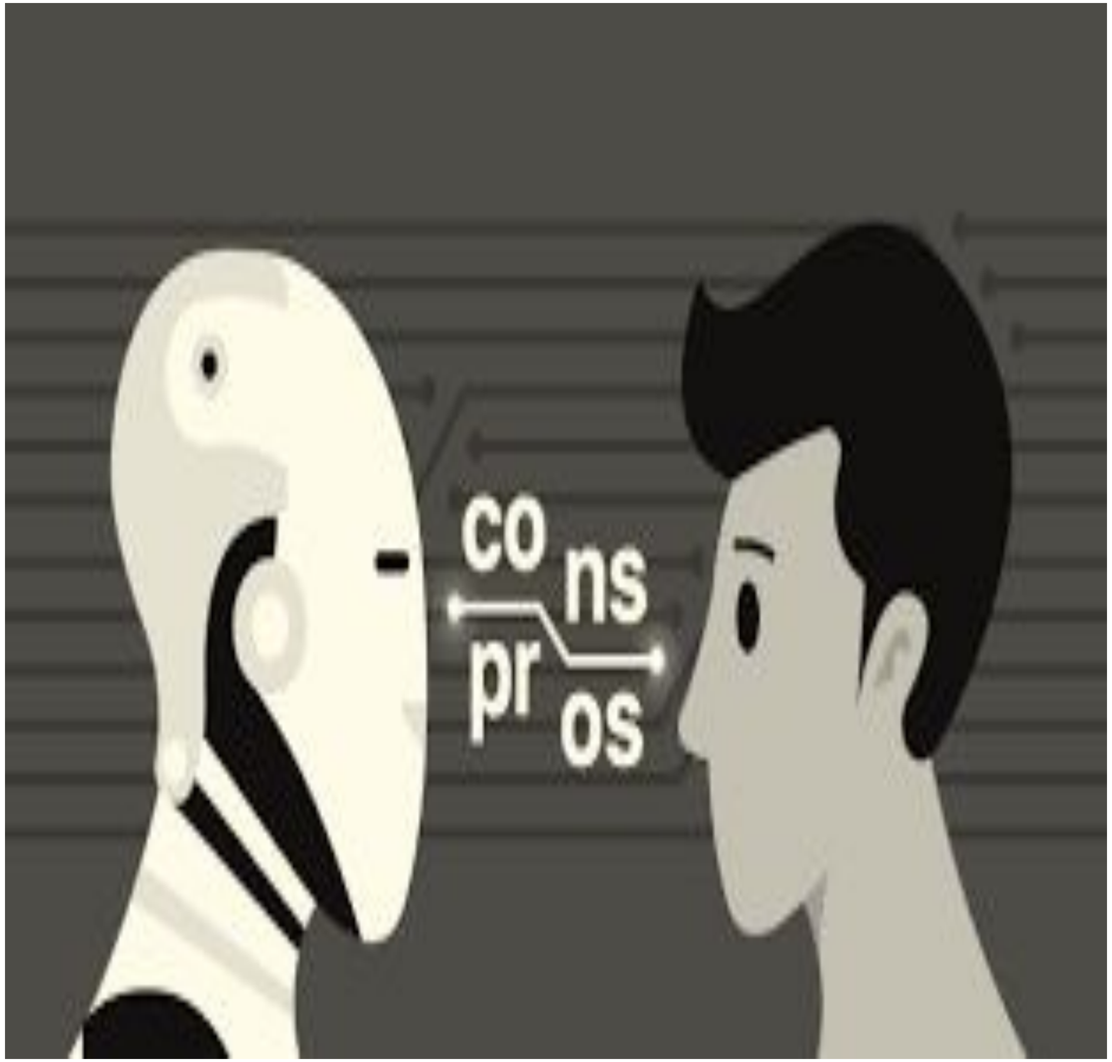
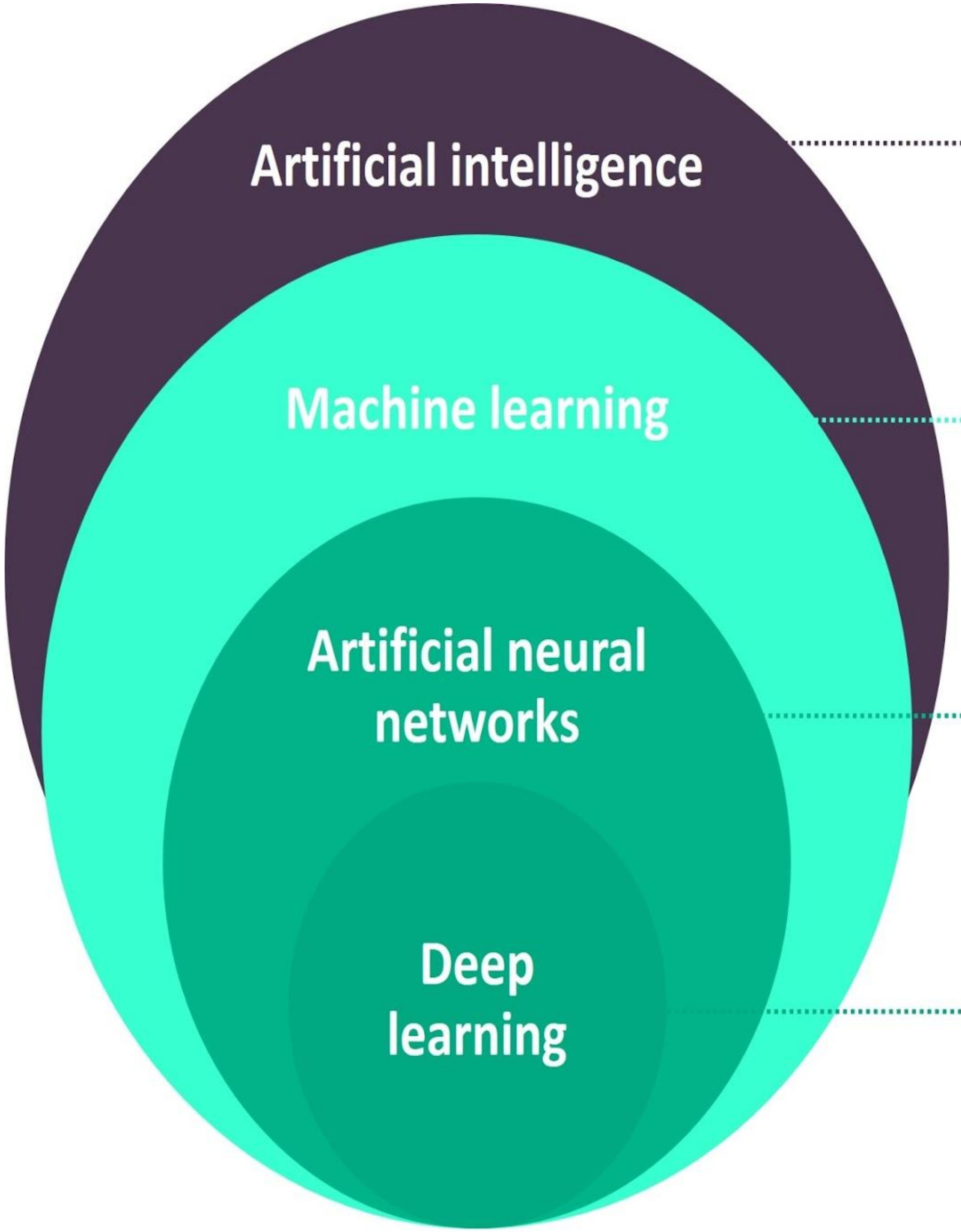
Introduction to AI





