01_systematic_search

April 11, 2019

1 Testat Systematic Search

1.1 Info

- All Questions answerd in the Document itself
- Code can be found on https://github.com/Inux/aiso

2 Exercise Search Algorithms

In the last session, we prepared different classes that are useful to solve search problems. You completed the Node class that we can use now for our first search strategy *breadth_first_tree_search*.

If you had problems implementing the node class, please come and see me. Without the Node class, you can't solve the following exercises.

First, you need to implement the breadth first search strategy:

Hints: - create the FIFO queue frontier using collections.py, that implements high performance data types. The collection.deque allows you to easily extend the queue with `frontier.append` and to remove items from the queue with `frontier.popleft()` - remember that you can access the children of a node with the following code: `node.expand(problem)` - return the goal node if you can find it

```
In [1]: %matplotlib inline

        from collections import deque
        from search import *

        def breadth_first_graph_search(problem):
            n = Node(problem.initial)

            if problem.goal_test(n.state):
                return n, 0, 0 #found the goal node

            frontier = deque([n]) #frontier
            exp = set([n]) #explored

            while frontier:
                n = frontier.popleft() #get new node
                exp.add(n)
                for c in n.expand(problem):
                    visited = [n.state for n in frontier] + [n.state for n in exp]
                    if c.state not in visited:
                        if problem.goal_test(c.state):
                            return c, len(exp), len(frontier) #found the goal node

                        frontier.append(c)

            return None #no goal node found
```

Lets create a map from the text book example:

```
In [2]: romania_map = UndirectedGraph(dict(
            Arad=dict(Zerind=75, Sibiu=140, Timisoara=118),
            Bucharest=dict(Urziceni=85, Pitesti=101, Giurgiu=90, Fagaras=211),
            Craiova=dict(Drobeta=120, Rimnicu=146, Pitesti=138),
            Drobeta=dict(Mehadia=75),
            Eforie=dict(Hirsova=86),
            Fagaras=dict(Sibiu=99),
            Hirsova=dict(Urziceni=98),
            Iasi=dict(Vaslui=92, Neamt=87),
            Lugoj=dict(Timisoara=111, Mehadia=70),
            Oradea=dict(Zerind=71, Sibiu=151),
            Pitesti=dict(Rimnicu=97),
            Rimnicu=dict(Sibiu=80),
            Urziceni=dict(Vaslui=142)))
        romania_map.locations = dict(
            Arad=(91, 492), Bucharest=(400, 327), Craiova=(253, 288),
            Drobeta=(165, 299), Eforie=(562, 293), Fagaras=(305, 449),
            Giurgiu=(375, 270), Hirsova=(534, 350), Iasi=(473, 506),
            Lugoj=(165, 379), Mehadia=(168, 339), Neamt=(406, 537),
            Oradea=(131, 571), Pitesti=(320, 368), Rimnicu=(233, 410),
            Sibiu=(207, 457), Timisoara=(94, 410), Urziceni=(456, 350),
            Vaslui=(509, 444), Zerind=(108, 531))
```

With this, we can test our search algorithm. We define our problem and let the breadth first search find a solution.

The following code will show you some information about the search:

```
In [3]: def print_info_about_search(node, exp, stored):
            print("The search algorithm reached " + node.state + " with a cost of " + str(node.p
            path = node.path()
            print("Nodes to visit: " + str(len(path)))
            print("Nodes explored: " + str(exp))
            print("Nodes stored: " + str(stored))

            #directions = ""
            #for n in path:
```

```
        #    directions = directions + " > " + n.state
        #print("The path is the following:" + directions)
```

```
In [4]: start = 'Arad'
        goal = 'Bucharest'
        problem = GraphProblem(start, goal, romania_map)
        node, exp, stored = breadth_first_graph_search(problem)
        print_info_about_search(node, exp, stored)
```

```
The search algorithm reached Bucharest with a cost of 450.
Nodes to visit: 4
Nodes explored: 6
Nodes stored: 2
```

Congratulations, you have implemented your first search algorithm!

2.1 Swiss Railway System

The SBB OpenData platform (https://data.sbb.ch/) provides all train lines and hubs (Betriebsknotenpunkte) of their railway system. I briefly mentioned the data set in the beginning.

