Artificial Intelligence Lab Report

Submitted by

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Batch: A3

Course: Artificial Intelligence
Course Code: 23CS5PCAIN
Sem & Section: 5A

BACHELOR OF ENGINEERING
in
COMPUTER SCIENCE AND ENGINEERING

B. M. S. COLLEGE OF ENGINEERING
(Autonomous Institution under VTU)
BENGALURU-560019
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B.M.S. COLLEGE OF ENGINEERING
DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

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This is to certify that the Artificial Intelligence(23CS5PCAIN) laboratory has been carried out by Ariz Ejaz Khan (1BM23CS051) during the 5^{th} Semester August 2025-December 2025

Signature of the Faculty In charge:

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Assistant Professor

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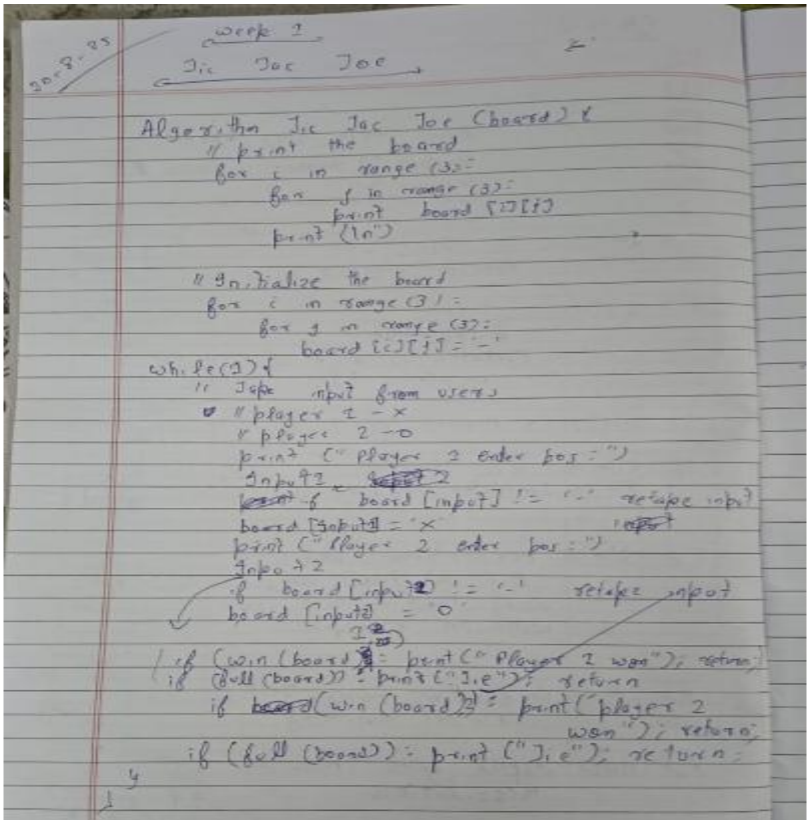
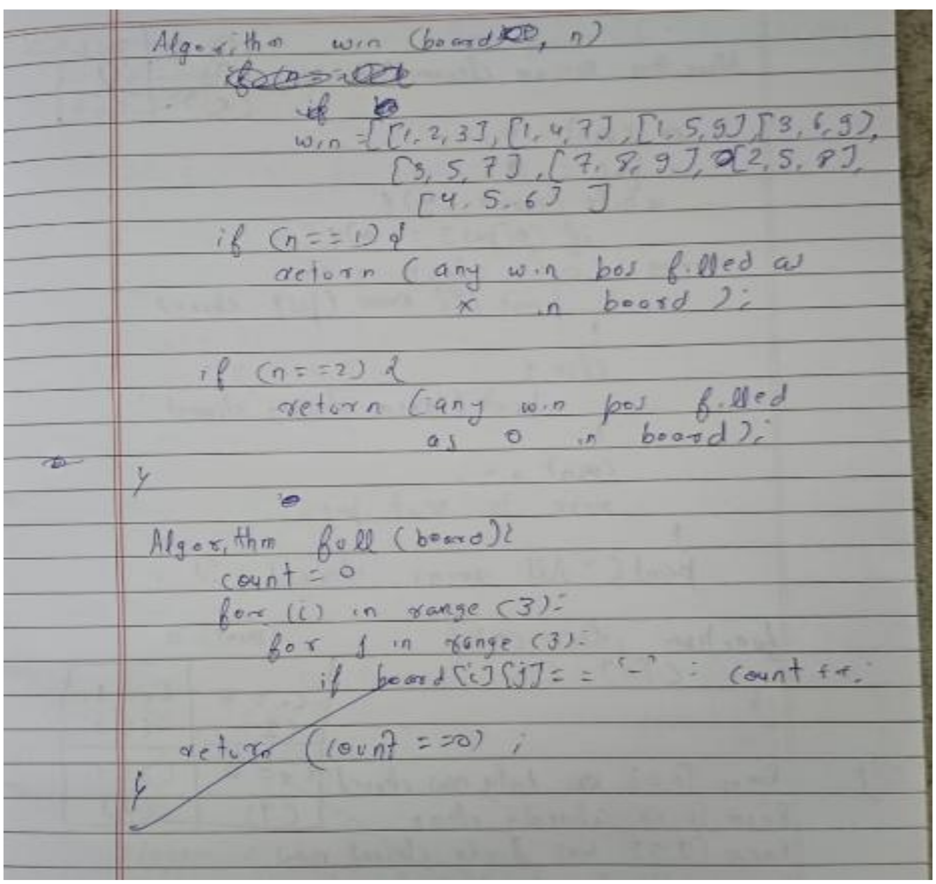
Program 1 - Tic Tac toe

Algorithm



```
20-3-25          week 1
        Tic Tac Toe

Algorithm Tic Tac Toe (board) {
    // print the board
    for i in range (3):
        for j in range (3):
            print board [i][j]
        print ("\n")

    // Initialize the board
    for i in range (3):
        for j in range (3):
            board [i][j] = '-'
while(1){
    // Take input from user
    // player 1 - x
    // player 2 - o
    print ("Player 1 enter pos:")
    input1
    if board [input] != '-' retake input
    board [input1] = 'x'
    print ("Player 2 enter pos:")
    input2
    if board [input2] != '-' retake input
    board [input2] = 'o'
    if (win (board, 1)): print ("Player 1 won"); return
    if (full (board)): print ("Tie"); return
    if (win (board, 2)): print ("player 2 won"); return;
    if (full (board)): print ("Tie"); return;
}
}
```



```
Algorithm win (board, n)
    win = [[1,2,3],[1,4,7],[1,5,9],[3,6,9],
           [3,5,7],[7,8,9],[2,5,8],
           [4,5,6]]
    if (n==1){
        return (any win pos filled as
                x in board);
    }
    if (n==2){
        return (any win pos filled
                as o in board);
    }
}

Algorithm full (board){
    count = 0
    for (i) in range (3):
        for j in range (3):
            if board[i][j] == '-' : count++;
    return (count == 0);
}
```

Tic Tac Toe

O/P :- Tic Tac Toe. Two player (1-9 version)
['-', '-', '-']
['-', '-', '-']
['-', '-', '-']
Player X position : 1
[X, -, -]
[-, -, -]
[-, -, -]

Player O, position : 2
[X, O, -]
[-, -, -]
[-, -, -]

Player X, position : 4
[X, O, -]
[X, -, -]
[-, -, -]

Player O, position : 3
[X, O, O]
[X, -, -]
[-, -, -]

Player X, position : 4
That cell is already taken. Try again

Player X, position : 7
[X, O, O]
[X, -, -]
[X, -, -]
Player X wins!