Artificial intelligence (AI)
Any techniques that enable machines to solve a task in a way like humans do

Machine learning (ML)
Algorithms that allow computers to learn from examples without being explicitly programmed

Artificial neural networks (ANN)
Brain-inspired machine learning models

Deep learning (DL)
A subset of ML which uses deep artificial neural networks as models and automatically builds a hierarchy of data representations

Machine Learning – An independent Domain

Applied AI(Classic & Declarative)

- Expert Systems
- Smart Systems
- Smart Devices
- Business Rule Engines
- CX Interfaces

Machine Learning (Generalized AI)

- Supervised Learning
- Unsupervised Learning
- Reinforcement Learning
- Deep Learning
- Support Vector Machine
- Neural Networks

Machine Learning (Generalized AI)

- Text Data Influential Learning
  - More Concerned with Machines
  - Supervised Learning
  - Unsupervised Learning
- Deep Learning (All Kind of data)
  - More Concerned with Real World
  - Deep Reinforcement Learning
  - Neural Networks

What is Artificial Intelligence(AI)?

It is a branch of Computer Science that pursues creating the computers or machines as intelligent as human beings.

It is the science and engineering of making intelligent machines, especially intelligent computer programs.

It is related to the similar task of using computers to understand human intelligence, but **AI** does not have to confine itself to methods that are biologically observable

Artificial Intelligence is the study of how to make computers do things, which, at the moment, people do better.

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.

Human brain stores information in a way that it is easier to have association and access information using that association.

For example if I ask you the name of an actor who is tall, aged over 70 and with spectacles, all most all of you will immediately respond that I am talking about Amitabh Bachhan

Artificial Intelligence is the ability for a computer to think, learn and simulate human mental processes, such as perceiving, reasoning, and learning.

It can also independently perform complex tasks that once required human input.

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

- The AI or Artificial Intelligence is to write computer programs which can mimic human brain problem solving capabilities.
- **Elaine Rich**, in her book “Artificial Intelligence” puts it as “AI is the study of programs at which, at the moment, people are better”.
- **One more author** puts it as “AI is about writing intelligent programs”.
- **One more definition** is “AI is about building entities which can understand, perceive, predict and manipulates like humans do”.

How does machine Learning Relate to AI?

Although the terms **artificial intelligence (AI)** and machine learning are frequently used interchangeably, (machine learning is a subset of the larger category of AI.)

Artificial intelligence signifies computers' general ability to mimic human thought while carrying out tasks in real-world environments

Machine learning implies to the technologies and algorithms that allow systems to recognize patterns, make decisions, and improve themselves through experience and data.

EXAMPLES

Virtual Assistance

Autonomous vehicles

Chatbots

E-commerce

AI can be used for various situations, but these are some examples of AI in our daily life.

Recommendation systems

Navigation apps

Facial recognition

Text editors

WHAT PROBLEMS CAN AI SOLVE?

Cyber security detecting spam

Healthcare medical records

Research : idea generation, finding data

Transportation : self driving cars

AI can solve a LOT of problems.

