Homework 2: Implementation of KDTree and Octree

This assignment includes three tasks:

(1) implement the construction and search of KDTree/Octree, including KNN search method and radius search method.

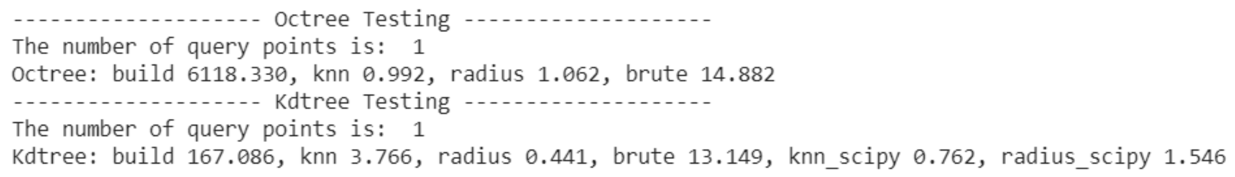
(2) compare running time of KDTree, Octree, Numpy brute-force search, and scipy.spatial.KDTee.

(3) optimize the implementation of KDTree/Octree; or tune the parameters to improve running time.

Experimental results:

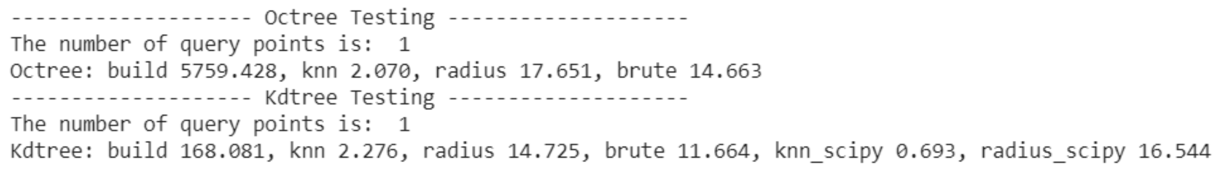
To investigate the effect of the number of query points on running time for a specific search algorithm, different query point amounts are selected, which are 1, 10, 100, 1000, 5000, 10000, respectively. The results are shown below.

N = 1 (first data point in point cloud data):



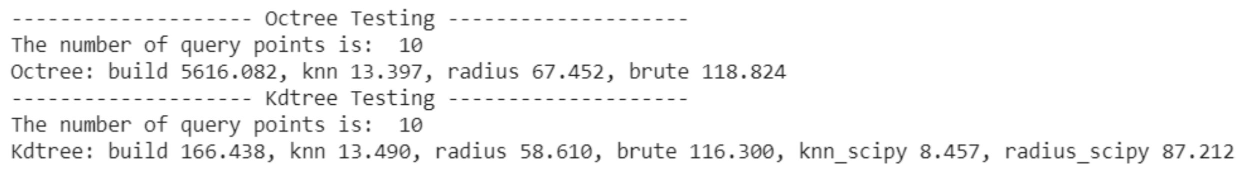
```
-------------------- Octree Testing --------------------
The number of query points is:  1
Octree: build 6118.330, knn 0.992, radius 1.062, brute 14.882
-------------------- Kdtree Testing --------------------
The number of query points is:  1
Kdtree: build 167.086, knn 3.766, radius 0.441, brute 13.149, knn_scipy 0.762, radius_scipy 1.546
```

N = 1 (randomly selected):



```
-------------------- Octree Testing --------------------
The number of query points is:  1
Octree: build 5759.428, knn 2.070, radius 17.651, brute 14.663
-------------------- Kdtree Testing --------------------
The number of query points is:  1
Kdtree: build 168.081, knn 2.276, radius 14.725, brute 11.664, knn_scipy 0.693, radius_scipy 16.544
```

N = 10 (randomly selected):