I created a SBB class that can be used to import the data from the json file:

```
In [5]: from sbb import SBB

        sbb = SBB()
        sbb.importData('linie-mit-betriebspunkten.json')
```

```
successfully imported 2787 hubs
successfully imported 401 train lines
```

The object sbb contains know all the hubs and trainlines. We can visualize the hubs with matplotlib:

```
In [6]: import matplotlib.pyplot as plt


        def plot_hubs(hubs, labelNames = False):
            fig = plt.figure(figsize=(10,10))
            x =[]; y = []; names = [];
            for h in hubs:
                new_x = hubs[h].x
                new_y = hubs[h].y
                x.append(new_x)
                y.append(new_y)
                if labelNames:
                    plt.text(new_x+0.01, new_y+0.01, h, fontsize=9)
            plt.scatter(x,y, marker='.', color='black')
            plt.axis('equal')

        #plot_hubs(sbb.hubs)
```

With a little imagination and geographic knowledge you can recognize the different regions of Switzerland.

We want to implement a search algorithm that finds the shortest way between 'Rotkreuz' and 'Thalwil'. In this exercise, we are not restricted to the official train lines. We can use the railway system with our own search agent and decide at each hub in which direction we want to go. If you have successfully implemented the classes above, the following code should execute and provide the directions between Rotkreuz and Zermatt.

2.2 More Uninformed Search Algorithms

As you know, the breadth-search algorithm is just one of many search strategies. Implement the following search algorithms and evaluate their performance. You might have to adapt (or create a subclass) of certain classes we used before, to determine the depth of the search tree for example. You can use the PriorityQueue class below to implement the Uniform Cost Search.

1. Depth First Search (DFS)
2. Depth Limited Search (DLS)
3. Iterative Deepening Search (IDS)
4. Uniform Cost Search (UCS)

Try to visualize which nodes (hubs) have been visited by the search algorithm. Create for each search strategy an image that shows the start, the goal, the solution path and all the visited nodes.

Answer the following questions for each algorithm:

1. How does your algorithm deal with loops?
2. Can you make an estimate about the time and memory requirements?
3. Is your algorithm complete and optimal?

Fill the following table:

Algorithm	start	goal	cost	number of nodes visited	maximal stored nodes	complete	optimal
BFS	Rotkreuz	Thalwil	36	17	154	yes	yes
DFS	Rotkreuz	Thalwil	740	309	1028	yes	yes
DLS	Rotkreuz	Thalwil	36	17	16	no	no
IDS	Rotkreuz	Thalwil	36	17	3446220	yes	yes
UCS	Rotkreuz	Thalwil	No Solution	No Solution	No Solution	?	?

What is special about the sbb railway map in terms of complexity (branching factor, depth)? How could you preprocess the data set in order to reduce the search space?

```
In [7]: import heapq

        class PriorityQueue:
            """A Queue in which the minimum (or maximum) element (as determined by f and
            order) is returned first.
            If order is 'min', the item with minimum f(x) is
            returned first; if order is 'max', then it is the item with maximum f(x).
            Also supports dict-like lookup."""

            def __init__(self, order='min', f=lambda x: x):
                self.heap = []

                if order == 'min':
                    self.f = f
                elif order == 'max':  # now item with max f(x)
                    self.f = lambda x: -f(x)  # will be popped first
                else:
                    raise ValueError("order must be either 'min' or max'.")

            def append(self, item):
                """Insert item at its correct position."""
                heapq.heappush(self.heap, (self.f(item), item))

            def extend(self, items):
                """Insert each item in items at its correct position."""
                for item in items:
                    self.append(item)

            def pop(self):
                """Pop and return the item (with min or max f(x) value
                depending on the order."""
                if self.heap:
                    return heapq.heappop(self.heap)[1]
                else:
                    raise Exception('Trying to pop from empty PriorityQueue.')

            def __len__(self):
                """Return current capacity of PriorityQueue."""
                return len(self.heap)

            def __contains__(self, item):
                """Return True if item in PriorityQueue."""
                return (self.f(item), item) in self.heap

            def __getitem__(self, key):
                for _, item in self.heap:
                    if item == key:
                        return item
```

```
    def __delitem__(self, key):
        """Delete the first occurrence of key."""
        self.heap.remove((self.f(key), key))
        heapq.heapify(self.heap)
```

