Artificial & Computational Intelligence

AIMLCZG557

Contributors & Designers of document content : Cluster Course Faculty Team

M2 : Problem Solving Agent using Search

PSO & ACO

BITS Pilani
Pilani Campus

Presented by
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Artificial and Computational Intelligence

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- I hereby acknowledge all the contributors for their material and inputs and gratefully acknowledge people others who made their course materials freely available online.
- .I have provided source information wherever necessary
- This is not a full fledged reading materials. Students are requested to refer to the textbook w.r.t detailed content of the presentation deck that is expected to be shared over e-learning portal - taxilla.
- I have added and modified the content to suit the requirements of the class dynamics & live session's lecture delivery flow for presentation

- **Slide Source / Preparation / Review:**
- From BITS Pilani WILP**:** Prof.Raja vadhana, Prof. Indumathi, Prof.Sangeetha
- From BITS Oncampus & External : Mr.Santosh GSK

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Course Plan

M1 Introduction to AI

M2 Problem Solving Agent using Search

M3 Game Playing

M4 Knowledge Representation using Logics

M5 Probabilistic Representation and Reasoning

M6 Reasoning over time

M7 Ethics in AI

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Optimization Problem

Goal : Navigate through a state space for a given problem such that an optimal solution can be found

Objective : Minimize or Maximize the objective evaluation function value

Scope : Local

Objective Function : Fitness Value evaluates the goodness of current solution

Local Search : Search in the state-space in the neighbourhood of current position until an optimal solution is found

Single Instance Based	Multiple Instance Based
Hill Climbing	Genetic Algorithm
Simulated Annealing	Particle Swarm Optimization
Local Beam Search	Ant Colony Optimization
Tabu Search	

Particle Swarm Optimization

Particle Swarm Optimization

Basic Flow of PSO

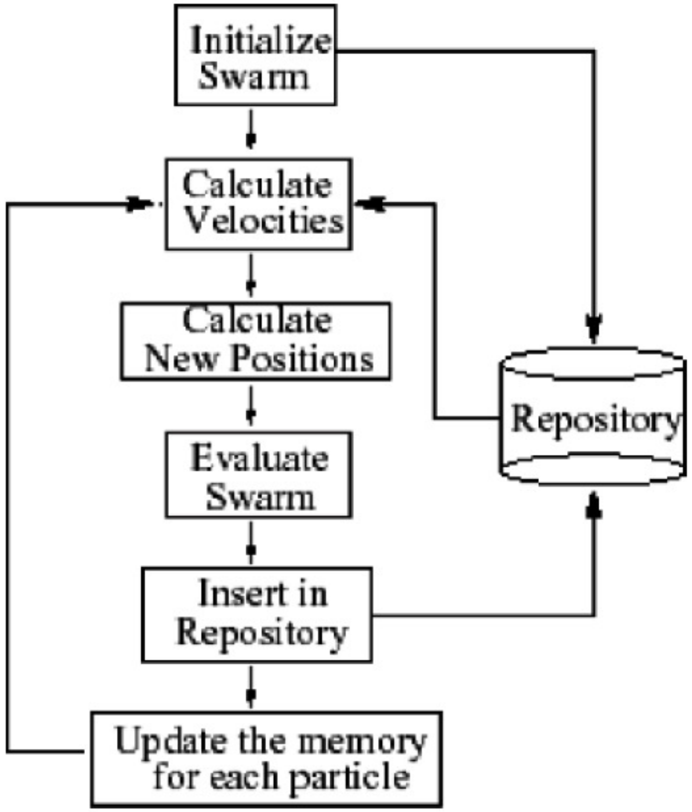
1.Initialize the swarm with random initializations

