VISVESVARAYA TECHNOLOGICAL UNIVERSITY

"JnanaSangama", Belgaum -590014, Karnataka.

LAB REPORT
on

Artificial Intelligence (23CS5PCAIN)

Submitted by

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in partial fulfillment for the award of the degree of
BACHELOR OF ENGINEERING
in
COMPUTER SCIENCE AND ENGINEERING

B.M.S. COLLEGE OF ENGINEERING
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B.M.S. College of Engineering,

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(Affiliated To Visvesvaraya Technological University, Belgaum)

Department of Computer Science and Engineering

CERTIFICATE

This is to certify that the Lab work entitled "Artificial Intelligence (23CS5PCAIN)" carried out by **Sanjeet Prajwal Pandit (1BM22CS241),** who is bonafide student of **B.M.S. College of Engineering.** It is in partial fulfillment for the award of **Bachelor of Engineering in Computer Science and Engineering** of the Visvesvaraya Technological University, Belgaum. The Lab report has been approved as it satisfies the academic requirements in respect of an Artificial Intelligence (23CS5PCAIN) work prescribed for the said degree.

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Github Link:
https://github.com/Sanjeet-108/AI_Lab

<u>Program 1</u>
Implement Tic –Tac –Toe Game
Implement vacuum cleaner agent

Algorithm:

DATE :

(1) Tic - Tac - Toe

Step1 Initialize array with blank character to show that the cell is empty

Step2 for the given input co-ordinates, check if it is valid and if the co-ordinate is valid check if the corresponding cell is empty in the array

Step3 check for horizontal, vertical and diagonal possibility of the input character

Step4 Display the array and winner of the game and break the loop

Step5 game is tie if no one is the winner

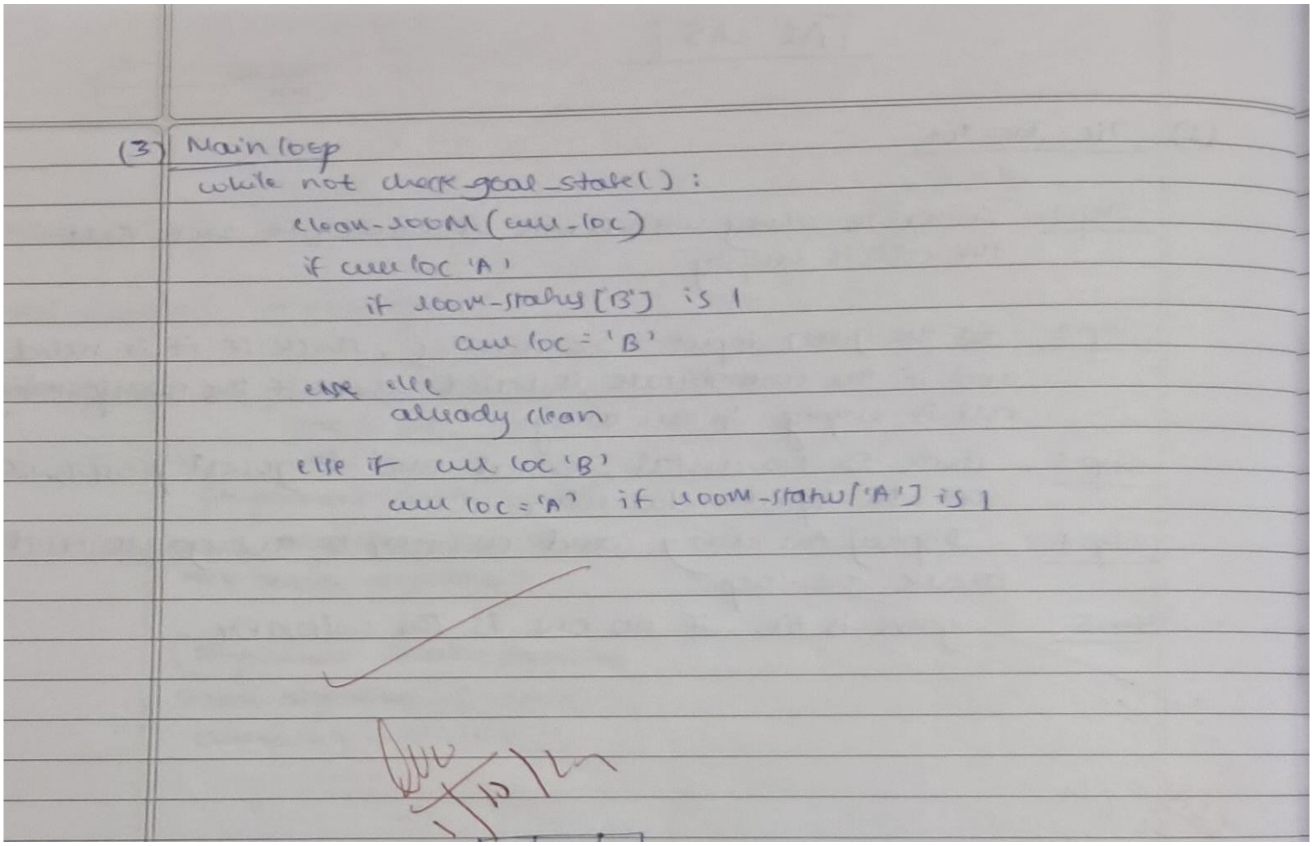
(2) Function Reflex-Vacuum-Agent [location, status] returns an action
if status = Dirty then return Suck
else if location = A then return Right
else if location = B then return left

| A | B |

| A | B |
| C | D |

(1) → set goalstate to ['A'; 0, 'B', 0]
room-status as {'A' : 1, 'B' : 0}
total-cost = 0
curr-loc = 'A'

(2) fxn check-goal-state : returns true if both are clean
fxn clean-room (room) :
if room-status [room] = 1 clean it by making it zero (increment total cost by 1)
else its already cleaned


(3) Main loop
while not check_goal_state():
    clean-room(curr-loc)
    if curr loc 'A'
        if room-status['B'] is 1
            curr loc = 'B'
    else
        already clean
    else if curr loc 'B'
        curr loc = 'A' if room-status['A'] is 1

Code:
(Tic –Tac –Toe)

```
import numpy as np

board=np.array([['-','-','-'],['-','-','-'],['-','-','-']])

current_player='X'
flag=0

def check_win():
    for i in range(3):
        if board[i][0] == board[i][1] == board[i][2] != '-':
            return True
    for i in range(3):
        if board[0][i] == board[1][i] == board[2][i] != '-':
            return True
    if board[0][0] == board[1][1] == board[2][2] != '-':
        return True
    if board[0][2] == board[1][1] == board[2][0] != '-':
        return True
    return False

def tic_tac_toe():
```

```
    n=0
    print(board)
    while n<9:
        if n%2==0:
            current_player='X'
        else :
            current_player='O'

        row = int(input("Enter row: "))
        col = int(input("Enter column: "))

        if(board[row][col]=='-'):
            board[row][col]=current_player
            print(board)
            flag=check_win();
            if flag==1:
                print(current_player+' wins')
                break
            else:
                n=n+1
        else :
            print("Invalid Position")

    if n==9:
        print("Draw")

tic_tac_toe()2
```

```
[['-' '-' '-']
 ['-' '-' '-']
 ['-' '-' '-']]
Enter row: 0
Enter column: 1
[['-' 'X' '-']
 ['-' '-' '-']
 ['-' '-' '-']]
Enter row: 0
Enter column: 0
[['O' 'X' '-']
 ['-' '-' '-']
 ['-' '-' '-']]
Enter row: 1
Enter column: 0
[['O' 'X' '-']
 ['X' '-' '-']
 ['-' '-' '-']]
Enter row: 1
Enter column: 1
[['O' 'X' '-']
 ['X' 'O' '-']
 ['-' '-' '-']]
Enter row: 1
Enter column: 2
[['O' 'X' '-']
 ['X' 'O' 'X']
 ['-' '-' '-']]
Enter row: 2
Enter column: 2
[['O' 'X' '-']
 ['X' 'O' 'X']
 ['-' '-' 'O']]
O wins
```

(vacuum cleaner agent)

```
cost =0
def vacuum_world(state, location):
  global cost
  if(state['A']==0 and state['B']==0):
    print('All rooms are clean')
    return

  if state[location]==1:
    state[location]=0
    cost+=1
    state[location]=(int(input('Is room '+ str(location) +' still dirty : ')))

    if state[location]==1:
      return vacuum_world(state, location)
```

```
    else:
      print('Room ' + str(location) + ' cleaned')

  next_location='B' if location=='A' else 'A'
  if state[next_location]==0:
    state[next_location]=(int(input('Is room '+ str(next_location) +' dirty : ')))
  print('Moving to room '+str(next_location))
  return vacuum_world(state, next_location)

state={}
state['A']=int(input('Enter status of room A : '))
state['B']=int(input('Enter status of room B : '))
location=input('Enter initial location of vacuum (A/B) : ')
vacuum_world(state,location)
print("Status = "+str(state))
print('Total cost: ' + str(cost))
```