Code

```
def create_board():
    return [["-" for _ in range(3)] for _ in range(3)]
def show_board(board):
    for row in board:
        # print(" | ".join(row))
        print(row," ")

# Map cell number (1-9) to row, col
def cell_to_coords(cell):
    cell -= 1 # shift to 0–8
    return cell // 3, cell % 3
def is_full(board):
    return all(board[r][c] != "-" for r in range(3) for c in range(3))

def check_winner(board, player):
    # rows
    for r in range(3):
        if all(board[r][c] == player for c in range(3)):
            return True
    # cols
    for c in range(3):
        if all(board[r][c] == player for r in range(3)):
            return True
    # diagonals
    if all(board[i][i] == player for i in range(3)):
        return True
    if all(board[i][2-i] == player for i in range(3)):
        return True
    return False

# Player move
def get_move(board, player):
    while True:
        try:
            cell = int(input(f"Player {player}, position: "))
            if cell < 1 or cell > 9:
                print("Please enter a number from 1 to 9.\n")
                continue
            r, c = cell_to_coords(cell)
            if board[r][c] != "-":
                print("That cell is already taken. Try again.\n")
                continue
            return r, c
        except ValueError:
            print("Please enter numbers only.\n")

# Main game loop
def play_game():
    board = create_board()
    current = "X" # Player X starts
    print("Tic Tac Toe — Two Players (1-9 version)\n")
    show_board(board)
```

```
    while True:
        r, c = get_move(board, current)
        board[r][c] = current
        show_board(board)

        if check_winner(board, current):
            print(f" Player {current} wins!")
            break
        if is_full(board):
            print("It's a draw!")
            break

        current = "O" if current == "X" else "X"

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

Output Snapshot

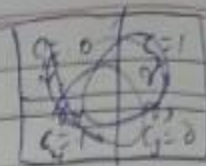
```
Tic Tac Toe — Two Players (1-9 version)

['-', '-', '-']
['-', '-', '-']
['-', '-', '-']
Player X, position: 1
['X', '-', '-']
['-', '-', '-']
['-', '-', '-']
Player O, position: 2
['X', 'O', '-']
['-', '-', '-']
['-', '-', '-']
Player X, position: 4
['X', 'O', '-']
['X', '-', '-']
['-', '-', '-']
Player O, position: 3
['X', 'O', 'O']
['X', '-', '-']
['-', '-', '-']
Player X, position: 4
That cell is already taken. Try again.

Player X, position: 7
['X', 'O', 'O']
['X', '-', '-']
['X', '-', '-']
 Player X wins!
```

Program 2 - Vacuum Cleaner

Algorithm

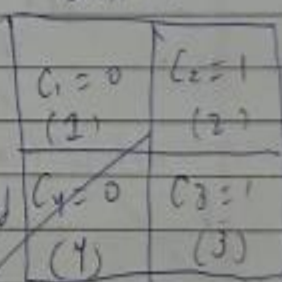
20-8-2025

Vaccum Cleaner,




```
Algorithm Vaccum cleaner (room){

    count = 0;
    pos = 1;
    while (count < 4) {
        if (c[pos] == 0){
room        clean room;
            print ("Room {pos} cleaned");
        }
        else {
            print ("Room already cleaned");
        }
        count ++;
        move to next pos;
    }
    print (" All rooms cleaned !");

function clean (n) {
    c[n] = 1;
}
```

Count = 0



O/P

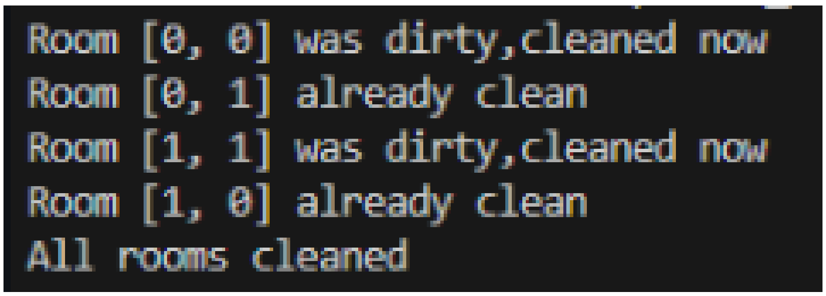
Room [0,0] was dirty, now cleaned
Room [0,1] already clean
Room [1,1] was dirty, cleaned now
Room [1,0] already cleaned
All rooms cleaned

20/8/25

Code

```
pos= [[0,0], [0,1], [1,1], [1,0]]
clean= [[0,1], [1,0]]

for i in pos:
    row=i[0]
    col=i[1]
    if(clean[row][col]):
        print(f"Room {i} already clean")
    else:
        print(f"Room {i} was dirty,cleaned now")
        clean[row][col]=1
print("All rooms cleaned")25
```

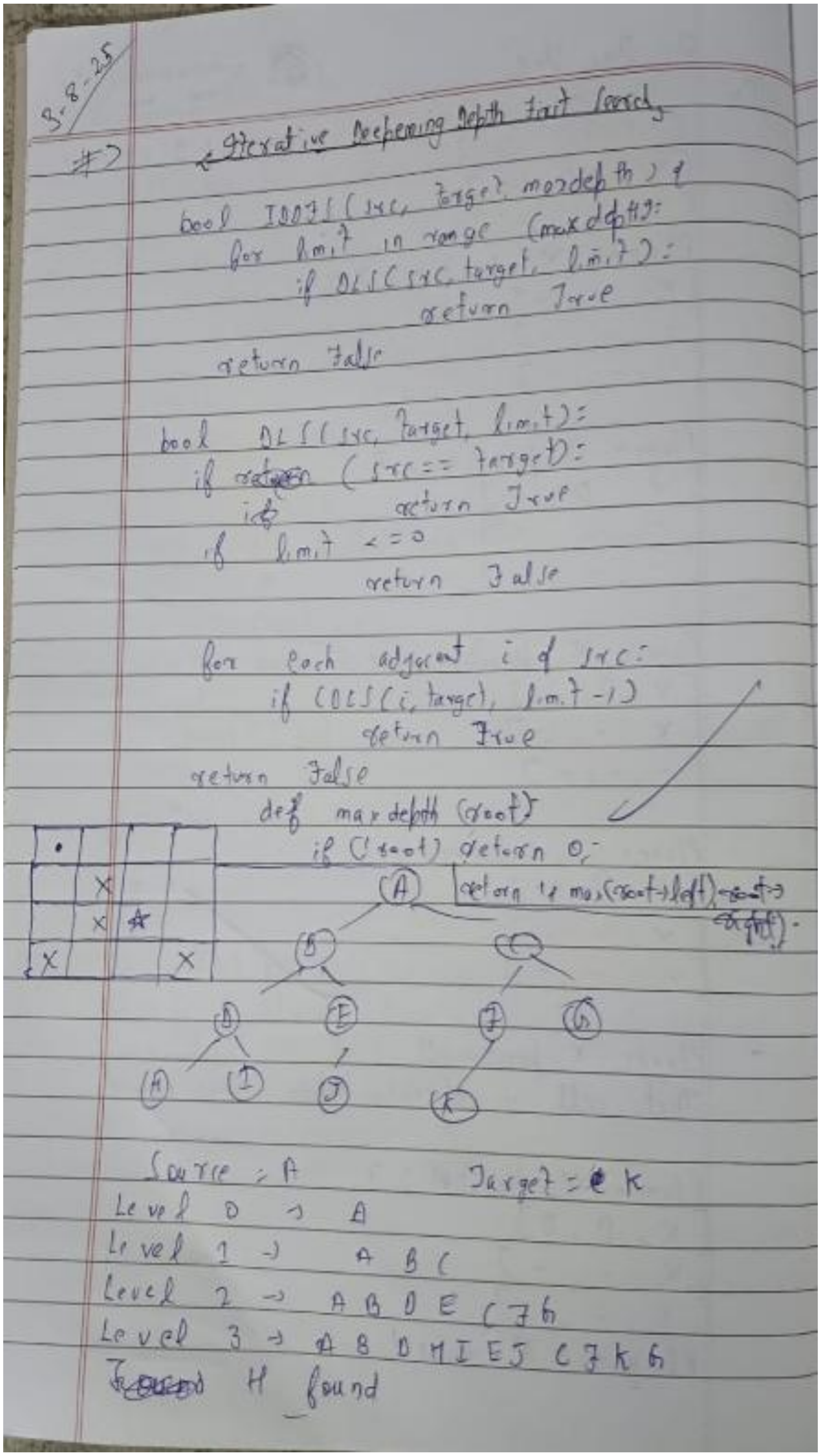
Output Snapshot