2.Evaluate fitness value for each of these individuals

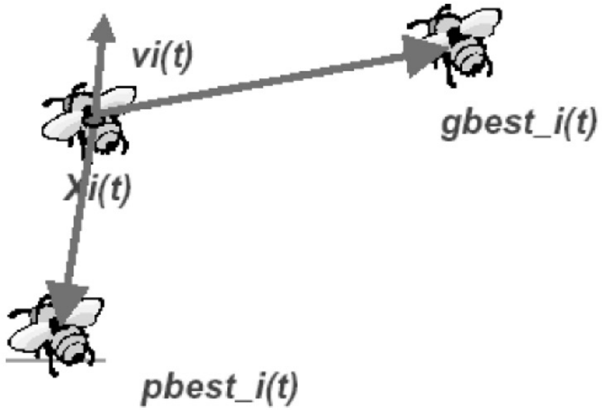
3.Modify **g**

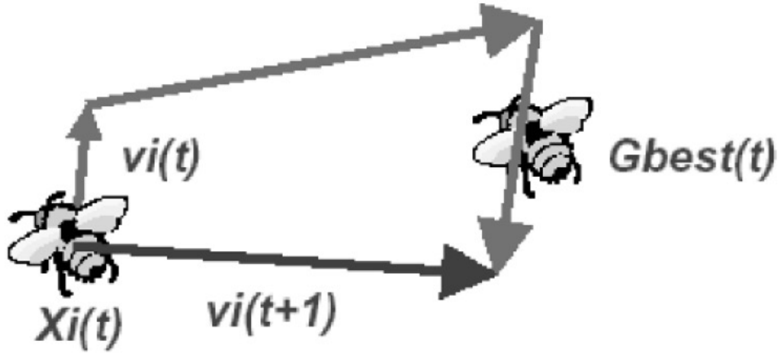
Particles velocities on each dimension

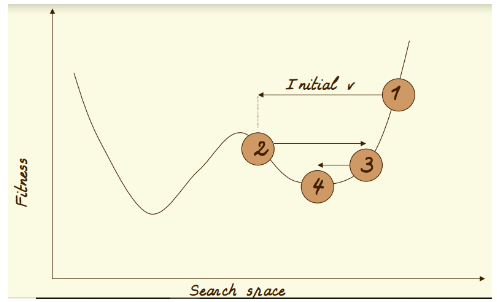
are clamped to a max velocity v_{max}



Particle Swarm Optimization







Updating velocity vector:

$$v_i(t+1) = \alpha\ v_i + c_1 \times rand \times (pbest(t)\text{-}x_i(t)) + c_2 \times rand \times (gbest(t)\text{-}x_i(t))$$

$$X_i(t+1) = X_i(t) + V_i(t+1)$$

α is inertia weight and controls exploration and exploitation
c_1 and c_2 the cognition and social components respectively
rand is a random number generator

Ant Colony Optimization

ACO Pseudocode and notations

General pseudo-code

Procedure *ACO*

Schedule Activities

Initialization

Construction

Update Pheromone

Daemon Actions {optional}

// local search, elitism

End schedule activities

End *ACO*

Parameters used in ACO

Parameter	Description
N	Total No of ants ; N>1
τ_o	Initial pheromone amount
τ_{ij}	Amount of pheromone deposited while traversing from i to j
η_{ij}	Cost of link (i,j)
α	Importance coefficient of pheromone intensity
β	Importance coefficient of route cost
ρ	evaporation co-efficient; $0<\rho<1$
$visit_k$	Visited nodes table of k^{th} ant
Q	Importance - Constant value pertaining to pheromone trail
f_k	Route cost obtained by ant k

ACO Steps

Initialization

Place predefined number of ants on starting point

Set values for parameters α, β, ρ.

Set τ_0 to 0.

Construction

Compute the next node transition probability

$$NTP_{ij} = \frac{\left(\tau_{ij}\right)^{\alpha} \left(\eta_{ij}\right)^{\beta}}{\sum_{h \notin visit_k} (\tau_{ih})^{\alpha} (\eta_{ih})^{\beta}}$$

ACO Steps

Pheromone updation:

Pheromone reinforcement & pheromone evaporation

Direct impact on the exploitation (enhancing found food path) & exploration (discovering new path) of ant algorithms

$$\tau_{ij}^{new} = (\rho)\tau_{ij}^{old} + \Delta\tau_{ij}^{k}$$

Amount of pheromone deposited on (i,j) by kth at that timestamp is given by

$$\Delta\tau_{ij}^{k} = \begin{cases} \dfrac{Q}{\boldsymbol{f_k}} & if\ k^{th} ant\ passes\ i\ and\ j \\ 0 & otherwise \end{cases}$$

Stopping criteria: reaching predetermined number of iterations

Problem: Reaching pre-determined number of iterations before reaching destination leading to ant drop

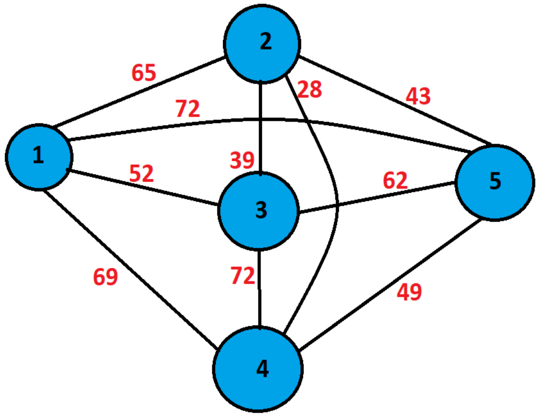
Travelling Salesman Problem

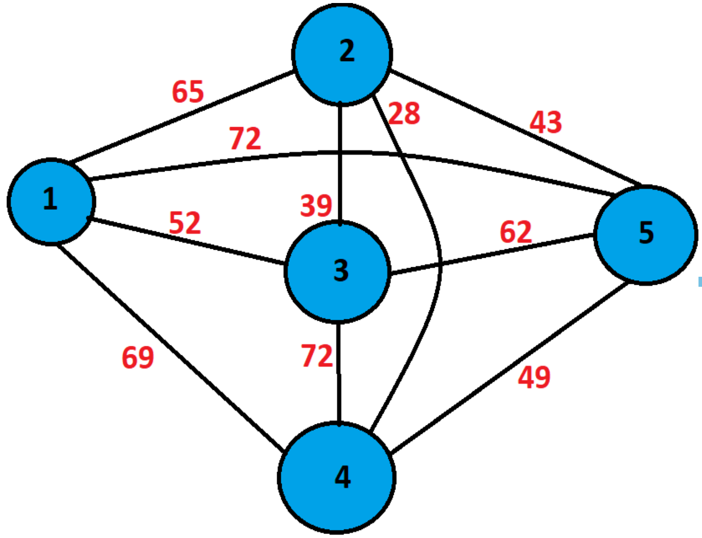
Problem: Given n cities, the goal is to find shortest path going through all cities and visiting each exactly once