2.2.1 Plotting

```
In [8]: def plot_it(node, start, goal):
            fig = plt.figure(figsize=(10, 10))

            def get_lims_for_node(start, goal, zoom=0.3):
                goal_hub = sbb.hubs[goal]
                start_hub = sbb.hubs[start]
                x = goal_hub.x - (goal_hub.x - start_hub.x) / 2.0
                y = goal_hub.y - (goal_hub.y - start_hub.y) / 2.0
                ylims = [y - zoom, y + zoom]
                xlims = [x - zoom, x + zoom]
                return xlims, ylims

            xlims, ylims = get_lims_for_node(start, goal)

            def plot_internal(hubs, color, labels=False):
                if fig is None:
                    plt.figure(figsize=(10, 10))

                x = [hubs[name].x for name in hubs]
                y = [hubs[name].y for name in hubs]

                plt.scatter(x, y, marker='.', color=color)
                plt.axis('equal')
                plt.axis('off')

                if ylims is not None:
                    plt.ylim(ylims)

                if xlims is not None:
                    plt.xlim(xlims)

                if labels:
                    for h in hubs:
                        if xlims is None or xlims[0] < hubs[h].x < xlims[1]:
                            show_because_of_x = True

                        if ylims is None or ylims[0] < hubs[h].y < ylims[1]:
                            show_because_of_y = True

                        if show_because_of_x and show_because_of_y:
```

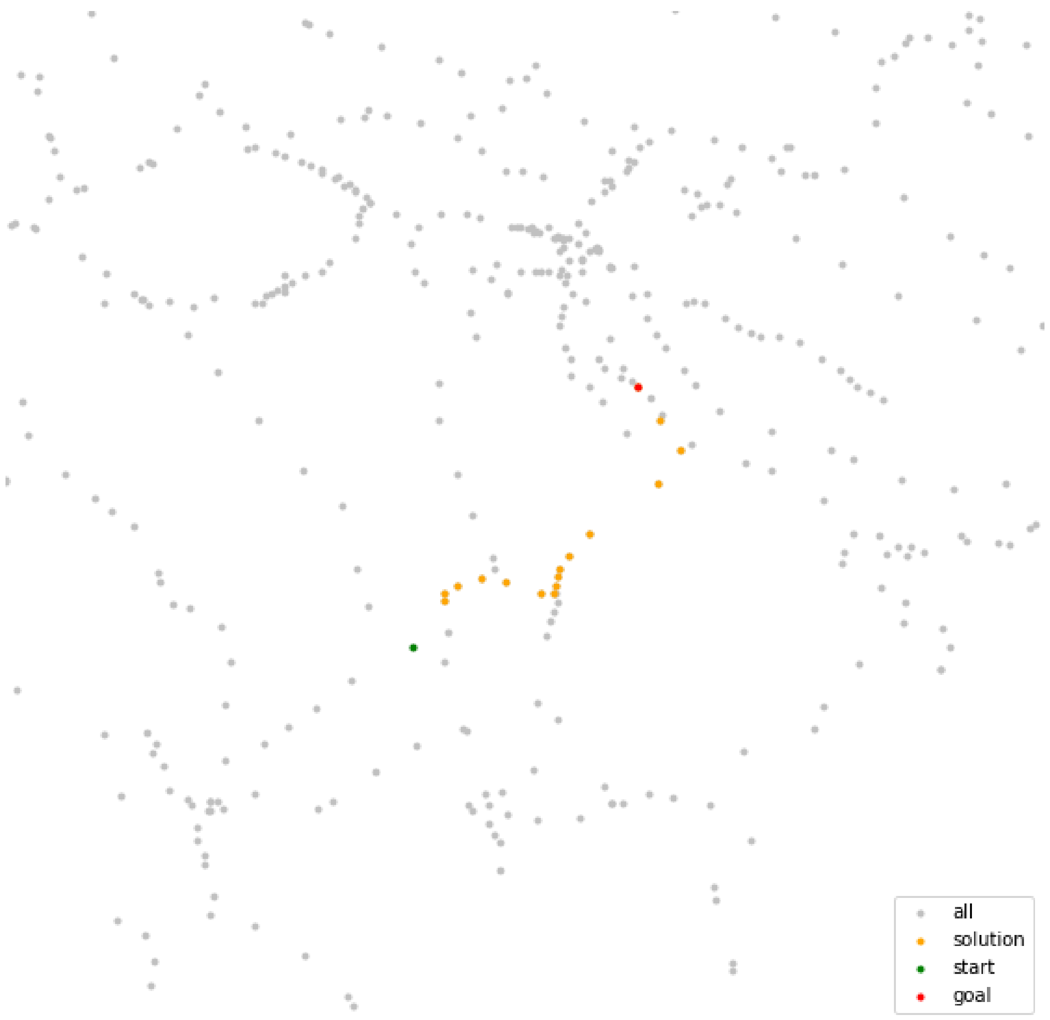
```
                        plt.text(hubs[h].x, hubs[h].y, h, fontsize=6)

            solution_nodes = node.solution() if isinstance(node, Node) else []
            solution_hubs = {name: sbb.hubs[name] for name in sbb.hubs if name in solution_nodes
            start_hub = {name: sbb.hubs[name] for name in sbb.hubs if name == start}
            goal_hub = {name: sbb.hubs[name] for name in sbb.hubs if name == goal}

            plot_internal(sbb.hubs, 'silver')
            plot_internal(solution_hubs, 'orange')
            plot_internal(start_hub, 'green')
            plot_internal(goal_hub, 'red')
            plt.gca().legend(('all', 'solution', 'start', 'goal'))
            plt.show()
```

