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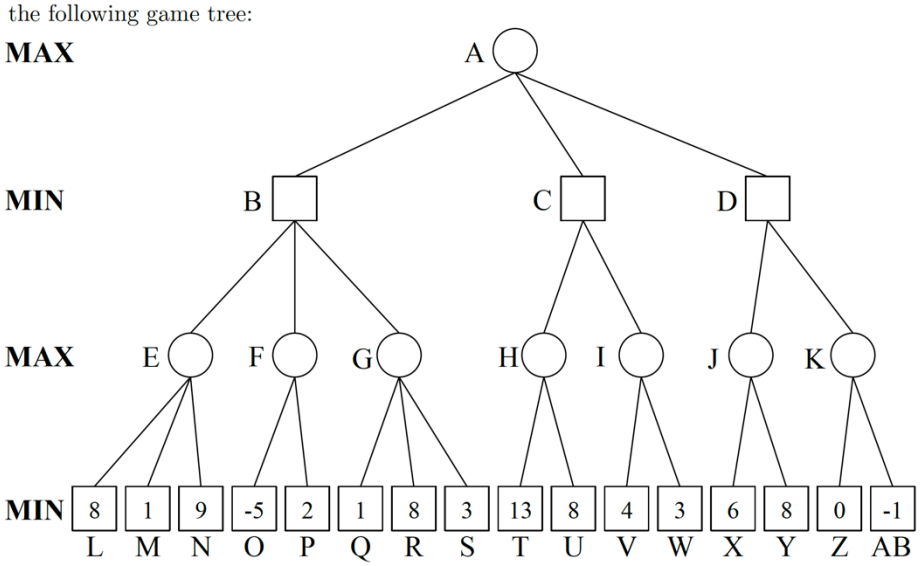
CSCE 476: Introduction to Artificial Intelligence
Homework 4

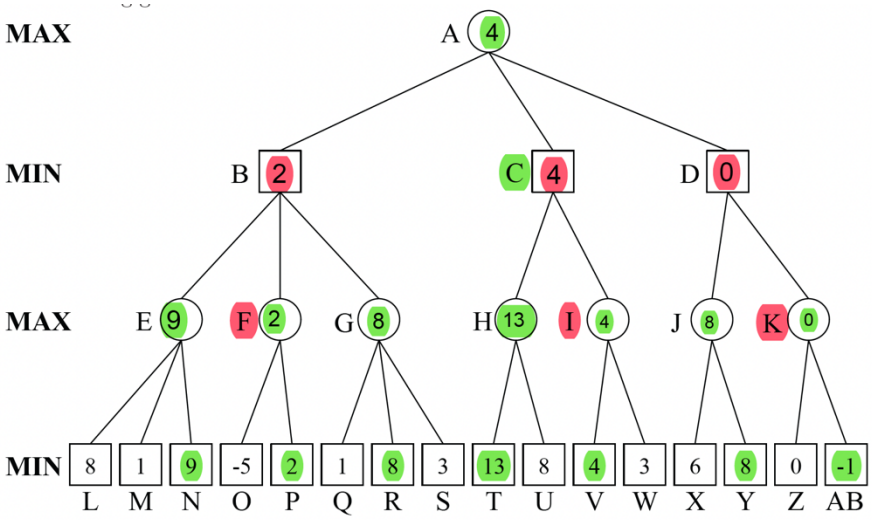
Sunday, October 3, 2021
10:42 PM

1 Adverserial Search (Total 5 points)

Consider the following game tree:



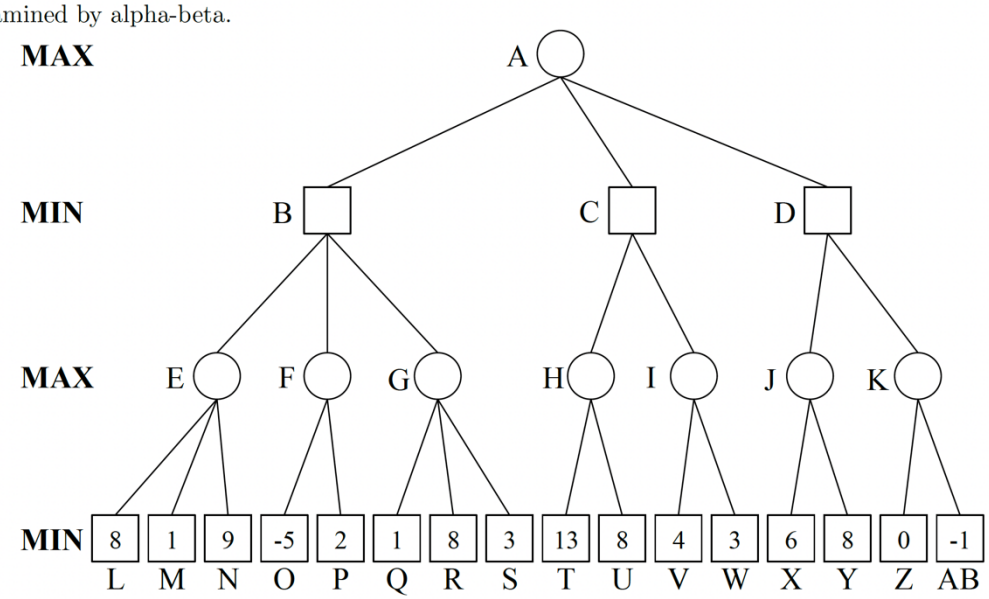
a. Compute the minimax decision. Show your answer by writing the values at the appropriate nodes in the above tree.

