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| **Experiment No.** | 8 | | |

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| **AIM:** | To implement 15 puzzle sum using the branch and bound |
| **THEORY:** | **What is Branch and Bound?**  Branch and bound algorithms are used to find the optimal solution for combinatory, discrete, and general mathematical optimization problems**.** In general, given an NP-Hard problem, a branch and bound algorithm explores the entire search space of possible solutions and provides an optimal solution.  A branch and bound algorithm consist of stepwise enumeration of possible candidate solutions by exploring the entire search space. With all the possible solutions, we first build a rooted decision tree. The root node represents the entire search space:    **Advantages**  In a branch and bound algorithm, we don’t explore all the nodes in the tree. That’s why the time complexity of the branch and bound algorithm is less when compared with other algorithms.  If the problem is not large and if we can do the branching in a reasonable amount of time, it finds an optimal solution for a given problem.  The branch and bound algorithm find a minimal path to reach the optimal solution for a given problem. It doesn’t repeat nodes while exploring the tree.  **Disadvantages**  The branch and bound algorithm are time-consuming. Depending on the size of the given problem, the number of nodes in the tree can be too large in the worst case.  Also, parallelization is extremely difficult in the branch and bound algorithm.  Lets solve an example for branch and bound for 15 puzzle problem |
| **PSEUDOCODE:** |  |
| **EXPERIMENT 1** | |
| **CODE:** | import java.util.\*;  class Node {      int[][] array;      int misplaced;      int recent;  *// 1 up| 2 right| 3 down| 4 left|*  }  class branchBounds {      int blankRow;      int blankRowIndex;*// row index*      int blackColIndex;*// column index*      int totalCost;      String isChoosen = "None";      int[][] targetMatrix = { { 1, 2, 3, 4 }, { 5, 6, 7, 8 }, { 9, 10, 11, 12 }, {              13, 14, 15, 0 } };      boolean isSolvable(int[][] arr, int row\_len) {          int inv = inversions(arr); *// method that counts the number of inversions (i<j, arr[i]>arr[j])*          if (arr.length % 2 != 0) {*// checks if n is odd*              if (inv % 2 == 0) {*// if the length is odd, and inversions are even the puzzle is solvable*                  return true;              }  *// row: even AND inversion: odd =>solvable*  *// row: odd AND inversion: even =>solvable*          } else {*// if n is even*              if (this.blankRow % 2 == 0 && inv % 2 != 0 || this.blankRow % 2 != 0 && inv % 2 == 0) {                  return true;              }          }          return false;      }      int inversions(int[][] arr) {  *// count the number of inversions*          int no\_inversions = 0;          int[] arr2 = new int[arr.length \* arr.length]; *// 1d array*          int k = 0;          for (int i = 0; i < arr.length; i++) {              for (int j = 0; j < arr.length; j++) {                  arr2[k] = arr[i][j]; *// converting 2d array into 1d array*                  if (arr[i][j] == 0) {*// blank tile(finding the index of the blank tile)*                      this.blankRow = arr.length - i; *// findimg the index according to the convention (bottom->top):*  *// 1..2 3.*                      this.blankRowIndex = i;                      this.blackColIndex = j;                  }                  k++;              }          }          printArray(arr);          System.out.println();          System.out.println("----------------------");          System.out.println("X Mark is at -> " + (blankRowIndex + 1) + ", " + (blackColIndex + 1));          System.out.println("----------------------");          System.out.println();          for (int i = 0; i < arr2.length; i++) {              for (int j = i + 1; j < arr2.length; j++) {                  if (arr2[i] > arr2[j] && arr2[j] != 0) { *// not considering the blank tile while finding out the*  *// inversions*                      no\_inversions++;                  }              }          }          System.out.println("Total inversions: " + no\_inversions);          return no\_inversions;      }      boolean isMatched(int[][] arr, int[][] sel) {  *// check if the selected array is the target array*          for (int i = 0; i < arr.length; i++) {              for (int j = 0; j < arr.length; j++) {                  if (arr[i][j] != sel[i][j]) {*// checks the array with the target array, as soon as it matches the while*  *// loop exits*                      return false;                  }              }          }          return true;      }      int mismatch(int[][] arr) {  *// misplaced tiles*          int mislocations = 0;          for (int i = 0; i < arr.length; i++) {              for (int j = 0; j < arr.length; j++) {                  if (arr[i][j] != this.targetMatrix[i][j] && arr[i][j] != 0) {*// checks the number of elements that dont*  *// match the target array*                      