2.2.2 Breadth First Search

- No endless loops (previous not explored again)
- Time: O(b^d) Space: O(b*d)

```
In [9]: start = 'Rotkreuz'
        goal = 'Thalwil'
        sbb_map = UndirectedGraph(sbb.createMap())
        problem = GraphProblem(start, goal, sbb_map)
        node, exp, stored = breadth_first_graph_search(problem)
        print_info_about_search(node, exp, stored)
        plot_it(node, start, goal)
```

```
The search algorithm reached Thalwil with a cost of 36.906.
Nodes to visit: 17
Nodes explored: 136
Nodes stored: 18
```



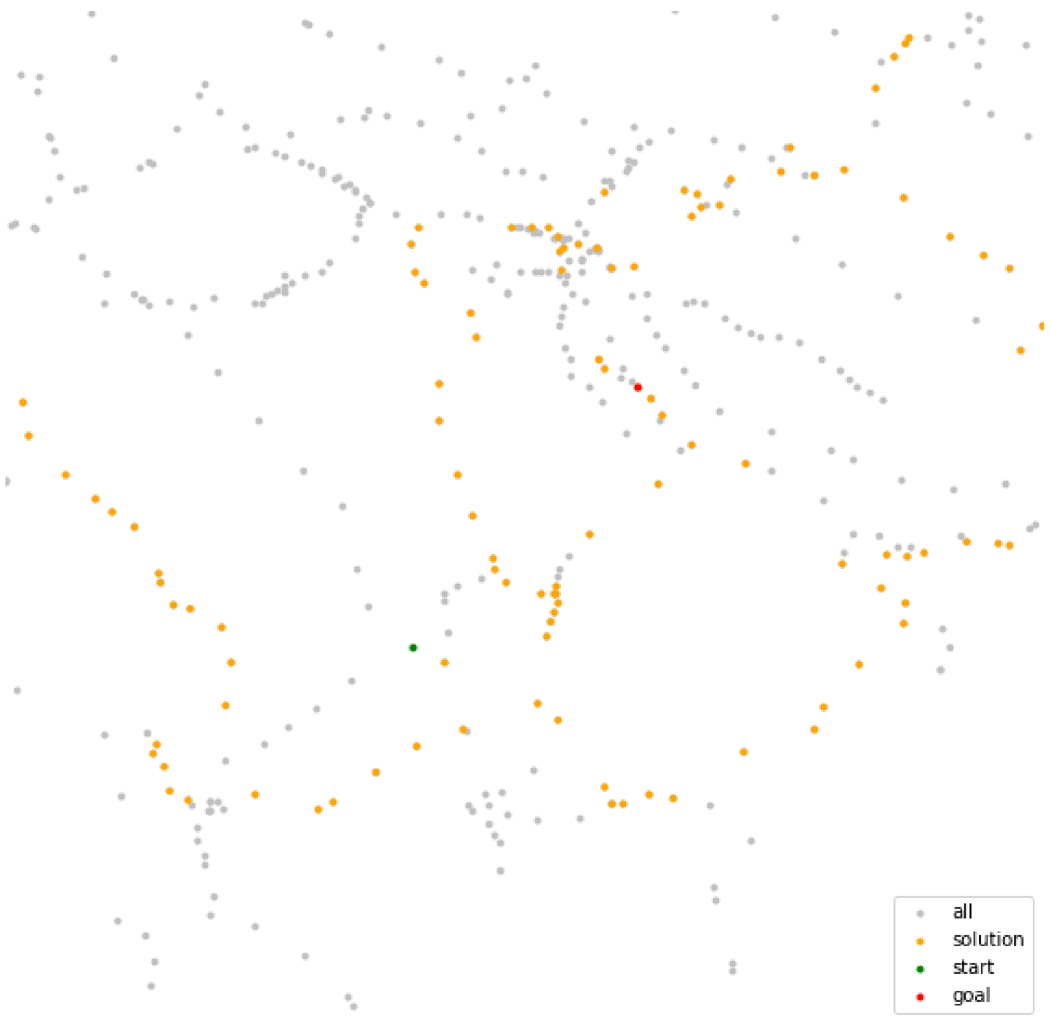
2.2.3 Depth First Search

- No endless loops (previous not explored again)
- Time: O(b^m) Space: O(b*m)

```
In [10]: def depth_first_search(problem):
             n = Node(problem.initial)

             if problem.goal_test(n.state):
                 return n, 0, 0 #found the goal node

             frontier = deque([n]) #frontier
             exp = set([n]) #explored

             while frontier:
```

```
            n = frontier.pop() #get new node
            exp.add(n)

            if problem.goal_test(n.state):
                return n, len(exp), len(frontier) #found the goal node

            for c in n.expand(problem):
                visited = [n.state for n in frontier] + [n.state for n in exp]
                if c.state not in visited:
                    frontier.append(c)

        return None, len(exp), len(frontier) #no goal node found

    node, exp, stored = depth_first_search(problem)
    print_info_about_search(node, exp, stored)
    plot_it(node, start, goal)
```

```
The search algorithm reached Thalwil with a cost of 740.0659999999996.
Nodes to visit: 309
Nodes explored: 937
Nodes stored: 81
```



