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SUB: AIML
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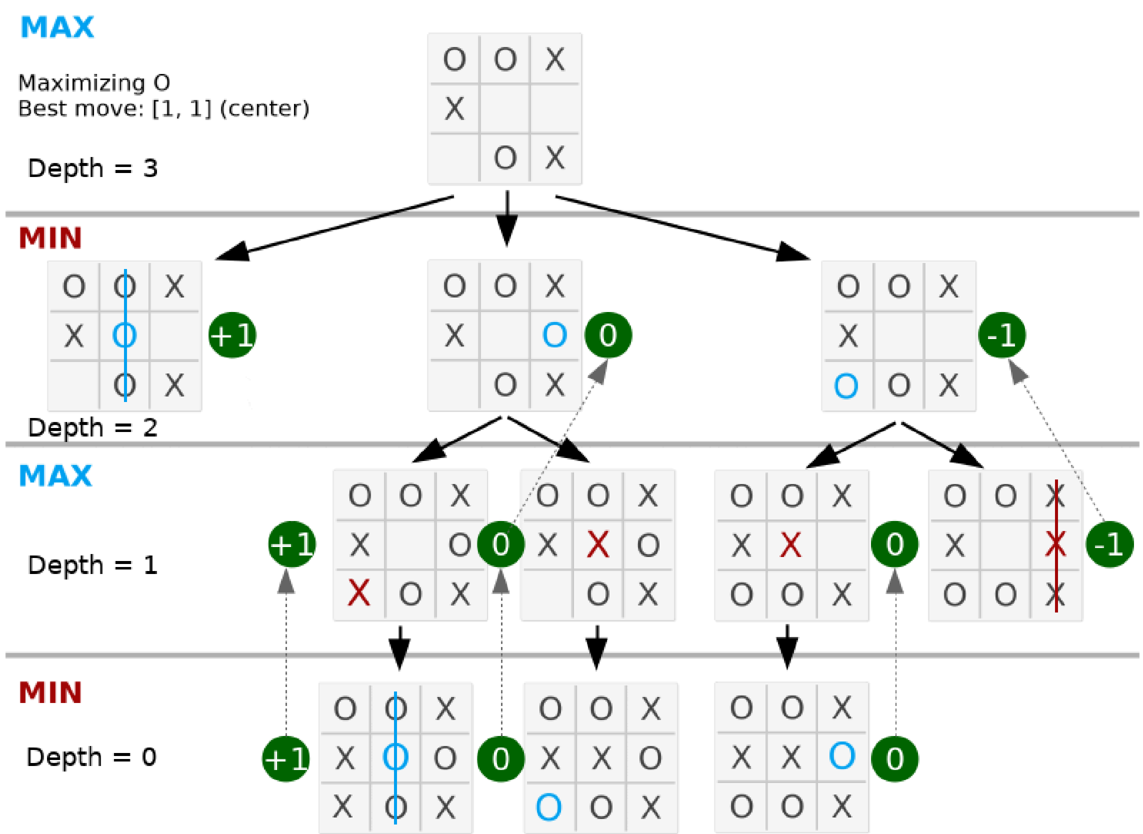
Exp no :	**04**
Aim :	**Implement the problem using the Informed searching technique min-max algorithm . Analyze the algorithm with respect to Completeness, Optimality, time and space Complexity** **a) Tic Tac Toe**
Thesis :	**Completeness, Optimality, Time, and Space Complexity:** ● **Completeness**: The Minimax algorithm is complete. It guarantees that a solution (win, lose, or draw) will be found if there is one because it explores all possible moves. ● **Optimality**: The Minimax algorithm is optimal when both players play perfectly. It always chooses the best possible move assuming the opponent is also playing optimally. ● **Time Complexity**: The time complexity of the Minimax algorithm is **O(b^d)**, where: ○ **b** = branching factor (number of possible moves per turn, up to 9 for Tic Tac Toe) ○ **d** = depth of the game tree (up to 9 for Tic Tac Toe) ● For Tic Tac Toe, the maximum time complexity is O(9!) or approximately 362,880 in the worst case, but pruning techniques like alpha-beta can reduce this. ● **Space Complexity**: The space complexity of the Minimax algorithm is **O(d)**, where: ○ **d** = maximum depth of the game tree (which is 9 for Tic Tac Toe) ● The space complexity depends on the depth of the recursion stack, which, in the case of Tic Tac Toe, is limited to 9 levels.