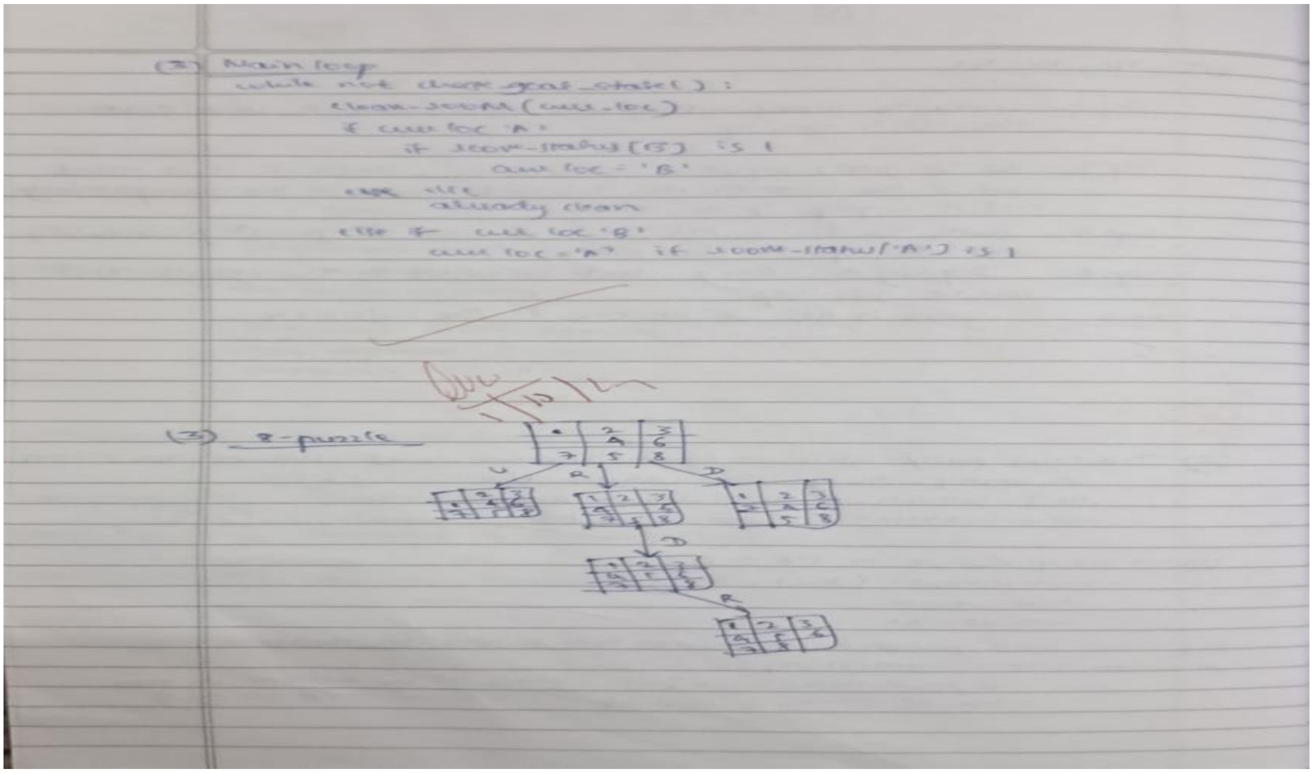
```
Enter status of room A : 1
Enter status of room B : 1
Enter initial location of vacuum (A/B) : A
Is room A still dirty : 0
Room A cleaned
Moving to room B
Is room B still dirty : 0
Room B cleaned
Is room A dirty : 0
Moving to room A
All rooms are clean
Status = {'A': 0, 'B': 0}
Total cost: 2
```

Program 2

Implement 8 puzzle problems using Depth First Search (DFS)

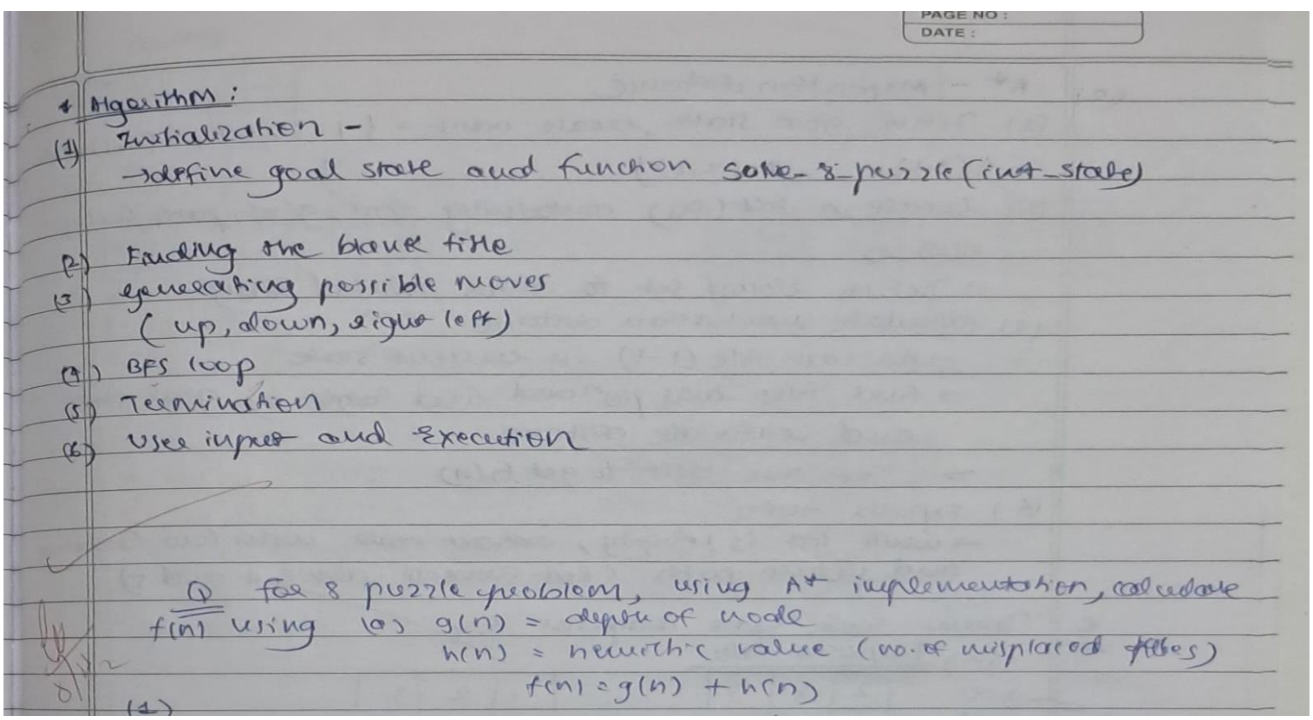
Implement Iterative deepening search algorithm

Algorithm:



(2) Main loop
while not check_goal_state():
clean_room(curr_loc)
if curr loc 'A':
if room_status['B'] is 1
curr loc = 'B'
else
already clean
else if curr loc 'B'
curr loc = 'A' if room_status['A'] is 1

(3) 8-puzzle



4 Algorithm:

(1) Initialization -
→define goal state and function solve_8_puzzle(init_state)

(2) Finding the blank tile

(3) generating possible moves
(up, down, right left)

(4) BFS loop

(5) Termination

(6) User input and Execution

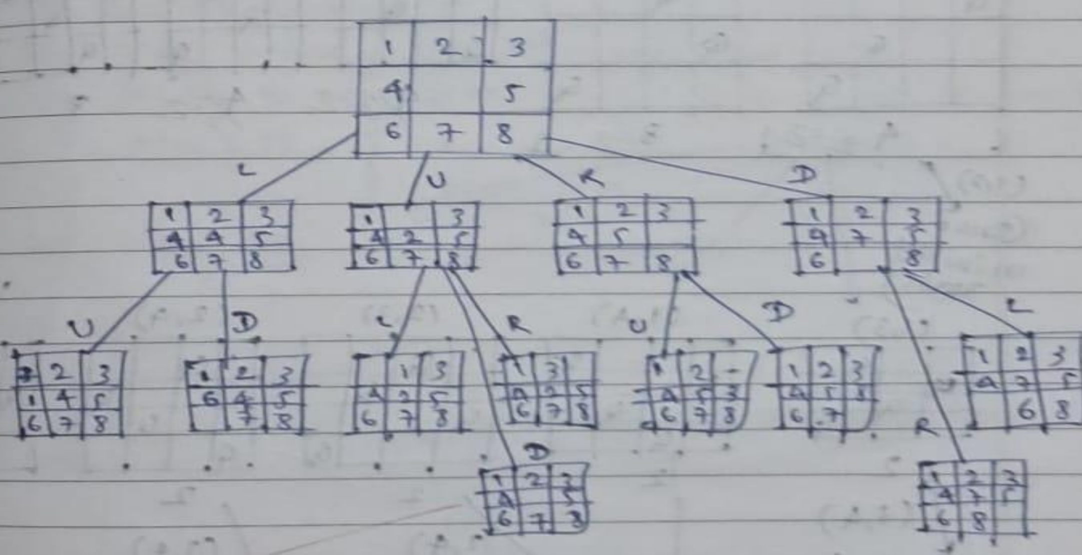
Q For 8 puzzle problem, using A* implementation, calculate
f(n) using (a) $g(n)$ = depth of node
$h(n)$ = heuristic value (no. of misplaced tiles)
$f(n) = g(n) + h(n)$

(1)

Iterative Deepening

(1) For each child of current node
(2) If it is target node, return
(3) If current maximum depth is reached, return
(4) Set current node to this node & go back to 1
(5) After having gone through all children, go to next child of parent (the next sibling)
(6) After having gone through all children of start node, increase maximum depth & go back to 1
(7) If we have reached all leaf (bottom) nodes, goal node doesn't exist

fxn It-Deep-Search (problem) return a soln, or failure
for depth = 0 to ∞ do
result ← Depth-limited-search (problem, depth)
if result ≠ cutoff then return result



Code:
(8 puzzle problems using Depth First Search (DFS))

```
cnt = 0;
def print_state(in_array):
global cnt
cnt += 1
for row in in_array:
print(' '.join(str(num) for num in row))
print() # Print a blank line for better readability


def helper(goal, in_array, row, col, vis):
# Mark the current position as visited
vis[row][col] = 1
drow = [-1, 0, 1, 0] # Directions for row movements: up, right, down, left
dcol = [0, 1, 0, -1] # Directions for column movements
dchange = ['U', 'R', 'D', 'L']


# Print the current state
print("Current state:")
print_state(in_array)


# Check if the current state is the goal state
if in_array == goal:
print_state(in_array)
print(f"Number of states : {cnt}")
return True


# Explore all possible directions
for i in range(4):
nrow = row + drow[i]
ncol = col + dcol[i]


# Check if the new position is within bounds and not visited
if 0 <= nrow < len(in_array) and 0 <= ncol < len(in_array[0]) and not vis[nrow][ncol]:
# Make the move (swap the empty space with the adjacent tile)
print(f"Took a {dchange[i]} move")
in_array[row][col], in_array[nrow][ncol] = in_array[nrow][ncol], in_array[row][col]


# Recursive call
if helper(goal, in_array, nrow, ncol, vis):
```

```
return True


# Backtrack (undo the move)
in_array[row][col], in_array[nrow][ncol] = in_array[nrow][ncol], in_array[row][col]
# Mark the position as unvisited before
returning vis[row][col] = 0
return False

# Example usage
initial_state = [[1, 2, 3], [0, 4, 6], [7, 5, 8]] # 0 represents the empty space
goal_state = [[1, 2, 3], [4, 5, 6], [7, 8, 0]]
visited = [[0] * 3 for _ in range(3)] # 3x3 visited matrix
empty_row, empty_col = 1, 0 # Initial position of the
empty space
found_solution = helper(goal_state, initial_state, empty_row, empty_col,
visited) print("Solution found:", found_solution)
```

```
Took a L move
Current state:
1 2 3
4 6 8
0 7 5

Took a D move
Current state:
1 2 3
4 5 6
7 0 8

Took a R move
Current state:
1 2 3
4 5 6
7 8 0

1 2 3
4 5 6
7 8 0

Number of states : 42
Solution found: True
```

