to be complete if it guarantees to return a solution if at least any solution exists for any random input.
- **Optimality:** If a solution found for an algorithm is guaranteed to be the best solution (lowest path cost) among all other solutions, then such a solution for is said to be an optimal solution.
- **Time Complexity:** Time complexity is a measure of time for an algorithm to complete its task.

- **Space Complexity:** It is the maximum storage space required at any point during the search, as the complexity of the problem.

## Types of search algorithms

Based on the search problems we can classify the search algorithms into uninformed (Blind search) search and informed search (Heuristic search) algorithms.



### Uninformed/Blind Search:

The uninformed search does not contain any domain knowledge such as closeness, the location of the goal. It operates in a brute-force way as it only includes information about how to traverse the tree and how to identify leaf and goal nodes. Uninformed search applies a way in which search tree is searched without any information about the search space like initial state operators and test for the goal, so it is also called blind search. It examines each node of the tree until it achieves the goal node.

**It can be divided into five main types:**

- Breadth-first search
- Uniform cost search

- Depth-first search
- Iterative deepening depth-first search
- Bidirectional Search

## **Informed Search**

Informed search algorithms use domain knowledge. In an informed search, problem information is available which can guide the search. Informed search strategies can find a solution more efficiently than an uninformed search strategy. Informed search is also called a Heuristic search.

A heuristic is a way which might not always be guaranteed for best solutions but guaranteed to find a good solution in reasonable time.

Informed search can solve much complex problem which could not be solved in another way.

An example of informed search algorithms is a traveling salesman problem.

1. Greedy Search
2. A\* Search
3. AO\* Search

## **Uninformed Search Algorithms**

Uninformed search is a class of general-purpose search algorithms which operates in brute force-way. Uninformed search algorithms do not have additional information about state or search space other than how to traverse the tree, so it is also called blind search.

Following are the various types of uninformed search algorithms:

1. Breadth-first Search
2. Depth-first Search
3. Depth-limited Search
4. Iterative deepening depth-first search
5. Uniform cost search
6. Bidirectional Search

### **1. Breadth-first Search:**

- Breadth-first search is the most common search strategy for traversing a tree or graph. This algorithm searches breadthwise in a tree or graph, so it is called breadth-first search.

- BFS algorithm starts searching from the root node of the tree and expands all successor node at the current level before moving to nodes of next level.
- The breadth-first search algorithm is an example of a general-graph search algorithm.
- Breadth-first search implemented using FIFO queue data structure.

**Advantages:**

- BFS will provide a solution if any solution exists.
- If there are more than one solutions for a given problem, then BFS will provide the minimal solution which requires the least number of steps.

**Disadvantages:**

- It requires lots of memory since each level of the tree must be saved into memory to expand the next level.
- BFS needs lots of time if the solution is far away from the root node.

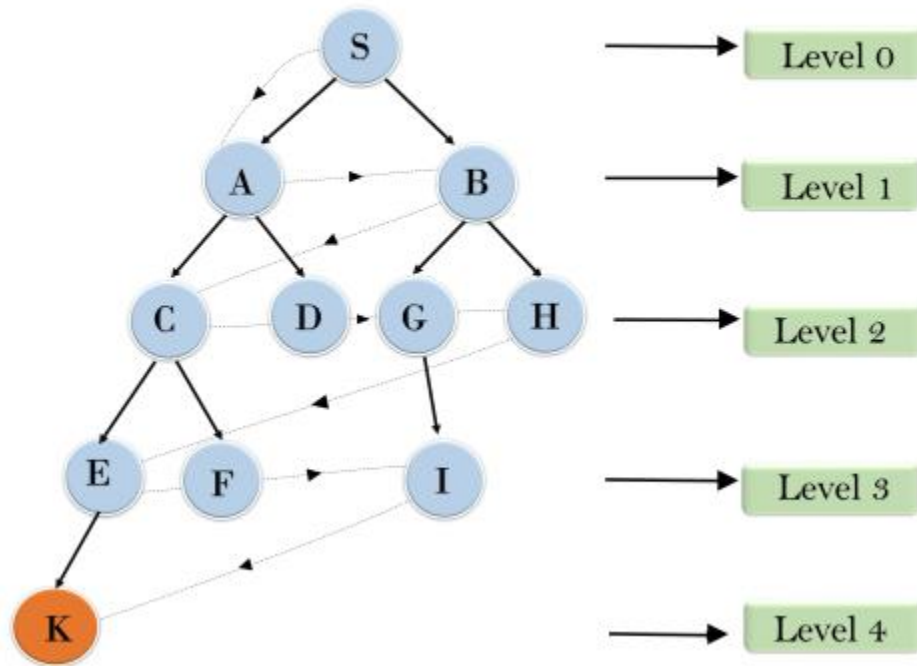
**Example:**

In the below tree structure, we have shown the traversing of the tree using BFS algorithm from the root node S to goal node K. BFS search algorithm traverse in layers, so it will follow the path which is shown by the dotted arrow, and the traversed path will be:

1. S---> A--->B---->C--->D---->G--->H--->E---->F---->I---->K



## Breadth First Search



**Time Complexity:** Time Complexity of BFS algorithm can be obtained by the number of nodes traversed in BFS until the shallowest Node. Where the  $d$  = depth of shallowest solution and  $b$  is a node at every state.

$$T(b) = 1 + b^2 + b^3 + \dots + b^d = O(b^d)$$

**Space Complexity:** Space complexity of BFS algorithm is given by the Memory size of frontier which is  $O(b^d)$ .

**Completeness:** BFS is complete, which means if the shallowest goal node is at some finite depth, then BFS will find a solution.

**Optimality:** BFS is optimal if path cost is a non-decreasing function of the depth of the node.

## 2. Depth-first Search:

- Depth-first search is a recursive algorithm for traversing a tree or graph data structure.
- It is called the depth-first search because it starts from the root node and follows each path to its greatest depth node before moving to the next path.
- DFS uses a stack data structure for its implementation.

- The process of the DFS algorithm is similar to the BFS algorithm.

**Note:** *Backtracking is an algorithm technique for finding all possible solutions using recursion.*

**Advantage:**

- DFS requires very less memory as it only needs to store a stack of the nodes on the path from root node to the current node.
- It takes less time to reach to the goal node than BFS algorithm (if it traverses in the right path).