Code :

```
#include <iostream>

#include <vector>

#include <limits.h>





using namespace std;
```

```
#define PLAYER 'X'  // Maximizing player

#define OPPONENT 'O'  // Minimizing player




// Function to print the board

void printBoard(char board[3][3]) {

   for (int row = 0; row < 3; row++) {

       for (int col = 0; col < 3; col++) {

           cout << board[row][col] << " ";

       }

       cout << endl;

   }

}




// Function to check if there are moves left on the board

bool isMovesLeft(char board[3][3]) {

   for (int i = 0; i < 3; i++)

       for (int j = 0; j < 3; j++)

           if (board[i][j] == '_')

               return true;
```

```
    return false;

}




// Function to evaluate the board state

int evaluate(char board[3][3]) {

    // Check rows for victory

    for (int row = 0; row < 3; row++) {

        if (board[row][0] == board[row][1] && board[row][1] ==
board[row][2]) {

            if (board[row][0] == PLAYER)

                return +10;

            else if (board[row][0] == OPPONENT)

                return -10;

        }

    }




    // Check columns for victory

    for (int col = 0; col < 3; col++) {

        if (board[0][col] == board[1][col] && board[1][col] ==
board[2][col]) {
```

```
            if (board[0][col] == PLAYER)
                return +10;
            else if (board[0][col] == OPPONENT)
                return -10;
        }
    }



    // Check diagonals for victory
    if (board[0][0] == board[1][1] && board[1][1] == board[2][2]) {
        if (board[0][0] == PLAYER)
            return +10;
        else if (board[0][0] == OPPONENT)
            return -10;
    }



    if (board[0][2] == board[1][1] && board[1][1] == board[2][0]) {
        if (board[0][2] == PLAYER)
            return +10;
        else if (board[0][2] == OPPONENT)
```

```
            return -10;
    }


    // No winner: return 0
    return 0;
}


// Minimax algorithm
int minimax(char board[3][3], int depth, bool isMax) {
    int score = evaluate(board);


    // If Maximizer or Minimizer has won, return the score
    if (score == 10)
        return score - depth; // Subtract depth to prioritize
shorter win
    if (score == -10)
        return score + depth; // Add depth to prioritize shorter
loss
```

	`` // If no moves are left, it's a draw if (!isMovesLeft(board)) return 0; // Maximizing player's move if (isMax) { int best = INT_MIN; for (int i = 0; i < 3; i++) { for (int j = 0; j < 3; j++) { if (board[i][j] == '_') { board[i][j] = PLAYER; best = max(best, minimax(board, depth + 1, false)); board[i][j] = '_'; } } } return best; } ```

	`` // Minimizing player's move else { int best = INT_MAX; for (int i = 0; i < 3; i++) { for (int j = 0; j < 3; j++) { if (board[i][j] == '_') { board[i][j] = OPPONENT; best = min(best, minimax(board, depth + 1, true)); board[i][j] = '_'; } } } return best; } } // Function to find the best move for the player pair<int, int> findBestMove(char board[3][3]) { int bestVal = INT_MIN; ```

	<pre>pair<int, int> bestMove = {-1, -1}; for (int i = 0; i < 3; i++) { for (int j = 0; j < 3; j++) { if (board[i][j] == '_') { board[i][j] = PLAYER; int moveVal = minimax(board, 0, false); board[i][j] = '_'; if (moveVal > bestVal) { bestMove = {i, j}; bestVal = moveVal; } } } } return bestMove;</pre>

	`` } int main() { char board[3][3] = { {'_', '_', '_'}, {'_', '_', '_'}, {'_', '_', '_'} }; while (isMovesLeft(board)) { int row, col; printBoard(board); // Ask the user (opponent) for their move cout << "Enter your move (row and column): "; cin >> row >> col; // Validate the user input ```

	<pre> if (row < 0 || row > 2 || col < 0 || col > 2 || board[row][col] != '_') { cout << "Invalid move. Please try again." << endl; continue; } // Make the opponent's move board[row][col] = OPPONENT; // Find the best move for the AI player pair<int, int> bestMove = findBestMove(board); // Make the best move for the AI player if (isMovesLeft(board) && bestMove.first != -1 && bestMove.second != -1) { board[bestMove.first][bestMove.second] = PLAYER; cout << "AI played (" << bestMove.first << ", " << bestMove.second << ")\n"; }</pre>

	`` // Check if the game has a winner int result = evaluate(board); if (result == 10) { cout << "AI wins!" << endl; break; } else if (result == -10) { cout << "You win!" << endl; break; } else if (!isMovesLeft(board)) { cout << "It's a draw!" << endl; break; } } printBoard(board); return 0; } ```

Output :

```
Output
/tmp/8Sl5HfyqHc.o
_ _ _
_ _ _
_ _ _
Enter your move (row and column): 2 2
AI played (1, 1)
_ _ _
_ X _
_ _ O
```

```
Enter your move (row and column): 1 1
Invalid move. Please try again.
_ _ _
_ X _
_ _ O
Enter your move (row and column): 1 2
AI played (0, 2)
_ _ X
_ X O
_ _ O
```

```
Enter your move (row and column): 1 2
AI played (0, 2)
_ _ X
_ X O
_ _ O
Enter your move (row and column): 0 1
AI played (2, 0)
AI wins!
_ O X
_ X O
X _ O


=== Code Execution Successful ===
```

Conclusion :	The Minimax algorithm is a powerful method for playing Tic Tac Toe optimally. It is both complete and optimal under the assumption of perfect play. However, its time complexity can be high for more complex games, but for Tic Tac Toe, it is manageable due to the relatively small state space. Additionally, techniques like alpha-beta pruning can significantly improve its performance.