(Iterative deepening search algorithm)

```
class PuzzleState:
    def __init__(self, board, empty_tile_pos, depth=0, path=[]):
        self.board = board
        self.empty_tile_pos = empty_tile_pos  # (row, col)
        self.depth = depth
        self.path = path  # Keep track of the path taken to reach this state

    def is_goal(self, goal):
        return self.board == goal

    def generate_moves(self):
        row, col = self.empty_tile_pos
        moves = []
        directions = [(-1, 0, 'Up'), (1, 0, 'Down'), (0, -1, 'Left'), (0, 1, 'Right')]  # up, down, left, right
        for dr, dc, move_name in directions:
            new_row, new_col = row + dr, col + dc
            if 0 <= new_row < 3 and 0 <= new_col < 3:
                new_board = self.board[:]
                new_board[row * 3 + col], new_board[new_row * 3 + new_col] = new_board[new_row *
3 + new_col], new_board[row * 3 + col]
                new_path = self.path + [move_name]  # Update the path with the new move
                moves.append(PuzzleState(new_board, (new_row, new_col), self.depth + 1, new_path))
        return moves

    def display(self):
        # Display the board in a matrix form
        for i in range(0, 9, 3):
            print(self.board[i:i + 3])
        print(f"Moves: {self.path}")  # Display the moves taken to reach this state
        print()  # Newline for better readability

def iddfs(initial_state, goal, max_depth):
    for depth in range(max_depth + 1):
        print(f"Searching at depth: {depth}")
        found = dls(initial_state, goal, depth)
        if found:
            print(f"Goal found at depth: {found.depth}")
            found.display()
            return found
    print("Goal not found within max depth.")
    return None

def dls(state, goal, depth):
    if state.is_goal(goal):
        return state
```

```
    if depth <= 0:
        return None

    for move in state.generate_moves():
        print("Current state:")
        move.display()  # Display the current state
        result = dls(move, goal, depth - 1)
        if result is not None:
            return result
    return None

def main():
    # User input for initial state, goal state, and maximum depth
    initial_state_input = input("Enter initial state (0 for empty tile, space-separated, e.g. '1 2 3 4 5 6 7 8 0'): ")
    goal_state_input = input("Enter goal state (0 for empty tile, space-separated, e.g. '1 2 3 4 5 6 7 8 0'): ")
    max_depth = int(input("Enter maximum depth: "))

    initial_board = list(map(int, initial_state_input.split()))
    goal_board = list(map(int, goal_state_input.split()))
    empty_tile_pos = initial_board.index(0) // 3, initial_board.index(0) % 3  # Calculate the position of the empty tile

    initial_state = PuzzleState(initial_board, empty_tile_pos)

    solution = iddfs(initial_state, goal_board, max_depth)

if __name__ == "__main__":
    main()
```

```
Enter initial state (0 for empty tile, space-separated, e.g. '1 2 3 4 5 6 7 8 0'): 1 2 3 0 4 6 7 5 8
Enter goal state (0 for empty tile, space-separated, e.g. '1 2 3 4 5 6 7 8 0'): 1 2 3 4 5 6 7 8 0
Enter maximum depth: 2
Searching at depth: 0
Searching at depth: 1
Current state:
[0, 2, 3]
[1, 4, 6]
[7, 5, 8]
Moves: ['Up']

Current state:
[1, 2, 3]
[7, 4, 6]
[0, 5, 8]
Moves: ['Down']

Current state:
[1, 2, 3]
[4, 0, 6]
[7, 5, 8]
Moves: ['Right']

Searching at depth: 2
Current state:
[0, 2, 3]
[1, 4, 6]
[7, 5, 8]
Moves: ['Up']
```

```
Current state:
[1, 2, 3]
[4, 0, 6]
[7, 5, 8]
Moves: ['Right']

Current state:
[1, 0, 3]
[4, 2, 6]
[7, 5, 8]
Moves: ['Right', 'Up']

Current state:
[1, 2, 3]
[4, 5, 6]
[7, 0, 8]
Moves: ['Right', 'Down']

Current state:
[1, 2, 3]
[0, 4, 6]
[7, 5, 8]
Moves: ['Right', 'Left']

Current state:
[1, 2, 3]
[4, 6, 0]
[7, 5, 8]
Moves: ['Right', 'Right']

Goal not found within max depth.
```

Program 3

Implement A* search algorithm Algorithm:

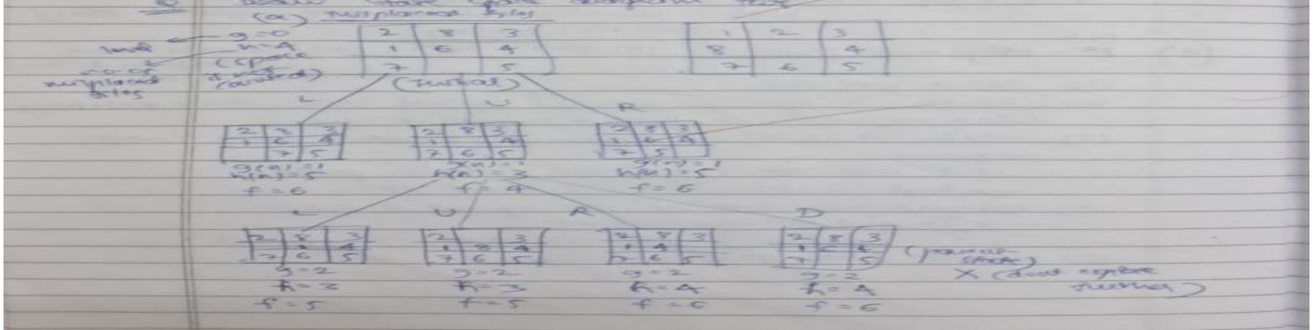
Q. For 8 puzzle problem, using A* implementation, calculate f(n) using (a) g(n) = depth of node
h(n) = heuristic value (no. of misplaced tiles)
f(n) = g(n) + h(n)
(b) g(n) = depth, h(n) = heuristic value (manhattan distance)
f(n) = g(n) + h(n)