**Disadvantage:**

- There is the possibility that many states keep re-occurring, and there is no guarantee of finding the solution.
- DFS algorithm goes for deep down searching and sometime it may go to the infinite loop.

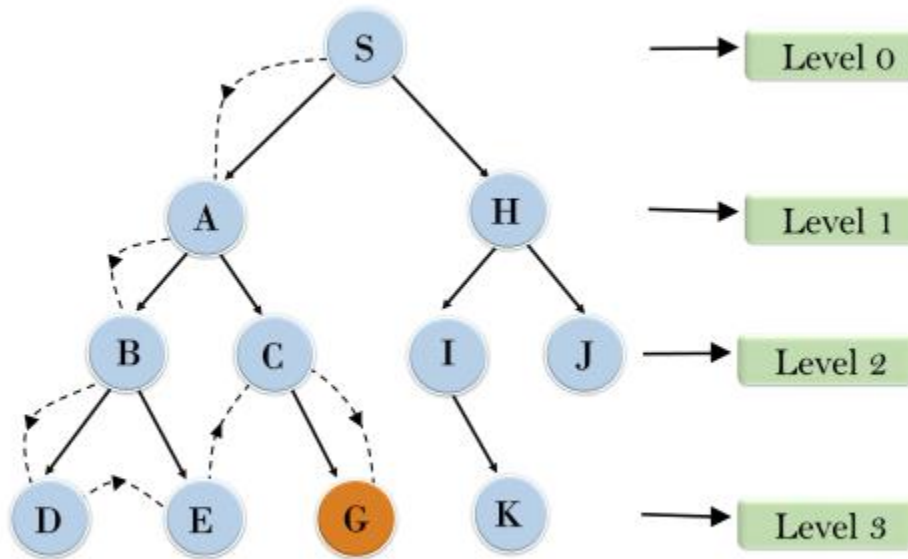
**Example:**

In the below search tree, we have shown the flow of depth-first search, and it will follow the order as:

Root node--->Left node ----> right node.

It will start searching from root node S, and traverse A, then B, then D and E, after traversing E, it will backtrack the tree as E has no other successor and still goal node is not found. After backtracking it will traverse node C and then G, and here it will terminate as it found goal node.

## Depth First Search



**Completeness:** DFS search algorithm is complete within finite state space as it will expand every node within a limited search tree.

**Time Complexity:** Time complexity of DFS will be equivalent to the node traversed by the algorithm. It is given by:

$$T(n) = 1 + n^2 + n^3 + \dots + n^m = O(n^m)$$

Where,  $m$  = maximum depth of any node and this can be much larger than  $d$  (Shallowest solution depth)

**Space Complexity:** DFS algorithm needs to store only single path from the root node, hence space complexity of DFS is equivalent to the size of the fringe set, which is  $O(bm)$ .

**Optimal:** DFS search algorithm is non-optimal, as it may generate a large number of steps or high cost to reach to the goal node.

### 3. Depth-Limited Search Algorithm:

A depth-limited search algorithm is similar to depth-first search with a predetermined limit. Depth-limited search can solve the drawback of the infinite path in the Depth-first search. In this algorithm, the node at the depth limit will treat as it has no successor nodes further.

Depth-limited search can be terminated with two Conditions of failure:

- Standard failure value: It indicates that problem does not have any solution.
- Cutoff failure value: It defines no solution for the problem within a given depth limit.

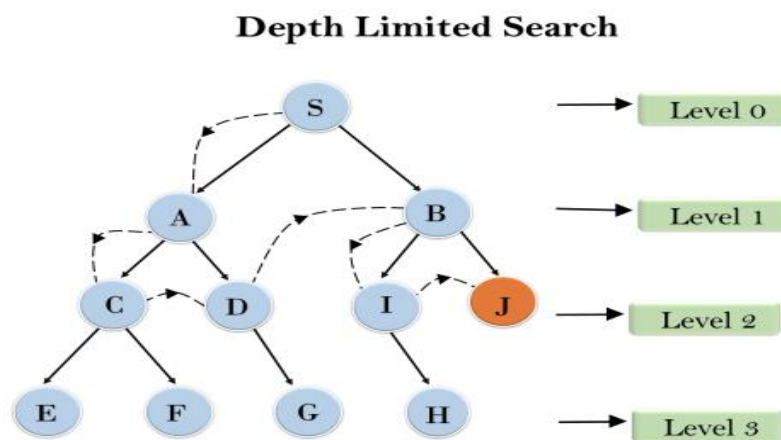
**Advantages:**

Depth-limited search is Memory efficient.

**Disadvantages:**

- Depth-limited search also has a disadvantage of incompleteness.
- It may not be optimal if the problem has more than one solution.

**Example:**



**Completeness:** DLS search algorithm is complete if the solution is above the depth-limit.

**Time Complexity:** Time complexity of DLS algorithm is  $O(b^l)$ .

**Space Complexity:** Space complexity of DLS algorithm is  $O(b \times l)$ .

**Optimal:** Depth-limited search can be viewed as a special case of DFS, and it is also not optimal even if  $l > d$ .

**4. Uniform-cost Search Algorithm:**

Uniform-cost search is a searching algorithm used for traversing a weighted tree or graph. This algorithm comes into play when a different cost is available for each edge. The primary goal of the uniform-cost search is to find a path to the goal node which has the lowest cumulative cost. Uniform-cost search expands nodes according to their path costs from the root node. It can be used to solve any graph/tree where the optimal cost is in demand. A uniform-cost search algorithm is implemented by

the priority queue. It gives maximum priority to the lowest cumulative cost. Uniform cost search is equivalent to BFS algorithm if the path cost of all edges is the same.

