Problem Solving – Basic Search methods in Artificial Intelligence

Lecture Module 2

Defining Artificial Intelligence

What is Intelligence?

Intelligence is a property of mind to interact with world (speech, vision, motion, perceive, understand, modify), and:

- reason, model, summarize
- plan
- solve problems
- think abstractly
- comprehend ideas and language and
- learn and improve performance
- adapt

What is Artificial Intelligence?

- To understand intelligence
- To build systems exhibiting intelligence

Artificial Intelligence

Quick Answer from Academia:

- Modeling human cognition or mental faculty using computers
- Study of making computers do things which at the moment people better
- Making computers do things which require intelligence

More Formal Definition of AI

AI is a branch of computer science which is concerned with the study and creation of computer systems that exhibit some form of intelligence

OR

those characteristics which we associate with intelligence in human behavior

Characteristics of AI systems

learn new concepts and tasks

reason and draw useful conclusions about the world around us

remember complicated interrelated facts and draw conclusions from them (inference)

understand a natural language or perceive and comprehend a visual scene

look through cameras and see what's there (vision), to move themselves and objects around in the real world (robotics)

Contd.

plan sequences of actions to complete a goal
offer advice based on rules and situations
may actually exceed human abilities
capable of performing intelligent tasks effectively and efficiently
perform tasks that require high levels of intelligence

Understanding of AI

Boundaries of AI are not well defined.

AI programs - like people - are usually not perfect, and even may make mistakes.

It may involve nonnumeric ways.

Understanding of AI also requires an understanding of ‘intelligence’.

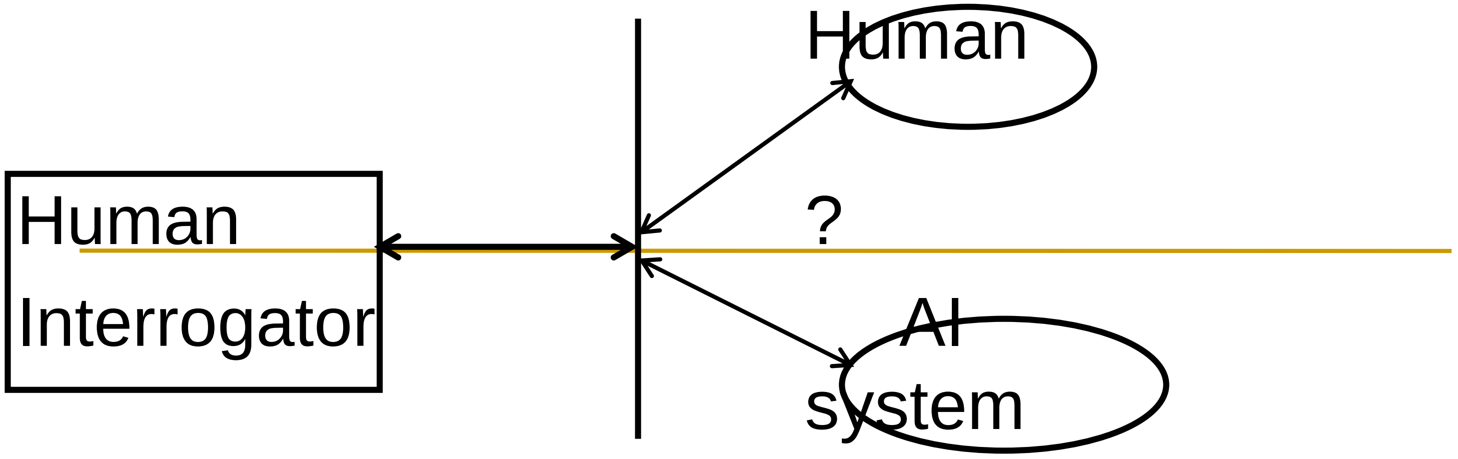
Categories of AI System

Systems that think/act like humans

Systems that think/act rationally

The Turing Test

Turing proposed operational test for intelligent behavior in 1950.