```
Room [0, 0] was dirty,cleaned now
Room [0, 1] already clean
Room [1, 1] was dirty,cleaned now
Room [1, 0] already clean
All rooms cleaned
```

program-03 IDDFS

Algorithm



3-8-25

#7 Iterative Deepening Depth First Search

bool IDDFS(src, target, maxdepth) {
for limit in range (maxdepth):
if DLS(src, target, limit):
return True
return False

bool DLS(src, target, limit):
if (src == target):
return True
if limit <= 0
return False

for each adjacent i of src:
if (DLS(i, target), limit-1)
return True
return False

def maxdepth (root)
if (!root) return 0;
return 1 + max(root->left, root->right).

Source : A   Target : K
Level 0 -> A
Level 1 -> A B C
Level 2 -> A B D E C F G
Level 3 -> A B D H I E J C F K G
H found

Code

```
class Node:
    def __init__(self, value):
```

```
        self.value = value
        self.children = []

# Build the tree
A = Node('A')
B = Node('B')
C = Node('C')
D = Node('D')
E = Node('E')
F = Node('F')
G = Node('G')
H = Node('H')

A.children = [B, C, D]
B.children = [E, F]
C.children = [G]
G.children = [H]

def dls(node, target, depth, visited_at_level):
    if node is None:
        return None
    visited_at_level.append(node.value)
    if node.value == target:
        return node
    if depth == 0:
        return None
    for child in node.children:
        found = dls(child, target, depth - 1, visited_at_level)
        if found:
            return found
    return None

def iddfs(root, target, max_depth):
    found_node = None
    for depth in range(max_depth + 1):
        visited_at_level = []
        dls(root, target, depth, visited_at_level)
        print(f"Depth {depth}: Visited nodes -> {', '.join(visited_at_level)}")
        if target in visited_at_level:
            found_node = target
            break
    if found_node:
        print(f"\nResult: Found '{target}' at depth {depth}")
    else:
        print(f"\nResult: '{target}' not found within depth {max_depth}")
```

```
# Example usage
target = 'H'
iddfs(A, target, max_depth=4)
```

Output Snapshot

```
Depth 0: Visited nodes -> A
Depth 1: Visited nodes -> A, B, C, D
Depth 2: Visited nodes -> A, B, E, F, C, G, D
Depth 3: Visited nodes -> A, B, E, F, C, G, H

Result: Found 'H' at depth 3
```

Program 04 - 8 Puzzle Using A*
Algorithm

8- Puzzle problem by Hueristic

$$\begin{array}{c|ccc} & 0 & 1 & 2 \\ \hline 0 & 1 & 2 & 3 \\ 1 & 0 & 4 & 6 \\ 2 & 7 & 5 & 8 \end{array}$$

```
goal_state = [[1, 2, 3],
              [4, 5, 6],
              [7, 8, 0]]
moves = [(1,0), (-1,0), (0,1), (0,-1)]

def findblank(state):
    for i in range(3):
        for j in range(3):
            if state[i][j] == 0:
                return i, j

def manhattan(state):
    d = 0
    for i in range(3):
        for j in range(3):
            v = state[i][j]
            if v != 0:
                gx, gy = divmod(v-1, 3)
                d += abs(i-gx) + abs(j-gy)
    return d
                d = |row - goalrow| + |col - goal_col|;

def misplaced_tiles(state):
    count = 0
    for i in range(3):
        for j in range(3):
            (if state[i][j] != 0 and
                state[i][j] != goal_state[i][j])
                count += 1
    return count
```

$$\begin{bmatrix} 1 & 2 & 3 \\ 0 & 4 & 6 \\ 7 & 5 & 8 \end{bmatrix} \xleftrightarrow{\text{End}} \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 0 \end{bmatrix}$$

initial   Final

Step 1

$$\begin{bmatrix} 1 & 2 & 3 \\ 4 & 0 & 6 \\ 7 & 5 & 8 \end{bmatrix}$$

Step 2

$$\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 0 & 8 \end{bmatrix}$$

Step 3

$$\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 0 \end{bmatrix}$$

3/7/3

10-9-25

Lab 3

8 Puzzle problem using A* method

1	2	3
4	5	6
7	8	_

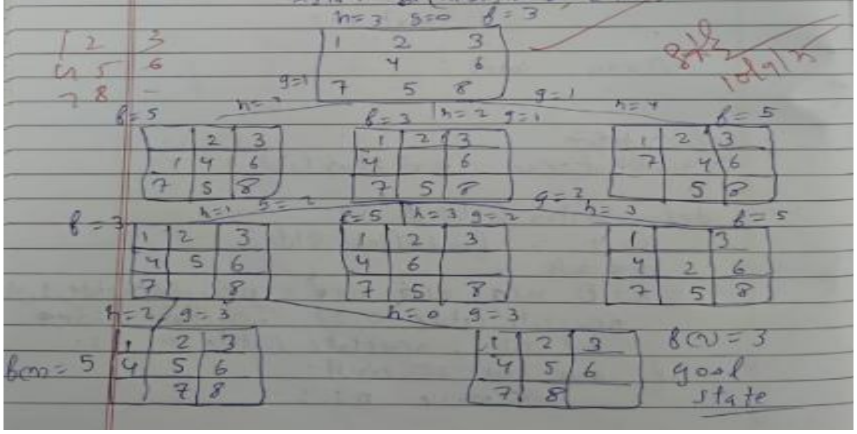
goal state

1	2	3
_	4	6
7	5	8

Start state

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

```
def misplaced_tiles(state):
    count = 0
    for i in range(3):
        for j in range(3):
            if (state[i][j] != 0 and state[i][j] != goal_state[i][j])
                count ++;

    return count;

i, j = findblank(state)

def Astar(state, d):
    i, j = findblank(state)
    ns1, ns2, ns3, ns4 = newstate(state, 1, 0),
    newstate(state, 0, 1), newstate(state,
    -1, 0), newstate(state, 0, -1);
    if any ns == Null:
        remove ns;

gn = [d, d, d, d]
hn = [ for i in
misplaced_tiles(ns[i]) range(4)]

for (i) in range 4:
    if ns_i == NULL
        fn[i] = NULL

fn[i] = hn[i] + gn[i]

nextstate = ns[min(fn)]

if checkfinal(nextstate):
    print(final state reached)
else:
    Astar(nextstate, d+1)
```



Code

```
import heapq
goal_state = [[1, 2, 3],
              [4, 5, 6],
              [7, 8, 0]]
moves = [(-1, 0), (1, 0), (0, -1), (0, 1)]  # up, down, left, right
def is_valid(x, y):
    return 0 <= x < 3 and 0 <= y < 3

def find_blank(state):
    for i in range(3):
        for j in range(3):
            if state[i][j] == 0:
                return i, j

def state_to_tuple(state):
    return tuple(tuple(row) for row in state)

# --------- Heuristics ---------
def manhattan_distance(state):
    d = 0
    for i in range(3):
        for j in range(3):
            v = state[i][j]
            if v != 0:
                gx, gy = divmod(v - 1, 3)
                d += abs(i - gx) + abs(j - gy)
    return d

def misplaced_tiles(state):
    count = 0
    for i in range(3):
        for j in range(3):
            if state[i][j] != 0 and state[i][j] != goal_state[i][j]:
                count += 1
    return count