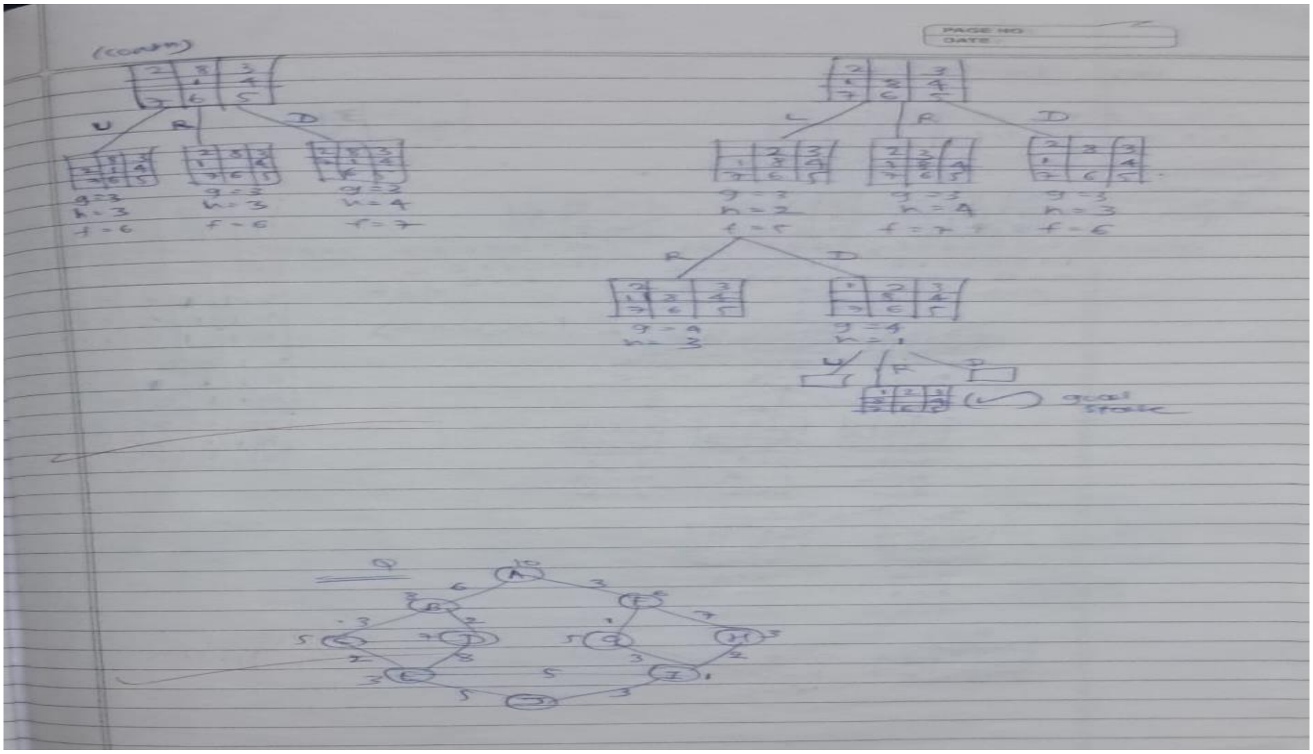
(1) A* - Misplaced Tiles

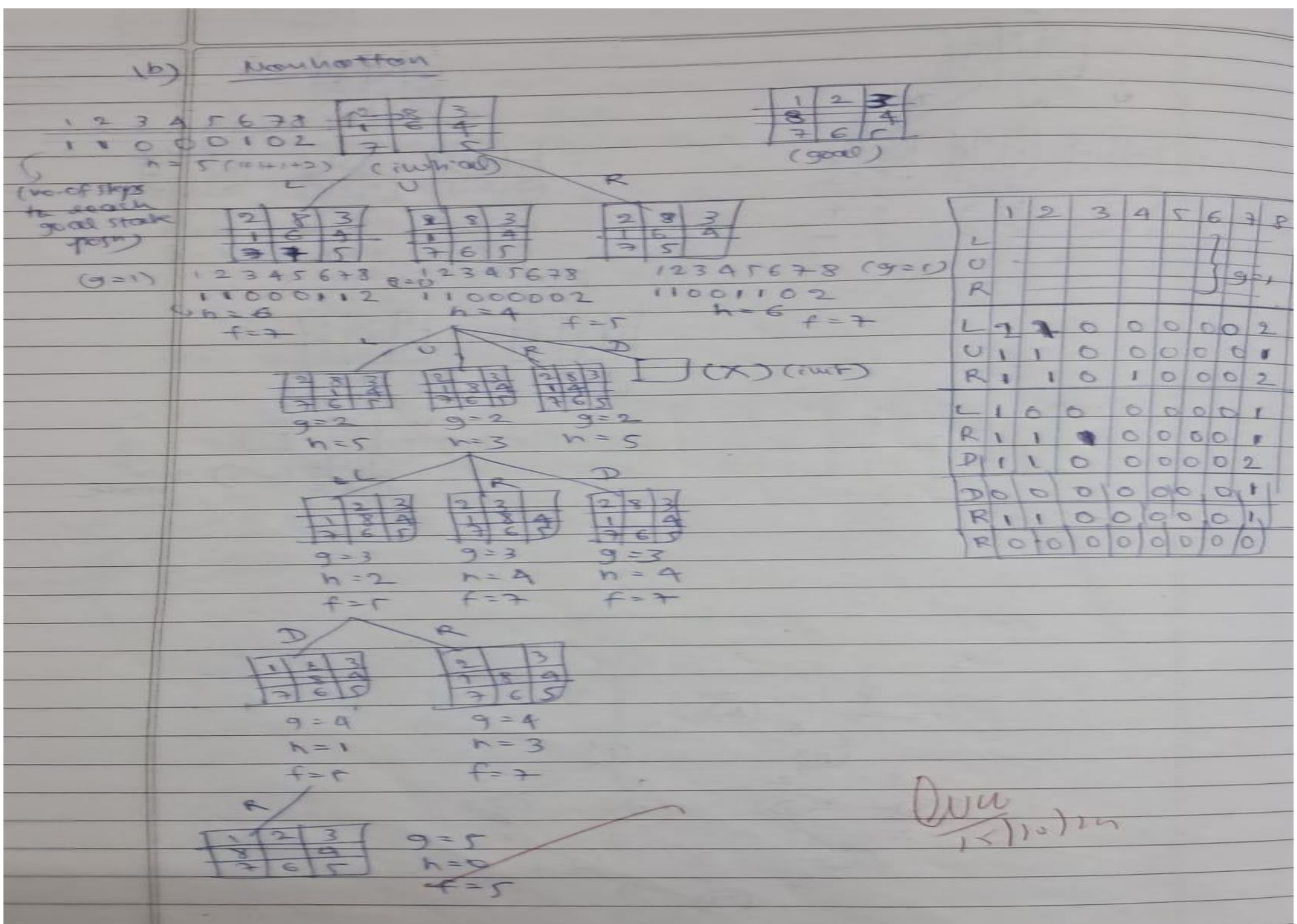
(1) Define goal state
(2) Define list (priority queue) & initial state f(n) = g(n) + h(n) where g(n) = 0 and h(n) → misplaced tiles
(3) While list is not empty, extract node with lowest frequency
→ If curr state is goal state, return path
→ Add the curr state to closed set
(4) Generate new state by moving U, D, L, R
→ If new state is not in closed set
→ calculate g(n) for new state and h(n) & f(n)
(5) Continue until goal reached.

(2) A* - manhattan distance
(1) Define goal state, create coord = {1: (0,0), 2: (0,1), 3: (0,2), 4 (1,1), ... 0: (2,2)}
(2) Create a list (PQ) containing f(n), g(n), path with g(n) = 0
→ Define closed set to track visited states
(3) Calculate manhattan distance
→ for each tile (1-8) in current state
→ find tiles curr pos^n and find target by goal state and calculate distance
→ Sum the diff to get h(n)
(4) Expand nodes
→ while list is not empty, extract node with low frequency and return path (rest same as above 4 and 5)

Q. Draw state space diagram for
(a) Misplaced tiles




(contd)
goal state


(b) Manhattan
(initial)
(goal)

Code:

```
class Node:
    def __init__(self, state, parent=None, move=None, cost=0):
        self.state = state
        self.parent = parent
        self.move = move
        self.cost = cost

    def heuristic(self):
        goal_state = [[1,2,3], [8,0,4], [7,6,5]]
        count = 0
        for i in range(len(self.state)):
            for j in range(len(self.state[i])):
                if self.state[i][j] != 0 and self.state[i][j] != goal_state[i][j]:
                    count += 1
        return count

def get_blank_position(state):
    for i in range(len(state)):
        for j in range(len(state[i])):
            if state[i][j] == 0:
                return i, j

def get_possible_moves(position):
    x, y = position
    moves = []
    if x > 0: moves.append((x - 1, y, 'Down'))
    if x < 2: moves.append((x + 1, y, 'Up'))
    if y > 0: moves.append((x, y - 1, 'Right'))
    if y < 2: moves.append((x, y + 1, 'Left'))
    return moves

def generate_new_state(state, blank_pos, new_blank_pos):
    new_state = [row[:] for row in state]
    new_state[blank_pos[0]][blank_pos[1]], new_state[new_blank_pos[0]][new_blank_pos[1]] = \
        new_state[new_blank_pos[0]][new_blank_pos[1]], new_state[blank_pos[0]][blank_pos[1]]
    return new_state

def a_star_search(initial_state):
    open_list = []
    closed_list = set()

    initial_node = Node(state=initial_state, cost=0)
    open_list.append(initial_node)

    while open_list:
```

```
        open_list.sort(key=lambda node: node.cost + node.heuristic())
        current_node = open_list.pop(0)


        move_description = current_node.move if current_node.move else "Start"
        print("Current state:")
        for row in current_node.state:
            print(row)
        print(f"Move: {move_description}")
        print(f"Heuristic value (misplaced tiles): {current_node.heuristic()}")
        print(f"Cost to reach this node: {current_node.cost}\n")

        if current_node.heuristic() == 0:

            path = []
            while current_node:
                path.append(current_node)
                current_node = current_node.parent
            return path[::-1]
        closed_list.add(tuple(map(tuple, current_node.state)))

        blank_pos = get_blank_position(current_node.state)
        for new_blank_pos in get_possible_moves(blank_pos):
            new_state = generate_new_state(current_node.state, blank_pos, (new_blank_pos[0],
new_blank_pos[1]))

            if tuple(map(tuple, new_state)) in closed_list:
                continue

            cost = current_node.cost + 1
            move_direction = new_blank_pos[2]
            new_node = Node(state=new_state, parent=current_node, move=move_direction, cost=cost)

            if new_node not in open_list:
                open_list.append(new_node)

    return None

initial_state = [[2,8,3], [1,6,4], [7,0,5]]
solution_path = a_star_search(initial_state)

if solution_path:
    print("Solution path:")
    for step in solution_path:
        for row in step.state:
            print(row)
        print()
```

```
else:
    print("No solution found.")
```

```
Current state:
[1, 2, 3]
[8, 0, 4]
[7, 6, 5]
Move: Left
Heuristic value (misplaced tiles): 0
Cost to reach this node: 5

Solution path:
[2, 8, 3]
[1, 6, 4]
[7, 0, 5]

[2, 8, 3]
[1, 0, 4]
[7, 6, 5]

[2, 0, 3]
[1, 8, 4]
[7, 6, 5]

[0, 2, 3]
[1, 8, 4]
[7, 6, 5]

[1, 2, 3]
[0, 8, 4]
[7, 6, 5]

[1, 2, 3]
[8, 0, 4]
[7, 6, 5]
```

```
class Node:
    def __init__(self, state, parent=None, move=None, cost=0):
        self.state = state
        self.parent = parent
        self.move = move
        self.cost = cost

    def heuristic(self):
        goal_positions = {
            1: (0, 0), 2: (0, 1), 3: (0, 2),
            8: (1, 0), 0: (1, 1), 4: (1, 2),
            7: (2, 0), 6: (2, 1), 5: (2, 2)
        }
```

```
        manhattan_distance = 0
        for i in range(len(self.state)):
            for j in range(len(self.state[i])):
                value = self.state[i][j]
                if value != 0:
                    goal_i, goal_j = goal_positions[value]
                    manhattan_distance += abs(i - goal_i) + abs(j - goal_j)
        return manhattan_distance

def get_blank_position(state):
    for i in range(len(state)):
        for j in range(len(state[i])):
            if state[i][j] == 0:
                return i, j

def get_possible_moves(position):
    x, y = position
    moves = []
    if x > 0: moves.append((x - 1, y, 'Down'))
    if x < 2: moves.append((x + 1, y, 'Up'))
    if y > 0: moves.append((x, y - 1, 'Right'))
    if y < 2: moves.append((x, y + 1, 'Left'))
    return moves

def generate_new_state(state, blank_pos, new_blank_pos):
    new_state = [row[:] for row in state]
    new_state[blank_pos[0]][blank_pos[1]], new_state[new_blank_pos[0]][new_blank_pos[1]] = \
        new_state[new_blank_pos[0]][new_blank_pos[1]], new_state[blank_pos[0]][blank_pos[1]]
    return new_state

def a_star_search(initial_state):
    open_list = []
    closed_list = set()

    initial_node = Node(state=initial_state, cost=0)
    open_list.append(initial_node)

    while open_list:

        open_list.sort(key=lambda node: node.cost + node.heuristic())
        current_node = open_list.pop(0)


        move_description = current_node.move if current_node.move else "Start"
        print("Current state:")
        for row in current_node.state:
            print(row)
```

```
        print(f"Move: {move_description}")
        print(f"Heuristic value (Manhattan distance): {current_node.heuristic()}")
        print(f"Cost to reach this node: {current_node.cost}\n")

        if current_node.heuristic() == 0:

            path = []
            while current_node:
                path.append(current_node)
                current_node = current_node.parent
            return path[::-1]
        closed_list.add(tuple(map(tuple, current_node.state)))

        blank_pos = get_blank_position(current_node.state)
        for new_blank_pos in get_possible_moves(blank_pos):
            new_state = generate_new_state(current_node.state, blank_pos, (new_blank_pos[0],
new_blank_pos[1]))

            if tuple(map(tuple, new_state)) in closed_list:
                continue

            cost = current_node.cost + 1
            move_direction = new_blank_pos[2]
            new_node = Node(state=new_state, parent=current_node, move=move_direction, cost=cost)

            if new_node not in open_list:
                open_list.append(new_node)

    return None

initial_state = [[2,8,3], [1,6,4], [7,0,5]]
solution_path = a_star_search(initial_state)

if solution_path:
    print("Solution path:")
    for step in solution_path:
        for row in step.state:
            print(row)
        print()
else:
    print("No solution found.")
```

```
Current state:
[1, 2, 3]
[8, 0, 4]
[7, 6, 5]
Move: Left
Heuristic value (Manhattan distance): 0
Cost to reach this node: 5

Solution path:
[2, 8, 3]
[1, 6, 4]
[7, 0, 5]

[2, 8, 3]
[1, 0, 4]
[7, 6, 5]

[2, 0, 3]
[1, 8, 4]
[7, 6, 5]

[0, 2, 3]
[1, 8, 4]
[7, 6, 5]

[1, 2, 3]
[0, 8, 4]
[7, 6, 5]

[1, 2, 3]
[8, 0, 4]
[7, 6, 5]
```