ELIZA

- Eliza was first program developed by Joseph Wiezbaum to converse in English in mid 1960's
  - It passed turing test.
- The following passage shows Eliza’s talking to a teenage girl. Blue text Eliza’s response

Men are all alike.

IN WHAT WAY

They're always bugging us about something or other.

CAN YOU THINK OF A SPECIFIC EXAMPLE

Well, my boyfriend made me come here.

YOUR BOYFRIEND MADE YOU COME HERE

He says that I am depressed all the time.

I AM SORRY TO HEAR THAT YOU ARE DEPRESSED

It's true that I am unhappy

DO YOU THINK COMING HERE WILL HELP YOU NOT TO BE UNHAPPY

I need help, that seems certain.

WHAT WOULD IT MEAN IF YOU GOT SOME HELP

Perhaps I could learn to get along with my mother.

TELL ME MORE ABOUT YOUR FAMILY

My mother takes care of me.

WHO ELSE IN YOUR FAMILY TAKES CARE OF YOU

My father.

YOUR FATHER

You are like my father in some ways.

WHAT RESEMBLANCE DO YOU SEE

You are not very aggressive but I think you don't want me to notice that.

WHAT MAKES YOU THINK THAT I AM NOT VERY AGGRESSIVE

You don’t argue with me.

WHY DO YOU THINK I DON’T ARGUE WITH YOU

You are afraid of me.

DOES IT PLEASE YOU TO BELIEVE, I AM AFRAID OF YOU

My father is afraid of everybody.

WHAT ELSE COMES TO MIND WHEN YOU THINK OF YOUR FATHER

Bullies.

DOES THAT HAVE ANYTHING TO DO WITH THE FACT THAT YOUR BOYFRIEND MADE YOU COME HERE

Foundations

- Uncertainty handling
  - Boolean logic
  - Fuzzy logic
  - Probability

Foundations - Neuroscience

- How do the brain works?
  - Early studies (1824) relied on injured and abnormal people to understand what parts of brain work
  - More recent studies use accurate sensors to correlate brain activity to human thought
  - How close are we to have a mechanical brain?
    - Parallel computation, remapping, interconnections,….

Foundations – Control Theory

Machines can modify their behavior in response to the environment (sense/action loop)

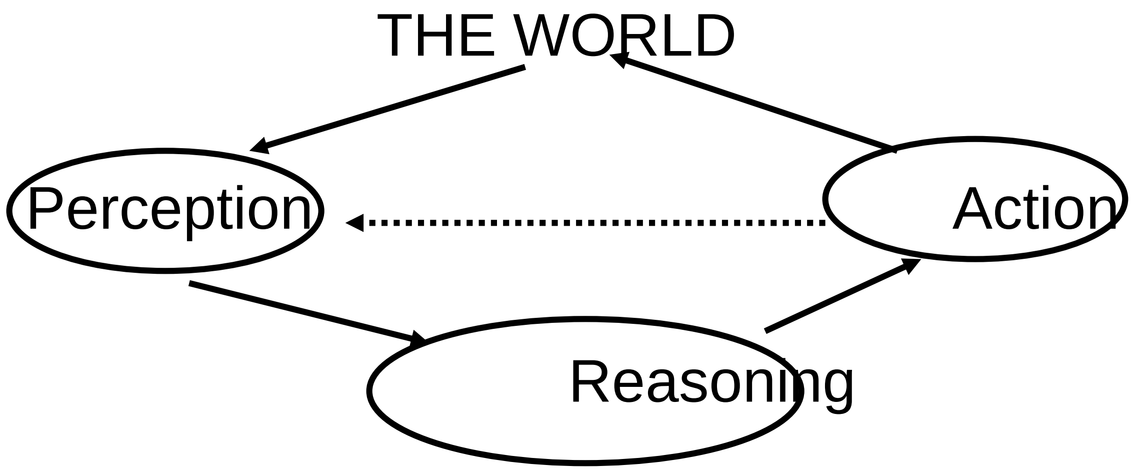
- Water-flow regulator, steam engine governor, thermostat