# --------- A* Search ---------
def a_star(start, heuristic):
    visited = set()
    pq = []
    heapq.heappush(pq, (heuristic(start), 0, start, []))
    while pq:
        f, g, state, path = heapq.heappop(pq)
        if state == goal_state:
            return path + [state]
        visited.add(state_to_tuple(state))
        x, y = find_blank(state)
        for dx, dy in moves:
            nx, ny = x + dx, y + dy
            if is_valid(nx, ny):
                new_state = [row[:] for row in state]
```

```
                new_state[x][y], new_state[nx][ny] = new_state[nx][ny], new_state[x][y]
                if state_to_tuple(new_state) not in visited:
                    g2 = g + 1
                    f2 = g2 + heuristic(new_state)
                    heapq.heappush(pq, (f2, g2, new_state, path + [state]))
    return None

# --------- Solver ---------
def solve(start, method="astar_manhattan"):
    if method == "astar_misplaced":
        return a_star(start, misplaced_tiles)
    else: # default: A* Manhattan
        return a_star(start, manhattan_distance)

# --------- Example Run ---------
start_state = [[1, 2, 3],
               [0, 4, 6],
               [7, 5, 8]]

for algo in ["astar_misplaced", "astar_manhattan"]:
    print("\nMethod:", algo)
    path = solve(start_state, algo)
    if path:
        print("Solved in", len(path) - 1, "moves")
        for step in path:
            for row in step: print(row)
            print("-----")
    else:
        print("No solution found")
```

Output Snapshot

```
Method: astar_misplaced
Solved in 3 moves
[1, 2, 3]
[0, 4, 6]
[7, 5, 8]
-----
[1, 2, 3]
[4, 0, 6]
[7, 5, 8]
-----
[1, 2, 3]
[4, 5, 6]
[7, 0, 8]
-----
[1, 2, 3]
[4, 5, 6]
[7, 8, 0]
-----

Method: astar_manhattan
Solved in 3 moves
[1, 2, 3]
[0, 4, 6]
[7, 5, 8]
-----
[1, 2, 3]
[4, 0, 6]
[7, 5, 8]
-----
[1, 2, 3]
[4, 5, 6]
[7, 0, 8]
-----
[1, 2, 3]
[4, 5, 6]
[7, 8, 0]
-----
```

Program-05 Hill Climbing

Algorithm

8-10-25

Hill Climbing - N Queens

			Q
	Q		
		Q	
Q			

Initial state
Queens at col 0 row 3,
col 1 row 1,
col 2 row 2,
col 3 row 0.

board = [3, 1, 2, 0]

Finally
A state where no queens intersect

cost function
|row diff| = |col diff| or $\boxed{\text{row 1} == \text{row2}}$

Check pairs
Q_1 (3,0) & Q_2 (1,1) → |3-1| ≠ |0-1|
3 ≠ 1 — count = 0

Q_1 & Q_3 → |3-2| ≠ |0-2|
3 ≠ 2 — count = 0

Q_1 & Q_4
|0-3| == |3-0| — count = 1

Q_2 & Q_3
|1-1| = |2-1| — count = 2

Q_2 & Q_4
|1-0| ≠ |3-1| &
1 ≠ 0 — count = 2

Q_3 & Q_4
|2-0| ≠ |2-3| & 2 ≠ 0 — count = 2

initial cost = 2

Algorithm
```
def random_state (N, max):
    for i in 1 to max:
        current ← random_board (n)
        while true:
            neighbours ← generate_neighbour (current)
            best_neighbour ← neighbour in neighbours
                                with min cost
            with min_conflict (neighbours)
                if evaluate (current) <=
                        evaluate ( best_neighbour)
                    break:

            else
                current ← best_neighbour
            if evaluate (current) == 0
                return current

    return failure.

def evaluate (state):
    int cost = 0
    for row, col in state:
        if (row_i == row_{i+1}     or
            (row_i - row_{i+1}) == (col_i - col_{i+1}))
                cost ++;

    return cost.
```

Code

```
import random

def conflicts(state):
    count = 0
    for i in range(4):
        for j in range(i + 1, 4):
            # same column or same diagonal
            if state[i] == state[j] or abs(state[i] - state[j]) == abs(i - j):
                count += 1
    return count

def print_board(state):
    for i in range(4):
        row = ["Q" if state[i] == j else "." for j in range(4)]
        print(" ".join(row))
    print()

def hill_climbing():
    state = [random.randint(0, 3) for _ in range(4)]
    current_conflicts = conflicts(state)

    while True:
        best_state = state
        best_conflicts = current_conflicts

        # Try moving each queen to every other column
        for row in range(4):
            for col in range(4):
                if col == state[row]:
                    continue
                new_state = state.copy()
                new_state[row] = col
                new_conflicts = conflicts(new_state)

                if new_conflicts < best_conflicts:
                    best_conflicts = new_conflicts
                    best_state = new_state

        # If no improvement, stop
        print("State space now:")
        print_board(state)
        print("no of conflicts=",best_conflicts,"\n")
        if best_conflicts == current_conflicts:
            break

        # Update to new better state
        state = best_state
        current_conflicts = best_conflicts

        # Stop early if solved
        if current_conflicts == 0:
```

```
            break

    return state, current_conflicts

# --- Run the 4-Queens Hill Climbing ---
solution, c = hill_climbing()
print_board(solution)

if c == 0:
    print("Found a valid 4-Queens solution!")
else:
    print("Stuck in local minimum (", c, "conflicts )")
```

OUTPUT

```
State space now:
Q . . .
. . . Q
. . Q .
. . Q .

no of conflicts= 1

State space now:
Q . . .
. . . Q
Q . . .
. . Q .

no of conflicts= 0

. Q . .
. . . Q
Q . . .
. . Q .

Found a valid 4-Queens solution!
```

Program-06 Simulated Annealing

Algorithm

8-10-25

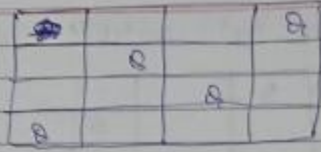
Simulated annealing
N-Queens

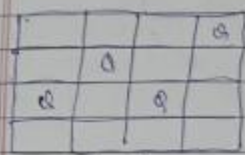
Formula: $P = e^{-\Delta E/kT}$

where
k = cooling factor
T = Temperature
ΔE = change cost
P = probability of change

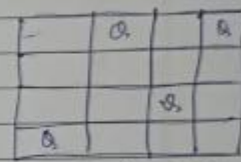
```
algorithm simulated-annealing(initial_state):
    current = initial_state
    T = initial_temp (=100)
    while T>0:
        neighbours = getNeighbours(current)
        if (neighbours == empty):
            return current

        for ne in neighbours:
            ΔE = cost(neighbours)
            if ΔE > 0 or random < e^(-ΔE/T):
                current = neighbour
    T = T * k
```

Initially cost = 2



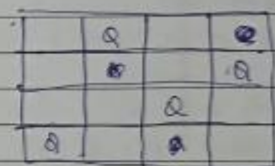


cost = 2



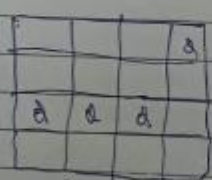
cost = 1

cost = 4

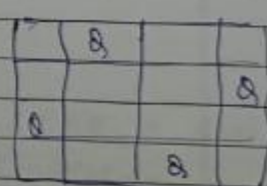


cost = 1

~~selecting best suitable~~

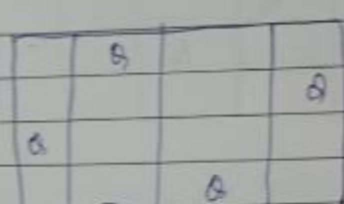


cost = 3



cost = 0

Selecting best suitable



8/10/25

Code