Program 4

Implement Hill Climbing search algorithm to solve N-Queens problem

Algorithm:

Q. Implement Hill climbing search Alg to solve N-Queens problem

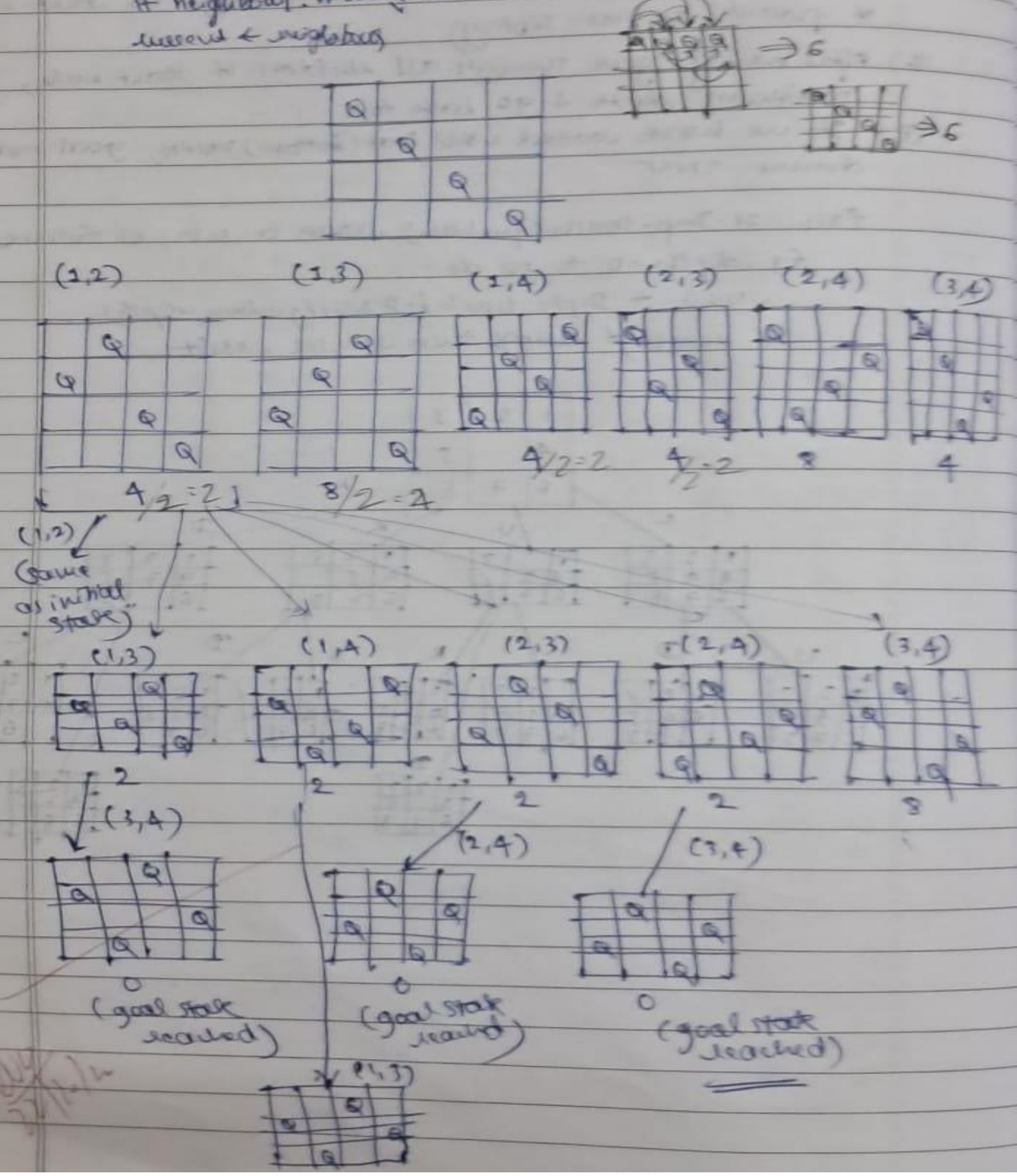
fn Hill-Climbing(problem, initial state)

loop do

neighbours ← a highest-valued successor of current

if neighbour.VALUE ≤ current.value then return current-state

current ← neighbours



Code:

```
import random
def calculate_cost(board):

    n = len(board)

    attacks = 0

    for i in range(n):

        for j in range(i + 1, n):

            if board[i] == board[j]:  # Same column

                attacks += 1

            if abs(board[i] - board[j]) == abs(i - j):  # Same diagonal

                attacks += 1

    return attacks


def get_neighbors(board):

    neighbors = []

    n = len(board)

    for col in range(n):

        for row in range(n):

            if row != board[col]:  # Only change the row of the queen

                new_board = board[:]

                new_board[col] = row

                neighbors.append(new_board)

    return neighbors
```

```
def hill_climb(board, max_restarts=100):
    current_cost = calculate_cost(board)
    print("Initial board configuration:")
    print_board(board, current_cost)
    iteration = 0
    restarts = 0

    while restarts < max_restarts:  # Add limit to the number of restarts
        while current_cost != 0:  # Continue until cost is zero
            neighbors = get_neighbors(board)
            best_neighbor = None
            best_cost = current_cost

            for neighbor in neighbors:
                cost = calculate_cost(neighbor)
                if cost < best_cost:  # Looking for a lower cost
                    best_cost = cost
                    best_neighbor = neighbor

            if best_neighbor is None:  # No better neighbor found
                break  # Break the loop if we are stuck at a local minimum

            board = best_neighbor
            current_cost = best_cost
```

```
            iteration += 1
            print(f"Iteration {iteration}:")
            print_board(board, current_cost)

        if current_cost == 0:
            break  # We found the solution, no need for further restarts
        else:
            # Restart with a new random configuration
            board = [random.randint(0, len(board)-1) for _ in range(len(board))]
            current_cost = calculate_cost(board)
            restarts += 1
            print(f"Restart {restarts}:")
            print_board(board, current_cost)

    return board, current_cost

def print_board(board, cost):
    n = len(board)
    display_board = [['.'] * n for _ in range(n)]  # Create an empty board
    for col in range(n):
        display_board[board[col]][col] = 'Q'  # Place queens on the board
    for row in range(n):
        print(' '.join(display_board[row]))  # Print the board
```

```python
    print(f"Cost: {cost}\n")


if __name__ == "__main__":
    n = int(input("Enter the number of queens (N): "))  # User input for N
    initial_state = list(map(int, input(f"Enter the initial state (row numbers for each column, space-separated): ").split()))
    if len(initial_state) != n or any(r < 0 or r >= n for r in initial_state):
        print("Invalid initial state. Please ensure it has N elements with values from 0 to N-1.")
    else:
        solution, cost = hill_climb(initial_state)
        if cost == 0:
            print(f"Solution found with no conflicts:")
        else:
            print(f"No solution found within the restart limit:")
        print_board(solution, cost)
```

```
Enter the number of queens (N): 4
Enter the initial state (row numbers for each column, space-separated): 0 1 2 3
Initial board configuration:
Q . . .
. Q . .
. . Q .
. . . Q
Cost: 6
```

```
Iteration 10:
. Q . .
. . . Q
Q . . .
. . Q .
Cost: 0

Solution found with no conflicts:
. Q . .
. . . Q
Q . . .
. . Q .
Cost: 0
```

Program 5

Simulated Annealing to Solve 8-Queens problem:

Algorithm:

PAGE NO :

DATE :