Foundations - Linguistics

- Speech demonstrates so much of human intelligence
  - Analysis of human language reveals thought taking place in ways not understood in other settings
    - Children can create sentences they have never heard before
    - Language and thought are believed to be tightly intertwined

Latest Perception of AI

- Three typical components of AI Systems



An AI Program

- AI program should have
  - knowledge base
  - navigational capability
  - inferencing

Knowledge Base

- Knowledge base consists of facts and rules.
- Characteristics of Knowledge:
  - It is voluminous in nature and requires proper structuring
  - It may be incomplete and imprecise
  - It may keep on changing (dynamic)
- AI programs should be learning in nature and update its knowledge accordingly.

Navigational Capability

- determines the rule to be applied
  - some heuristics may be applied

Inferencing

- Inferencing requires
  - search through knowledge base

    and
  - derive new knowledge

Problem Characteristics

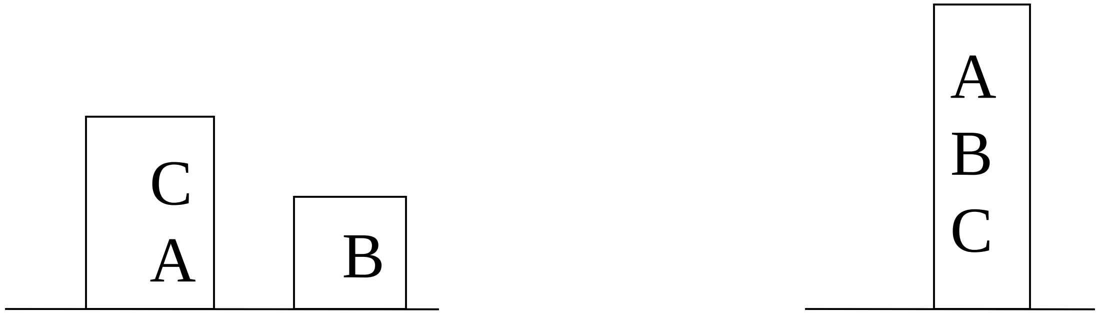
- Heuristic search is a very general method applicable to a large class of problem.
- In order to choose the most appropriate method (or combination of methods) for a particular problem it is necessary to analyze the problem along several key dimensions.
  - Is the problem decomposable into a set of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

Contd..

- Use of decomposing problems:
  - Each sub-problem is simpler to solve.
  - Each sub-problem can be handed over to a different processor. Thus can be solved in parallel processing environment.

- There are non decomposable problems.
  - For example, Block world problem is non decomposable.

Initial State (State0) Goal State



Start: ON(C, A) ….

Goal: ON(B, C) $\wedge$ ON(A, B)

Contd..

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

Example - Ignorable

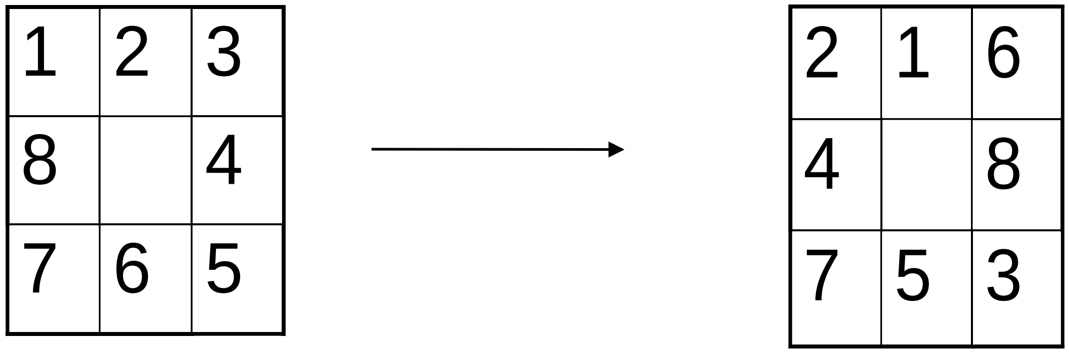
- **(Ignorable)**: **In theorem proving** - (solution steps can be ignored)
  - Suppose we have proved some lemma in order to prove a theorem and eventually realized that lemma is no help at all, then ignore it and prove another lemma.
  - Can be solved by using simple **control strategy**?