```
import random
import math

N = 4

def cost(state):
    """Compute number of attacking queen pairs."""
    conflicts = 0
    for i in range(N):
        for j in range(i+1, N):
            if state[i] == state[j] or abs(state[i] - state[j]) == abs(i - j):
                conflicts += 1
    return conflicts

def random_neighbor(state):
    """Generate a neighbor by moving one queen to another row."""
    neighbor = state.copy()
    col = random.randrange(N)
    new_row = random.randrange(N-1)
    if new_row >= neighbor[col]:
        new_row += 1
    neighbor[col] = new_row
    return neighbor

def simulated_annealing(
    T0=5.0, alpha=0.995, Tmin=1e-6, max_iters=50000
):
    # Start with a random placement of queens
    state = [random.randrange(N) for _ in range(N)]
    current_cost = cost(state)
    T = T0
    it = 0

    while T > Tmin and it < max_iters and current_cost != 0:
        neighbor = random_neighbor(state)
        neighbor_cost = cost(neighbor)
        delta = neighbor_cost - current_cost

        if delta <= 0 or random.random() < math.exp(-delta / T):
            state, current_cost = neighbor, neighbor_cost
            print(f"Iteration {it}, Cost {current_cost}, State: {state}")

        T *= alpha
```

```
        it += 1

    return state, current_cost

def print_board(state):
    """Pretty-print the board."""
    for r in range(N):
        row = ""
        for c in range(N):
            row += "Q " if state[c] == r else ". "
        print(row)
    print()

# Run SA for 4-queens
solution, c = simulated_annealing()

print("Final state (col -> row):", solution)
print("Cost:", c)
print("\nBoard:")
print_board(solution)
```

Output Snapshot

```
Iteration 0, Cost 2, State: [1, 3, 1, 2]
Iteration 1, Cost 4, State: [1, 1, 1, 2]
Iteration 2, Cost 3, State: [1, 1, 2, 2]
Iteration 3, Cost 5, State: [2, 1, 2, 2]
Iteration 4, Cost 4, State: [0, 1, 2, 2]
Iteration 5, Cost 3, State: [1, 1, 2, 2]
Iteration 6, Cost 2, State: [1, 3, 2, 2]
Iteration 7, Cost 0, State: [1, 3, 0, 2]
Final state (col -> row): [1, 3, 0, 2]
Cost: 0

Board:
. . Q .
Q . . .
. . . Q
. Q . .
```

Program-07 Entailment in prepositional logic

Algorithm

15-10-25

Propositional Logic

Truth Table for connectivities

P	Q	¬P	P ∧ Q	P ∨ Q	P ⇔ Q
F	F	T	F	F	T
F	T	T	F	T	F
T	F	F	F	T	F
T	T	F	T	T	T

Algorithm

function TT-Entails?(KB, α) returns true or false
    inputs: KB, the knowledge base, a sentence
            in propositional logic
        α, the query, a sentence in Prop logic
    symbols ← a list of the proposition
            symbols in KB & 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 returns
            PL-True? (α, model)
        else return true // when KB false, ret 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}))

Q. Consider a KB that contains the following propositional logic sentences:

$Q \to P$

$P \to \neg Q$

$Q \vee R$

i) Construct a truth table that shows the truth value of each sentence in KB & indicate the models in which the KB is true.

ii) Does KB entail R?

iii) Does KB entail $R \to P$?

iv) Does KB entail $Q \to R$?

Truth Table

$KB = (Q \to P) \wedge (P \to \neg Q) \wedge (Q \vee R)$

i)

P	Q	R	$Q \to P$	$P \to \neg Q$	$Q \vee R$	$R \to P$	$Q \to R$	KB=T
F	F	F	T	T	F	T	T	F
F	F	T	T	T	T	F	T	T
F	T	F	F	T	T	T	F	F
F	T	T	F	T	T	F	T	F
T	F	F	T	T	F	T	T	F
T	F	T	T	T	T	T	T	T
T	T	F	T	F	T	T	F	F
T	T	T	T	F	T	T	T	F

ii) Yes KB entail R

iii) No KB entail $R \to P$

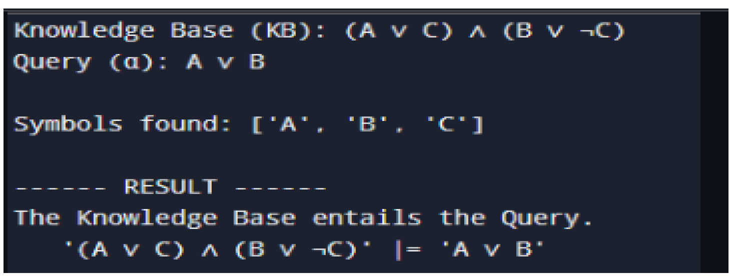
iv) Yes KB entails $Q \to R$

Code

```
import re
from itertools import product

def pl_true(sentence, model):
    try:
        return eval(sentence, model)
    except NameError:
        return False

def tt_entails(kb, alpha):
    kb = kb.replace('¬', 'not ').replace('∧', ' and ').replace('∨', ' or ')
    alpha = alpha.replace('¬', 'not ').replace('∧', ' and ').replace('∨', ' or ')
    symbols = sorted(list(set(re.findall(r'[A-Z]', kb + alpha))))
```

```
    print(f"Symbols found: {symbols}")
    for values in product([True, False], repeat=len(symbols)):
        model = dict(zip(symbols, values))
        if pl_true(kb, model):
            if not pl_true(alpha, model):
                print(f"Counterexample found: {model}")
                return False
    return True
if __name__ == "__main__":
    kb_formula = "(A ∨ C) ∧ (B ∨ ¬C)"
    alpha_formula = "A ∨ B"
    print(f"Knowledge Base (KB): {kb_formula}")
    print(f"Query (α): {alpha_formula}\n")
    result = tt_entails(kb_formula, alpha_formula)
    print("\n------ RESULT ------")
    if result:
        print(f"The Knowledge Base entails the Query.")
        print(f"   '{kb_formula}' |= '{alpha_formula}'")
    else:
        print(f"The Knowledge Base does NOT entail the Query.")
        print(f"   '{kb_formula}' |/= '{alpha_formula}'")
```

Output Snapshot



```
Knowledge Base (KB): (A v C) ∧ (B v ¬C)
Query (α): A v B

Symbols found: ['A', 'B', 'C']

------ RESULT ------
The Knowledge Base entails the Query.
   '(A v C) ∧ (B v ¬C)' |= 'A v B'
```

Program-8 Unification in FOL

Algorithm

23-10-25

First Order Logic

Unification : It deals with finding a common substitution for variables in different terms to make them match.

Unification Algorithm

unify (Ψ_1, Ψ_2)

1> If Ψ_1 or Ψ_2 is a variable then:
   a> If Ψ_1 or Ψ_2 are identical, return NIL
   b> Else if Ψ_1 is a variable
      i> then if Ψ_1 occurs in Ψ_2, return FAIL
      ii> else return {Ψ_2/Ψ_1}
   c> Else if Ψ_2 is a variable
      i> if Ψ_2 occurs in Ψ_1, return FAIL
      ii> else return {(Ψ_1/Ψ_2)}
   d> else return FAIL

2> If initial predicate in Ψ_1, Ψ_2 don't match, return FAIL

3> If Ψ_1 and Ψ_2 don't have identical no of elements, return FAIL

4> Set substitution set (SUBST) to NIL

5> for i=1 to no of elements in Ψ_1:
   a> Call unify with i^{th} ele of Ψ_1 & Ψ_2 & put result in S.
   b> If S = failure then returns FAIL
   c> If S ≠ NIL then do
      i> apply S to remainder of both L_1 & L_2
      ii> SUBST = APPEND(S, SUBST)

return SUBST

Unification examples

1> $P(f(x), g(y), y)$, $P(f(g(z)), g(f(a)), f(a))$

2> $Q(x, f(x))$, $Q(f(y), y)$

3> $H(x, g(x))$, $H(g(y), g(g(z)))$

1> $\{g(z) / x\}$

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

1> $\{g(z)/x\}$

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

$\{f(a)/y\}$

$P(f(x), g(y), y)$, $P(f(x), g(y), y)$

$\theta = \{g(z)/x, f(a)/y\}$

2> $Q(x, f(x))$

1> $\{x / g(z)\}$

$P(f(g(z)), g(y), y)$, $P(f(g(z)), g(f(a)), f(a))$

$\{y / f(a)\}$

$P(f(g(z)), g(f(a)), f(a))$, $P(f(g(z)), g(f(a)), f(a))$

$\theta = \{x / g(z), y / f(a)\}$

2> $x / f(y)$

$\theta(f(y), f(f(y)))$, $\theta(f(y), y)$

Fails

3> $H(x, g(x))$, $H(g(y), g(g(z)))$

$\{x / g(y)\}$

$H(g(y), g(g(y)))$, $H(g(y), g(g(z)))$

$\{y / z\}$

$H(g(y), g(g(z)))$, $H(g(y), g(g(z)))$

$\theta = \{x / g(y), y/(z)\}$

30/10/23

Code