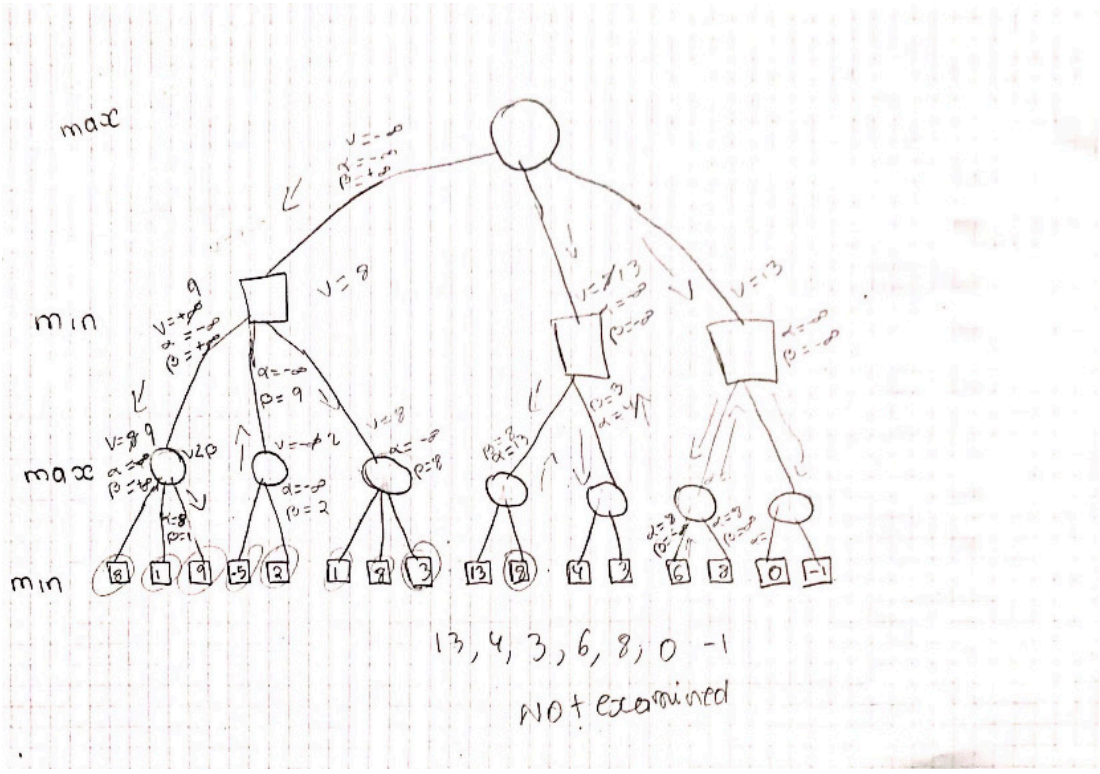


b. What move should Max choose?
   i. Max should chooses the maximum move (the greater number)

2 Alpha-beta Pruning (Total 5 points)

Using the *alpha-beta pruning method*, with standard left-to-right evaluation of nodes, show what nodes are *not* examined by alpha-beta.

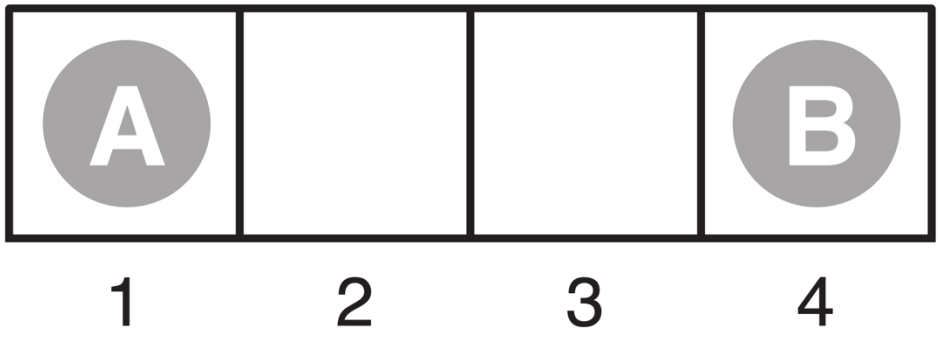




3 Chapter 5, Exercise 8, Source: AIMA online site. (Total 10 points)

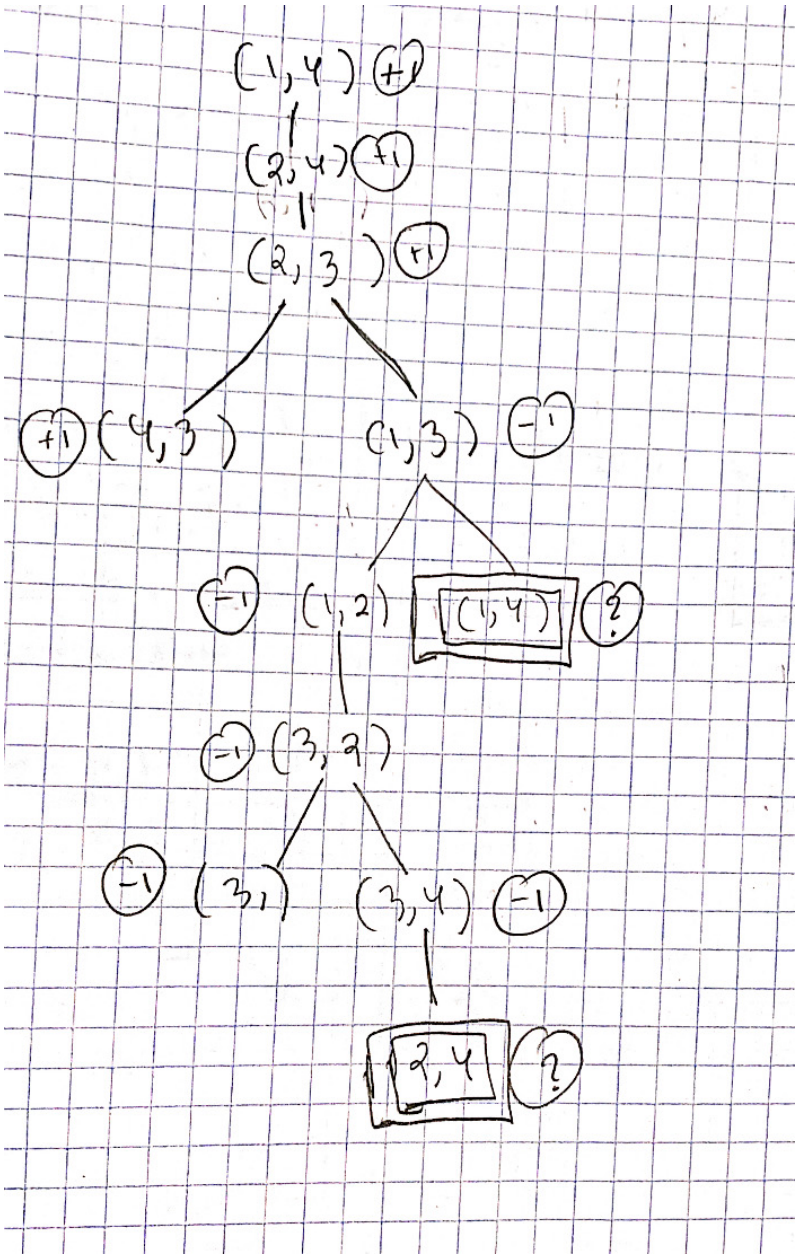
Consider the two-player game described in Chapter 5, Exercise 7.