Applications of AI

- Perception
  - Machine vision
  - Speech understanding
  - Touch (*tactile* or *haptic*) sensation
- Robotics
- Natural Language Processing
  - Natural Language Understanding
  - Speech Understanding
  - Language Generation
  - Machine Translation
- Planning
- Expert Systems
- Machine Learning
- Theorem Proving
- Symbolic Mathematics

uses of AI (ADVANTAGES OF AI)

Image and facial recognition

It can help make data safer and more secure.
For example, face authentication can ensure that only the appropriate person has access to sensitive information that is intended specifically for them.

Medical diagnosis

Provides more exact diagnoses, detects hidden patterns in imaging investigations, and predicts how patients will respond to specific medications. This leads to better treatment strategies, fewer clinical errors, and more accurate diagnosis.

Customer service

- Customer service teams
- can get feedback from customers by using AI. For example, AI- powered information

can provide agents with

information on client intent, language, and sentiment so they are aware of how to

approach an encounter.

Recommendation systems

AI content recommendations help people stay engaged and informed.
For example,
Virtual(Siri and Alexa.),
Personalized content on streaming platforms, Apps that suggest best routes based on traffic.

what are the disadvantages of AI?

Lack of Transparency → lying about using AI

Bias and Discrimination → assumtion based of incorrect information

Privacy Concerns

Ethical Dilemmas

Security Risks

Concentration of Power

Dependence on AI

Job Displacement

AI Vocabulary

- **Intelligence** relates to tasks involving higher mental processes, e.g. creativity, solving problems, pattern recognition, classification, learning, induction, deduction, building analogies, optimization, language processing, knowledge and many more. Intelligence is the computational part of the ability to achieve goals.

- **Intelligent behavior** is depicted by perceiving one's environment, acting in complex environments, learning and understanding from experience, reasoning to solve problems and discover hidden knowledge, applying knowledge successfully in new situations, thinking abstractly, using analogies, communicating with others and more.

- **Science based goals of AI** pertain to developing concepts, mechanisms and understanding biological intelligent behavior. The emphasis is on understanding intelligent behavior.

- **Engineering based goals of AI** relate to developing concepts, theory and practice of building intelligent machines. The emphasis is on system building.

- **AI Techniques** depict how we represent, manipulate and reason with knowledge in order to solve problems. Knowledge is a collection of 'facts'. To manipulate these facts by a program, a suitable representation is required. A good representation facilitates problem solving.

- **Learning** means that programs learn from what facts or behavior can represent. Learning denotes changes

RESPONSIBLE AI USE

- AI can help do repetitive work for humans, but humans should still be prioritized. Create a culture that utilizes creativity, empathy, and dexterity from humans and AI for increased efficiency.
- Businesses should adopt strong security measures, limit access to sensitive data, and anonymize data whenever possible to secure data privacy with AI and ML technologies.
- There needs to be fairness in AI which entails identifying and eliminating discrimination by using training models with equal representation.
- Develop explainable AI that is visible across processes and functions to generate trust among employees and customers. Provide examinability, comprehension, and traceability.

Second lec

Problems of AI

Intelligence does not imply perfect understanding; every intelligent being has limited perception, memory and computation.
AI seeks to understand the computations required from intelligent behavior and to produce computer systems that exhibit intelligence.
AI include perception, communicational using human languages, reasoning, planning, learning and memory.

The following questions are to be considered before we can step forward:

- ✔ What are the underlying assumptions about intelligence?
- ✔ What kinds of techniques will be useful for solving AI problems?
- ✔ At what level human intelligence can be modeled?
- ✔ When will it be realized when an intelligent program has been built?

Branches of AI:

- **Logical AI —** In general the facts of the specific situation in which it must act, and its goals are all represented by sentences of some mathematical logical language. The program decides what to do by inferring that certain actions are appropriate for achieving its goals.

- **Search —** Artificial Intelligence programs often examine large numbers of possibilities – for example, moves in a chess game and inferences by a theorem proving program.

- **Pattern Recognition —** When a program makes observations of some kind, it is often planned to compare what it sees with a pattern. For example, a vision program may try to match a pattern of eyes and a nose in a scene in order to find a face. More complex patterns are like a natural language text, a chess position or in the history of some event. Different methods require to understand this.

- **Representation —** Usually languages of mathematical logic are used to represent the facts about the world.

Branches of AI:

- **Inference —** Others can be inferred from some facts. The simplest kind of non-monotonic reasoning is default reasoning in which a conclusion is to be inferred by default. But the conclusion can be withdrawn if there is evidence to the divergent.

For example, when we hear of a bird, we infer that it can fly, but this conclusion can be reversed when we hear that it is a penguin

- **Common sense knowledge and Reasoning —** This is the area in which AI is extreme from the human level, in spite of the fact that it has been an active research area since the 1950s. While there has been considerable progress in developing systems of *non-monotonic reasoning* and theories of action, yet more new ideas are needed.

- **Learning from experience —** There are some rules expressed in logic for learning. Programs can only learn what facts or behavior and unfortunately learning systems are almost all based on very limited abilities to represent information.

Branches of AI:

Planning — Planning starts with general facts about the world (especially facts about the effects of actions), facts about the particular situation and a statement of a goal. From these, planning programs generate a strategy, sequence of actions for achieving the goal.

Epistemology — This is a study of the kinds of knowledge that are required for solving problems in the world.

Ontology — Ontology is the study of the kinds of things that exist. In AI the programs and sentences deal with various kinds of objects and we study what these kinds are and what their basic properties are.

Heuristics — A heuristic is a way of trying to discover something or an idea embedded in a program. The term is used variously in AI. *Heuristic functions* are used in some approaches to search or to measure how far a node in a search tree seems to be from a goal. *Heuristic predicates* that compare two nodes in a search tree to see if one is better than the other, i.e. constitutes an advance toward the goal, and may be more useful.