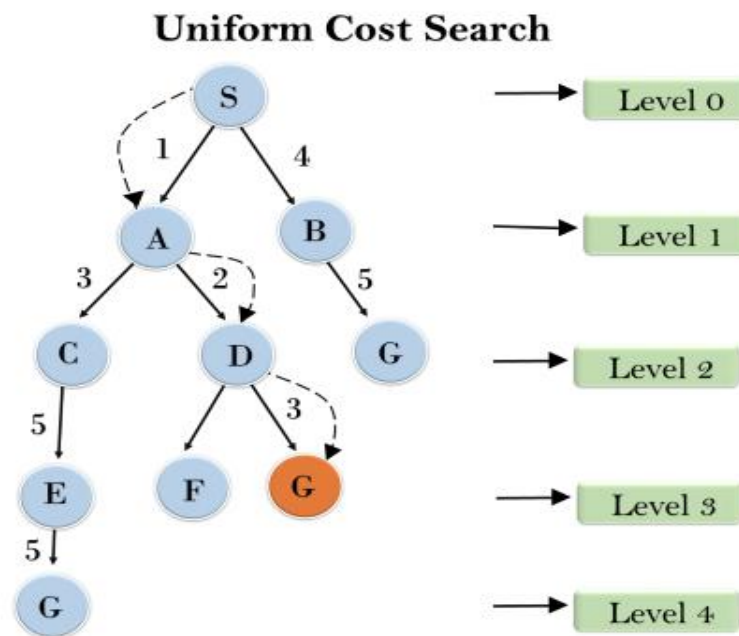
**Advantages:**

- Uniform cost search is optimal because at every state the path with the least cost is chosen.

**Disadvantages:**

- It does not care about the number of steps involve in searching and only concerned about path cost. Due to which this algorithm may be stuck in an infinite loop.

**Example:**



**Completeness:**

Uniform-cost search is complete, such as if there is a solution, UCS will find it.

**Time Complexity:**

Let  $C^*$  is Cost of the optimal solution, and  $\epsilon$  is each step to get closer to the goal node. Then the number of steps is  $= C^*/\epsilon + 1$ . Here we have taken +1, as we start from state 0 and end to  $C^*/\epsilon$ .

Hence, the worst-case time complexity of Uniform-cost search is  $O(b^{1 + \lceil C^*/\epsilon \rceil})$ .

**Space Complexity:**

The same logic is for space complexity so, the worst-case space complexity of Uniform-cost search is  $O(b^{1 + \lceil C^*/\epsilon \rceil})$ .

**Optimal:**

Uniform-cost search is always optimal as it only selects a path with the lowest path cost.

**5. Iterative deepening depth-first Search:**

The iterative deepening algorithm is a combination of DFS and BFS algorithms. This search algorithm finds out the best depth limit and does it by gradually increasing the limit until a goal is found.

This algorithm performs depth-first search up to a certain "depth limit", and it keeps increasing the depth limit after each iteration until the goal node is found.

This Search algorithm combines the benefits of Breadth-first search's fast search and depth-first search's memory efficiency.

The iterative search algorithm is useful uninformed search when search space is large, and depth of goal node is unknown.

**Advantages:**

- It combines the benefits of BFS and DFS search algorithm in terms of fast search and memory efficiency.

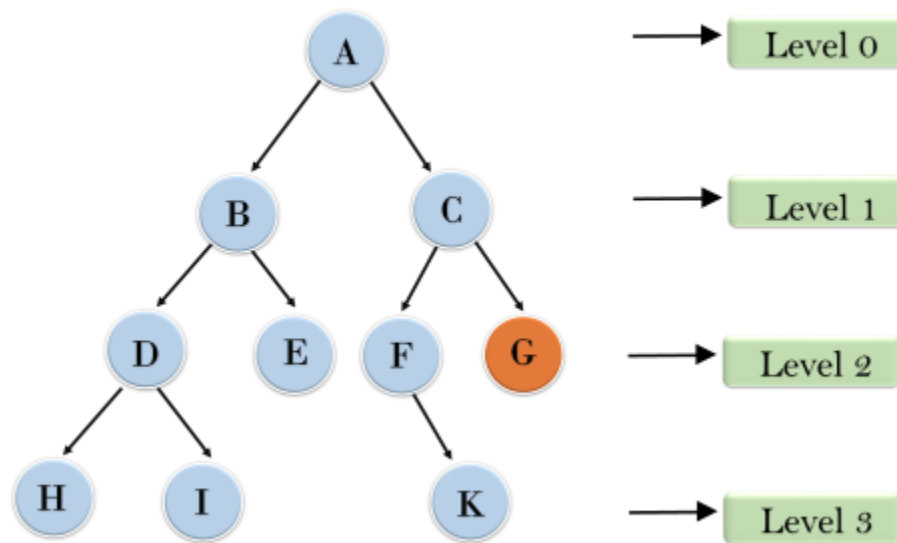
**Disadvantages:**

- The main drawback of IDDFS is that it repeats all the work of the previous phase.

**Example:**

Following tree structure is showing the iterative deepening depth-first search. IDDFS algorithm performs various iterations until it does not find the goal node. The iteration performed by the algorithm is given as:

## Iterative deepening depth first search



1'st Iteration-----> A

2'nd Iteration-----> A, B, C

3'rd Iteration----->A, B, D, E, C, F, G

4'th Iteration----->A, B, D, H, I, E, C, F, K, G

In the fourth iteration, the algorithm will find the goal node.

### Completeness:

This algorithm is complete is if the branching factor is finite.

### Time Complexity:

Let's suppose b is the branching factor and depth is d then the worst-case time complexity is  $O(b^d)$ .

### Space Complexity:

The space complexity of IDDFS will be  $O(bd)$ .

### Optimal:

IDDFS algorithm is optimal if path cost is a non- decreasing function of the depth of the node.

## 6. Bidirectional Search Algorithm:

Bidirectional search algorithm runs two simultaneous searches, one from initial state called as forward-search and other from goal node called as backward-search, to find the goal node. Bidirectional search replaces one single search graph with two small subgraphs in which one starts the search from an initial vertex and other starts from goal vertex. The search stops when these two graphs intersect each other.