Player A moves first. The two players take turns moving, and each player must move his token to an open adjacent space in either direction. If the opponent occupies an adjacent space, then a player may jump over the opponent to the next open space if any. (For example, if A is on 3 and B is on 2, then A may move back to 1.) The game ends when one player reaches the opposite end of the board. If player A reaches space 4 first, then the value of the game to A is $+1$; if player B reaches space 1 first, then the value of the game to A is -1.



The starting position of a simple game.

1. Draw the complete game tree, using the following conventions:
   - Write each state as (s_A, s_B), where s_A and s_B denote the token locations.
   - Put each terminal state in a square box and write its game value in a circle.
   - Put *loop states* (states that already appear on the path to the root) in double square boxes. Since their value is unclear, annotate each with a "?" in a circle.

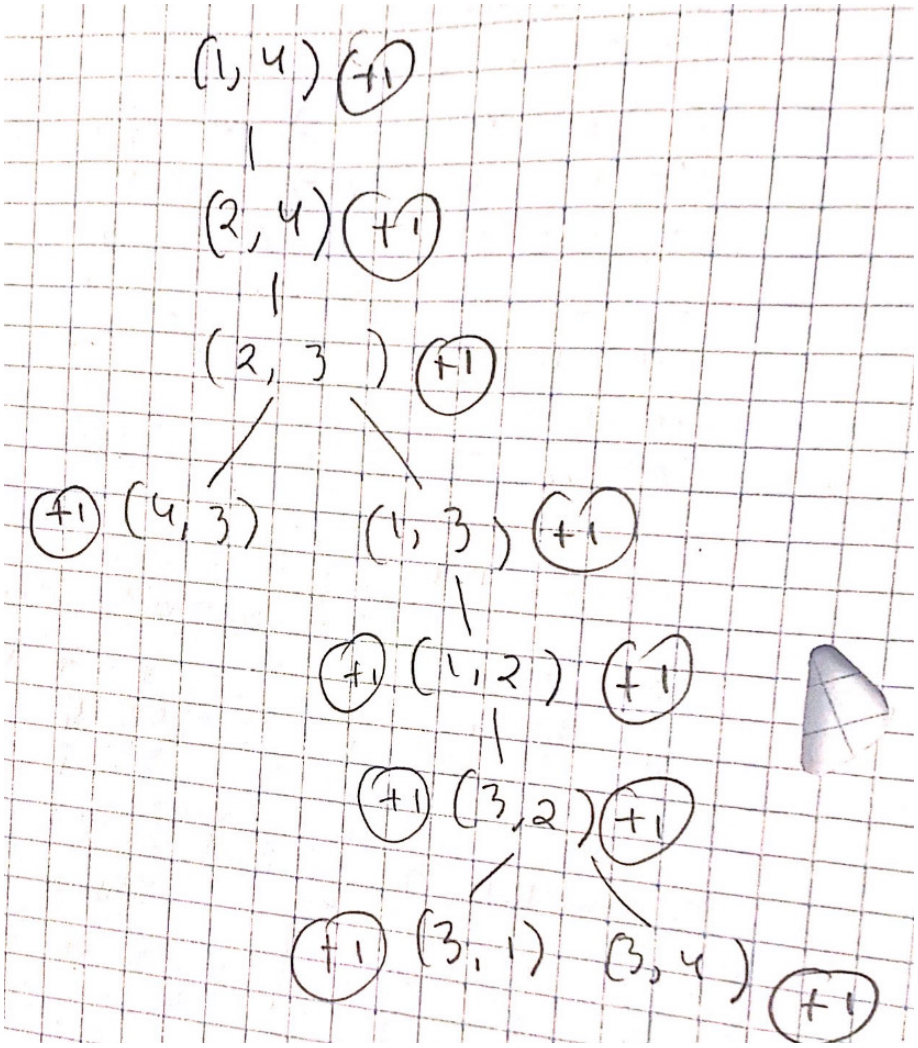


2. Now mark each node with its backed-up minimax value (also in a circle). Explain how you handled the "?" values and why.

When we have a chance of choosing "?" values (which takes us to a node we've already visited) it will never be chosen so the backed up minimax value becomes -1

3. Explain why the standard minimax algorithm would fail on this game tree and briefly sketch how you might fix it, drawing on your answer to part (2). Does your modified algorithm give optimal decisions for all games with loops?

Standard minimax algorithm would fail because it might get stuck in an infinite loop, we could add a variable that checks if a node has been visited already.



4. This 4-square game can be generalized to n squares for any $n > 2$. Prove that A wins if n is even and loses if n is odd.

4 Romanian Holidays (Total 100 points)

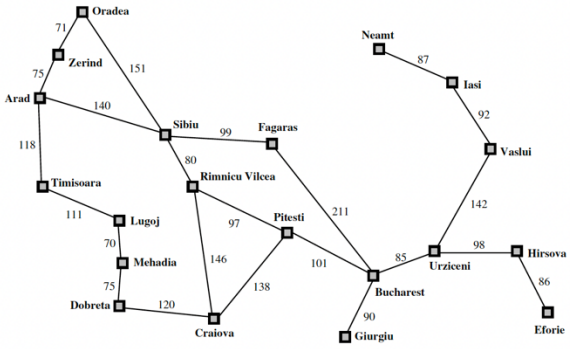
This exercise will guide you, step by step, to implement the data structures representing Romania's map and the search algorithms for conducting search. It is mandatory to all students.