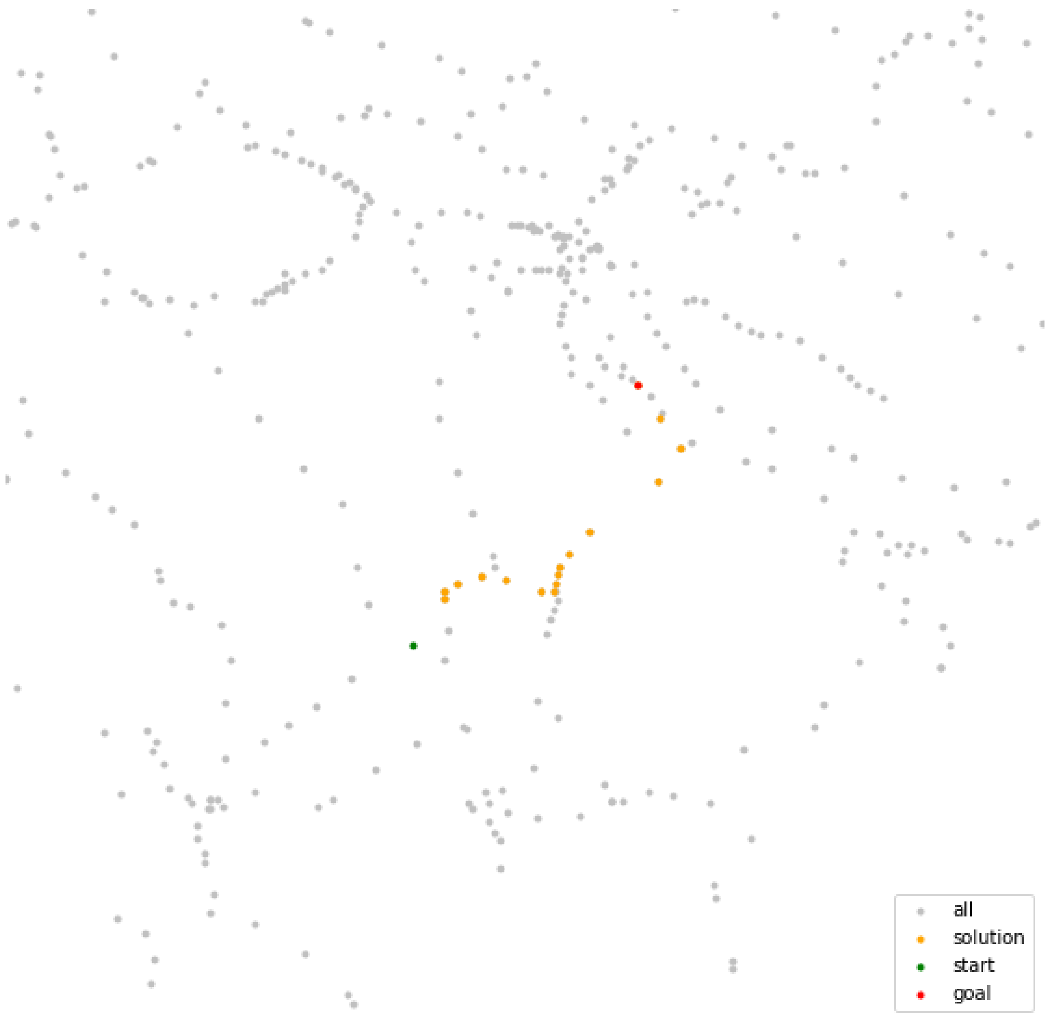
2.2.4 Depth Limited Search

- No endless loops (previous not explored again & cutoff)
- Time: O(b^l) Space: O(b*l)

```
In [11]: def depth_limited_search(n, prob, l, exp=0):
             if prob.goal_test(n.state):
                 return n, exp # found goal node

             elif l == 0:
                 return True, exp

             else:
                 cut = False
                 for c in n.expand(prob):
```

```
            r, exp = depth_limited_search(c, prob, l-1, exp+1)

            if isinstance(r, Node):
                return r, exp
            elif r is True:
                c = True

        if c is True:
            return True, exp
        else:
            return False, exp

n, exp = depth_limited_search(Node(problem.initial), problem, 20, 0)
print_info_about_search(n, exp, 0)
plot_it(n, start, goal)
```

```
The search algorithm reached Thalwil with a cost of 36.906.
Nodes to visit: 17
Nodes explored: 16
Nodes stored: 0
```