Genetic programming — Genetic programming is an automated method for creating a working computer program from a high-level problem statement of a problem. Genetic programming starts from a high-level statement of 'what needs to be done' and automatically creates a computer program to solve the problem.

- The knowledge captures generalizations that share properties, are grouped together, rather than being allowed separate representation.
- It can be understood by people who must provide it—even though for many programs bulk of the data comes automatically from readings.
- In many AI domains, how the people understand the same people must supply the knowledge to a program.
- It can be easily modified to correct errors and reflect changes in real conditions.
- It can be widely used even if it is incomplete or inaccurate.
- It can be used to help overcome its own sheer bulk by helping to narrow the range of possibilities that must be usually considered.

- **Example-1: Tic-Tac-Toe-Various approaches**
  - An element contains the value 0 for blank, 1 for X and 2 for O. A MOVETABLE vector consists of 19,683 elements (3^9) and is needed where each element is a nine element vector
  - The structure of the data is as before but we use 2 for a blank, 3 for an X and 5 for an O. A variable called TURN indicates 1 for the first move and 9 for the last. The algorithm consists of various actions.
  - This algorithm looks ahead to make a decision on the next move by deciding which the most promising move or the most suitable move at any stage would be and selects the same.

Example 2- Text- Rani went shopping for a new Coat. She found a red one she really liked. When she got home, she found that it went perfectly with her favourite dress.

-
  - **Question**
    - What did Rani go shopping for?
    - What did Rani find that she liked?
    - Did Rani buy anything?

- Method 1
- A set of templates that match common questions and produce patterns used to match against inputs. Templates and patterns are used so that a template that matches a given question is associated with the corresponding pattern to find the answer in the input text.
- Answering a question requires the following four steps to be followed:
    - Compare the template against the questions and store all successful matches to produce a set of text patterns.
    - Pass these text patterns through a substitution process to change the person or voice and produce an expanded set of text patterns.
    - Apply each of these patterns to the text; collect all the answers and then print the answers.

- In **question 1** we use the template WHAT DID X Y which generates Rani go shopping for **z** and after substitution we get Rani goes shopping for **z** and Rani went shopping for **z** giving **z** [equivalence] a new coat
- In **question 2** we need a very large number of templates and also a scheme to allow the insertion of ‘find’ before ‘that she liked’; the insertion of ‘really’ in the text; and the substitution of ‘she’ for ‘Rani’ gives the answer ‘a red one’.
- **Question 3** cannot be answered.

- There are three types of such knowledge representation systems: production rules of the form ‘if x then y’, slot and filler systems and statements in mathematical logic. The system used here will be the slot and filler system.
- Take, for example sentence:

“She found a red one she really liked”

Event2 instance:	finding	**Event2** instance:	liking
tense:	past	tense:	past
agent:	Rani	modifier:	much
object:	Thing1	object:	Thing1
Thing1 instance:	coat		
colour:	red		

The question is stored in two forms: as input and in the above form.

- **Algorithm**

- Convert the question to a structured form using English know how, then use a marker to indicate the substring (like ‘who’ or ‘what’) of the structure, that should be returned as an answer. The answer appears by matching this structured form against the structured text.
- The structured form is matched against the text and the requested segments of the question are returned.

- **Examples**

- Both questions 1 and 2 generate answers via a new coat and a red coat respectively.
- Question 3 cannot be answered, because there is no direct response.
- *This approach is more meaningful than the previous one and so is more effective. The extra power given must be paid for by additional search time in the knowledge bases*

- A new approach with some modifications can handle, , questions of the following form with the answer—

Text: Saturday morning Rani went shopping. Her brother tried to meet her but she did not answer.

- **Question:** Why couldn't Rani's brother reach her?
- **Answer:** Because she was not in home.
- *This answer is derived because we have supplied an additional fact that a person cannot be in two places at once*.

Shopping Script: C - Customer, S - Salesperson

Props: M - Merchandize, D - Money-dollars, Location: L - a Store.