**Bidirectional search can use search techniques such as BFS, DFS, DLS, etc.**

### Advantages:

- Bidirectional search is fast.
- Bidirectional search requires less memory

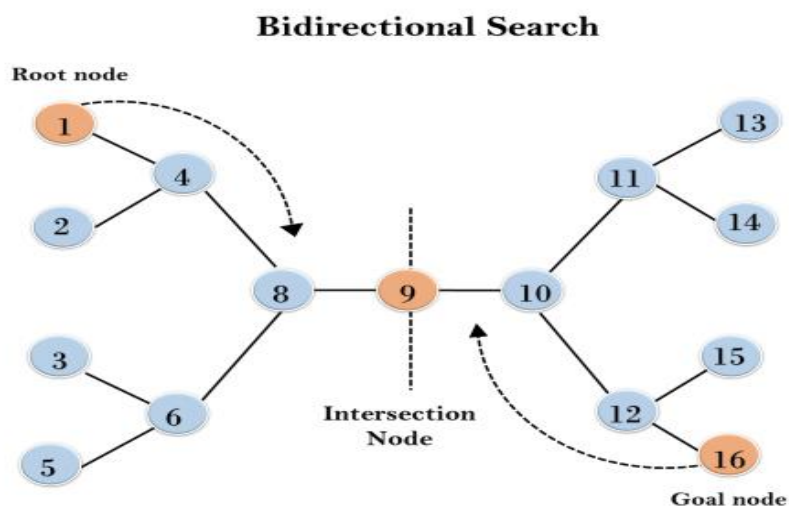
### Disadvantages:

- Implementation of the bidirectional search tree is difficult.
- **In bidirectional search, one should know the goal state in advance.**

### Example:

In the below search tree, bidirectional search algorithm is applied. This algorithm divides one graph/tree into two sub-graphs. It starts traversing from node 1 in the forward direction and starts from goal node 16 in the backward direction.

The algorithm terminates at node 9 where two searches meet.



**Completeness:** Bidirectional Search is complete if we use BFS in both searches.

**Time Complexity:** Time complexity of bidirectional search using BFS is  $O(b^d)$ .



**Space Complexity:** Space complexity of bidirectional search is  $O(b^d)$ .

**Optimal:** Bidirectional search is Optimal.

## Informed (Heuristic) Search Algorithms

To solve large problems with large number of possible states, problem-specific knowledge needs to be added to increase the efficiency of search algorithms.

The uninformed search algorithms which looked through search space for all possible solutions of the problem without having any additional knowledge about search space. But informed search algorithm contains an array of knowledge such as how far we are from the goal, path cost, how to reach to goal node, etc. This knowledge help agents to explore less to the search space and find more efficiently the goal node.

The informed search algorithm is more useful for large search space. Informed search algorithm uses the idea of heuristic, so it is also called Heuristic search.

**Heuristics function:** Heuristic is a function which is used in Informed Search, and it finds the most promising path. It takes the current state of the agent as its input and produces the estimation of how close agent is from the goal. The heuristic method, however, might not always give the best solution, but it guaranteed to find a good solution in reasonable time. Heuristic function estimates how close a state is to the goal. It is represented by  $h(n)$ , and it calculates the cost of an optimal path between the pair of states. The value of the heuristic function is always positive.

### Pure Heuristic Search

It expands nodes in the order of their heuristic values. It creates two lists, a closed list for the already expanded nodes and an open list for the created but unexpanded nodes.

In each iteration, a node with a minimum heuristic value is expanded, all its child nodes are created and placed in the closed list. Then, the heuristic function is applied to the child nodes and they are placed in the open list according to their heuristic value. The shorter paths are saved and the longer ones are disposed.

In the informed search we will discuss three main algorithms which are given below:

- **Best First Search Algorithm(Greedy search)**
- **A\* Search Algorithm**
- **AO\* Search Algorithm**

## 1.) Best-first Search Algorithm (Greedy Search):

Greedy best-first search algorithm always selects the path which appears best at that moment. It is the combination of depth-first search and breadth-first search algorithms. It uses the heuristic function and search. Best-first search allows us to take the advantages of both algorithms. With the help of best-first search, at each step, we can choose the most promising node. In the best first search algorithm, we expand the node which is closest to the goal node and the closest cost is estimated by heuristic function, i.e.

$$f(n) = g(n) + h(n)$$

Where,  $h(n)$  = estimated cost from node  $n$  to the goal.

The greedy best first algorithm is implemented by the priority queue.

### Best first search algorithm:

- **Step 1:** Place the starting node into the OPEN list.
- **Step 2:** If the OPEN list is empty, Stop and return failure.
- **Step 3:** Remove the node  $n$ , from the OPEN list which has the lowest value of  $h(n)$ , and places it in the CLOSED list.
- **Step 4:** Expand the node  $n$ , and generate the successors of node  $n$ .
- **Step 5:** Check each successor of node  $n$ , and find whether any node is a goal node or not. If any successor node is goal node, then return success and terminate the search, else proceed to Step 6.
- **Step 6:** For each successor node, algorithm checks for evaluation function  $f(n)$ , and then check if the node has been in either OPEN or CLOSED list. If the node has not been in both list, then add it to the OPEN list.
- **Step 7:** Return to Step 2.

### Advantages:

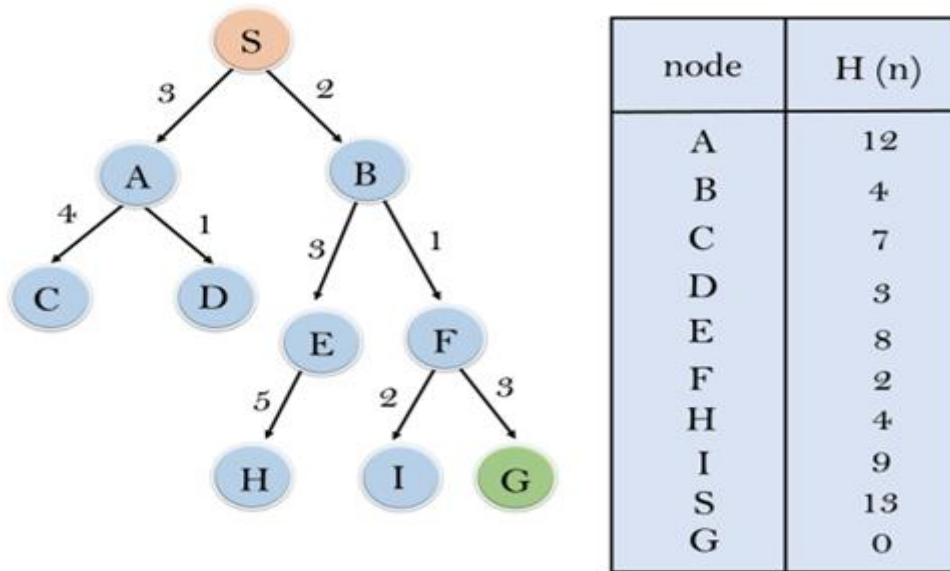
- Best first search can switch between BFS and DFS by gaining the advantages of both the algorithms.
- This algorithm is more efficient than BFS and DFS algorithms.