Note that in the following sections, we refer to variable and function names that may not be accepted by the programming language you choose (e.g., C, C++, and Java variables cannot contain hyphens). In these cases, just use names that are similar but acceptable by the language by, for example, using camel case instead of hyphens. Additionally, an association list is merely a list of key-value pairs.

It is not necessary to implement these structures *exactly*, but your implementation should be similar enough that the graders can clearly see the analogous variables and structures.

4.1 Data structures (50 points)

Create the data structures required to represent the map of Romania. Include the information about the distances between two cities linked by a road as well as the distance from any given city to Bucharest as indicated in Figure 1.



Arad	366	**Mehadia**	241
Bucharest	0	**Neamt**	234
Craiova	160	**Oradea**	380
Dobreta	242	**Pitesti**	100
Eforie	161	**Rimnicu Vilcea**	193
Fagaras	176	**Sibiu**	253
Giurgiu	77	**Timisoara**	329
Hirsova	151	**Urziceni**	80
Iasi	226	**Vaslui**	199
Lugoj	244	**Zerind**	374

Figure 1: Map of Romania with road distances in kilometers and straight-line distances to Bucharest.

- $cities.dat$
  - Delimited file that stores information given in Figure 1.
  - Each line in the file has the following information
    - $city; neighbor_1: distance; \ldots.; neighbor_i: distance; \mathrm{h}(city)_{SLD}$
- *City.java*
  - data structure for a city
    - name: name of city
    - neighbors: neighboring cities
    - h: value of the straight-line distance to Bucharest
    - visited: Boolean that states whether the current city has been visited or not
- Ways to access the cities
  - $ArrayList < City > \ allCities$
    - Stores every city object read from cities.dat
  - $HashMap < String, HashMap < String, Integer >> \ allCitiesHash$
    - Stores every city object read from cities.dat in key/value format where the key is the city and value is another key/value map storing neighboring city along with distance.

4.1.1 Tasks

Designing, implementing and testing the map.

a. Write a function $allCitiesFromList$ that takes a global variable, $allCitiesList$, and returns a list of all names of cities on the map.

```java
/***
 * takes a global variable, allCitiesList, and returns a list of all names of
 * cities on the map.
 *
 * @param allCities
 * @return
 */
public static ArrayList<String> allCitiesFromList() {

    ArrayList<String> cities = new ArrayList<String>();
    for (City city : allCities) {
        cities.add(city.getName());
    }

    return cities;

}
```

```
1. Design, implement and test your map.

       Type:    class java.util.ArrayList
       Size:    20

       Graph Uniform Cost Search
       Example: City [name=Arad, neighboors={Zerind=75, Sibiu=140, Timisoara=118}, h=366]
       Path:    [Arad, Sibiu, Rimnicu Vilcea, Pitesti, Bucharest]
       Cost:    418

2. Write a function allCitiesFromList that takes a global variable,
  allCitiesList, and returns a list of all names of cities on the map.

       Oradea
       Zerind
       Arad
       Sibiu
       Timisoara
       Lugoj
       Mehadia
       Dobreta
       Craiova
       Rimnicu Vilcea
       Pitesti
       Fagaras
       Bucharest
       Giurgiu
       Urziceni
       Hirsova
       Eforie
       Vaslui
       Iasi
       Neamt
```

b. Write a function $allCitiesFromHtable$ that takes a variable, $allCitiesHtable$ and returns a list of all the structures of cities on the map.

```java
/**
 * takes a variable, allCitiesHtable and returns a list of all the structures of
 * cities on the map.
 *
 * take the hash of the cities and return it back into a list
 *
 * @param allCitieshash
 */
public static ArrayList<City> allCitiesFromHtable() {

    ArrayList<City> structures = new ArrayList<City>();

    for (Entry<String, HashMap<String, Integer>> entry : allCitiesHash.entrySet()) {
        String key = entry.getKey();
        HashMap<String, Integer> value = entry.getValue();

        for (Entry<String, Integer> cities : value.entrySet()) {

            String item = cities.getKey();
            City cite = getCityFromList(item);
            structures.add(cite);

        }

    }
    return structures;
}
```