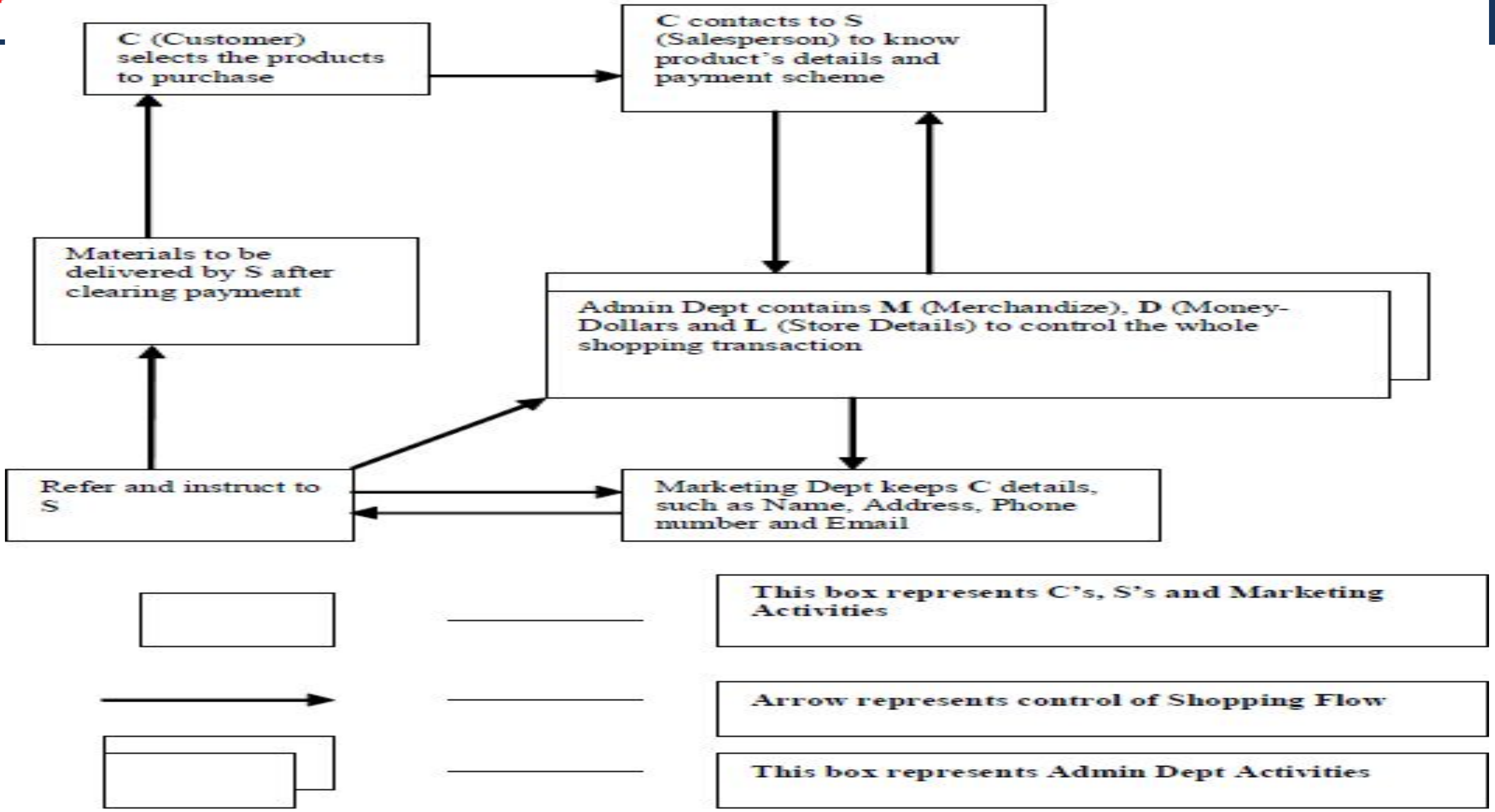


Fig. 1.1 Diagrammatic Representation of Shopping Script

Two classes of problems

- First class-AI techniques usually include a search, as no direct method is available, the use of knowledge about the objects involved in the problem area and abstraction on which allows an element of pruning to occur, and to enable a solution to be found in real time; otherwise, the data could explode in size.
- The second class of problems attempts to solve problems that are non-trivial for a computer and use AI techniques. We wish to model human performance on these:
  - To test psychological theories of human performance. Ex. PARRY [Colby, 1975] – a program to simulate the conversational behavior of a paranoid person.
  - To enable computers to understand human reasoning – for example, programs that answer questions based upon newspaper articles indicating human behavior.

- To solve the problem of building a system you should take the following steps:
  - Define the problem accurately including detailed specifications and what constitutes a suitable solution.
  - Scrutinize the problem carefully, for some features may have a central affect on the chosen method of solution.
  - Segregate and represent the background knowledge needed in the solution of the problem.
  - Choose the best solving techniques for the problem to solve a solution.

- ***Problem solving*** **is a process** of generating solutions from observed data.
    - a *'problem'* is characterized by a set of *goals*,
    - a set of *objects*, and
    - a set of *operations*.

A 'problem space' is an abstract space.

- A problem space encompasses all **valid states** that can be generated by the application of any **combination of operators** on any **combination of objects**. The problem space may contain one or more solutions. **A solution is a combination of operations and objects that achieve the goals.**

A 'search' refers to the search for a solution in a problem space.

- Search proceeds with different types of 'search control strategies'.
- The ***depth-first search and breadth-first search*** are the two common search strategies.

- *Problem solving* is a process of generating solutions from observed or given data. It is however not always possible to use direct methods (i.e. go directly from data to solution). It often needs to use indirect or model based methods.
- **General Problem Solver (GPS)** can solve any formalized symbolic problem, such as theorems proof and geometric problems and chess playing. It solved many simple problems, such as the Towers of Hanoi, that could be sufficiently formalized, but **GPS could not solve any real-world problems.**

- To build a system to solve a particular problem:
  - Define the problem precisely – find input situations as well as final situations for an acceptable solution to the problem
  - Analyze the problem – find few important features that may have impact on the appropriateness of various possible techniques for solving the problem
  - Isolate and represent task knowledge necessary to solve the problem
  - Choose the best problem-solving technique(s) and apply to the particular problem

Problem definitions

A problem is defined by its ‘***elements***’ and their ‘***relations***’**.** To provide a formal description of a problem, we need to do the following:

- Define a ***state space*** that contains all the possible configurations of the relevant objects, including some impossible ones.
- Specify one or more states that describe possible situations, from which the problem- solving process may start. These states are called ***initial states***.
- Specify one or more states that would be acceptable solution to the problem.-These states are called ***goal states***.
- Specify a set of ***rules*** that describe the actions (*operators*) 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 a more direct method is not known.
  - *Search* provides the framework into which more direct methods for solving subparts of a problem can be embedded. A very large number of AI problems are formulated as search problems.
- A ***problem space*** is represented by a directed graph, where ***nodes*** represent search state and ***paths*** represent the operators applied to change the *state*.