### Disadvantages:

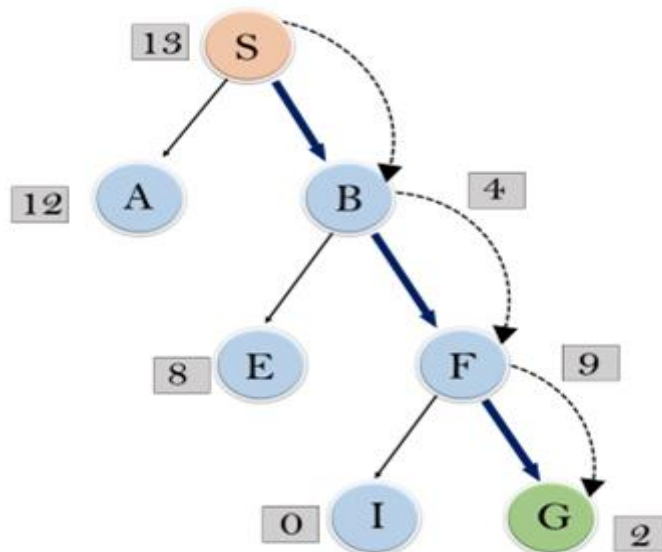
- It can behave as an unguided depth-first search in the worst case scenario.
- It can get stuck in a loop as DFS.
- This algorithm is not optimal.

**Example:**

Consider the below search problem, and we will traverse it using greedy best-first search. At each iteration, each node is expanded using evaluation function  $f(n)=h(n)$ , which is given in the below table.



In this search example, we are using two lists which are **OPEN** and **CLOSED** Lists. Following are the iteration for traversing the above example.



### Expand the nodes of S and put in the CLOSED list

- **Initialization:** Open [A, B], Closed [S]
- **Iteration 1:** Open [A], Closed [S, B]
- **Iteration 2:** Open [E, F, A], Closed [S, B]  
: Open [E, A], Closed [S, B, F]
- **Iteration 3:** Open [I, G, E, A], Closed [S, B, F]  
: Open [I, E, A], Closed [S, B, F, G]

Hence the final solution path will be: **S----> B----->F-----> G**

**Time Complexity:** The worst case time complexity of Greedy best first search is  $O(b^m)$ .

**Space Complexity:** The worst case space complexity of Greedy best first search is  $O(b^m)$ . Where, m is the maximum depth of the search space.

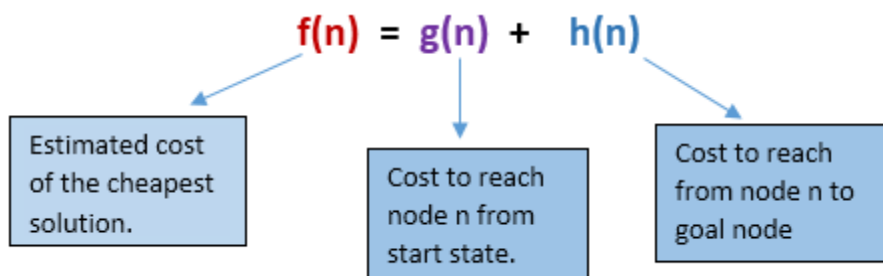
**Complete:** Greedy best-first search is also incomplete, even if the given state space is finite.

**Optimal:** Greedy best first search algorithm is not optimal.

## 2.) A\* Search Algorithm:

A\* search is the most commonly known form of best-first search. It uses heuristic function  $h(n)$ , and cost to reach the node  $n$  from the start state  $g(n)$ . It has combined features of UCS and greedy best-first search, by which it solve the problem efficiently. A\* search algorithm finds the shortest path through the search space using the heuristic function. This search algorithm expands less search tree and provides optimal result faster. A\* algorithm is similar to UCS except that it uses  $g(n)+h(n)$  instead of  $g(n)$ .

In A\* search algorithm, we use search heuristic as well as the cost to reach the node. Hence we can combine both costs as following, and this sum is called as a **fitness number**.



At each point in the search space, only those node is expanded which have the lowest value of  $f(n)$ , and the algorithm terminates when the goal node is found.

### **Algorithm of A\* search:**

**Step 1:** Place the starting node in the OPEN list.

**Step 2:** Check if the OPEN list is empty or not, if the list is empty then return failure and stops.

**Step 3:** Select the node from the OPEN list which has the smallest value of evaluation function ( $g+h$ ), if node  $n$  is goal node then return success and stop, otherwise

**Step 4:** Expand node  $n$  and generate all of its successors, and put  $n$  into the closed list. For each successor  $n'$ , check whether  $n'$  is already in the OPEN or CLOSED list, if not then compute evaluation function for  $n'$  and place into Open list.

**Step 5:** Else if node  $n'$  is already in OPEN and CLOSED, then it should be attached to the back pointer which reflects the lowest  $g(n')$  value.

**Step 6:** Return to **Step 2**.

### **Advantages:**

- A\* search algorithm is the best algorithm than other search algorithms.
- A\* search algorithm is optimal and complete.
- This algorithm can solve very complex problems.

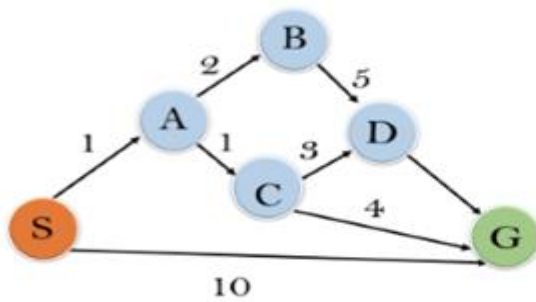
### **Disadvantages:**

- It does not always produce the shortest path as it mostly based on heuristics and approximation.
- A\* search algorithm has some complexity issues.
- The main drawback of A\* is memory requirement as it keeps all generated nodes in the memory, so it is not practical for various large-scale problems.