- Consider a complete graph

- d_{ij} is the route cost over (i,j) $\{f_k\}$

- Each ant builds its own tour from starting city
- Each ant chooses a town to go to with a probability
- Keep tabs on visit list of each ant
- When tour completed, lay pheromone on each edge visited
- Next city *j* after city *i* chosen according to probability rule





Initially No. of ants = No. of cities.
start at 4. $\alpha = 0.5$ $\beta = 0.75$ (0–1)
$Q = 100$ $\rho = 0.1$

$T = 0$

$\tau_{12} = \tau_{21} = 0.54$

$\tau_{13} = \tau_{31} = 0.53$

$\tau_{14} = \tau_{41} = 0.35$

$\tau_{15} = \tau_{51} = 0.24$

$\tau_{23} = \tau_{32} = 0.53$

$\tau_{24} = \tau_{42} = 0.39$

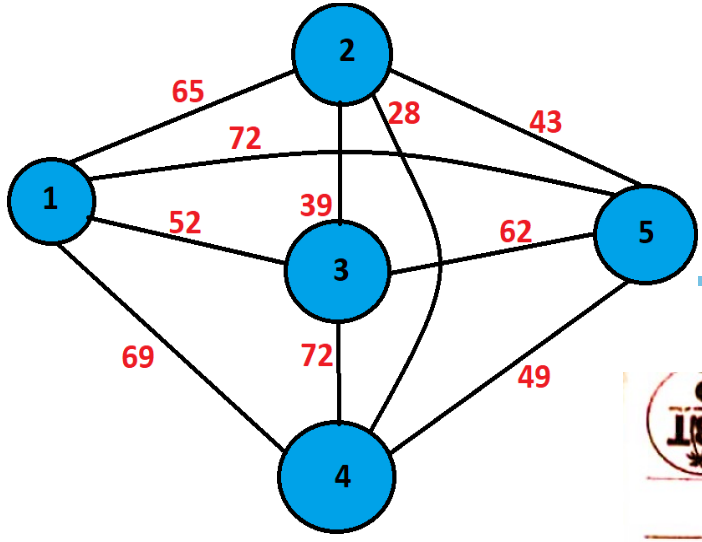
$\tau_{25} = \tau_{52} = 0.18$

$\tau_{34} = \tau_{43} = 0.32$

$\tau_{35} = \tau_{53} = 0.90$

$\tau_{45} = \tau_{54} = 0.68.$

$$\begin{array}{c|ccccc} & 1 & 2 & 3 & 4 & 5 \\ \hline 1 & 0 & 65 & 52 & 69 & 72 \\ 2 & 65 & 0 & 39 & 28 & 43 \\ 3 & 52 & 39 & 0 & 72 & 62 \\ 4 & 69 & 28 & 72 & 0 & 49 \\ 5 & 72 & 43 & 62 & 49 & 0 \end{array}$$



Initially No. of ants = No. of cities.

start at 4. $\alpha = 0.5$ $\beta = 0.75$ (0–1)

$Q = 100$ $\rho = 0.1$

$\tau = 0$

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$\tau_{35} = \tau_{53} = 0.90$

$\tau_{45} = \tau_{54} = 0.68$

Next Transition Probability.

$1/d_{ij}$

$\eta_{41} = 0.014$

$\eta_{45} = 0.02$

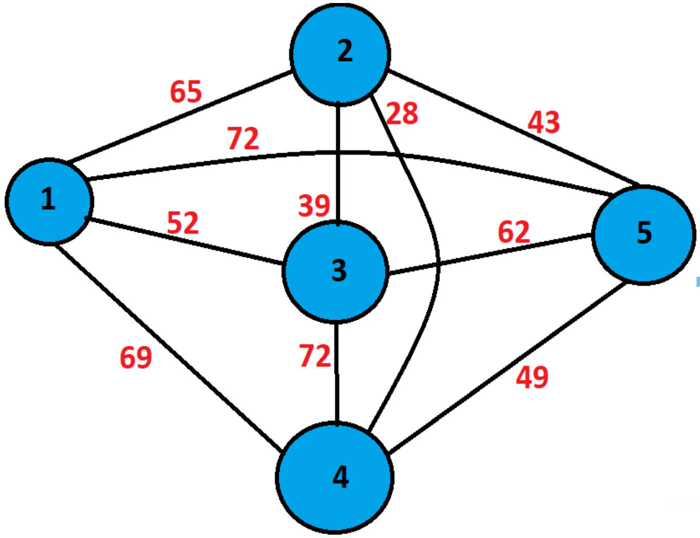
$\eta_{43} = 0.014$

$\eta_{42} = 0.036$

$$P_{41} = \frac{(\tau_{41})^{\alpha}(\eta_{41})^{\beta}}{(\tau_{41})^{\alpha}(\eta_{41})^{\beta} + (\tau_{42})^{\alpha}(\eta_{42})^{\beta} + (\eta_{43})^{\beta}(\tau_{43})^{\alpha} + (\eta_{45})^{\beta}(\tau_{45})^{\alpha}}$$