Tree

- To simplify search algorithms, it is often convenient to logically and programmatically represent a problem space as a **tree**. A *tree* usually decreases the complexity of a search at a cost. A ***tree*** *is a graph* in which any two vertices are connected by exactly one path. Alternatively, any **connected *graph with no cycles is a tree*.**

Types of Search in AI

Categorized as informed (Heuristic) and uninformed (Blind)

1. Uninformed Search

Apart from the problem definition, these algorithms don't know anything else about the states.

- **Breadth-First Search (BFS)**: Before going on to nodes at the next depth level, the Breadth-First Search (BFS) method investigates every node at the current depth.
- **Depth-First Search (DFS)**: Investigates a branch as far as it can go before turning around.
- **Cost Search**: To find the lowest-cost solution, uniform cost search expands the least-cost node.

2. Informed Search

These algorithms make use of heuristics or extra information to direct the search more effectively in the direction of the desired state. Typical knowledgeable search tactics consist of :

- **Greedy Best-First Search**: Chooses the node that seems to be closest to the objective using a heuristic.
- **A***: Sums the projected cost from a node with the cost to get there.
- Beginning with the original state, the search process investigates potential courses of action to produce new states. Iteratively, the process is carried out until the desired condition is attained or a workable solution is discovered.

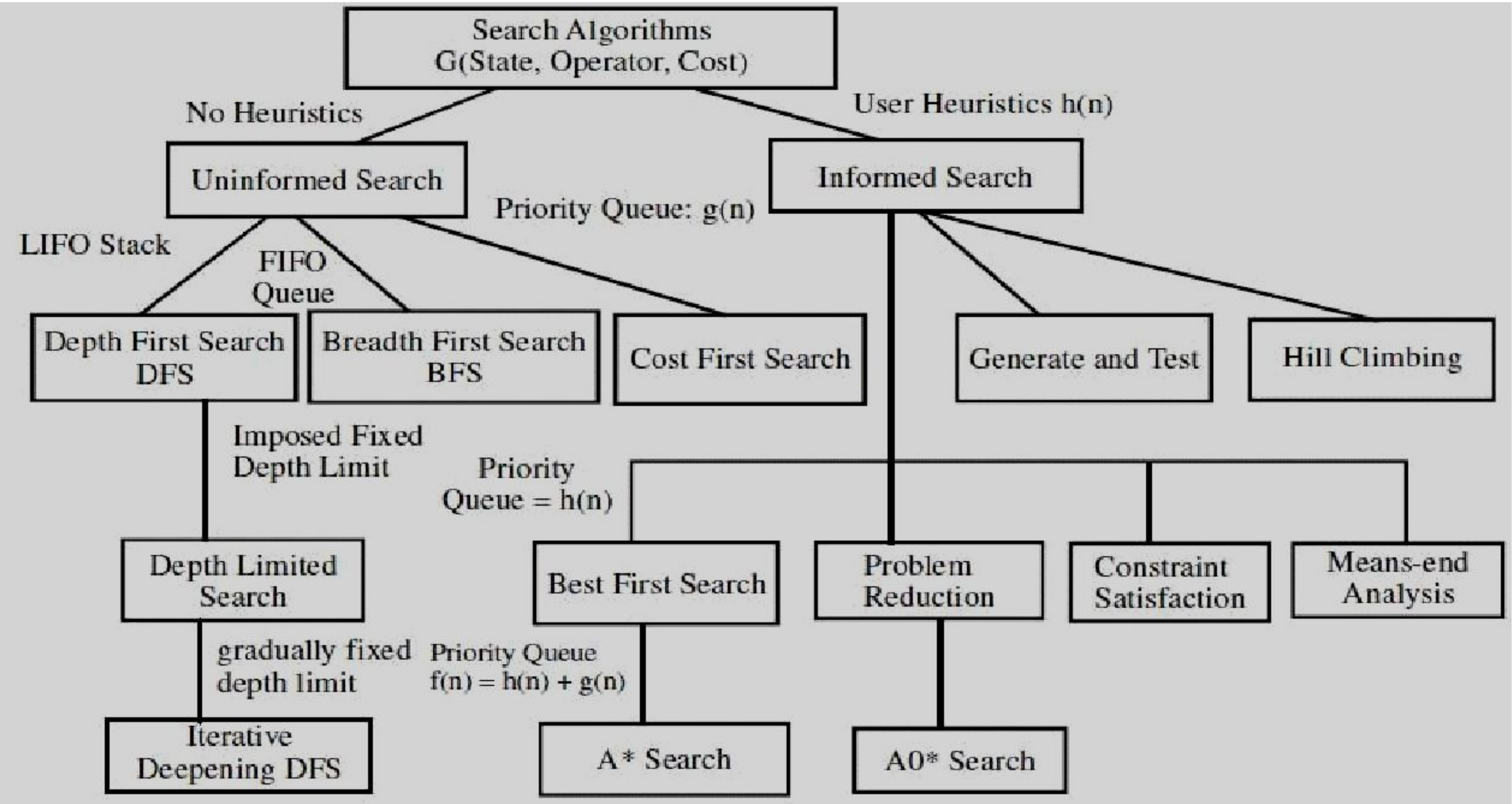


Fig. Different Search Algorithms

Problem solving

- Problem solving is a systematic search through a range of possible actions to reach some predefined goal or solution. Problem-solving methods are categorized as ***special purpose*** **and** ***general purpose***.
- A ***special-purpose method*** is tailor-made for a particular problem, often exploits very specific features of the situation in which the problem is embedded.
- A ***general-purpose method*** is applicable to a wide variety of problems. One General-purpose technique used in AI is ***'means-end analysis':*** a step-by step, or incremental, reduction of the difference between current state and final goal.