mislocations++;                  }              }          }          return mislocations;      }      void solve(int[][] arr) {  *// Solving the puzzle*          int cost = Integer.MAX\_VALUE;          int level = 0;          int[][] temp\_array = new int[arr.length][arr.length];          while (!isMatched(arr, targetMatrix)) {              level++;              for (int i = 0; i < arr.length; i++) {                  for (int j = 0; j < arr.length; j++) {  *// blank tile index*  *// checking where the x mark is*                      if (arr[i][j] == 0) {                          this.blankRow = arr.length - i;                          this.blankRowIndex = i;                          this.blackColIndex = j;                      }                  }              }              System.out.print("\nCosts->\n");              int left[][] = leftShift(arr, temp\_array, blankRowIndex, blackColIndex, level, cost);              System.out.println("Left shift: " + ((int) mismatch(left) + (int) level));              int up[][] = upShift(arr, left, temp\_array, blankRowIndex, blackColIndex, level, cost);              System.out.println("Up shift: " + ((int) mismatch(up) + (int) level));              int right[][] = rightShift(arr, up, temp\_array, blankRowIndex, blackColIndex, level, cost);              System.out.println("Right shift: " + ((int) mismatch(right) + (int) level));              int[][] down = downShift(arr, right, temp\_array, blankRowIndex, blackColIndex, level, cost);              System.out.println("Down shift: " + ((int) mismatch(down) + (int) level));              for (int i = 0; i < down.length; i++) { *// storing the array for down shift*                  for (int j = 0; j < down.length; j++) {                      down[i][j] = arr[i][j];                  }              }              if (blankRowIndex != arr.length - 1) {*// checks if the down shift is possible and doesnt go out of bounds*                  int temp = down[blankRowIndex + 1][blackColIndex];                  down[blankRowIndex + 1][blackColIndex] = down[blankRowIndex][blackColIndex];                  down[blankRowIndex][blackColIndex] = temp;              }              if (mismatch(down) + level <= cost) {*// checking if the cost is lower*                  cost = mismatch(down) + level;                  for (int i = 0; i < left.length; i++) {                      for (int j = 0; j < left.length; j++) {                          temp\_array[i][j] = down[i][j];                      }                  }              }              System.out.print("\nMinimum possible cost: " + ((int) mismatch(down) + (int) level) + "\n");              System.out.print("\nOperation performed: " + isChoosen + "\n\n");  *// after filtering through the whole level printing the current*              for (int i = 0; i < down.length; i++) {                  for (int j = 0; j < down.length; j++) {                      arr[i][j] = temp\_array[i][j];  *// status of the matrix*                  }              }              printArray(arr);              totalCost = totalCost + cost;          }          System.out.println("Total cost: " + totalCost);      }      public void printArray(int arr[][]) {          for (int i = 0; i < arr.length; i++) {              System.out.println("----------------------------");              for (int j = 0; j < arr.length; j++) {                  System.out.print(String.format("| %3d  ", arr[i][j]));              }              System.out.println("|");          }          System.out.println("-----------------------------");      }      public int[][] leftShift(int[][] arr, int[][] temp\_array, int blankRowIndex, int blackColIndex, int level,              int cost) {  *// left shift*          int[][] left = new int[arr.length][arr.length];  *// storing the array for left shift*          for (int i = 0; i < left.length; i++) {              for (int j = 0; j < left.length; j++) {                  left[i][j] = arr[i][j];              }          }  *// checks if the left shift is possible and doesnt go out of bounds*          if (blackColIndex != 0) {              int temp = left[blankRowIndex][blackColIndex];              left[blankRowIndex][blackColIndex] = left[blankRowIndex][blackColIndex - 1];              left[blankRowIndex][blackColIndex - 1] = temp;          }  *// checking if the cost is minimum*          if (mismatch(left) + level <= cost) {              isChoosen = "Shifting left";              cost = mismatch(left) + level; *// assigning lower cost*              for (int i = 0; i < left.length; i++) {                  for (int j = 0; j < left.length; j++) {                      temp\_array[i][j] = left[i][j]; *// potential candidate*                  }              }          }          return temp\_array;      }      public int[][] rightShift(int[][] arr, int[][] up, int[][] temp\_array, int blankRowIndex, int blackColIndex,              int level,              int cost) {  *// right shift*          int[][] right = new int[arr.length][arr.length];  *// storing the array for right shift*          for (int