### **Example:**

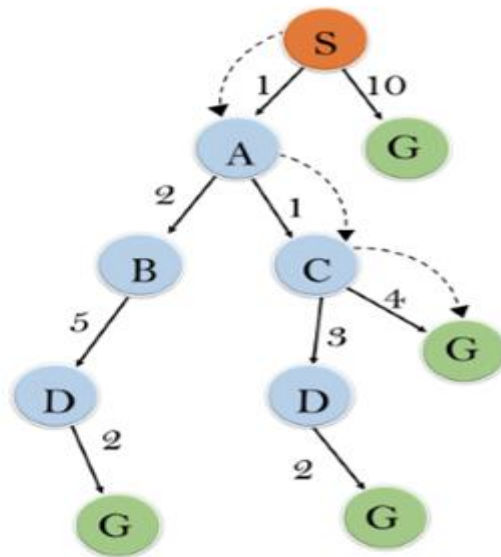
In this example, we will traverse the given graph using the A\* algorithm. The heuristic value of all states is given in the below table so we will calculate the  $f(n)$  of each state using the formula  $f(n) = g(n) + h(n)$ , where  $g(n)$  is the cost to reach any node from start state.

Here we will use OPEN and CLOSED list.



State	h(n)
S	5
A	3
B	4
C	2
D	6
G	0

**Solution:**



- **Initialization:**  $\{(S, 5)\}$
- **Iteration1:**  $\{(S \rightarrow A, 4), (S \rightarrow G, 10)\}$
- **Iteration2:**  $\{(S \rightarrow A \rightarrow C, 4), (S \rightarrow A \rightarrow B, 7), (S \rightarrow G, 10)\}$
- **Iteration3:**  $\{(S \rightarrow A \rightarrow C \rightarrow G, 6), (S \rightarrow A \rightarrow C \rightarrow D, 11), (S \rightarrow A \rightarrow B, 7), (S \rightarrow G, 10)\}$
- **Iteration 4** will give the final result, as  $S \rightarrow A \rightarrow C \rightarrow G$  it provides the optimal path with cost 6.

**Points to remember:**

- A\* algorithm returns the path which occurred first, and it does not search for all remaining paths.

- The efficiency of A\* algorithm depends on the quality of heuristic.
- A\* algorithm expands all nodes which satisfy the condition  $f(n) \leq l_i$

**Complete:** A\* algorithm is complete as long as:

- Branching factor is finite.
- Cost at every action is fixed.

**Optimal:** A\* search algorithm is optimal if it follows below two conditions:

- **Admissible:** the first condition requires for optimality is that  $h(n)$  should be an admissible heuristic for A\* tree search. An admissible heuristic is optimistic in nature.
- **Consistency:** Second required condition is consistency for only A\* graph-search.

If the heuristic function is admissible, then A\* tree search will always find the least cost path.

**Time Complexity:** The time complexity of A\* search algorithm depends on heuristic function, and the number of nodes expanded is exponential to the depth of solution  $d$ . So the time complexity is  $O(b^d)$ , where  $b$  is the branching factor.

**Space Complexity:** The space complexity of A\* search algorithm is  $O(b^d)$

### 3.) AO\* Search Algorithm:

Our real-life situations can't be exactly decomposed into either AND tree or OR tree but is always a combination of both. So, we need an AO\* algorithm where O stands for 'ordered'. AO\* algorithm represents a part of the search graph that has been explicitly generated so far. AO\* algorithm is given as follows:

- Step-1: Create an initial graph with a single node (start node).
- Step-2: Transverse the graph following the current path, accumulating node that has not yet been expanded or solved.
- Step-3: Select any of these nodes and explore it. If it has no successors then call this value-FUTILITY else calculate  $f(n)$  for each of the successors.
- Step-4: If  $f(n)=0$ , then mark the node as SOLVED.
- Step-5: Change the value of  $f(n)$  for the newly created node to reflect its successors by backpropagation.
- Step-6: Whenever possible use the most promising routes, If a node is marked as SOLVED then mark the parent node as SOLVED.

- Step-7: If the starting node is SOLVED or value is greater than FUTILITY then stop else repeat from Step-2.

## Hill Climbing Algorithm

- Hill climbing algorithm is a local search algorithm which continuously moves in the direction of increasing elevation/value to find the peak of the mountain or best solution to the problem. It terminates when it reaches a peak value where no neighbor has a higher value.
- Hill climbing algorithm is a technique which is used for optimizing the mathematical problems. One of the widely discussed examples of Hill climbing algorithm is Traveling-salesman Problem in which we need to minimize the distance traveled by the salesman.
- It is also called greedy local search as it only looks to its good immediate neighbor state and not beyond that.
- A node of hill climbing algorithm has two components which are state and value.
- Hill Climbing is mostly used when a good heuristic is available.
- In this algorithm, we don't need to maintain and handle the search tree or graph as it only keeps a single current state.

### Features of Hill Climbing:

Following are some main features of Hill Climbing Algorithm:

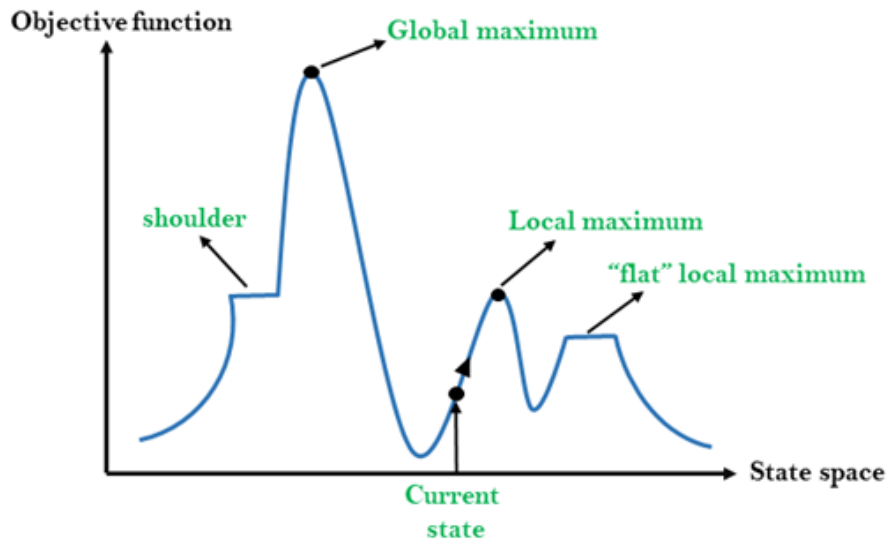
- **Generate and Test variant:** Hill Climbing is the variant of Generate and Test method. The Generate and Test method produce feedback which helps to decide which direction to move in the search space.
- **Greedy approach:** Hill-climbing algorithm search moves in the direction which optimizes the cost.
- **No backtracking:** It does not backtrack the search space, as it does not remember the previous states.

### State-space Diagram for Hill Climbing:

The state-space landscape is a graphical representation of the hill-climbing algorithm which is showing a graph between various states of algorithm and Objective function/Cost.

On Y-axis we have taken the function which can be an objective function or cost function, and state-space on the x-axis. If the function on Y-axis is cost then, the goal of search is to find the global minimum and local minimum. If the function of Y-axis is Objective function, then the goal of the search is to find the global maximum and local maximum.





### Different regions in the state space landscape:

**Local Maximum:** Local maximum is a state which is better than its neighbor states, but there is also another state which is higher than it.

**Global Maximum:** Global maximum is the best possible state of state space landscape. It has the highest value of objective function.

**Current state:** It is a state in a landscape diagram where an agent is currently present.

**Flat local maximum:** It is a flat space in the landscape where all the neighbor states of current states have the same value.

**Shoulder:** It is a plateau region which has an uphill edge.

### Types of Hill Climbing Algorithm:

- Simple hill Climbing:
- Steepest-Ascent hill-climbing:
- Stochastic hill Climbing:

#### 1. Simple Hill Climbing:

Simple hill climbing is the simplest way to implement a hill climbing algorithm. **It only evaluates the neighbor node state at a time and selects the first one which optimizes current cost and set it as a current state.** It only checks it's one successor state, and if it finds better than the current state, then move else be in the same state. This algorithm has the following features:

- Less time consuming
- Less optimal solution and the solution is not guaranteed

### **Algorithm for Simple Hill Climbing:**

- **Step 1:** Evaluate the initial state, if it is goal state then return success and Stop.
- **Step 2:** Loop Until a solution is found or there is no new operator left to apply.
- **Step 3:** Select and apply an operator to the current state.
- **Step 4:** Check new state:
  - a. If it is goal state, then return success and quit.
  - b. Else if it is better than the current state then assign new state as a current state.
  - c. Else if not better than the current state, then return to step2.
- **Step 5:** Exit.

### **2. Steepest-Ascent hill climbing:**

The steepest-Ascent algorithm is a variation of simple hill climbing algorithm. This algorithm examines all the neighboring nodes of the current state and selects one neighbor node which is closest to the goal state. This algorithm consumes more time as it searches for multiple neighbors

### **Algorithm for Steepest-Ascent hill climbing:**

- **Step 1:** Evaluate the initial state, if it is goal state then return success and stop, else make current state as initial state.
- **Step 2:** Loop until a solution is found or the current state does not change.
  - a. Let SUCC be a state such that any successor of the current state will be better than it.
  - b. For each operator that applies to the current state:
    - a. Apply the new operator and generate a new state.
    - b. Evaluate the new state.
    - c. If it is goal state, then return it and quit, else compare it to the SUCC.
    - d. If it is better than SUCC, then set new state as SUCC.
    - e. If the SUCC is better than the current state, then set current state to SUCC.
- **Step 5:** Exit.

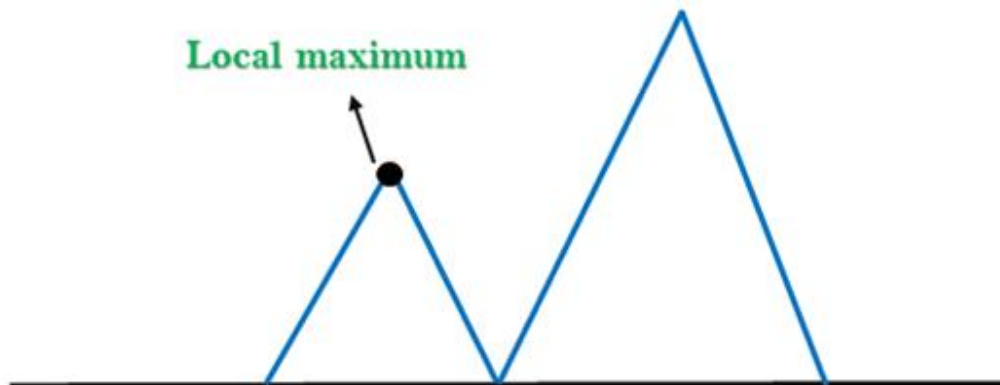
### **3. Stochastic hill climbing:**

Stochastic hill climbing does not examine for all its neighbor before moving. Rather, this search algorithm selects one neighbor node at random and decides whether to choose it as a current state or examine another state.

### **Problems in Hill Climbing Algorithm:**

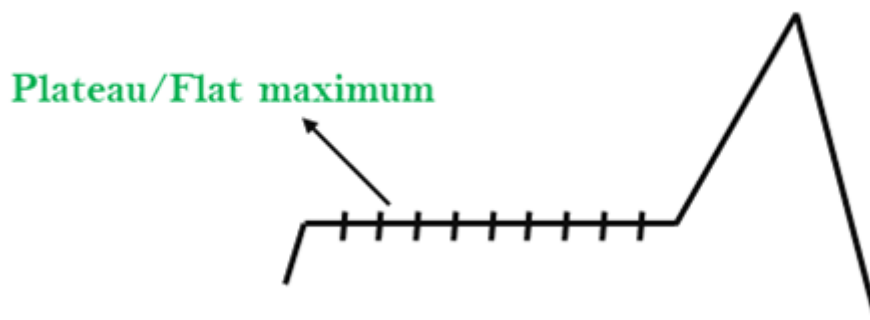
**1. Local Maximum:** A local maximum is a peak state in the landscape which is better than each of its neighboring states, but there is another state also present which is higher than the local maximum.