To solve the problem of playing a game

- The rules of the game are required
- Targets for winning as well as representing positions in the game.
- opening position -initial state and a winning position - goal state.
- Moves from initial state to other states leading to the goal state follow legally.
- The rules are far too abundant in most games— especially in chess

A ***state*** *space*

A ***state*** *space* represents a problem in terms of ***states* and *operators*** that change states. A state space consists of:

- A representation of the ***states*** the system can be in. For example, in a board game, the board represents the current state of the game.
- A set of ***operators*** that can change one state into another state. In a board game, the operators are the legal moves from any given state. Often the operators are represented as programs that change a state representation to represent the new state.
- An ***initial*** *state*.
- A set of ***final*** *states*; some of these may be desirable, others undesirable. This set is often represented implicitly by a program that detects terminal states.

PRODUCTION SYSTEMS

- Production systems provide appropriate structures for performing and describing search processes. A production system has four basic components as enumerated below.
  - 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 the rule is applied.
  - A database of current facts established during the process of inference.
  - A control strategy that specifies the order in which the rules will be compared with facts in the database and also specifies how to resolve conflicts in selection of several rules or selection of more facts.
  - A rule firing module.

PROBLEM CHARACTERISTICS

AI can be described as the study of techniques for solving exponentially hard problems in polynomial time by exploiting knowledge about problem domain.

To use the heuristic search for problem solving, we suggest analysis of the problem for the following considerations:

- Decomposability of the problem into a set of independent smaller sub problems
- Possibility of undoing solution steps, if they are found to be unwise
- Predictability of the problem universe
- Possibility of obtaining an obvious solution to a problem without comparison of all other possible solutions
- Type of the solution: whether it is a state or a path to the goal state
- Role of knowledge in problem solving
- Nature of solution process: with or without interacting with the user

Production systems provide us with good ways of describing the operations that can be performed in a search for a solution to a problem.

- Can production systems be described by a set of characteristics? And how can they be easily implemented?
- What relationships are there between the problem types and the types of production systems well suited for solving the problems?

To answer these questions, consider the following definitions of classes of production systems:

- A **monotonic production system is** a production system in which 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.
- A **non-monotonic production system** is one in which this is not true.
- A partially communicative production system is a production system with the property that if the application of a particular sequen rules that is allowable also transforms state F
- A commutative pr **ially commutative.**

Table 2.1 Four Categories of Production Systems

Production System	Monotonic	Non-monotonic
Partially Commutative	Theorem Proving	Robot Navigation
Non-partially Commutative	Chemical Synthesis	Bridge

Issues in the searching

The following issues arise when searching:

- The tree can be searched forward from the initial node to the goal state or backwards from the goal state to the initial state.
- To select applicable rules, it is critical to have an efficient procedure for matching rules against states.
- How to represent each node of the search process? –the knowledge representation problem or the frame problem.
- In games, an array suffices; in other problems, more complex data structures are needed.

Search algorithms

Uninformed search algorithms or ***Brute-force algorithms***, search through the search space all possible candidates for the solution checking whether each candidate satisfies the problem's statement.

Informed search algorithms use ***heuristic functions*** that are specific to the problem, apply them to guide the search through the search space to try to reduce the amount of time spent in searching

Some prominent intelligent search algorithms are stated below:

1. ***Generate and Test Search***
2. ***Best-first Search***
3. ***Greedy Search***
4. ***A* Search***
5. ***Constraint Search***
6. ***Means-ends analysis***

There are some more algorithms- improvements or combinations of these.

1. **Hierarchical Representation of Search Algorithms:** A Hierarchical representation of most search algorithms is illustrated below. The representation begins with two types of search:
2. **Uninformed Search:** Also called blind, exhaustive or brute-force search, it uses no information about the problem to guide the search and therefore may not be very efficient.
3. **Informed Search:** Also called heuristic or intelligent search, this uses information about the problem to guide the search—usually guesses the distance to a goal state and is therefore efficient, but the search may not be always possible.

Properties of Search Algorithms:

Following are the four essential properties of search algorithms to compare the efficiency of these 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.

Heuristic search

- Heuristic search methods use knowledge about the problem domain and choose promising operators first. These heuristic search methods use heuristic functions to evaluate the next state towards the goal state.

For finding a solution, by using the heuristic technique, one should carry out the following steps:

- Add domain—specific information to select what is the best path to continue searching along.
- Define a heuristic function h(n) that estimates the ‘goodness’ of a node n.
- Specifically, h(n) = estimated cost(or distance) of minimal cost path from n to a goal state.
- The term, heuristic means ‘serving to aid discovery’ and is an estimate, based on domain specific information that is computable.