$$= \frac{(0.35)^{0.5}(0.014)^{0.75}}{(0.35)^{0.5}(0.014)^{0.75} + (0.379)^{0.5}(0.036)^{0.75} + (0.326)^{0.5}(0.014)^{0.75} + (0.683)^{0.5}(0.02)^{0.75}}$$

$$= \frac{0.024}{0.143} = 0.168.$$



Initially No. of ants = No. of cities.
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$Q = 100$ $\rho = 0.1$

$t = 0$

$\tau_{12} = \tau_{21} = 0.54$
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$\tau_{34} = \tau_{43} = 0.32$
$\tau_{35} = \tau_{53} = 0.90$
$\tau_{45} = \tau_{54} = 0.68$

$$= \frac{0.024}{0.143} = 0.168.$$

$$P_{42} = \frac{0.053}{0.142} = 0.364 \quad \underline{max}$$

$$P_{43} = \frac{0.023}{0.143} = 0.160.$$

$$P_{45} \approx 0.308$$

Since P_{42} is max, move from 4 to 2.

Initially No. of ants = No. of cities.
start at 4. $\alpha = 0.5$ $\beta = 0.75$ (0–1)
$Q = 100$ $\rho = 0.1$

Pheromone Updation (t=1)

$\tau_{12} = \rho(\tau_{12}) + \Delta\tau_{12}$

$= 0.054$.

excepting for (4,2) & (2,4) $\Delta\tau_{ij}$ is zero for all other (i,j)

$\tau_{13} = 0.053$, $\tau_{14} = 0.035$,

$\tau_{15} = 0.026$, $\tau_{23} = 0.05$,

$\tau_{24} = 0.039 + Q/d_{ij} = 0.039 + 100/28 = 3.610$

$\tau_{25} = 0.018$, $\tau_{34} = 0.032$, $\tau_{35} = 0.09$

$\tau_{45} = 0.068$.

Now ant is at 2.

$P_{21} = 0.320$

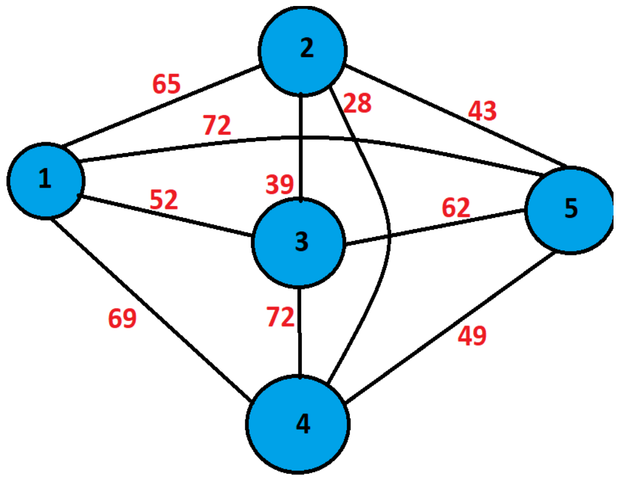
$P_{23} = 0.429$ Max.

$P_{25} = 0.250$

Now ant moves to 3!

$$\Delta\tau_{ij}^k = \begin{cases} \dfrac{Q}{\boldsymbol{f_k}} & \text{if } k^{th} \text{ ant passes } i \text{ and } j \\ 0 & \text{otherwise} \end{cases}$$

$$\tau_{ij}^{new} = (\rho)\tau_{ij}^{old} + \Delta\tau_{ij}^k$$



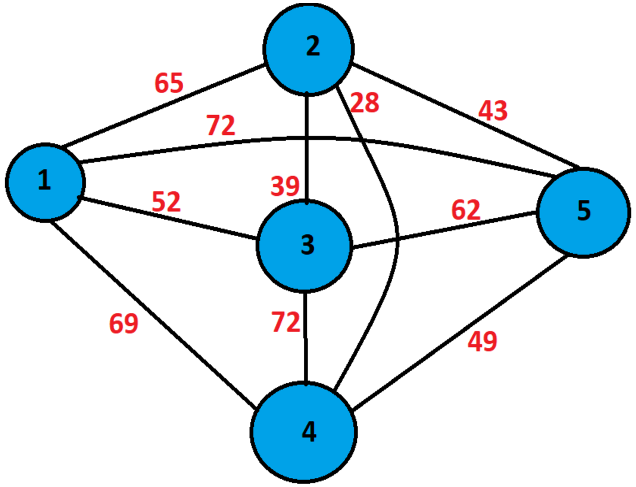
Pheromone Updation $(t=2)$:

$\tau_{12} = 0.005$, $\tau_{13} = 0.005$, $\tau_{14} = 0.003$,

$\tau_{15} = 0.002$, $\tau_{23} = 0.005 + 100/39 = 2.569$

$\tau_{24} = \rho(3.616) = 0.361$, $\tau_{25} = 0.001$

$\tau_{34} = 0.003$, $\tau_{35} = 0.009$, $\tau_{45} = 0.006$



From 3, find P_{31}, P_{35}

$P_{31} = 0.500$

$P_{35} = 0.5571$ – Max.

From 3, ant moves to 5.

Tabu list $\boxed{4, 2, 3, 5}$

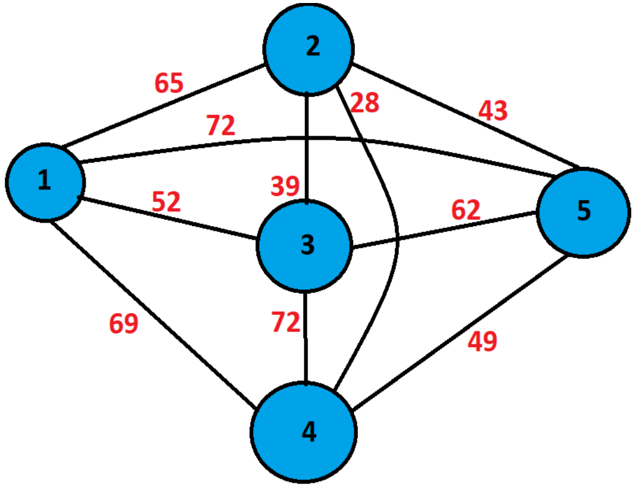
Pheromone updation $t = 3$.

$\tau_{12} = 0.0005$, $\tau_{13} = 0.0005$, $\tau_{14} = 0.0003$,

$\tau_{15} = 0.0002$, $\tau_{23} = 0.25$, $\tau_{24} = 0.03$,

$\tau_{25} = 0.0001$, $\tau_{34} = 0.0003$, $\tau_{35} = 0.0009 + 100/62 = 1.613$

$\tau_{45} = 0.0006$



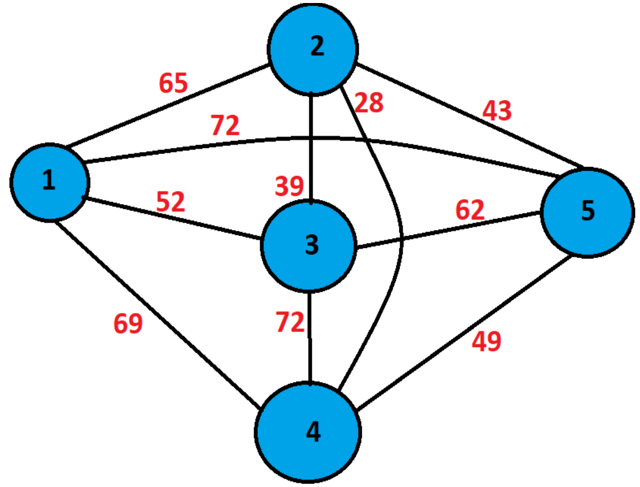
From 5, move to 1 since it is the only non-visited city. Update pheromone.

$\tau_{12} = 0.00005$, $\tau_{13} = 0.00005$, $\tau_{14} = 0.00003$,

$\cancel{\tau_{13} = 0.00002}$, $\cancel{\tau_{23} = 0}$ $\tau_{15} = 1.388$, $\tau_{23} = 0.025$

$\tau_{24} = 0.003$, $\tau_{25} = 0.00001$, $\tau_{34} = 0.00003$

$\tau_{35} = 0.16$, $\tau_{45} = 0.00006$.



Now back to origin, since all the states are visited.

update $\tau_{14} = \tau_{41} = 0.00003 \times 100/69$
$= 1.449$

Final route,

$\boxed{4 - 2 - 3 - 5 - 1 - 4}$.

Previous Year Sample Question

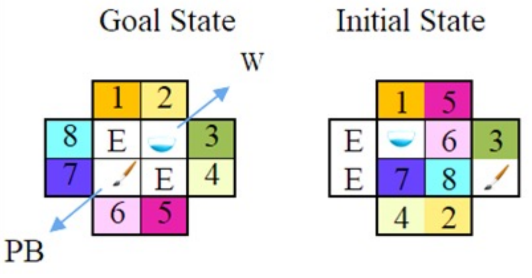
Searching - Sample Question

Consider the below initial and goal state of the problem and answer the following questions. In a color palette board arrangement problem, there are 8 different colors, a water bowl (W), a paint brush (PB), and two empty cells (E) provided. The neighboring elements of an empty tile on the color palette board, such as colored tiles, the water bowl, and the paintbrush, can swap their positions with the empty tile. An agent should find a path ie., series to swapping from the Initial state to achieve the Goal state.