WAP to implement Simulated-Annealing

function Simulated-Annealing(problem, schedule) returns a solution state

inputs: problem : a problem

schedule: a mapping from time to "temperature"

current ← MAKE-NODE(problem, initial state)

for i = 1 to ∞ do

T ← schedule(t)

if T = 0 then return current

next ← a randomly selected successor of current

ΔE ← next.VALUE - current.VALUE

if ΔE > 0 then current ← next

else current ← next only with probability $e^{\Delta E/T}$

Alg:

(1) Start at random pt x

(2) Choose a new point x, on neighbourhood $N(x)$

(3) Decide to move or not to new pt x based on prob fxn

$$p(x_i, x_j, T) = \begin{cases} 1 & si \quad F(x_j) \geq F(x) \\ e^{\frac{F(x_j) - F(x)}{T}} & si \quad F(x_j) < F(x) \end{cases}$$

(4) Reduce T

→ (8 queens)

The best position found is: [5 2 6 1 3 7 0 4]

The number of queens that are not attacking each other is: 8.0

→ (TSP)

Result structure: (array([1,0,3,5,4,2]), 21.02934, None)

Best route found: [1 0 3 5 4 2]

Total distance of best route: 21.02934

Code:

```
#!pip install mlrose-hiive joblib
#!pip install --upgrade joblib
#!pip install joblib==1.1.0
import mlrose_hiive as mlrose
import numpy as np

def queens_max(position):
    no_attack_on_j = 0
    queen_not_attacking = 0
    for i in range(len(position) - 1):
        no_attack_on_j = 0
        for j in range(i + 1, len(position)):
            if (position[j] != position[i]) and (position[j] != position[i] + (j - i)) and (position[j] !=
position[i] - (j - i)):
                no_attack_on_j += 1
        if (no_attack_on_j == len(position) - 1 - i):
            queen_not_attacking += 1
    if (queen_not_attacking == 7):
        queen_not_attacking += 1
    return queen_not_attacking

objective = mlrose.CustomFitness(queens_max)

problem = mlrose.DiscreteOpt(length=8, fitness_fn=objective, maximize=True, max_val=8)
T = mlrose.ExpDecay()

initial_position = np.array([4, 6, 1, 5, 2, 0, 3, 7])

#The simulated_annealing function returns 3 values, we need to capture all 3
best_position, best_objective, fitness_curve = mlrose.simulated_annealing(problem=problem,
schedule=T, max_attempts=500,
                                              init_state=initial_position)

print('The best position found is:', best_position)
print('The number of queens that are not attacking each other is:', best_objective)
```

```
The best position found is: [4 0 7 5 2 6 1 3]
The number of queens that are not attacking each other is: 8.0
```

Program 6

Create a knowledge base using propositional logic and show that the given query entails the knowledge base or not.

Algorithm:

12/11

Wumpus world using Propositional logic

$R_1: \neg P_{1,1}$ pit in (x,y) $P_{x,y}$ KB + α → query, knowledge base

$R_2: B_{1,1} \Leftrightarrow P_{1,2} \vee P_{2,1}$ wumpus " " $W_{x,y}$

$R_3: B_{2,1} \Leftrightarrow (P_{1,1} \vee P_{2,2} \vee P_{3,1})$ Breeze " " $B_{x,y}$

Stench " " $S_{x,y}$

Function TT-ENTAILS? (KB, α) returns true or false

inputs: KB, knowledge base, sentence in PL

the query, a sentence in PL

symbols - a list of proposition symbols in KB and α

return TT-CHECK-ALL (KB, α, symbols, { })

function TT-CHECK-ALL(KB, α, symbols, model) returns true or false

if EMPTY? (symbols) then

if PL-TRUE? (KB, model) then return PL-TRUE? (α, model)

else return true // when KB is false, always return true

else do

P ← first(symbols)

rest ← REST (symbols)

return (TT-CHECK-ALL (KB, α, rest, model ∪ {P = true})

and

TT-CHECK-ALL (KB, α, rest, model ∪ {P = false}))

Propositional Inference : Enumeration Method

$\alpha = A \vee B$ $KB = (A \vee C) \wedge (B \vee \neg C)$

checking that $KB \models \alpha$

A	B	C	$A \vee C$	$B \vee \neg C$	KB	α
F	F	F	F	T	F	F
F	F	T	T	F	F	F
F	T	F	F	T	F	T
F	T	T	T	T	T	T
T	F	F	T	T	T	T
T	F	T	T	F	F	T
T	T	F	T	T	T	T
T	T	T	T	T	T	T

O/P Seen

12/11/24.

Code:

```
import pandas as pd


# Define the truth table for all combinations of A, B, C
truth_values = [(False, False, False),
                (False, False, True),
                (False, True, False),
                (False, True, True),
                (True, False, False),
                (True, False, True),
                (True, True, False),
                (True, True, True)]



# Columns: A, B, C
table = pd.DataFrame(truth_values, columns=["A", "B", "C"])


# Calculate intermediate columns
table["A or C"] = table["A"] | table["C"]          # A ∨ C
table["B or not C"] = table["B"] | ~table["C"]     # B ∨ ¬C


# Knowledge Base (KB): (A ∨ C) ∧ (B ∨ ¬C)
table["KB"] = table["A or C"] & table["B or not C"]



# Alpha (α): A ∨ B
table["Alpha (α)"] = table["A"] | table["B"]





# Define a highlighting function
def highlight_rows(row):
    if row["KB"] and row["Alpha (α)"]:
        return ['background-color: blue'] * len(row)
    else:
        return [''] * len(row)

# Apply the highlighting function
```

```
styled_table = table.style.apply(highlight_rows, axis=1)

# Display the styled table
styled_table
```

	A	B	C	A or C	B or not C	KB	Alpha (α)
0	False	False	False	False	True	False	False
1	False	False	True	True	False	False	False
2	False	True	False	False	True	False	True
3	False	True	True	True	True	True	True
4	True	False	False	True	True	True	True
5	True	False	True	True	False	False	True
6	True	True	False	True	True	True	True
7	True	True	True	True	True	True	True

Program 7

Implement unification in first order logic

Algorithm:

19/11

Q Implement Unification in First Order logic

Alg: Unify (Ψ_1, Ψ_2)

Step1: If Ψ_1 or Ψ_2 is a variable or const then:

(a) If Ψ_1 or Ψ_2 are identical, then return NIL

(b) else if Ψ_1 is a variable,

(a) then if Ψ_1 occurs in Ψ_2, then return FAILURE

(b) else return $\{(\Psi_2/\Psi_1)\}$

(c) else if Ψ_2 is a variable

(a) if Ψ_2 occurs in Ψ_1 then return FAILURE

(b) else return $\{(\Psi_1/\Psi_2)\}$

(d) else return FAILURE

Step2: If the initial predicate symbol in Ψ_1 & Ψ_2 are not same, then return FAILURE

Step3: If Ψ_1 & Ψ_2 have diff^nt no. of args, then return FAILURE

Step4: Set substitution set (SUBST) to NIL

Step5: For i=1 to no of ele in Ψ_1

(a) call unify function with i^th ele of Ψ_1 & i^th ele of Ψ_2 & put result into S

(b) If S = failure then return FAILURE

(c) If S ≠ NIL then do,

(a) Apply S to remainder of both L1 & L2

(b) SUBST = APPEND (S, SUBST)

Step6: RETURN SUBST

P(x, F(y)) — ①

P(a, F(g(x))) — ②

① & ② are identical if x is replaced with in(·)

P(a, F(y)) — ①

if y is replaced with $g(x)$

$p(a, F(g(x)))$ - 1

$P(a, g(x,a), f(y))$ - 1

$Q(a, g(f(b),a), x)$ - 2

$f(b)$ is replaced with x in 2

$Q(a, g(x,a), x)$

x is replaced with $f(y)$ in 2

$Q(a, g(x,a), f(y))$ - 2

(1) $\varphi_1 = p(f(a), g(y)) \qquad \varphi_2 = p(x, x)$

- SUBST $(f(a)/x)$

$\varphi_1 = p(f(a), g(y)) \qquad \varphi_2 = p(f(a), f(a))$

- SUBST $(f(a)/g(y))$

Failed

(2) $\varphi_1 = p(b, x, f(g(z))) \qquad \varphi_2 = p(z, f(y), f(y))$

- SUBST (b, z)