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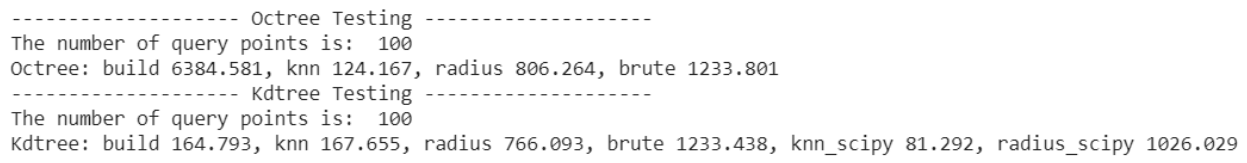
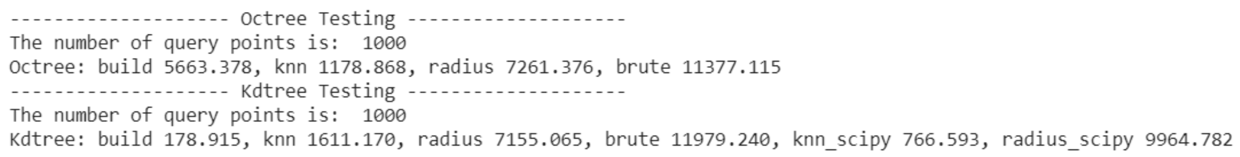
-------------------- Octree Testing --------------------
The number of query points is:  10
Octree: build 5616.082, knn 13.397, radius 67.452, brute 118.824
-------------------- Kdtree Testing --------------------
The number of query points is:  10
Kdtree: build 166.438, knn 13.490, radius 58.610, brute 116.300, knn_scipy 8.457, radius_scipy 87.212
```

N = 100 (randomly selected):



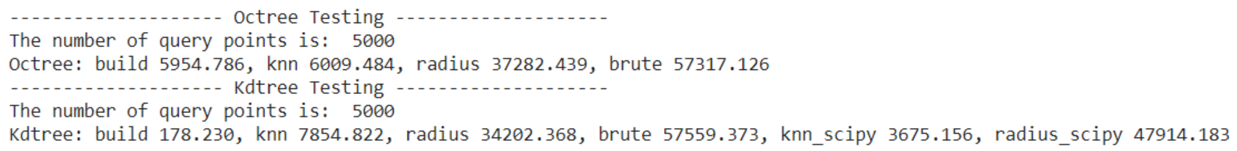
```
-------------------- Octree Testing --------------------
The number of query points is:  100
Octree: build 6384.581, knn 124.167, radius 806.264, brute 1233.801
-------------------- Kdtree Testing --------------------
The number of query points is:  100
Kdtree: build 164.793, knn 167.655, radius 766.093, brute 1233.438, knn_scipy 81.292, radius_scipy 1026.029
```

N = 1000 (randomly selected):



```
-------------------- Octree Testing --------------------
The number of query points is:  1000
Octree: build 5663.378, knn 1178.868, radius 7261.376, brute 11377.115
-------------------- Kdtree Testing --------------------
The number of query points is:  1000
Kdtree: build 178.915, knn 1611.170, radius 7155.065, brute 11979.240, knn_scipy 766.593, radius_scipy 9964.782
```

N = 5000 (randomly selected):



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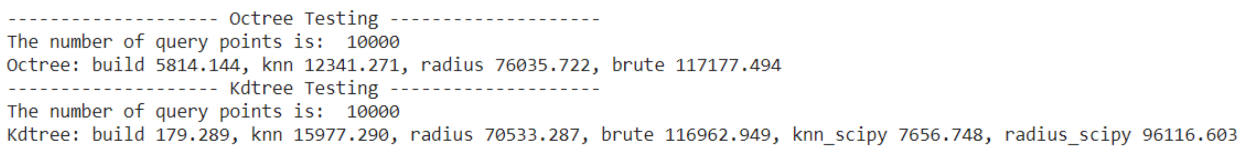
-------------------- Octree Testing --------------------
The number of query points is:  5000
Octree: build 5954.786, knn 6009.484, radius 37282.439, brute 57317.126
-------------------- Kdtree Testing --------------------
The number of query points is:  5000
Kdtree: build 178.230, knn 7854.822, radius 34202.368, brute 57559.373, knn_scipy 3675.156, radius_scipy 47914.183
```

N = 10000 (randomly selected):