Note: To understand the definition of neighbors, in the Goal state below colored tile Light Blue (8), Dark Orange (1) and water bowl (W), Paint brush (PB) are neighbors to one of the empty tile. Each transition will add a uniform path cost = 10 if the empty tiles are neither in the same row nor in the same column w.r.t resultant state. If they are in same column or in the same row the path cost must be cost = 5. When swapping the water bowl with an empty tile, add an additional cost of 3 for that resultant state.

H1: Number of Misplaced colored Tiles, water bowl and paint brush w.r.t to the goal state.

H2: Sum of Manhattan distances of all the misplaced tiles w.r.t to the goal state



Searching - Sample Question

Each transition will add a uniform path cost = 10 if the empty tiles are neither in the same row nor in the same column w.r.t resultant state. If they are in same column or in the same row the path cost must be cost = 5. When swapping the water bowl with an empty tile, add an additional cost of 3 for that resultant state.

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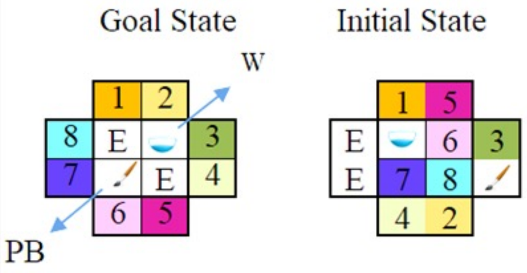
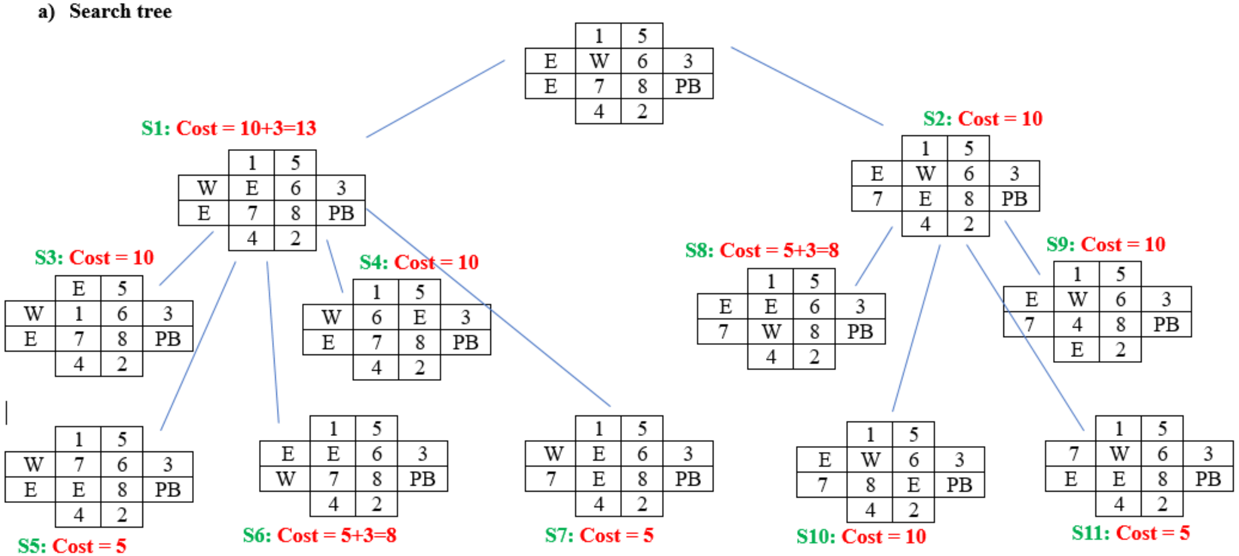
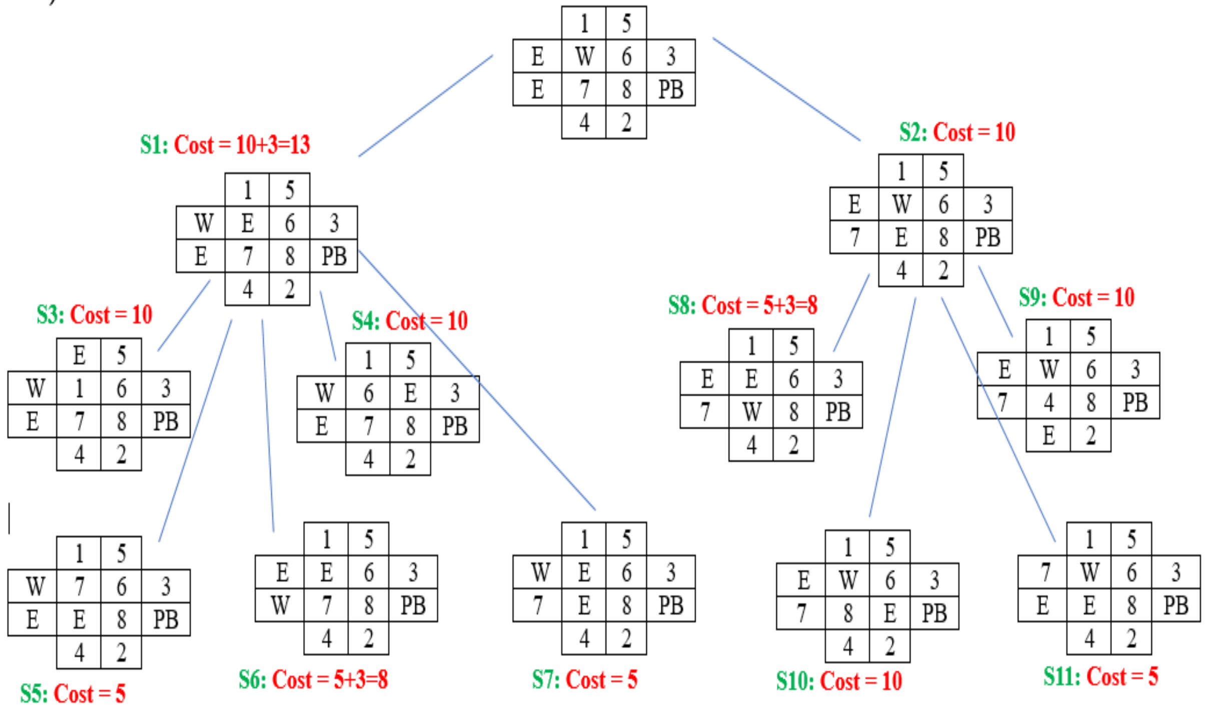