3. Write a function allCitiesFromHtable that takes a variable, allCitiesHtable and returns a list of all the structures of cities on the map.

```
City [name=Zerind, neighboors={Oradea=71, Arad=75}, h=374]
City [name=Sibiu, neighboors={Oradea=151, Rimnicu Vilcea=80, Arad=140, Fagaras=99}, h=253]
City [name=Oradea, neighboors={Zerind=71, Sibiu=151}, h=380]
City [name=Arad, neighboors={Zerind=75, Sibiu=140, Timisoara=118}, h=366]
City [name=Urziceni, neighboors={Hirsova=98, Vaslui=142, Bucharest=85}, h=80]
City [name=Giurgiu, neighboors={Bucharest=90}, h=77]
City [name=Fagaras, neighboors={Bucharest=211, Sibiu=99}, h=176]
City [name=Pitesti, neighboors={Rimnicu Vilcea=97, Craiova=138, Bucharest=101}, h=100]
City [name=Hirsova, neighboors={Urziceni=98, Eforie=86}, h=151]
City [name=Vaslui, neighboors={Urziceni=142, Iasi=92}, h=199]
City [name=Bucharest, neighboors={Urziceni=85, Giurgiu=90, Fagaras=211, Pitesti=101}, h=0]
City [name=Zerind, neighboors={Oradea=71, Arad=75}, h=374]
City [name=Sibiu, neighboors={Oradea=151, Rimnicu Vilcea=80, Arad=140, Fagaras=99}, h=253]
City [name=Timisoara, neighboors={Arad=118, Lugoj=111}, h=329]
City [name=Dobreta, neighboors={Craiova=120, Mehadia=75}, h=242]
City [name=Lugoj, neighboors={Mehadia=70, Timisoara=111}, h=244]
City [name=Iasi, neighboors={Vaslui=92, Neamt=87}, h=226]
City [name=Vaslui, neighboors={Urziceni=142, Iasi=92}, h=199]
City [name=Neamt, neighboors={Iasi=92}, h=234]
City [name=Arad, neighboors={Zerind=75, Sibiu=140, Timisoara=118}, h=366]
City [name=Lugoj, neighboors={Mehadia=70, Timisoara=111}, h=244]
City [name=Rimnicu Vilcea, neighboors={Craiova=146, Sibiu=80, Pitesti=97}, h=193]
City [name=Craiova, neighboors={Rimnicu Vilcea=146, Dobreta=120, Pitesti=138}, h=160]
City [name=Bucharest, neighboors={Urziceni=85, Giurgiu=90, Fagaras=211, Pitesti=101}, h=0]
City [name=Hirsova, neighboors={Urziceni=98, Eforie=86}, h=151]
City [name=Rimnicu Vilcea, neighboors={Craiova=146, Sibiu=80, Pitesti=97}, h=193]
City [name=Dobreta, neighboors={Craiova=120, Mehadia=75}, h=242]
City [name=Pitesti, neighboors={Rimnicu Vilcea=97, Craiova=138, Bucharest=101}, h=100]
City [name=Craiova, neighboors={Rimnicu Vilcea=146, Dobreta=120, Pitesti=138}, h=160]
City [name=Sibiu, neighboors={Oradea=151, Rimnicu Vilcea=80, Arad=140, Fagaras=99}, h=253]
City [name=Pitesti, neighboors={Rimnicu Vilcea=97, Craiova=138, Bucharest=101}, h=100]
City [name=Urziceni, neighboors={Hirsova=98, Vaslui=142, Bucharest=85}, h=80]
City [name=Eforie, neighboors={Hirsova=86}, h=161]
City [name=Urziceni, neighboors={Hirsova=98, Vaslui=142, Bucharest=85}, h=80]
City [name=Iasi, neighboors={Vaslui=92, Neamt=87}, h=226]
City [name=Bucharest, neighboors={Urziceni=85, Giurgiu=90, Fagaras=211, Pitesti=101}, h=0]
City [name=Oradea, neighboors={Zerind=71, Sibiu=151}, h=380]
City [name=Rimnicu Vilcea, neighboors={Craiova=146, Sibiu=80, Pitesti=97}, h=193]
City [name=Arad, neighboors={Zerind=75, Sibiu=140, Timisoara=118}, h=366]
City [name=Fagaras, neighboors={Bucharest=211, Sibiu=99}, h=176]
City [name=Craiova, neighboors={Rimnicu Vilcea=146, Dobreta=120, Pitesti=138}, h=160]
City [name=Mehadia, neighboors={Dobreta=75, Lugoj=70}, h=241]
City [name=Mehadia, neighboors={Dobreta=75, Lugoj=70}, h=241]
City [name=Timisoara, neighboors={Arad=118, Lugoj=111}, h=329]
City [name=Bucharest, neighboors={Urziceni=85, Giurgiu=90, Fagaras=211, Pitesti=101}, h=0]
City [name=Sibiu, neighboors={Oradea=151, Rimnicu Vilcea=80, Arad=140, Fagaras=99}, h=253]
```

c. Write two functions $getCityFromList$ and $getCityFromHtable$ that take the name of a city as input and return the corresponding structure (by accessing a variable, $allCitiesList$ and $allCitiesHtable$, respectively).

```java
/**
 * take the name of a city as input and return the corresponding structure from
 * allCities hash table
 *
 * @param city
 * @return
 */

public static Entry<String, HashMap<String, Integer>> getCityFromHtable(String city) {
    Entry<String, HashMap<String, Integer>> structure = null;
    for (Entry<String, HashMap<String, Integer>> entry : allCitiesHash.entrySet()) {
        String key = entry.getKey();

        if (city.equals(key)) {
            structure = entry;
        }

    }
    return structure;

}
```

```
4. Write two functions getCityFromList and getCityFromHtable that take the name of a
  city as input and return the corresponding structure (by accessing a variable, allCitiesList and
  allCitiesHtable, respectively).

       City: Arad
              Value in allCitiesList
              City [name=Arad, neighboors={Zerind=75, Sibiu=140, Timisoara=118}, h=366]

              Value in allCitiesHtable
              Arad={Zerind=75, Sibiu=140, Timisoara=118}
```

d. Write two functions $neighborsUsingList$ and $neighborsUsingHtable$ that take the name of a city as input and return the list of structures of its direct neighbors. $neighborsUsingList$ and $neighborsUsingHtable$ should use $getCityFromList$ and $getCityFromHtable$, respectively.

```
/**
 * take the name of a city as input and return the list of structures of its
 * direct neighbors using getCityFromHtable,
 *
 * @param city
 * @return
 */

public static ArrayList<City> neighborsUsingHtable(String city) {
    ArrayList<City> neighbors = new ArrayList<City>();

    Entry<String, HashMap<String, Integer>> struct = getCityFromHtable(city);

    for (Entry<String, Integer> entry : struct.getValue().entrySet()) {
        neighbors.add(getCityFromList(entry.getKey()));

    }

    return neighbors;

}

/**
 * take the name of a city as input and return the list of structures of its
 * direct neighbors using getCityFromList
 *
 * @param city
 */
public static ArrayList<City> neighborsUsingList(String city) {
    ArrayList<City> neighbors = new ArrayList<City>();

    for (Entry<String, Integer> entry : getCityFromList(city).getNeighboors().entrySet()) {
        neighbors.add(getCityFromList(entry.getKey()));

    }

    return neighbors;

}
```

```
5.Write two functions neighborsUsingList and neighborsUsingHtable that take the name
  of a city as input and return the list of structures of its direct neighbors. neighborsUsingList and
  neighborsUsingHtable should use getCityFromList and getCityFromHtable, respectively.

       City: Arad
              Neighbors using list
              City [name=Zerind, neighboors={Oradea=71, Arad=75}, h=374]
              City [name=Sibiu, neighboors={Oradea=151, Rimnicu Vilcea=80, Arad=140, Fagaras=99}, h=253]
              City [name=Timisoara, neighboors={Arad=118, Lugoj=111}, h=329]

              Neighbors using hash table
              City [name=Zerind, neighboors={Oradea=71, Arad=75}, h=374]
              City [name=Sibiu, neighboors={Oradea=151, Rimnicu Vilcea=80, Arad=140, Fagaras=99}, h=253]
              City [name=Timisoara, neighboors={Arad=118, Lugoj=111}, h=329]
```