```
import re

def is_variable(x):
    return x[0].islower() and x.isalpha()

def parse(term):
    term = term.strip()
    if '(' not in term:
        return term
    name, args = term.split('(', 1)
    args = args[:-1]  # remove closing parenthesis
    return name.strip(), [parse(a.strip()) for a in args.split(',')]

def occurs_check(var, expr):
    if var == expr:
        return True
    if isinstance(expr, tuple):
        _, args = expr
        return any(occurs_check(var, a) for a in args)
    return False

def substitute(subs, expr):
    if isinstance(expr, str):
        if expr in subs:
            return substitute(subs, subs[expr])
        return expr
    else:
        func, args = expr
        return (func, [substitute(subs, a) for a in args])

def unify(x, y, subs=None):
    if subs is None:
        subs = {}

    x = substitute(subs, x)
    y = substitute(subs, y)

    if x == y:
        return subs

    if isinstance(x, str) and is_variable(x):
        if occurs_check(x, y):
```

```
            return None
        subs[x] = y
        return subs

    if isinstance(y, str) and is_variable(y):
        if occurs_check(y, x):
            return None
        subs[y] = x
        return subs

    if isinstance(x, tuple) and isinstance(y, tuple):
        if x[0] != y[0] or len(x[1]) != len(y[1]):
            return None
        for a, b in zip(x[1], y[1]):
            subs = unify(a, b, subs)
            if subs is None:
                return None
        return subs

    return None


def term_to_str(t):
    if isinstance(t, str):
        return t
    func, args = t
    return f"{func}({', '.join(term_to_str(a) for a in args)})"

def pretty_print(subs):
    return ', '.join(f"{v} : {term_to_str(t)}" for v, t in subs.items())


pairs = [
    ("P(f(x),g(y),y)", "P(f(g(z)),g(f(a)),f(a))"),
    ("Q(x,f(x))", "Q(f(y),y)"),
    ("H(x,g(x))", "H(g(y),g(g(z)))")
]

for s1, s2 in pairs:
    print(f"\nUnifying: {s1}  and  {s2}")
    result = unify(parse(s1), parse(s2))
    if result:
        print("=> Substitution:", pretty_print(result))
    else:
```

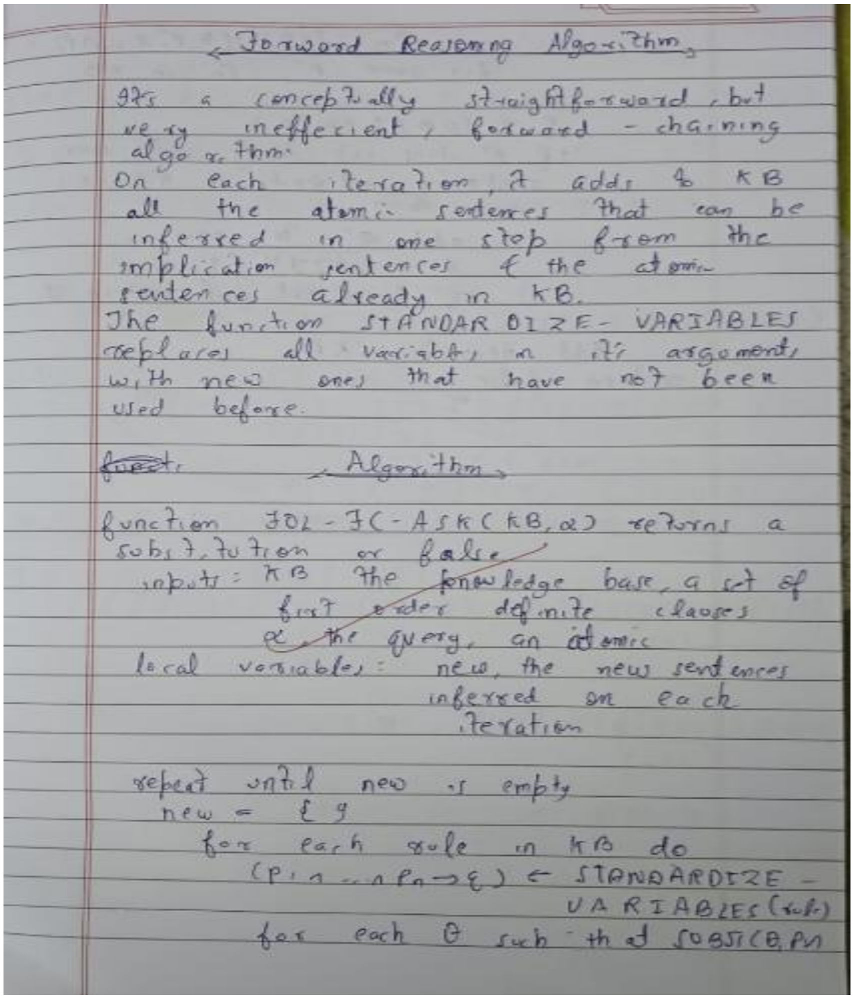
```
print("=> Not unifiable.")
```

Output Snapshot

```
Unifying: P(f(x),g(y),y)  and  P(f(g(z)),g(f(a)),f(a))
=> Substitution: x : g(z), y : f(a)

Unifying: Q(x,f(x))  and  Q(f(y),y)
=> Not unifiable.

Unifying: H(x,g(x))  and  H(g(y),g(g(z)))
=> Substitution: x : g(y), y : z
```

Program-9 Forward Reasoning in FOL

Algorithm



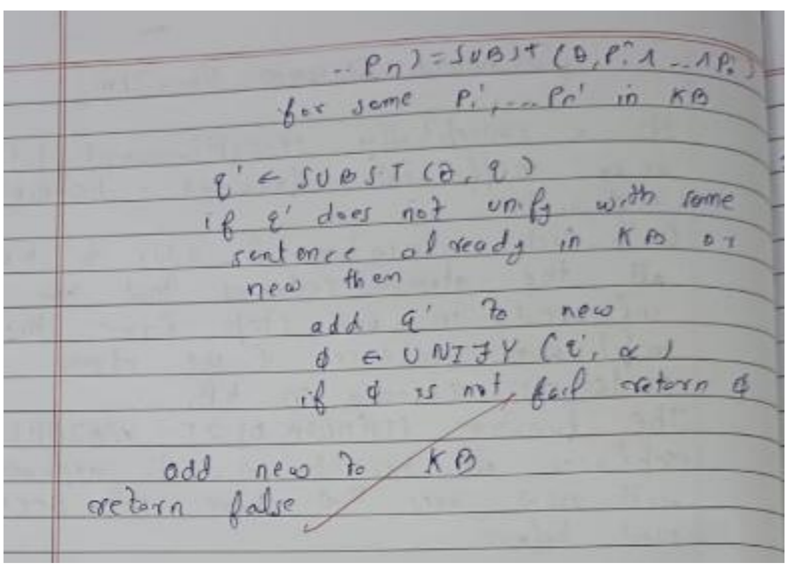
Forward Reasoning Algorithm

It's a conceptually straightforward, but very inefficient, forward-chaining algorithm.
On each iteration, it adds to KB all the atomic sentences that can be inferred in one step from the implication sentences & the atomic sentences already in KB.
The function STANDARDIZE-VARIABLES replaces all variables in its arguments with new ones that have not been used before.

~~funct.~~ Algorithm

function FOL-FC-ASK(KB, α) returns a substitution or false
inputs: KB the knowledge base, a set of first order definite clauses
α, the query, an atomic
local variables: new, the 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, P₁' ∧ ... ∧ Pn')
for some P₁', ... Pn' in KB

q' ← SUBST(θ, q)
if q' does not unify with some sentence already in KB or new then
add q' to new
φ ← UNIFY(q', α)
if φ is not fail return φ

add new to KB
return false

Code

from copy import deepcopy

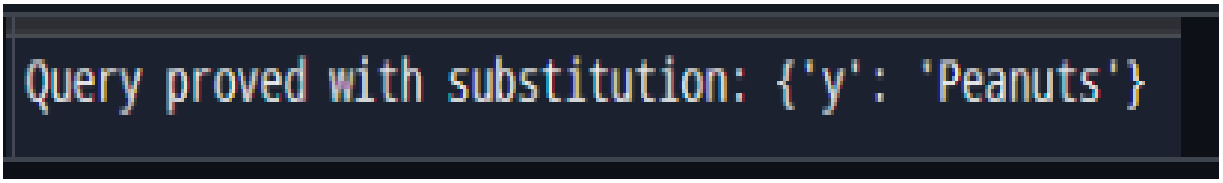
```
def standardize_variables(rule, var_count):
    """
    Standardize variables by renaming them with a unique suffix to avoid clashes.
    """
    new_rule = []
    for literal in rule:
        new_literal = []
        for token in literal:
            if token.islower() and token.isalpha():
                new_literal.append(token + str(var_count))
            else:
                new_literal.append(token)
        new_rule.append(tuple(new_literal))
    return new_rule