$\varphi_1 = p(b, x, f(g(b))) \qquad \varphi_2 = p(b, f(y), f(y))$

- SUBST $(f(y), x)$

$\varphi_1 = p(b, f(y), f(g(b))) \qquad \varphi_2 = p(b, f(y), f(y))$

- SUBST $(g(b)/y)$

$\varphi_1 = p(b, F(g(b)), f(g(b)))$

$\varphi_2 = p(b, f(g(b)), f(g(b)))$

Code:

```
import re

def occurs_check(var, x):
    """Checks if var occurs in x (to prevent circular substitutions)."""
    if var == x:
        return True
    elif isinstance(x, list):  # If x is a compound expression (like a function or predicate)
        return any(occurs_check(var, xi) for xi in x)
    return False


def unify_var(var, x, subst):
    """Handles unification of a variable with another term."""
    if var in subst:  # If var is already substituted
        return unify(subst[var], x, subst)
    elif isinstance(x, (list, tuple)) and tuple(x) in subst:  # Handle compound expressions
        return unify(var, subst[tuple(x)], subst)
    elif occurs_check(var, x):  # Check for circular references
        return "FAILURE"
    else:
        # Add the substitution to the set (convert list to tuple for hashability)
        subst[var] = tuple(x) if isinstance(x, list) else x
        return subst


def unify(x, y, subst=None):
    """
    Unifies two expressions x and y and returns the substitution set if they can be unified.
    Returns 'FAILURE' if unification is not possible.
    """
    if subst is None:
        subst = {}  # Initialize an empty substitution set

    # Step 1: Handle cases where x or y is a variable or constant
    if x == y:  # If x and y are identical
        return subst
    elif isinstance(x, str) and x.islower():  # If x is a variable
        return unify_var(x, y, subst)
    elif isinstance(y, str) and y.islower():  # If y is a variable
        return unify_var(y, x, subst)
    elif isinstance(x, list) and isinstance(y, list):  # If x and y are compound expressions (lists)
        if len(x) != len(y):  # Step 3: Different number of arguments
            return "FAILURE"
```

```
        # Step 2: Check if the predicate symbols (the first element) match
        if x[0] != y[0]:  # If the predicates/functions are different
            return "FAILURE"

        # Step 5: Recursively unify each argument
        for xi, yi in zip(x[1:], y[1:]):  # Skip the predicate (first element)
            subst = unify(xi, yi, subst)
            if subst == "FAILURE":
                return "FAILURE"
        return subst
    else:  # If x and y are different constants or non-unifiable structures
        return "FAILURE"


def unify_and_check(expr1, expr2):
    """
    Attempts to unify two expressions and returns a tuple:
    (is_unified: bool, substitutions: dict or None)
    """
    result = unify(expr1, expr2)
    if result == "FAILURE":
        return False, None
    return True, result


def display_result(expr1, expr2, is_unified, subst):
    print("Expression 1:", expr1)
    print("Expression 2:", expr2)
    if not is_unified:
        print("Result: Unification Failed")
    else:
        print("Result: Unification Successful")
        print("Substitutions:", {k: list(v) if isinstance(v, tuple) else v for k, v in subst.items()})


def parse_input(input_str):
    """Parses a string input into a structure that can be processed by the unification algorithm."""
    # Remove spaces and handle parentheses
    input_str = input_str.replace(" ", "")

    # Handle compound terms (like p(x, f(y)) -> ['p', 'x', ['f', 'y']])
    def parse_term(term):
        # Handle the compound term
        if '(' in term:
            match = re.match(r'([a-zA-Z0-9_]+)
', term)
            if match:
```

```
            predicate = match.group(1)
            arguments_str = match.group(2)
            arguments = [parse_term(arg.strip()) for arg in arguments_str.split(',')]
            return [predicate] + arguments
        return term

    return parse_term(input_str)


# Main function to interact with the user
def main():
    while True:
        # Get the first and second terms from the user
        expr1_input = input("Enter the first expression (e.g., p(x, f(y))): ")
        expr2_input = input("Enter the second expression (e.g., p(a, f(z))): ")

        # Parse the input strings into the appropriate structures
        expr1 = parse_input(expr1_input)
        expr2 = parse_input(expr2_input)

        # Perform unification
        is_unified, result = unify_and_check(expr1, expr2)

        # Display the results
        display_result(expr1, expr2, is_unified, result)

        # Ask the user if they want to run another test
        another_test = input("Do you want to test another pair of expressions? (yes/no): ").strip().lower()
        if another_test != 'yes':
            break


if __name__ == "__main__":
    main(
```

```
Enter the first expression (e.g., p(x, f(y))): p(b,x,f(g(z)))
Enter the second expression (e.g., p(a, f(z))): p(z,f(y),f(y))
Expression 1: ['p', 'b', 'x', ['f', ['g', 'z']]]
Expression 2: ['p', 'z', ['f', 'y'], ['f', 'y']]
Result: Unification Successful
Substitutions: {'b': 'z', 'x': ['f', 'y'], 'y': ['g', 'z']}
Do you want to test another pair of expressions? (yes/no): yes
Enter the first expression (e.g., p(x, f(y))): p(x,h(y))
Enter the second expression (e.g., p(a, f(z))): p(a,f(z))
Expression 1: ['p', 'x', ['h', 'y']]
Expression 2: ['p', 'a', ['f', 'z']]
Result: Unification Failed
Do you want to test another pair of expressions? (yes/no): yes
Enter the first expression (e.g., p(x, f(y))): p(f(a),g(y))
Enter the second expression (e.g., p(a, f(z))): p(x,x)
Expression 1: ['p', ['f', 'a'], ['g', 'y']]
Expression 2: ['p', 'x', 'x']
Result: Unification Failed
Do you want to test another pair of expressions? (yes/no): no
```

Program 8

Create a knowledge base consisting of first order logic statements and prove the given query using forward reasoning.

```
function FOL-FC-ASK(KB, α) returns a substitution or false
    inputs: KB, set of first-order definite clauses, α, query,
            atomic sentence
    local variables: new, new sentences inferred on each iteration

    repeat until new is empty
        new ← { }
        for each rule in KB do
            (p1 ∧ ... ∧ pn ⇒ q) ← standardize-variables(rule)
            for each θ such that SUBST(θ, p1 ∧ ... pn)
                = SUBST(θ, p'1 ∧ ... ∧ p'n)
                    for some p'1, ..., p'n in KB
                q' ← SUBST(θ, q)
                if q' doesnot unify some sentence already
                in KB or new then
                    add q' to new
                    φ ← UNIFY(q', α)
                    if φ is not fail then return φ
        add new to KB
    return false
```

3/12/24

Missiles are weapons

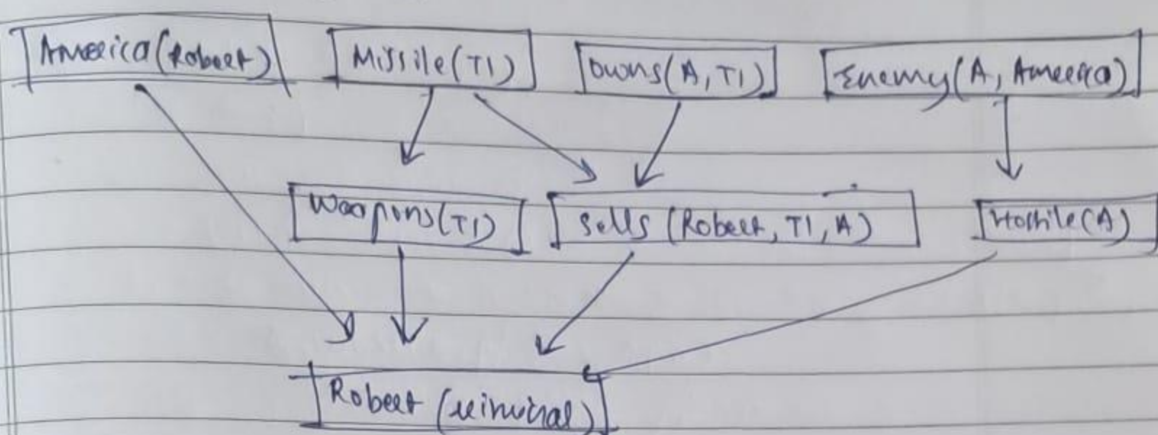
Missile(x) ⇒ weapon(x)

Enemy of America is known as hostile

$\forall x$ Enemy(x, America) ⇒ Hostile(x)

To prove:

Criminal (Robert)

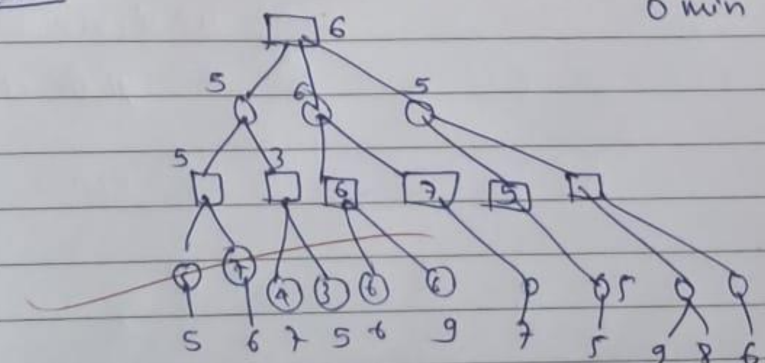


American(p) ∧ Weapon(q) ∧ sells (p,q,r) ∧ Hostile(r) ⇒ criminal(p)

eg (Alpha-beta Pruning Alg:)

op: 6

□ Max
○ min



2-12-24

Code:

```
class KnowledgeBase:
    def __init__(self):
        self.facts = set()   # Set of known facts
        self.rules = []      # List of rules

    def add_fact(self, fact):
        self.facts.add(fact)

    def add_rule(self, rule):
        self.rules.append(rule)

    def infer(self):
        inferred = True
        while inferred:
            inferred = False
            for rule in self.rules:
                if rule.apply(self.facts):
                    inferred = True

# Define the Rule class
class Rule:
    def __init__(self, premises, conclusion):
        self.premises = premises  # List of conditions
        self.conclusion = conclusion  # Conclusion to add if premises are met

    def apply(self, facts):
        if all(premise in facts for premise in self.premises):
            if self.conclusion not in facts:
                facts.add(self.conclusion)
                print(f"Inferred: {self.conclusion}")
                return True
        return False

# Initialize the knowledge base
kb = KnowledgeBase()

# Facts in the problem
kb.add_fact("American(Robert)")
kb.add_fact("Missile(T1)")
kb.add_fact("Owns(A, T1)")
kb.add_fact("Enemy(A, America)")

# Rules based on the problem
# 1. Missile(x) implies Weapon(x)
kb.add_rule(Rule(["Missile(T1)"], "Weapon(T1)"))
```

```
# 2. Enemy(x, America) implies Hostile(x)
kb.add_rule(Rule(["Enemy(A, America)"], "Hostile(A)"))

# 3. Missile(x) and Owns(A, x) imply Sells(Robert, x, A)
kb.add_rule(Rule(["Missile(T1)", "Owns(A, T1)"], "Sells(Robert, T1, A)"))

# 4. American(p) and Weapon(q) and Sells(p, q, r) and Hostile(r) imply Criminal(p)
kb.add_rule(Rule(["American(Robert)", "Weapon(T1)", "Sells(Robert, T1, A)", "Hostile(A)"],
"Criminal(Robert)"))

# Infer new facts based on the rules
kb.infer()

# Check if Robert is a criminal
if "Criminal(Robert)" in kb.facts:
   print("Conclusion: Robert is a criminal.")
else:
   print("Conclusion: Unable to prove Robert is a criminal.")
```

```
Inferred: Weapon(T1)
Inferred: Hostile(A)
Inferred: Sells(Robert, T1, A)
Inferred: Criminal(Robert)
Conclusion: Robert is a criminal.
```