e. Using $allCitiesHtable$, write a function $neighborsWithinD$ that takes the name of a city $myCity$ and a number distance, then returns, for all direct neighbors within distance from $myCity$ ($\leq$), an association list of the structures of the neighbors of $myCity$ and their distance to $myCity$.

```java
/**
 * Using allCitiesHtable,a function that takes the name of a city myCity and a
 * number distance, then returns, for all direct neighbors within distance from
 * myCity (LEQ), an association list of the structures of the neighbors of
 * myCity and their distance to myCity
 *
 * @return
 */

public static HashMap<City, Integer> neighborsWithinD(String myCity, int distance) {
    HashMap<City, Integer> neighbors = new HashMap<City, Integer>();

    Entry<String, HashMap<String, Integer>> city = getCityFromHtable(myCity); // this function uses allCitiesHash

    HashMap<String, Integer> everyNeighbor = city.getValue();

    for (Entry<String, Integer> entry : everyNeighbor.entrySet()) {

        City cite = getCityFromList(entry.getKey());
        int dist = entry.getValue();
        if (distance <= dist) {
            neighbors.put(cite, dist);
        }

    }

    return neighbors;
}
```

```
6. Using allCitiesHtable, write a function neighborsWithinD that takes the name of a city
  myCity and a number distance, then returns, for all direct neighbors within distance from myCity
  (less than or equal), an association list of the structures of the neighbors of myCity and their distance to myCity.

      City: Arad
      Nieghbors within 204 km
      NONE


      City: Arad
      Nieghbors within 76 km
      {Timisoara=118, Sibiu=140}
```

f. Using $allCitiesHtable$, write a function $neighborsP$ that takes the name of two cities $cityOne$ and $cityTwo$, and returns the distance between them if they are directly connected or nil if they are not.

```java
/**
 * Using allCitiesHtable, a function that takes the name of two cities cityOne
 * and cityTwo, and returns the distance between them if they are directly
 * connected or nil if they are not
 *
 * @return
 */
public static int neighborsP(String cityOne, String cityTwo) {
    int dist = 0;
    HashMap<String, Integer> neighbors = allCitiesHash.get(cityOne);
    for (Entry<String, Integer> entry : neighbors.entrySet()) {

        if (entry.getKey().equals(cityTwo)) {
            dist = entry.getValue();
        }

    }

    return dist;
}
```

7. Using allCitiesHtable, write a function neighborsP that takes the name of two cities cityOne and cityTwo, and returns the distance between them if they are directly connected or n they are not.

Example: Arad and Hirsova
distance: 0

4.2 Implementing Search (50 points)

You are asked to implement search the following search strategies, first as a TREE-SEARCH then as a GRAPH-SEARCH:

- Any uninformed search strategy of your choice, 10 points
- A Greedy search strategy, and 10 points
- An A* search strategy. 10 points

a. Uninformed search strategy: Uniform Cost Search

$\longrightarrow$ Uniform-cost expands first lowest-cost node on the fringe

Uniform Cost Tree Search (Uninformed)

City Name	#nodes visited	Path to Bucharest	Total cost of path	CPU time
Arad	53	[Arad, Sibiu, Rimnicu Vilcea, Pitesti, Bucharest]	418	3985000 ns
Bucharest	1	[Bucharest]	0	0 ns
Craiova	8	[Craiova, Pitesti, Bucharest]	239	177000 ns
Dobreta	21	[Dobreta, Craiova, Pitesti, Bucharest]	359	445000 ns
Eforie	6	[Eforie, Hirsova, Urziceni, Bucharest]	269	80000 ns
Fagaras	5	[Fagaras, Bucharest]	211	84000 ns
Giurgiu	2	[Giurgiu, Bucharest]	90	28000 ns
Hirsova	5	[Hirsova, Urziceni, Bucharest]	183	69000 ns
Iasi	11	[Iasi, Vaslui, Urziceni, Bucharest]	319	158000 ns
Lugoj	73	[Lugoj, Mehadia, Dobreta, Craiova, Pitesti, Bucharest]	504	2292000 ns
Mehadia	46	[Mehadia, Dobreta, Craiova, Pitesti, Bucharest]	434	878000 ns
Neamt	12	[Neamt, Iasi, Vaslui, Urziceni, Bucharest]	411	93000 ns
Oradea	45	[Oradea, Sibiu, Rimnicu Vilcea, Pitesti, Bucharest]	429	979000 ns
Pitesti	3	[Pitesti, Bucharest]	101	19000 ns
Rimnicu Vilcea	8	[Rimnicu Vilcea, Pitesti, Bucharest]	198	67000 ns
Sibiu	17	[Sibiu, Rimnicu Vilcea, Pitesti, Bucharest]	278	169000 ns
Timisoara	91	[Timisoara, Arad, Sibiu, Rimnicu Vilcea, Pitesti, Bucharest]	536	2465000 ns
Urziceni	2	[Urziceni, Bucharest]	85	10000 ns
Vaslui	6	[Vaslui, Urziceni, Bucharest]	227	37000 ns
Zerind	93	[Zerind, Arad, Sibiu, Rimnicu Vilcea, Pitesti, Bucharest]	493	2879000 ns

Uniform Cost Graph Search (Uninformed)