Example - Recoverable

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

The Eights Puzzle

- Sliding blocks puzzle, more usually 15 puzzle
  - how many moves between these states?



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Example - Irrecoverable

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

Contd..

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

Example : Water Jug Problem

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

Traveling Salesman Problem

- Consider 5 cities.
  - A salesman is supposed to visit each of 5 cities.
  - All cities are pair wise connected by roads.
  - There is one start city.
  - The problem is to find the shortest route for the salesman who has to
    - visit each city only once and
    - returns to back to start city.

Contd…

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

Contd…

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

Problem Solving

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

Production System - PS

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

Production Rules

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

Advantages of PS

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

Example : Water Jug Problem

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  - Goal state is (2, N) for any value of N.

Production Rules

- Following are the production rules for this problem.

R1:	$(X, Y \mid X < 4) \rightarrow (4,Y)$	{Fill 4-gallon jug}
R2:	$(X, Y \mid Y < 3) \rightarrow (X,3)$	{Fill 3-gallon jug}
R3:	$(X, Y \mid X > 0) \rightarrow (0,Y)$	{Empty 4-gallon jug}
R4:	$(X, Y \mid Y > 0) \rightarrow (X,0)$	{Empty 3-gallon jug}
R5:	$(X, Y \mid X+Y >= 4 \wedge Y > 0) \rightarrow (4, Y - (4 - X))$	{Pour water from 3- gallon jug into 4-gallon jug until 4-gallon jug is full}

Contd..

R6: $(X, Y \mid X+Y >= 3 \wedge X > 0) \rightarrow (X - (3 - Y), 3)$
{Pour water from 4-gallon jug into 3-gallon jug until 3-gallon jug is full}

R7: $(X, Y \mid X+Y <= 4 \wedge Y > 0) \rightarrow (X+Y, 0)$
{Pour all water from 3-gallon jug into 4-gallon jug }

R8: $(X, Y \mid X+Y <= 3 \wedge X > 0) \rightarrow (0, X+Y)$
{Pour all water from 4-gallon jug into 3-gallon jug }

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

R9: $(X, Y \mid X > 0) \rightarrow (X - D, Y)$
{Pour some water D out from 4-gallon jug}

R10: $(X, Y \mid Y > 0) \rightarrow (X, Y - D)$
{Pour some water D out from 3- gallon jug}

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

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

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

- Note that there may be more than one solutions.

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

Important Points

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

- Summary: In order to provide a formal description of a problem, it is necessary to do the following things:

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

Control Strategies

- Control Strategy decides which rule to apply next during the process of searching for a solution to a problem.
- Requirements for a good Control Strategy
    - **It should cause motion**

      In water jug problem, if we apply a simple control strategy of starting each time from the top of rule list and choose the first applicable one, then we will never move towards solution.
    - **It should explore the solution space in a systematic manner**

      If we choose another control strategy, say, choose a rule randomly from the applicable rules then definitely it causes motion and eventually will lead to a solution. But one may arrive to same state several times. This is because control strategy is not systematic.

Systematic Control Strategies (Blind searches)

- Blind searches are exhaustive in nature.
- These are uninformed searches.
- If the problem is simple then
  - any control strategy that causes motion and is systematic will lead to an answer.
- But in order to solve some real world problems,
  - we must use a control strategy that is efficient.
- Let us discuss these strategies using water jug problem.
- These may be applied to any search problem.