**Solution:** Backtracking technique can be a solution of the local maximum in state space landscape. Create a list of the promising path so that the algorithm can backtrack the search space and explore other paths as well.



**2. Plateau:** A plateau is the flat area of the search space in which all the neighbor states of the current state contains the same value, because of this algorithm does not find any best direction to move. A hill-climbing search might be lost in the plateau area.

**Solution:** The solution for the plateau is to take big steps or very little steps while searching, to solve the problem. Randomly select a state which is far away from the current state so it is possible that the algorithm could find non-plateau region.



**3. Ridges:** A ridge is a special form of the local maximum. It has an area which is higher than its surrounding areas, but itself has a slope, and cannot be reached in a single move.

**Solution:** With the use of bidirectional search, or by moving in different directions, we can improve this problem.

Ridge



### Simulated Annealing:

A hill-climbing algorithm which never makes a move towards a lower value guaranteed to be incomplete because it can get stuck on a local maximum. And if algorithm applies a random walk, by moving a successor, then it may complete but not efficient. **Simulated Annealing** is an algorithm which yields both efficiency and completeness.

In mechanical term **Annealing** is a process of hardening a metal or glass to a high temperature then cooling gradually, so this allows the metal to reach a low-energy crystalline state. The same process is used in simulated annealing in which the algorithm picks a random move, instead of picking the best move. If the random move improves the state, then it follows the same path. Otherwise, the algorithm follows the path which has a probability of less than 1 or it moves downhill and chooses another path.

## Constraint Satisfaction Problems

### Previous search problems:

- Problems can be solved by searching in a space of states
- state is a “black box” – any data structure that supports successor function, heuristic function, and goal test – problem-specific

### Constraint satisfaction problem

- states and goal test conform to a standard, structured and simple representation
- general-purpose heuristic

A constraint satisfaction problem (or CSP) is defined by a set of variables-  $X_1, X_2, \dots, X_n$ , and a set of constraints,  $C_1, C_2, \dots, C_m$ . Each variable  $X_i$  has a CONSTRAINTS nonempty domain  $D_i$  of

possible values. Each constraint  $C_i$  involves some subset of the DOMAIN VALUES variables and specifies the allowable combinations of values for that subset. A state of the problem is defined by an assignment of values to some or all of the variables,  $\{X_i = v_i, X_j = \text{ASSIGNMENT } v_j, \dots\}$ . An assignment that does not violate any constraints is called a consistent or legal CONSISTENT assignment. A complete assignment is one in which every variable is mentioned, and a solution to a CSP is a complete assignment that satisfies all the constraints. Some CSPs also require a solution that maximizes an objective function.

**CSP is defined by 3 components (X, D, C):**

- state: a set of variables X, each  $X_i$ , with values from domain  $D_i$
- goal test: a set of constraints C, each  $C_i$  involves some subset of the variables and specifies the allowable combinations of values for that subset
- Each constraint  $C_i$  consists of a pair  $\langle \text{scope}, \text{rel} \rangle$ , where scope is a tuple of variables and rel is the relation, either represented explicitly or abstractly

**X1 and X2 both have the domain {A, B}**

- Constraints:
- $\langle (X_1, X_2), [(A, B), (B, A)] \rangle$ , or
- $\langle (X_1, X_2), X_1 \neq X_2 \rangle$

**Solution:**

- Each state in a CSP is defined by an assignment of values to some or all of the variables
- An assignment that does not violate any constraints is called a consistent or legal assignment
- A complete assignment is one in which every variable is assigned
- A solution to a CSP is consistent and complete assignment
- Allows useful general-purpose algorithms with more power than standard search algorithms

**Example: Map Colouring**



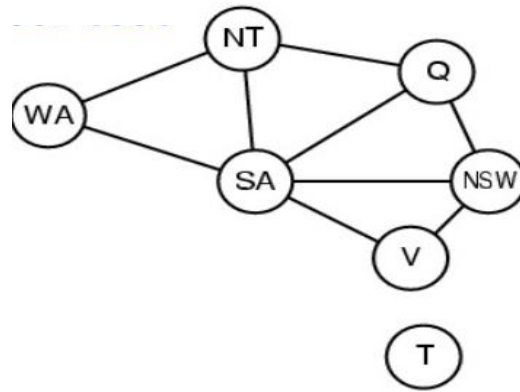
- **Variables:**  $X = \{WA, NT, Q, NSW, V, SA, T\}$
- **Domains:**  $D_i = \{\text{red, green, blue}\}$
- **Constraints:** adjacent regions must have different colors
- **Solution?**

## Solution: Complete and Consistent Assignment



- **Variables:**  $X = \{WA, NT, Q, NSW, V, SA, T\}$
- **Domains:**  $D_i = \{\text{red, green, blue}\}$
- **Constraints:** adjacent regions must have different colors
- **Solution?**  $\{WA = \text{red}, NT = \text{green}, Q = \text{red}, NSW = \text{green}, V = \text{red}, SA = \text{blue}, T = \text{red}\}$ .

- Constraint graph: nodes are variables, arcs are constraints
- Binary CSP: each constraint relates two variables
- CSP conforms to a standard pattern
  - a set of variables with assigned values
  - generic successor function and goal test
  - generic heuristics
  - reduce complexity



### CSP as a Search Problem

Initial state:

- {} – all variables are unassigned

Successor function:

- a value is assigned to one of the unassigned variables with no conflict

Goal test:

- a complete assignment

Path cost:

- a constant cost for each step
- Solution appears at depth  $n$  if there are  $n$  variables
- Depth-first or local search methods work well

### CSP Solvers Can be Faster

- CSP solver can quickly eliminate large part of search space
- If {SA = blue}, Then  $3^5$  assignments can be reduced to  $2^5$  assignments, a reduction of 87%
- In a CSP, if a partial assignment is not a solution, we can immediately discard further refinements of it