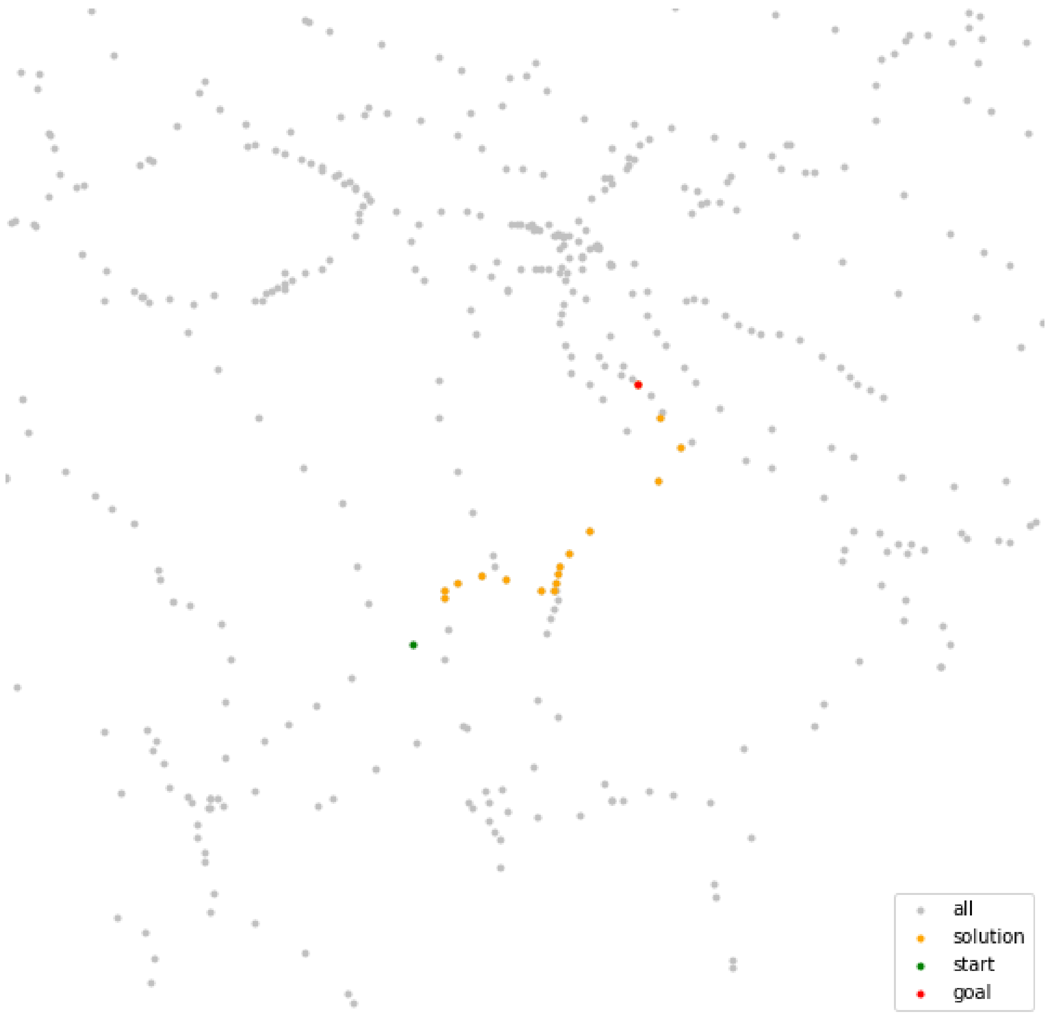
2.2.5 Iterative Depth First Search

- No endless loops (previous not explored again & cutoff)
- Time: O(bˆd) Space: O(b*d)

```
In [12]: def iter_depth_search(prob, exp=0):
             limit = 1
             iteration = 0
             max_iterations = 10000
             while iteration < max_iterations:
                 iteration = iteration + 1
                 r, exp = depth_limited_search(Node(prob.initial), prob, limit, exp)

                 if isinstance(r, Node):
                     return r, exp
```

```
                elif r is False:
                    return None, exp
                else:
                    limit = limit + 1

        n, exp = iter_depth_search(problem, 0)
        print_info_about_search(n, exp, 0)
        plot_it(n, start, goal)
```

```
The search algorithm reached Thalwil with a cost of 36.906.
Nodes to visit: 17
Nodes explored: 3446220
Nodes stored: 0
```