Breadth First Search – BFS : Water Jug Problem

- BFS
  - Construct a tree with the initial state of the problem as its root.
  - Generate all the offspring of the root by applying each of the applicable rules to the initial state.
  - For each leaf node, generate all its successors by applying all the rules that are appropriate.
  - Repeat this process till we find a solution, if it exists.

$$\begin{tikzcd}
 & (0, 0) \arrow[dl] \arrow[dr] & \\
(4, 0) & & (0, 3)
\end{tikzcd}$$

$$\begin{tikzcd}
 & & & (0, 0) \arrow[dll] \arrow[drr] & & & \\
 & (4, 0) \arrow[dl] \arrow[d] \arrow[dr] & & & & (0, 3) \arrow[dl] \arrow[d] \arrow[dr] & \\
(4, 3) & (0, 0) & (1, 3) & & (4, 3) & (0, 0) & (3, 0)
\end{tikzcd}$$

Depth First Search - DFS

- Here we pursue a single branch of the tree until it yields a solution or some pre-specified depth has reached.
- If solution is not found then
  - go back to immediate previous node and
  - explore other branches in DF fashion.
- Let us see the tree formation for water jug problem using DFS

$$\begin{tikzcd}
 & & & & & (0, 0) \arrow[dl] & & \textbf{Start State} \arrow[ll] \\
 & & & & (4,0) \arrow[dll] \arrow[d] \arrow[drr] & & & \\
 & & (4, 3) \arrow[dl] \arrow[dr] & & (0, 0) & & (1, 3) & \\
 & (0, 3) \arrow[dl] \arrow[d] \arrow[dr] & & (4, 0) & & & & \\
\times (4, 3) & \times (0, 0) & (3, 0) \arrow[dl] \arrow[d] \arrow[dr] & & & & & \\
 & (3, 3) \arrow[dl] \arrow[d] \arrow[dr] & (0, 0) & (0, 3) & & & & \\
\times (3, 0) & \times (0, 3) & (4, 2) \arrow[dl] \arrow[d] \arrow[dr] & & & & & \\
 & (0, 2) \arrow[dl] \arrow[d] \arrow[dr] & (3, 3) & (4, 0) & & & & \\
\times (4, 2) & \times (0, 0) & (2, 0) & & \textbf{Goal state} \arrow[ll] & & &
\end{tikzcd}$$

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- Consider 5 cities.
  - A salesman is supposed to visit each of 5 cities.
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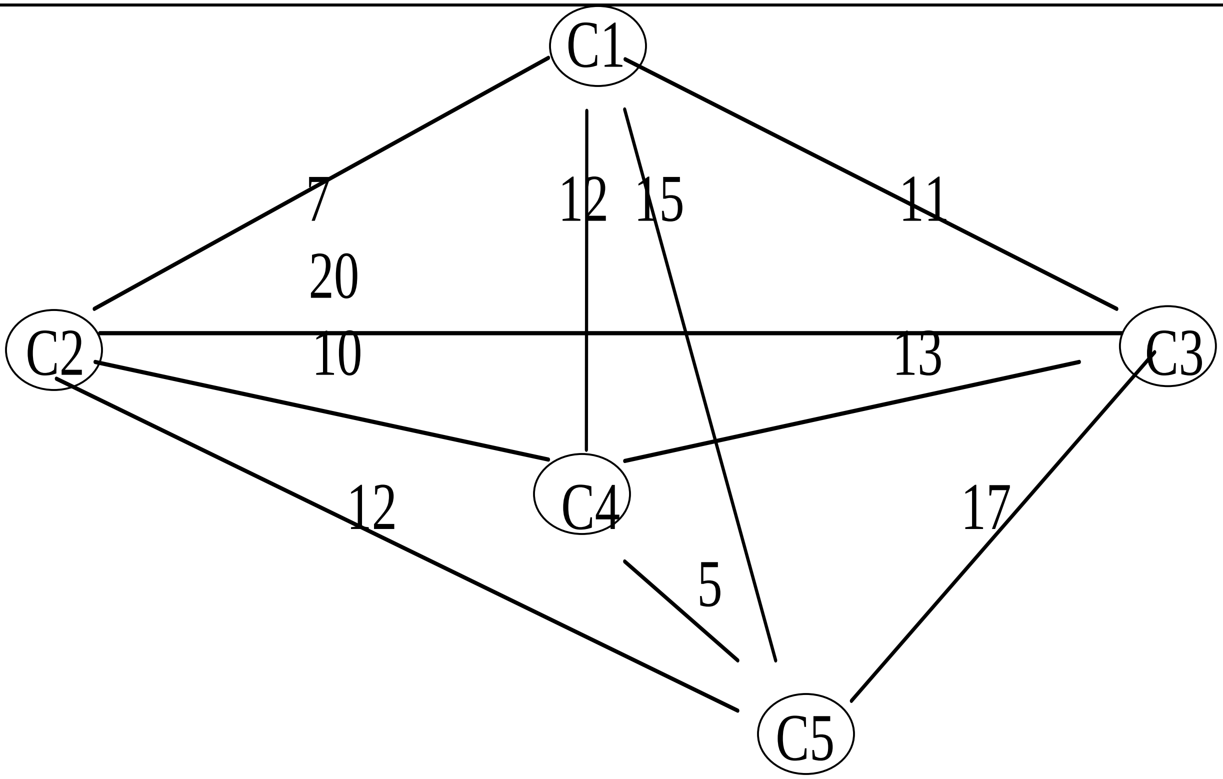
Traveling Salesman Problem (Example) – Start city is C1