i = 0; i < right.length; i++) {              for (int j = 0; j < right.length; j++) {                  right[i][j] = arr[i][j];              }          }  *// checks if the right shift is possible and doesnt go out of bounds*          if (blackColIndex != arr.length - 1) {              int temp = right[blankRowIndex][blackColIndex];              right[blankRowIndex][blackColIndex] = right[blankRowIndex][blackColIndex + 1];              right[blankRowIndex][blackColIndex + 1] = temp;          }  *// checking if the cost is minimum*          if (mismatch(right) + level <= cost) {              isChoosen = "Shifting right";              cost = mismatch(right) + level; *// assigning lower cost*              for (int i = 0; i < right.length; i++) {                  for (int j = 0; j < right.length; j++) {                      temp\_array[i][j] = right[i][j]; *// potential candidate*                  }              }          }          return temp\_array;      }      public int[][] upShift(int arr[][], int left[][], int temp\_array[][], int blankRowIndex, int blankColIndex,              int level,              int cost) {          int[][] up = new int[arr.length][arr.length];          for (int i = 0; i < up.length; i++) {              for (int j = 0; j < up.length; j++) {                  up[i][j] = arr[i][j]; *// storing the array for up shift*              }          }          if (blankRowIndex != 0) { *// checks if the up shift is possible and doesn't go out of bounds*              int temp = up[blankRowIndex - 1][blankColIndex];              up[blankRowIndex - 1][blankColIndex] = up[blankRowIndex][blankColIndex];              up[blankRowIndex][blankColIndex] = temp;          }          if (mismatch(up) + level <= cost) { *// checking if the cost is lower*              isChoosen = "Shifting Up";              cost = mismatch(up) + level;              for (int i = 0; i < left.length; i++) {                  for (int j = 0; j < left.length; j++) {                      temp\_array[i][j] = up[i][j];                  }              }          }          return temp\_array;      }      public int[][] downShift(int arr[][], int left[][], int temp\_array[][], int blankRowIndex, int blankColIndex,              int level,              int cost) {          int[][] down = new int[arr.length][arr.length];          for (int i = 0; i < down.length; i++) {              for (int j = 0; j < down.length; j++) {                  down[i][j] = arr[i][j]; *// storing the array for down shift*              }          }          if (blankRowIndex != arr.length - 1) { *// checks if the down shift is possible and doesn't go out of bounds*              int temp = down[blankRowIndex + 1][blankColIndex];              down[blankRowIndex + 1][blankColIndex] = down[blankRowIndex][blankColIndex];              down[blankRowIndex][blankColIndex] = temp;          }          if (mismatch(down) + level <= cost) { *// checking if the cost is lower*              isChoosen = "Shifting Down";              cost = mismatch(down) + level;              for (int i = 0; i < left.length; i++) {                  for (int j = 0; j < left.length; j++) {                      temp\_array[i][j] = down[i][j];                  }              }          }          return temp\_array;      }  }  public class puzzleSolver {      public static void main(String[] args) {          Scanner sc = new Scanner(System.in);          branchBounds obj = new branchBounds();          System.out.println("--------------15 puzzle solve----------------");          System.out.println("Input Matrix: ");          System.out.print("\nEnter the size of the matrix: ");          int size = sc.nextInt();          int[][] table = new int[size][size];          System.out.print("\nEnter the elements of the matrix: ");          for (int i = 0; i < size; i++) {              for (int j = 0; j < size; j++) {                  table[i][j] = sc.nextInt();              }          }          System.out.println("The Length of the puzzle is: " + table.length);          if (obj.isSolvable(table, table[0].length)) {              System.out.println("\nPuzzle is solvable");              obj.solve(table);*// solving the matrix*          } else {              System.out.println("\n Puzzle is not solvable");          }          sc.close();      }  } |
| **SCREENSHOT:** | Not Solvable    Solvable |
| **TIME COMPLEXITY** | The Time complexity of the branch and Bound algorithm is  given below:  **Time Complexity: O(n^2)**  The Space Complexity of the branch and Bound Algorithm is given below:  **Space Complexity: O(n)** |
| **OUTPUT:** |  |
| **CONCLUSION:** Things learnt during the procedural programming of the problem of branch and bound   * Learnt one of the most popular algorithms used in the optimization problem is the branch and bound algorithm. * Learnt about some advantages and disadvantages of the branch and bound algorithm * Also noted how and when a branch and bound algorithm would be the right choice for a user to use. * Used branch and bound based algorithm for solving the 15 puzzle problem. | |