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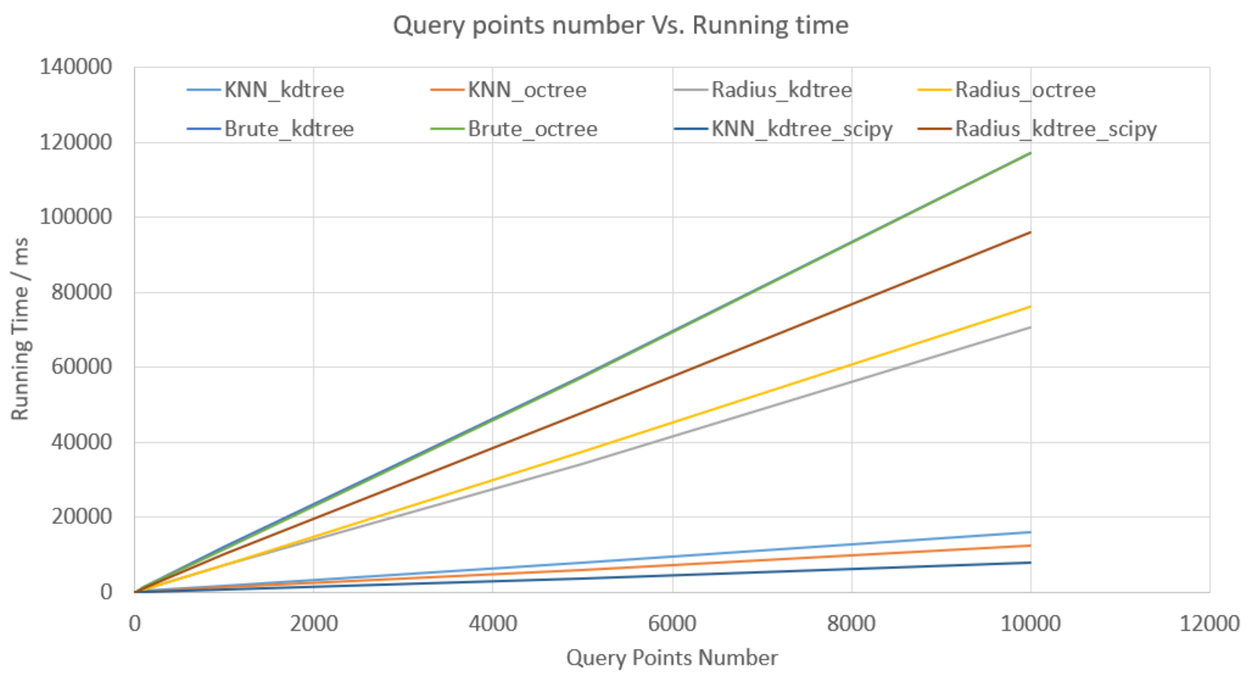
-------------------- Octree Testing --------------------
The number of query points is:  10000
Octree: build 5814.144, knn 12341.271, radius 76035.722, brute 117177.494
-------------------- Kdtree Testing --------------------
The number of query points is:  10000
Kdtree: build 179.289, knn 15977.290, radius 70533.287, brute 116962.949, knn_scipy 7656.748, radius_scipy 96116.603
```

The results are summarized in the following table.

Table 1 Performance of different search algorithms with different query points number

	N=1		**N=10**		**N=100**	
	Kdtree(ms)	**Octree(ms)**	**Kdtree(ms)**	**Octree(ms)**	**Kdtree(ms)**	**Octree(ms)**
Build tree	168.081	5759.428	166.438	5616.082	164.793	6384.581
KNN search	2.276	2.070	13.490	13.397	167.655	124.167
Radius search	14.725	17.651	58.610	67.452	766.093	806.264
Brute force	11.664	14.663	116.3	118.824	1233.438	1233.801
KNN_scipy	0.693	-	8.457	-	81.292	-
Radius_scipy	16.544	-	87.212	-	1026.029	-
	N=1000		**N=5000**		**N=10000**	
	Kdtree(ms)	**Octree(ms)**	**Kdtree(ms)**	**Octree(ms)**	**Kdtree(ms)**	**Octree(ms)**
Build tree	178.915	5663.378	178.23	5954.786	179.289	5814.144
KNN search	1611.170	1178.868	7854.822	6009.484	15977.29	12341.271
Radius search	7155.065	7261.376	34202.368	37282.439	70533.287	76035.722
Brute force	11979.240	11377.115	57559.373	57317.126	116962.949	117177.494