D(C1,C2) = 7; D(C1,C3) = 11; D(C1,C4) = 12; D(C1,C5) = 15; D(C2,C3) =20;

D(C2,C4) = 10; D(C2,C5) =12; D(C3,C4) =13; D(C3,C5) = 17; D(C4,C5) =5;

Contd..

- A simple motion and systematic control structure could, in principle, solve this problem.
- Explore the search tree of all possible paths and return the shortest path.
- This will require 4! paths to be examined.
- If number of cities grow, say 25 cities, then the time required to wait a salesman to get the information about the shortest path is of 0(24!) which is not a practical situation.

Contd..

- This phenomenon is called **combinatorial explosion**.
- We can improve the above strategy as follows:
  - Begin generating complete paths, keeping track of the shortest path found so far.
  - Give up exploring any path as soon as its partial length becomes greater than the shortest path found so far.
  - This algorithm is efficient than the first one, still requires exponential time.

Paths explored. Assume C1 to be the start city	**Distance**
1. C1 → C2 → C3 → C4 → C5 → C1 7 20 13 5 15 27 40 45 60 current best path	60 √ ×
2. C1 → C2 → C3 → C5 → C4 → C1 7 20 17 5 12 27 44 49 61	61 ×
3. C1 → C2 → C4 → C3 → C5 → C1 7 10 13 17 15 17 40 57 72	72 ×
4. C1 → C2 → C4 → C5 → C3 → C1 7 10 5 17 11 17 22 39 50 current best path, cross path at S.No 1.	50 √ ×
5. C1 → C2 → C5 → C3 → C4 → C1 7 12 17 13 12 19 36 49 61	61 ×
6. C1 → C2 → C5 → C4 → C3 → C1 7 12 5 13 11 19 24 37 48 current best path, cross path at S.No. 4.	48 √
7. C1 → C3 → C2 → C4 → C5 7 20 10 5 37 47 52 (not to be expanded further)	52 ×
8. C1 → C3 → C2 → C5 → C4 11 20 12 5 37 49 54 (not to be expanded further)	54 ×
9. C1 → C3 → C4 → C2 → C5 → C1 11 13 10 12 15 24 34 46 61	61 ×
10. C1 → C3 → C4 → C5 → C2 → C1 11 13 5 12 7 24 29 41 48 same as current best path at S. No. 6.	48 √
11. C1 → C3 → C5 → C2 11 17 12 38 50 (not to be expanded further)	50 ×
12. C1 → C3 → C5 → C4 → C2 11 17 5 10 38 43 53 (not to be expanded further)	53 ×
13. C1 → C4 → C2 → C3 → C5 12 10 20 17 22 42 55 (not to be expanded further)	59 ×
Continue like this	