Program 9

Create a knowledge base consisting of first order logic statements and prove the given query using Resolution

(26/11)

(W-9) Q Convert a given FOL statement into CNF (Conjunctive Normal Form)

(1) Convert all sentences to CNF

(2) Negate conclusion S & convert result to CNF

(3) Add negated conclusion S to premise clauses

(4) Repeat until contradiction or no progress is made

(a) Select 2 clauses (call them parent clauses)

(b) Resolve them together, performing all reqd unifications

(c) If resolvent is empty clause, contradiction has been found (i.e S follows premises)

(d) If not, add resolvent to premises

If we succeed in step 4, we have proved the conclusion

KB =

(1) food(x) → likes(John, x)

(2) food(Apple)

(3) ¬eats(y, z) ∨ killed(y) ∨ food(z)

(4) eats(Anil, Peanuts)

(5) alive(Anil)

(6) ¬eats(Anil, w) ∨ eats(Harry, w)

(7) killed(g) alive(g)

(8) ¬alive(k) ∨ ¬killed(k)

(9) likes(John, peanuts)

¬likes(John, Peanuts) ¬food(x) ∨ likes(John, x)

¬food(peanuts) ¬eats(y, z) ∨ killed ∨ food(z) (peanuts/z)

¬eats(y, peanuts) ∨ killed(y) eats(Anil, Peanuts)

killed(Anil) ¬alive(k) ∨ ¬killed(k)

¬alive(Anil) alive

{ }

op:

Proved by contradiction John likes peanuts

3-12-24

Code:

```python
KB = {
    "food(Apple)": True,
    "food(vegetables)": True,
    "eats(Anil, Peanuts)": True,
    "alive(Anil)": True,
    "likes(John, X)": "food(X)",  # Rule: John likes all food
    "food(X)": "eats(Y, X) and not killed(Y)",  # Rule: Anything eaten and not killed is food
    "eats(Harry, X)": "eats(Anil, X)",  # Rule: Harry eats what Anil eats
    "alive(X)": "not killed(X)",  # Rule: Alive implies not killed
    "not killed(X)": "alive(X)",  # Rule: Not killed implies alive
}

# Function to evaluate if a predicate is true based on the KB
def resolve(predicate):
    # If it's a direct fact in KB
    if predicate in KB and isinstance(KB[predicate], bool):
        return KB[predicate]

    # If it's a derived rule
    if predicate in KB:
        rule = KB[predicate]
        if " and " in rule:  # Handle conjunction
            sub_preds = rule.split(" and ")
            return all(resolve(sub.strip()) for sub in sub_preds)
        elif " or " in rule:  # Handle disjunction
            sub_preds = rule.split(" or ")
            return any(resolve(sub.strip()) for sub in sub_preds)
        elif "not " in rule:  # Handle negation
            sub_pred = rule[4:]  # Remove "not "
            return not resolve(sub_pred.strip())
        else:  # Handle single predicate
            return resolve(rule.strip())

    # If the predicate is a specific query (e.g., likes(John, Peanuts))
    if "(" in predicate:
        func, args = predicate.split("(")
        args = args.strip(")").split(", ")
        if func == "food" and args[0] == "Peanuts":
            return resolve("eats(Anil, Peanuts)") and not resolve("killed(Anil)")
        if func == "likes" and args[0] == "John" and args[1] == "Peanuts":
            return resolve("food(Peanuts)")

    # Default to False if no rule or fact applies
    return False
```

```
# Query to prove: John likes Peanuts
query = "likes(John, Peanuts)"
result = resolve(query)

# Print the result
print(f"Does John like peanuts? {'Yes' if result else 'No'}")
```

```
Does John like peanuts? Yes
```

Program 10

Implement Alpha-Beta Pruning.

(w-10) Alpha-Beta Pruning Algorithm.

→ to find optimal path w/o looking at every node in the game tree

→ Max contains (α) & Min contains (β) bound during calculation

→ In both MIN & MAX node, we return when $\alpha \geq \beta$ which compares with its parent node only

Both minimax & α-β cut-off give same path

→ α-β gives optimal solution as it takes less time to get value for root node.

(Forward Reasoning)

Q) Consider problem, as per law, it is a crime for an american to sell weapons to hostile nations. Country A, an enemy of America, has some missiles & all missiles were sold to it by Robert, who is a American citizen

A) PT "Robert is criminal"

Repⁿ in FOL

It is a crime for an American to sell weapons to hostile nations

Lets say p, q & r variables

$American(p) \wedge weapon(q) \wedge sells(p,q,r) \wedge Hostile(r) \Rightarrow criminal(p)$

Country A has some missiles

$\exists x\ owns(A,x) \wedge Missiles(x)$

Robert is a American

$American(Robert)$

Existential Instantiation, introducing a new const T1:

$Owns(A, T1)$

$Missile(T1)$

Country A, an enemy of America

$Enemy(A, America)$

All of missiles were sold to country A Robert $\forall x\ Missile(x) \wedge Owns(A,x) \Rightarrow Sells(Robert, x, A)$

Missiles are weapons

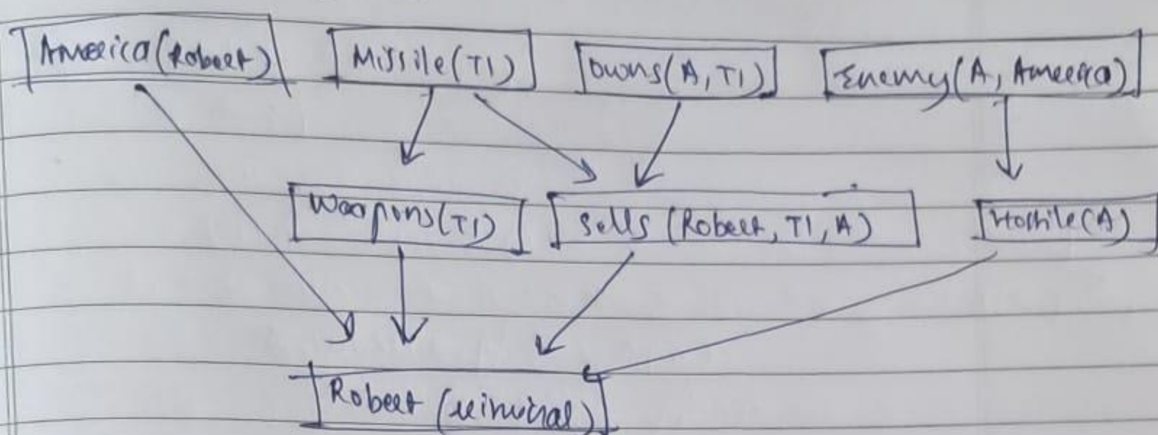
Missile(x) $\Rightarrow$ weapon(x)

Enemy of America is known as hostile

$\forall x$ Enemy(x, America) $\Rightarrow$ Hostile(x)

To prove:

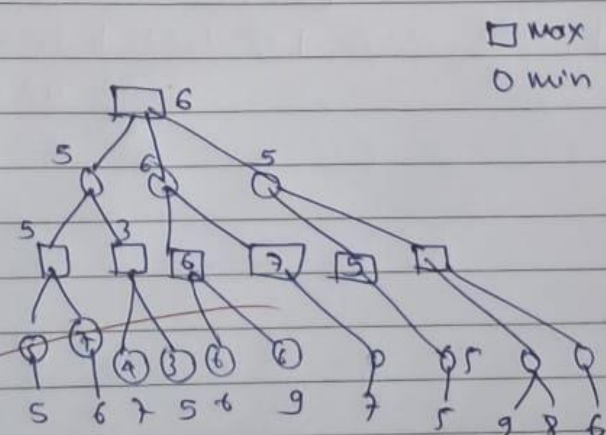
$\boxed{\text{Criminal(Robert)}}$



American(p) $\wedge$ Weapon(q) $\wedge$ sells(p,q,r) $\wedge$ Hostile(r) $\Rightarrow$ criminal(p)

eg (Alpha-beta Pruning Alg:)

op: 6



-12-24

Code:

```
import math
def minimax(node, depth, is_maximizing):
    """
    Implement the Minimax algorithm to solve the decision tree.

    Parameters:
    node (dict): The current node in the decision tree, with the following structure:
        {
            'value': int,
            'left': dict or None,
            'right': dict or None
        }
    depth (int): The current depth in the decision tree.
    is_maximizing (bool): Flag to indicate whether the current player is the maximizing player.

    Returns:
    int: The utility value of the current node.
    """
    # Base case: Leaf node
    if node['left'] is None and node['right'] is None:
        return node['value']

    # Recursive case
    if is_maximizing:
        best_value = -math.inf
        if node['left']:
            best_value = max(best_value, minimax(node['left'], depth + 1, False))
        if node['right']:
            best_value = max(best_value, minimax(node['right'], depth + 1, False))
        return best_value
    else:
        best_value = math.inf
        if node['left']:
            best_value = min(best_value, minimax(node['left'], depth + 1, True))
        if node['right']:
            best_value = min(best_value, minimax(node['right'], depth + 1, True))
        return best_value

# Example usage
decision_tree = {
    'value': 5,
    'left': {
        'value': 6,
        'left': {
            'value': 7,
```

```
        'left': {
            'value': 4,
            'left': None,
            'right': None
        },
        'right': {
            'value': 5,
            'left': None,
            'right': None
        }
    },
    'right': {
        'value': 3,
        'left': {
            'value': 6,
            'left': None,
            'right': None
        },
        'right': {
            'value': 9,
            'left': None,
            'right': None
        }
    }
},
'right': {
    'value': 8,
    'left': {
        'value': 7,
        'left': {
            'value': 6,
            'left': None,
            'right': None
        },
        'right': {
            'value': 9,
            'left': None,
            'right': None
        }
    },
    'right': {
        'value': 8,
        'left': {
            'value': 6,
            'left': None,
            'right': None
        },
```

```
            'right': None
        }
    }
}

# Find the best move for the maximizing player
best_value = minimax(decision_tree, 0, True)
print(f"The best value for the maximizing player is: {best_value}")
```

The best value for the maximizing player is: 6