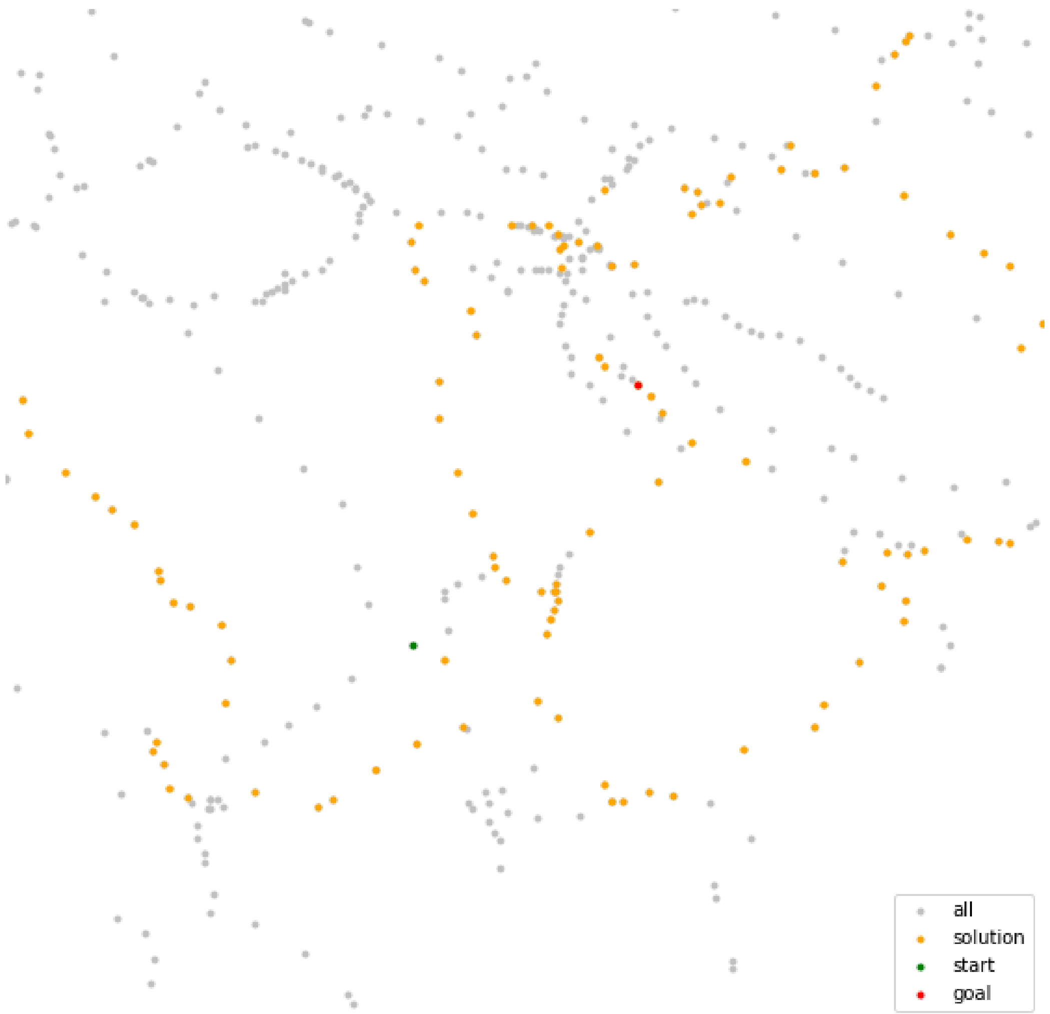


2.2.6 Uniform Cost Search

- Somehow not working

```
In [14]: def uniform_cost_search(prob):
             n = Node(prob.initial)

             frontier = PriorityQueue()
             frontier.append(n)
             exp = set([n])

             iteration = 0
             max_iterations = 10000

             while len(frontier) > 0 and iteration < max_iterations:
                 iteration = iteration + 1
                 print("Iteration:", iteration)
                 n = frontier.pop()

                 if prob.goal_test(n.state):
                     return n, len(exp), len(frontier)

                 exp.add(n)

                 for c in n.expand(prob):
                     if c is not None and c not in exp and frontier.__contains__(c):
                         frontier.append(c)
                     elif not frontier.__contains__(c):
                         frontier.append(c)

             return None, len(exp), len(frontier)

         #n, exp, stored = uniform_cost_search(problem)
         if n is not None:
             print_info_about_search(n, exp, stored)
             plot_it(node, start, goal)
         else:
             print("Uniform Cost Search: Not Solution")
```

```
The search algorithm reached Thalwil with a cost of 36.906.
Nodes to visit: 17
Nodes explored: 3446220
Nodes stored: 81
```


all
solution
start
goal