KNN_scipy	766.593	-	3675.156	-	7656.748	-
Radius_scipy	9964.782	-	47914.183	-	96116.603	-

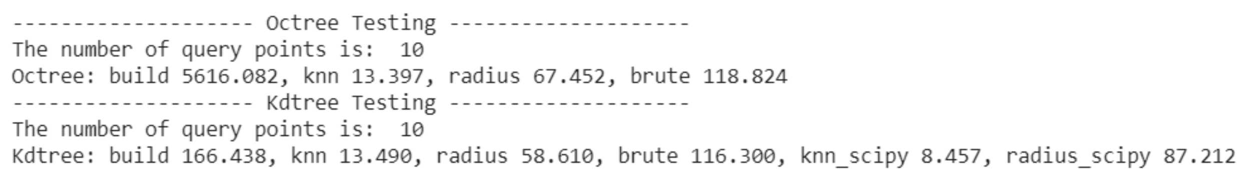
The dependency of running time on the number of query points is plotted as follows.



As shown in the figure, it is obvious that brute force search is the worst one among all the methods. With the increase of query points, the query speed becomes slower (higher running time) when compared to other algorithms. It can be observed that the query speed is slower in radius search than that in KNN search for the results from KDTree, Octree, and Scipy library. Radius search in KDtree outperforms the search in Octree and Scipy library. In contrast, KNN search performs better in Octree than that in KDTree. It is expected that the result in Scipy library is better than that in KDTree or Octree because the splitting method in current implementation is simple and needs to be optimized.

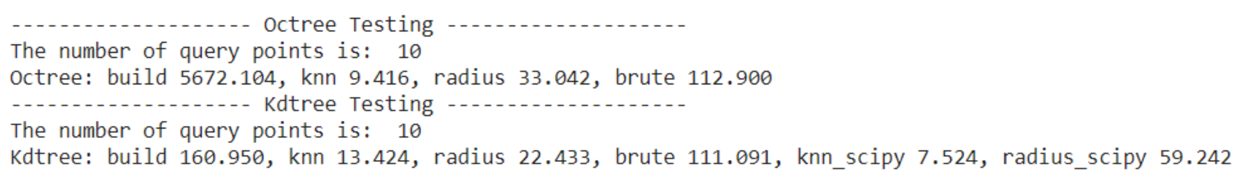
Normally, the query speeds from radius search and KNN search should be close. But this is not case as shown in the figure. To figure out how the big difference occurs, various radius is utilized to explore the effect of radius on the running time of KNN search and radius search. At a fixed query point number (N = 10), different radii are selected, which are 1, 0.5, 0.1, 0.05, 0.01, respectively. The results are shown below.

N=10, R=1:



```
-------------------- Octree Testing --------------------
The number of query points is:  10
Octree: build 5616.082, knn 13.397, radius 67.452, brute 118.824
-------------------- Kdtree Testing --------------------
The number of query points is:  10
Kdtree: build 166.438, knn 13.490, radius 58.610, brute 116.300, knn_scipy 8.457, radius_scipy 87.212
```

N=10, R=0.5:



```
-------------------- Octree Testing --------------------
The number of query points is:  10
Octree: build 5672.104, knn 9.416, radius 33.042, brute 112.900
-------------------- Kdtree Testing --------------------
The number of query points is:  10
Kdtree: build 160.950, knn 13.424, radius 22.433, brute 111.091, knn_scipy 7.524, radius_scipy 59.242
```

N=10, R=0.1:

```
-------------------- Octree Testing --------------------
The number of query points is:  10
Octree: build 6291.254, knn 12.762, radius 8.098, brute 124.061
-------------------- Kdtree Testing --------------------
The number of query points is:  10
Kdtree: build 163.819, knn 15.066, radius 8.501, brute 111.774, knn_scipy 6.980, radius_scipy 16.972
```

N=10, R=0.05:

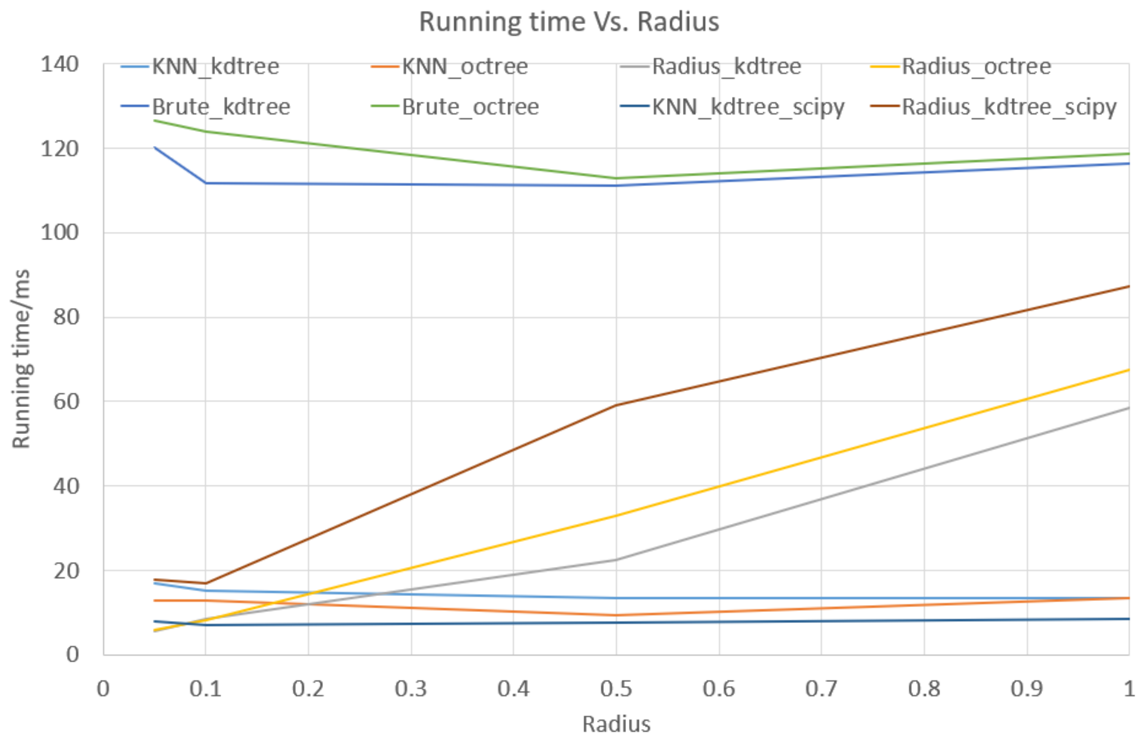
```
-------------------- Octree Testing --------------------
The number of query points is:  10
Octree: build 5933.784, knn 12.963, radius 5.839, brute 126.612
-------------------- Kdtree Testing --------------------
The number of query points is:  10
Kdtree: build 172.684, knn 16.818, radius 5.545, brute 120.175, knn_scipy 7.816, radius_scipy 17.881
```

The results are summarized in the Table 2.

Table 2 Performance of different search algorithms with different search radii

	R=1		**R=0.5**		**R=0.1**		R=0.05	
	Kdtree(ms)	**Octree(ms)**	**Kdtree(ms)**	**Octree(ms)**	**Kdtree(ms)**	**Octree(ms)**	**Kdtree(ms)**	**Octree(ms)**
Build tree	166.438	5616.082	160.95	5672.104	163.819	6291.254	172.684	5933.784
KNN search	13.490	13.397	13.424	9.416	15.066	12.762	16.818	12.963
Radius search	58.61	67.452	22.433	33.042	8.501	8.098	5.545	5.839
Brute force	116.3	118.824	111.091	112.9	111.774	124.061	120.175	126.612
KNN_scipy	8.457	-	7.524	-	6.980	-	7.816	-
Radius_scipy	87.212	-	59.242	-	16.972	-	17.881	-

The dependency of running time on the number of query points is plotted as follows.



As seen from the results, the radius value has a significant effect on the running time. The running time increases as the radius becomes larger. This increasing trend can be observed in the radius search of KDTree, Octree, and KDtree_scipy. In addition, the radius value has little influence on KNN search and brute force search.

Conclusions

Based on above observation, it is obvious that brute force method definitely cannot be used for querying nodes efficiently with the increase of query points. The running time for KNN search is smaller than that for radius search. In terms of the data structure, the construction of Octree (~6000ms) is slower than that of KDTree (~16ms) while the query efficiency of the former is higher than that of the latter, especially when the number of query points is huge. Furthermore, the radius of value has a great effect on the query time which increases as the radius increases.

In a nutshell, when the number of query points is small, both KNN search and radius search in KDTree can be used; when the number of query points is large, it is preferable to leverage the search method in Octree.