City Name	#nodes visited	Path to Bucharest	Total cost of path	CPU time
Arad	14	[Arad, Sibiu, Rimnicu Vilcea, Pitesti, Bucharest]	418	1092000 ns
Bucharest	1	[Bucharest]	0	0 ns
Craiova	8	[Craiova, Pitesti, Bucharest]	239	366000 ns
Dobreta	10	[Dobreta, Craiova, Pitesti, Bucharest]	359	370000 ns
Eforie	4	[Eforie, Hirsova, Urziceni, Bucharest]	269	218000 ns
Fagaras	4	[Fagaras, Bucharest]	211	117000 ns
Giurgiu	2	[Giurgiu, Bucharest]	90	44000 ns
Hirsova	4	[Hirsova, Urziceni, Bucharest]	183	100000 ns
Iasi	5	[Iasi, Vaslui, Urziceni, Bucharest]	319	145000 ns
Lugoj	15	[Lugoj, Mehadia, Dobreta, Craiova, Pitesti, Bucharest]	504	389000 ns
Mehadia	12	[Mehadia, Dobreta, Craiova, Pitesti, Bucharest]	434	316000 ns
Neamt	5	[Neamt, Iasi, Vaslui, Urziceni, Bucharest]	411	131000 ns
Oradea	12	[Oradea, Sibiu, Rimnicu Vilcea, Pitesti, Bucharest]	429	303000 ns
Pitesti	3	[Pitesti, Bucharest]	101	62000 ns
Rimnicu Vilcea	6	[Rimnicu Vilcea, Pitesti, Bucharest]	198	133000 ns
Sibiu	11	[Sibiu, Rimnicu Vilcea, Pitesti, Bucharest]	278	218000 ns
Timisoara	16	[Timisoara, Arad, Sibiu, Rimnicu Vilcea, Pitesti, Bucharest]	536	466000 ns
Urziceni	2	[Urziceni, Bucharest]	85	39000 ns
Vaslui	5	[Vaslui, Urziceni, Bucharest]	227	91000 ns
Zerind	18	[Zerind, Arad, Sibiu, Rimnicu Vilcea, Pitesti, Bucharest]	493	515000 ns

b. Greedy Search strategy: Best First Search

Greedy best-first search chooses the node n closest to the goal such as $h(n)$ is minimal

Greedy Best First Tree Search

City Name	#nodes visited	Path to Bucharest	Total cost of path	CPU time
Arad	4	[Arad, Sibiu, Fagaras, Bucharest]	450	47000 ns
Bucharest	1	[Bucharest]	0	0 ns
Craiova	3	[Craiova, Pitesti, Bucharest]	239	41000 ns
Dobreta	4	[Dobreta, Craiova, Pitesti, Bucharest]	359	39000 ns
Eforie	4	[Eforie, Hirsova, Urziceni, Bucharest]	269	48000 ns
Fagaras	2	[Fagaras, Bucharest]	211	17000 ns
Giurgiu	2	[Giurgiu, Bucharest]	90	38000 ns
Hirsova	3	[Hirsova, Urziceni, Bucharest]	183	35000 ns
Iasi	4	[Iasi, Vaslui, Urziceni, Bucharest]	319	26000 ns
Lugoj	6	[Lugoj, Mehadia, Dobreta, Craiova, Pitesti, Bucharest]	504	38000 ns
Mehadia	5	[Mehadia, Dobreta, Craiova, Pitesti, Bucharest]	434	72000 ns
Neamt	5	[Neamt, Iasi, Vaslui, Urziceni, Bucharest]	411	45000 ns
Oradea	4	[Oradea, Sibiu, Fagaras, Bucharest]	461	98000 ns
Pitesti	2	[Pitesti, Bucharest]	101	11000 ns
Rimnicu Vilcea	3	[Rimnicu Vilcea, Pitesti, Bucharest]	198	34000 ns
Sibiu	3	[Sibiu, Fagaras, Bucharest]	310	16000 ns
Timisoara	7	[Timisoara, Lugoj, Mehadia, Dobreta, Craiova, Pitesti, Bucharest]	615	125000 ns
Urziceni	2	[Urziceni, Bucharest]	85	9000 ns
Vaslui	3	[Vaslui, Urziceni, Bucharest]	227	33000 ns
Zerind	5	[Zerind, Arad, Sibiu, Fagaras, Bucharest]	525	46000 ns

Greedy Best First Graph Search

City Name	#nodes visited	Path to Bucharest	Total cost of path	CPU time
Arad	4	[Arad, Sibiu, Fagaras, Bucharest]	450	38000 ns
Bucharest	1	[Bucharest]	0	0 ns
Craiova	3	[Craiova, Pitesti, Bucharest]	239	24000 ns
Dobreta	4	[Dobreta, Craiova, Pitesti, Bucharest]	359	33000 ns
Eforie	4	[Eforie, Hirsova, Urziceni, Bucharest]	269	33000 ns
Fagaras	2	[Fagaras, Bucharest]	211	15000 ns
Giurgiu	2	[Giurgiu, Bucharest]	90	19000 ns
Hirsova	3	[Hirsova, Urziceni, Bucharest]	183	25000 ns
Iasi	4	[Iasi, Vaslui, Urziceni, Bucharest]	319	65000 ns
Lugoj	6	[Lugoj, Mehadia, Dobreta, Craiova, Pitesti, Bucharest]	504	49000 ns
Mehadia	5	[Mehadia, Dobreta, Craiova, Pitesti, Bucharest]	434	43000 ns
Neamt	5	[Neamt, Iasi, Vaslui, Urziceni, Bucharest]	411	37000 ns
Oradea	4	[Oradea, Sibiu, Fagaras, Bucharest]	461	36000 ns
Pitesti	2	[Pitesti, Bucharest]	101	15000 ns
Rimnicu Vilcea	3	[Rimnicu Vilcea, Pitesti, Bucharest]	198	65000 ns
Sibiu	3	[Sibiu, Fagaras, Bucharest]	310	23000 ns
Timisoara	7	[Timisoara, Lugoj, Mehadia, Dobreta, Craiova, Pitesti, Bucharest]	615	58000 ns
Urziceni	2	[Urziceni, Bucharest]	85	13000 ns
Vaslui	3	[Vaslui, Urziceni, Bucharest]	227	23000 ns
Zerind	5	[Zerind, Arad, Sibiu, Fagaras, Bucharest]	525	86000 ns