def unify(x, y, subst={}):
    """
    Unify two literals (tuples) x and y with current substitution subst.
    Returns updated substitution or None if cannot unify.
    """
    if subst is None:
        return None
    elif x == y:
        return subst
    elif isinstance(x, str) and x.islower():
        return unify_var(x, y, subst)
    elif isinstance(y, str) and y.islower():
        return unify_var(y, x, subst)
    elif isinstance(x, tuple) and isinstance(y, tuple) and len(x) == len(y):
        for a, b in zip(x, y):
            subst = unify(a, b, subst)
        return subst
    else:
        return None

def unify_var(var, x, subst):
    if var in subst:
        return unify(subst[var], x, subst)
    elif x in subst:
        return unify(var, subst[x], subst)
    else:
        subst[var] = x
        return subst

def substitute(sentence, subst):
```

```
    """
    Apply substitution subst to a sentence (list of literals).
    """
    new_sentence = []
    for literal in sentence:
        new_literal = []
        for token in literal:
            if token in subst:
                new_literal.append(subst[token])
            else:
                new_literal.append(token)
        new_sentence.append(tuple(new_literal))
    return new_sentence

def fol_fc_ask(KB, alpha):
    """
    Forward chaining algorithm for First Order Logic.

    KB: list of rules in the form [ (premises), conclusion ]
    alpha: query, atomic sentence as a tuple
    """

    var_count = 0
    new = []
    while True:
        new = []
        for (premises, conclusion) in KB:
            # Standardize variables in rule
            var_count += 1
            standardized_premises = standardize_variables(premises, var_count)
            standardized_conclusion = standardize_variables([conclusion], var_count)[0]

            # Try to unify each premise with some sentence in KB or new
            for fact in KB:
                subst = {}
                for premise in standardized_premises:
                    subst = unify(premise, fact[1], subst)
                    if subst is None:
                        break
                if subst is not None:
                    # Apply substitution
                    inferred = substitute([standardized_conclusion], subst)[0]
                    if inferred not in KB and inferred not in new:
                        new.append(inferred)
                    # Check if query is proven
```

```
            subst_alpha = unify(alpha, inferred, {})
            if subst_alpha is not None:
                return subst_alpha

    if not new:
        return False
    KB.extend([((), fact) if isinstance(fact, tuple) else fact for fact in new])

# Example usage:
# Represent atomic sentences as tuples, e.g. Likes(John, Food) -> ("Likes", "John", "Food")

if __name__ == "__main__":
    # KB: List of rules: (premises, conclusion)
    # premises and conclusion are list/tuple of literals (predicates as tuples)

    KB = [
        # John likes all food: Food(x) => Likes(John, x)
        ( [("Food", "x")], ("Likes", "John", "x") ),

        # Apple and Vegetable are food
        ( [], ("Food", "Apple") ),
        ( [], ("Food", "Vegetable") ),

        # Anything eaten and not killed is food: Eats(x,y) ^ ¬Killed(x) => Food(y)
        ( [("Eats", "x", "y"), ("NotKilled", "x")], ("Food", "y") ),

        # Anil eats peanuts and not killed
        ( [], ("Eats", "Anil", "Peanuts") ),
        ( [], ("NotKilled", "Anil") ),

        # Harry eats everything Anil eats: Eats(Anil,y) => Eats(Harry,y)
        ( [("Eats", "Anil", "y")], ("Eats", "Harry", "y") ),

        # Alive implies not killed: Alive(x) => NotKilled(x)
        ( [("Alive", "x")], ("NotKilled", "x") ),

        # Not killed implies alive: NotKilled(x) => Alive(x)
        ( [("NotKilled", "x")], ("Alive", "x") )
    ]

    # Query: Likes(John, Peanuts)
    query = ("Likes", "John", "Peanuts")

    result = fol_fc_ask(KB, query)
    if result:
```

```
        print("Query proved with substitution:", result)
    else:
        print("Query cannot be proved.")
```

OutputSnapshot



Program-10 Resolution in FOL.

Algorithm

12-11-25

Resolution in FOL

Algorithm FOL-Resolution (KB, Q)

Input :
KB → Knowledge Base (a set of FOL sentences)
Q – Query (sentence to be proven)

Output :
True if KB ⊨ Q
False otherwise

→ Convert all sentences in KB into CNF :
- Eliminate ⇔ & →
- Move ¬ inwards
- Standardize variables apart by renaming them each quantifier should use a different variable
- Skolemize each existential variable
- ~~Drop universal quantifier~~
- Distribute ∧ over ∨

→ Negate Query & to ¬Q & add to KB
→ Initialize Resolvents {}
→ Repeat until contradiction is found or no new clause :
a.) Select two clauses C1 & C2 from KB.
b) Resolve them together, performing all required unifications
c) If resolvent is empty clause, a contradiction has been found
d) If not, add the resolvent to the premises

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

O/P

Initial Clauses :
- Food (x) ∨ Likes (John, x)
Food (Apple)
Food (Vegetable)
- Eats (x, y) ∨ ¬ Killed (x) ∨ Food (y)
- Eats (Anil, Peanuts)
- Killed (Anil)
- Eats (x, y) ∨ Eats (Harry, y)
- Alive (x) ∨ - Killed (x)
- - Killed (x) ∨ Alive (x)
- Likes (John, Peanuts)

Resolution steps

Contradiction found between - Killed (x) and - - Killed (x)
So query is proved.

Code

```
from itertools import product

# Helper function: check if a literal is negated
def is_negative(literal):
    return literal.startswith("¬")

# Negate a literal
def negate(literal):
    return literal[1:] if is_negative(literal) else "¬" + literal

# Unification function (basic variable substitution)
def unify(x, y, substitution={}):
    if substitution is None:
        return None
    elif x == y:
        return substitution
    elif isinstance(x, str) and x.islower():  # variable
        return unify_var(x, y, substitution)
    elif isinstance(y, str) and y.islower():
        return unify_var(y, x, substitution)
    elif isinstance(x, tuple) and isinstance(y, tuple) and len(x) == len(y):
        for a, b in zip(x, y):
            substitution = unify(a, b, substitution)
        return substitution
    else:
        return None

def unify_var(var, x, substitution):
    if var in substitution:
        return unify(substitution[var], x, substitution)
    elif x in substitution:
        return unify(var, substitution[x], substitution)
    else:
        substitution[var] = x
        return substitution