Example

- Finding a route from one city to another city is an example of a search problem in which different search orders and the use of heuristic knowledge are easily understood.
- **State:** The current city in which the traveller is located.
- **Operators:** Roads linking the current city to other cities.
- **Cost Metric:** The cost of taking a given road between cities.
- **Heuristic information:** The search could be guided by the direction of the goal city from the current city, or we could use airline distance as an estimate of the distance to the goal. **Heuristic search techniques**

Characteristics of heuristic search

- Heuristics are knowledge about domain, which help search and reasoning in its domain.
- Heuristic search incorporates domain knowledge to improve efficiency over blind search.
- Heuristic is a function that, when applied to a state, returns value as estimated merit of state, with respect to goal.
  - Heuristics might (for reasons) *underestimate* or *overestimate* the merit of a state with respect to goal.
  - Heuristics that underestimate are desirable and called admissible.
- Heuristic evaluation function estimates likelihood of given state leading to goal state.
- Heuristic search function estimates cost from current state to goal, presuming function is efficient

Comparison

Brute force / Blind search

Can only search what it has knowledge state about already

No knowledge about how far a node goal node from goal state

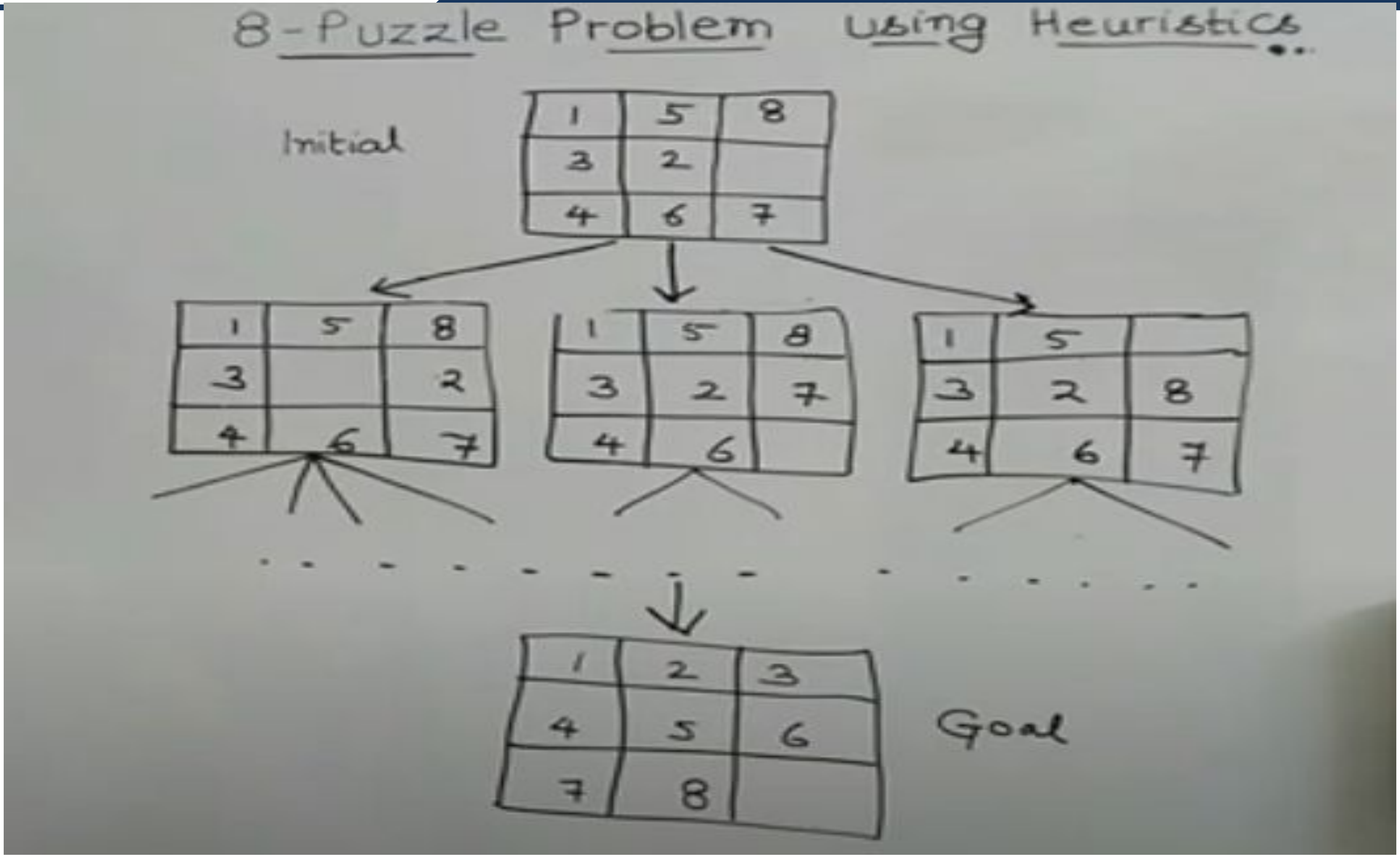
Heuristic search

Estimates 'distance' to goal through explored nodes

Guides search process toward

Prefers states (nodes) that lead close to and not away from goal state

8-Puzzle problem



The 8-puzzle is a 3 × 3 array containing eight square pieces, numbered 1 through 8, and one empty space. A piece can be moved horizontally or vertically into the empty space, in effect exchanging the positions of the piece and the empty space. There are four possible moves, UP (move the blank space up), DOWN, LEFT and RIGHT. The aim of the game is to make a sequence of moves that will convert the board from the start state into the goal state:

2	3	4
8	6	2
7		5

Initial State

1	2	3
8		4
7	6	5

Goal State

This example can be solved by the operator sequence UP, RIGHT, UP, LEFT, DOWN.

Water Jug problem: Video link