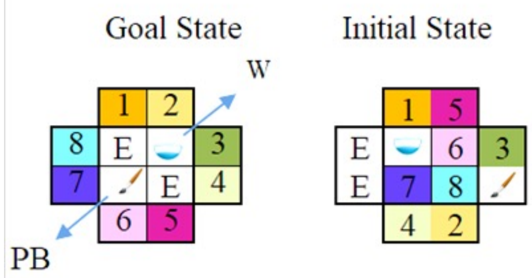
a) Search tree



Searching - Sample Question

a) Search tree





To find H1 & H2

H1 = Number of misplaced tiles, WB and PB with respect to Goal state

H2 = Sum of Manhattan distances of all the misplaced tiles with respect to the Goal state

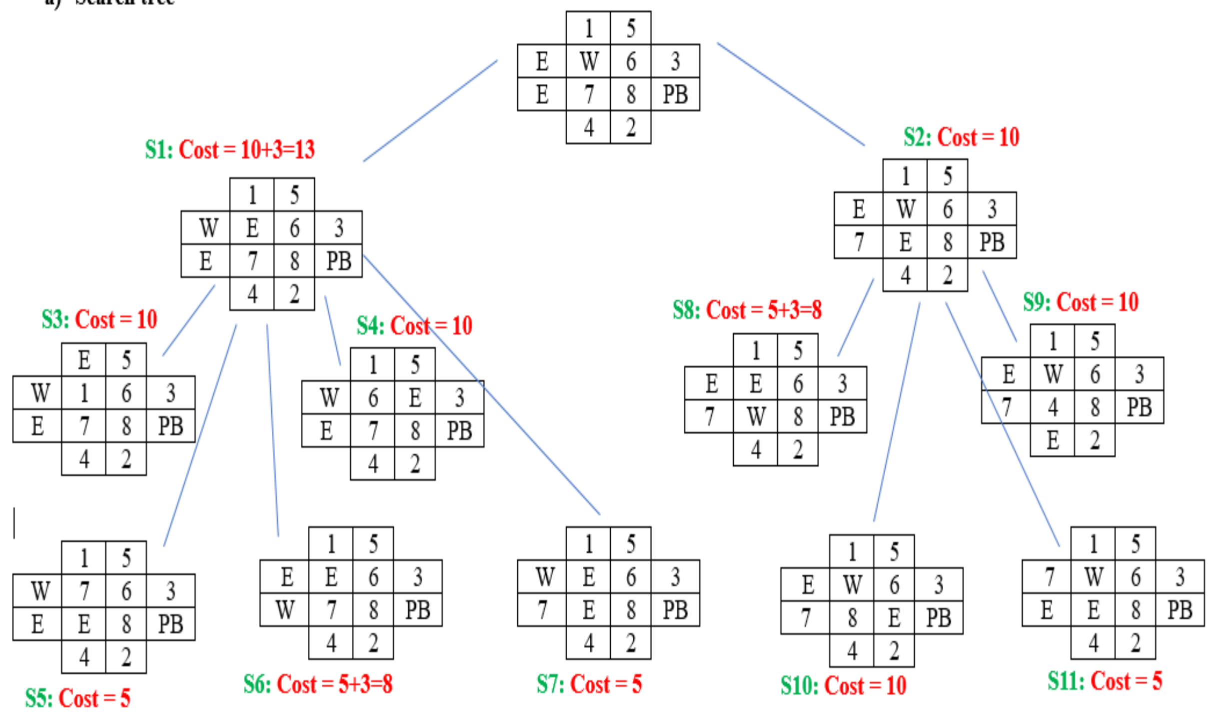
Goal State:

	1	2	
8	E	W	3
7	PB	E	4
	6	5	

Node	H1	H2	H(n) = h2(n) + g(n)
S1	8	3+2+3+1+3+2+3+3=20	33
S2	7	3+1+3+3+2+3+3=18	28
S3	9	21	31
S4	8	19	29

Searching - Sample Question

a) Search tree



To find H1 & H2

H1 = Number of misplaced tiles, WB and PB with respect to Goal state

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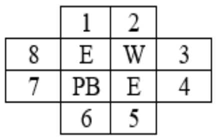
Goal State:



Node	H1	H2	H(n) = h2(n) + g(n)
S1	8	3+2+3+1+3+2+3+3=20	33
S2	7	3+1+3+3+2+3+3=18	28
S3	9	21	31
S4	8	19	29

Note:

Instruct the students to practice all the algorithms listed below. Emphasize that they should use the tabulated trace recommended by the faculty in class to show the step by step working of algorithm till first 4 iterations or the 3 levels of search tree generation whichever is achieved the latest in respective algorithms.

- Breadth first search
- Depth First Search
- Uninform Cost search
- Iterative Deepening Depth First search
- Greedy Best First Search
- A* search
- Iterative Deepening A*
- Recursive Best First Search

Genetic Algorithm Sample Question

You have been asked to solve below linear equation problem with multiple variables:

$$2a + 7b - 5c + d = 0$$

where a, b,c, and d are integers in the range [-20,20] (equation can have more than one solution)
You have decided to solve this question using genetic algorithm. Show all the steps involved in solving this using Genetic Algorithm. Number each of your steps, and provide appropriate title to those steps. (No need to get the final solution, just the first iteration of each step involved in the algorithm)

Most likely representation of chromosome could be a list with 4 integers with each integer representing variables a,b,c or d. For example [3,2,3,1] would imply a=3,b=2,c=3,d=1.

Generate random population (list of lists)

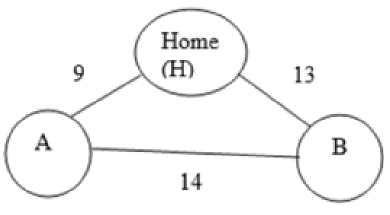
Fitness function - use a fitness function (most likely f(x) = 2a + 7b -5c +d) and calculate the fitness of each individual

Apply some selection criteria based on fitness value (could be roulette or the best fit etc.) to come up with initial population

Apply crossover and mutation (how students chose to incorporate crossover and mutation may differ but it should be consistent)

ACO - Sample Question

a) Abhay is on a tour. He starts from home and visits two cities and has to reach back home. The cost of each route between cities and between his home and cities is given below in the form of graph. Determine the shortest path through Ant Colony Optimization. Use the following information regarding the various parameters for ACO.



Pheromone matrix is as given below:

	H	A	B
H	0	0.15	0.26
A	0.15	0	0.48
B	0.26	0.48	0

Rate of evaporation = 0.1; Q = 90; The relative importance of pheromone is 0.3 and the relative importance of distance is 0.4;

MID SEM Syllabus

Session #	List of Topic Title (from content structure in Part A)	References
1	(1) What is Artificial Intelligence: Acting Humanly, Thinking humanly, Thinking rationally, Acting Rationally (2) Foundations of AI (3) Brief Overview of Modern AI & Application Domains.	T1: 1.1 T1: 1.2, 1.4
2	(1) Intelligent Agents: Notion of Agents and Environments, Rationality (2) Nature of Environments, Structure of Agents	T1: Chapter 2
3	Problem Solving Agent: (1) Problem Formulation - Examples (2) Uninformed Search Algorithms: Uniform cost Search, Depth Limited Search, Iterative Deepening Search. (3) Notion of Heuristics (4) Informed Search Algorithms : Greedy best first search, A* search	T1: Chapter 3.1-3.4, 3.5.1, 3.5.2
4	Problem Solving Agent using Informed Search: (1) Optimality of A* Heuristic Functions: (1) Heuristic Accuracy & Algorithm performance (2) Admissible heuristics from relaxed problems, pattern databases. & Experience	T1: Chapter 3.5.2, 3.6
5	Local Search Algorithms & Optimization Problems (1) Hill Climbing Search (2) Simulated Annealing, (3) Local Beam Search	T1: Chapter 4.1
6	Local Search Algorithms & Optimization Problems (1) Genetic Algorithm	T1: Chapter 4.1, Research papers & web resources
7	Local Search Algorithms & Optimization Problems (1) Ant Colony Optimization (2) Particle Swarm Optimization	Research papers & web resources

Required Reading: AIMA - Chapter # 4.1, #4.2, #5.1

Thank You for all your Attention

Note : Some of the slides are adopted from AIMA TB materials