# Resolution algorithm
def resolution(kb, query):
```

```
    clauses = kb + [negate(query)]
    new = set()

    print("Initial clauses:")
    for c in clauses:
        print(" -", c)
    print("\nResolution steps:")

    while True:
        pairs = [(clauses[i], clauses[j]) for i in range(len(clauses)) for j in range(i + 1, len(clauses))]
        for (ci, cj) in pairs:
            resolvents = resolve(ci, cj)
            if "" in resolvents:
                print(f"\nContradiction found between {ci} and {cj}")
                print(" Therefore, the query is PROVED true.")
                return True
            new = new.union(resolvents)

        if new.issubset(set(clauses)):
            print("\nNo new clauses can be added.")
            print( Query cannot be proved.")
            return False
        for c in new:
            if c not in clauses:
                clauses.append(c)

# Resolve two clauses
def resolve(ci, cj):
    resolvents = set()
    ci_literals = ci.split(" ∨ ")
    cj_literals = cj.split(" ∨ ")

    for di in ci_literals:
        for dj in cj_literals:
            if di == negate(dj):
                new_clause = list(set(ci_literals + cj_literals))
                new_clause.remove(di)
                new_clause.remove(dj)
                resolvent = " ∨ ".join(sorted(set(new_clause)))
```

```
            resolvents.add(resolvent)
    return resolvents

if __name__ == "__main__":
    KB = [
        "¬Food(x) ∨ Likes(John, x)",                # John likes all food
        "Food(Apple)",                              # Apple is food
        "Food(Vegetable)",                          # Vegetable is food
        "¬Eats(x, y) ∨ ¬¬Killed(x) ∨ Food(y)",      # Anything anyone eats and not killed is food
        "Eats(Anil, Peanuts)",                      # Anil eats peanuts
        "¬Killed(Anil)",                            # Anil is still alive
        "¬Eats(x, y) ∨ Eats(Harry, y)",             # Harry eats everything Anil eats
        "¬Alive(x) ∨ ¬Killed(x)",                   # Alive ⇒ not killed
        "¬¬Killed(x) ∨ Alive(x)"                    # not killed ⇒ alive
    ]
    QUERY = "Likes(John, Peanuts)"
    resolution(KB, QUERY)
```

<u>OUTPUT:</u>

```
Initial clauses:
 - ¬Food(x) v Likes(John, x)
 - Food(Apple)
 - Food(Vegetable)
 - ¬Eats(x, y) v ¬¬Killed(x) v Food(y)
 - Eats(Anil, Peanuts)
 - ¬Killed(Anil)
 - ¬Eats(x, y) v Eats(Harry, y)
 - ¬Alive(x) v ¬Killed(x)
 - ¬¬Killed(x) v Alive(x)
 - ¬Likes(John, Peanuts)

Resolution steps:

Contradiction found between ¬Killed(x) v ¬¬Killed(x) and ¬¬Killed(x)
Therefore, the query is PROVED true.
```

Program-11 Alpha-Beta Pruning

Algorithm

12-11-25

Alpha Beta Pruning,

function Alpha-Beta Search (state) returns an action

$v \leftarrow$ MAX-VALUE (state, $-\infty$, $+\infty$)
return an action in ACTIONS (state) with value v

function MAX-VALUE (state, α, β) returns a utility value
if leaf-Node (state)
return utility (state)

$v \leftarrow -\infty$
for each a in ACTIONS (state) do
$v \leftarrow$ MAX (v, MIN-VALUE (RESULT (S, a), α, β))

if $v \geq \beta$ return v

$\alpha \leftarrow$ MAX (α, v)

return v

function MIN-VALUE (state, α, β) returns a utility value
if leaf (state) then
return utility (state)

$v \leftarrow +\infty$

for each a in Actions (state) do
$v \leftarrow$ MIN (v, MA-VALUE (RESULT (s, a), α, β))

if $v \leq \alpha$ then return v
$\beta \leftarrow$ MIN (β, v)

return v

o/p Initially
User → X AI → O

```
1 | 2 | 3
4 | 5 | 6
7 | 8 | 9
```

Enter move : 1 AI moves

```
x |   |
  | o |
  |   |
```

Enter your move : 9 AI moves

```
x | o |
  | o |
  |   | x
```

Enter your move : 3 AI moves

```
x | o | x
  | o |
  | o | x
```

O wins ;

Code

```
import math

# Initialize board
board = [" " for _ in range(9)]

# Function to print the board
def print_board(board):
    print()
    for i in range(3):
        print(" | ".join(board[i*3:(i+1)*3]))
        if i < 2:
            print("---------")
    print()

# Check winner or draw
def check_winner(board):
    win_positions = [
        (0, 1, 2), (3, 4, 5), (6, 7, 8),
        (0, 3, 6), (1, 4, 7), (2, 5, 8),
        (0, 4, 8), (2, 4, 6)
    ]
    for (x, y, z) in win_positions:
        if board[x] == board[y] == board[z] and board[x] != " ":
            return board[x]
    if " " not in board:
        return "Draw"
    return None

def available_moves(board):
    return [i for i in range(9) if board[i] == " "]

# Alpha-Beta Pruning (Minimax)
def minimax(board, is_maximizing, alpha, beta):
    winner = check_winner(board)
    if winner == "O":
        return 1
    elif winner == "X":
        return -1
    elif winner == "Draw":
        return 0

    if is_maximizing:
        best_val = -math.inf
        for move in available_moves(board):
            board[move] = "O"
            val = minimax(board, False, alpha, beta)
            board[move] = " "
            best_val = max(best_val, val)
            alpha = max(alpha, val)
            if beta <= alpha:
                break
```

```
        return best_val
    else:
        best_val = math.inf
        for move in available_moves(board):
            board[move] = "X"
            val = minimax(board, True, alpha, beta)
            board[move] = " "
            best_val = min(best_val, val)
            beta = min(beta, val)
            if beta <= alpha:
                break
        return best_val

# AI selects best move
def best_move(board):
    best_val = -math.inf
    move = None
    for i in available_moves(board):
        board[i] = "O"
        move_val = minimax(board, False, -math.inf, math.inf)
        board[i] = " "
        if move_val > best_val:
            best_val = move_val
            move = i
    return move

# Game loop
def play_game():
    print("Welcome to Tic-Tac-Toe! You are X, and AI is O.")
    print_board(board)

    while True:
        # Human move
        try:
            human_move = int(input("Enter your move (1-9): ")) - 1
            if human_move not in range(9):
                print("Invalid input! Choose 1–9.")
                continue
            if board[human_move] != " ":
                print("That spot is taken! Try again.")
                continue
        except ValueError:
            print("Enter a number between 1–9.")
            continue

        board[human_move] = "X"

        # Check if player wins before AI moves
        if check_winner(board):
            break

        # AI move
```

```
        ai_move = best_move(board)
        board[ai_move] = "O"

        # Print board only after both have played
        print_board(board)

        # Check winner after AI move
        if check_winner(board):
            break

    winner = check_winner(board)
    if winner == "Draw":
        print("It's a draw!")
    else:
        print(f"{winner} wins!")
if __name__ == "__main__":
    play_game()
```

OUTPUT:

```
Welcome to Tic-Tac-Toe! You are X, and AI is O.

  |   |
---------
  |   |
---------
  |   |

Enter your move (1-9): 1

X |   |
---------
  | O |
---------
  |   |

Enter your move (1-9): 9

X | O |
---------
  | O |
---------
  |   | X

Enter your move (1-9): 3

X | O | X
---------
  | O | O
---------
  |   | X

Enter your move (1-9): 4

X | O | X
---------
X | O | O
---------
  | O | X

O wins!
```