c. A^* Search: Best First A^* search

A* search chooses the least-cost solution

$$\text{solution cost } f(n) \begin{cases} g(n)\text{: cost from root to a given node } n \\ + \\ h(n)\text{: cost from the node } n \text{ to the goal node} \end{cases}$$

such as $f(n) = g(n) + h(n)$ is minimal

Best First A* Tree Search

City Name	#nodes visited	Path to Bucharest	Total cost of path	CPU time
Arad	6	[Arad, Sibiu, Rimnicu Vilcea, Pitesti, Bucharest]	418	52000 ns
Bucharest	1	[Bucharest]	0	0 ns
Craiova	3	[Craiova, Pitesti, Bucharest]	239	20000 ns
Dobreta	5	[Dobreta, Craiova, Pitesti, Bucharest]	359	29000 ns
Eforie	4	[Eforie, Hirsova, Urziceni, Bucharest]	269	22000 ns
Fagaras	2	[Fagaras, Bucharest]	211	11000 ns
Giurgiu	2	[Giurgiu, Bucharest]	90	9000 ns
Hirsova	3	[Hirsova, Urziceni, Bucharest]	183	17000 ns
Iasi	4	[Iasi, Vaslui, Urziceni, Bucharest]	319	22000 ns
Lugoj	11	[Lugoj, Mehadia, Dobreta, Craiova, Pitesti, Bucharest]	504	136000 ns
Mehadia	8	[Mehadia, Dobreta, Craiova, Pitesti, Bucharest]	434	56000 ns
Neamt	5	[Neamt, Iasi, Vaslui, Urziceni, Bucharest]	411	27000 ns
Oradea	6	[Oradea, Sibiu, Rimnicu Vilcea, Pitesti, Bucharest]	429	51000 ns
Pitesti	2	[Pitesti, Bucharest]	101	11000 ns
Rimnicu Vilcea	3	[Rimnicu Vilcea, Pitesti, Bucharest]	198	34000 ns
Sibiu	5	[Sibiu, Rimnicu Vilcea, Pitesti, Bucharest]	278	49000 ns
Timisoara	12	[Timisoara, Arad, Sibiu, Rimnicu Vilcea, Pitesti, Bucharest]	536	163000 ns
Urziceni	2	[Urziceni, Bucharest]	85	9000 ns
Vaslui	3	[Vaslui, Urziceni, Bucharest]	227	17000 ns
Zerind	9	[Zerind, Arad, Sibiu, Rimnicu Vilcea, Pitesti, Bucharest]	493	67000 ns

Best First A* Graph Search

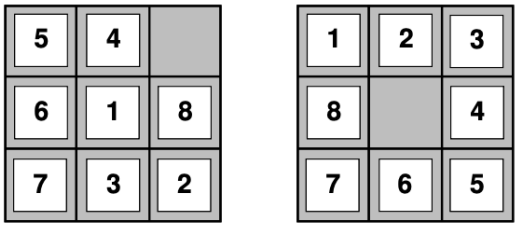
City Name	#nodes visited	Path to Bucharest	Total cost of path	CPU time
Arad	6	[Arad, Sibiu, Rimnicu Vilcea, Pitesti, Bucharest]	418	145000 ns
Bucharest	1	[Bucharest]	0	0 ns
Craiova	3	[Craiova, Pitesti, Bucharest]	239	51000 ns
Dobreta	5	[Dobreta, Craiova, Pitesti, Bucharest]	359	92000 ns
Eforie	4	[Eforie, Hirsova, Urziceni, Bucharest]	269	75000 ns
Fagaras	2	[Fagaras, Bucharest]	211	27000 ns
Giurgiu	2	[Giurgiu, Bucharest]	90	24000 ns
Hirsova	3	[Hirsova, Urziceni, Bucharest]	183	50000 ns
Iasi	4	[Iasi, Vaslui, Urziceni, Bucharest]	319	143000 ns
Lugoj	8	[Lugoj, Mehadia, Dobreta, Craiova, Pitesti, Bucharest]	504	169000 ns
Mehadia	6	[Mehadia, Dobreta, Craiova, Pitesti, Bucharest]	434	116000 ns
Neamt	5	[Neamt, Iasi, Vaslui, Urziceni, Bucharest]	411	95000 ns
Oradea	6	[Oradea, Sibiu, Rimnicu Vilcea, Pitesti, Bucharest]	429	140000 ns
Pitesti	2	[Pitesti, Bucharest]	101	25000 ns
Rimnicu Vilcea	3	[Rimnicu Vilcea, Pitesti, Bucharest]	198	51000 ns
Sibiu	5	[Sibiu, Rimnicu Vilcea, Pitesti, Bucharest]	278	93000 ns
Timisoara	12	[Timisoara, Arad, Sibiu, Rimnicu Vilcea, Pitesti, Bucharest]	536	282000 ns
Urziceni	2	[Urziceni, Bucharest]	85	24000 ns
Vaslui	3	[Vaslui, Urziceni, Bucharest]	227	52000 ns
Zerind	9	[Zerind, Arad, Sibiu, Rimnicu Vilcea, Pitesti, Bucharest]	493	384000 ns

Source code submitted on Handin

5 Eight-Piece Sliding Puzzle (Bonus 80 points)

The goal is to implement A* search for solving the Eight-Piece Sliding Puzzle Problem with the two admissible heuristics: the displaced tile and the Manhattan distance heuristics.

$$\text{8-puzzle:} \begin{cases} h_1(n) = \text{number of misplaced tiles} \\ h_2(n) = \text{total Manhattan distance} \end{cases}$$



Start State **Goal State**

I think I have a solution (displaced tiles) for the bonus but I'm not able to generate random solvable states. Source code for problem 5 is also submitted