Indian Institute of Technology, Kharagpur
Department of Computer Science and Engineering
Software Engineering (CS 20202), Spring 2024

Assignment 5 – C++ Programming

Total marks: 100

Grading guidelines:

1. *Zero marks for a submission if it does not pass the plagiarism test.*
2. *Break-up of Credits will be as follows:*
   (a) *Percentage of features implemented: 70%*
   (b) *Code understanding – code clarity, comments: 10%*
   (c) *Whether reasonably able to answer questions: 20%*

In the previous assignment, you have implemented the following abstract data type (ADT) called *DataVector*:

```
class DataVector {
    vector<double> v;
    public:
    DataVector(int dimension=0);
    ~DataVector();
    DataVector(const DataVector& other);
    DataVector & operator=(const DataVector &other);
    void setDimension(int dimension=0);
    DataVector operator+(const DataVector &other);
    DataVector operator-(const DataVector &other);
    double operator*(const DataVector &other);
}
```

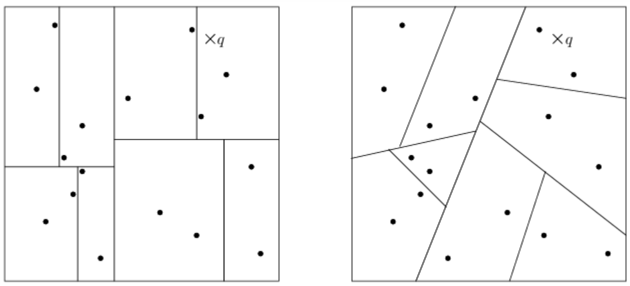
Using the above ADT, you have implemented a simple approximate nearest neighbour search (ANN) algorithm which given a test vector *v* and a vector dataset *D*, quickly find other vectors *v' in D* which are closest to *v*. You have run and tested your algorithm on the Fashion MNIST dataset from the following link:
https://github.com/zalandoresearch/fashion-mnist

In this assignment, you have to implement a class of **ANN indices**, which are tree-based indices. An **ANN index** is a data structure that stores a dataset of vectors in a format that can be used to quickly search for the k-nearest neighbors of a given test vector. A tree-based index is a one where, the set of vectors are arranged in a binary tree hierarchy. We start with the full dataset at the root node, and at each node n the set S_n is split in two parts using a rule, and the children of the node n represent the two splits of S_n. The rules for splitting are designed such that vectors in a node represent a spatial region in the vector space. For any tree-based index, given a test point, we can reach a leaf node which contains the region to which the test point must reach. The search algorithm should backtrack the recursion path towards the root node, and search for k-nearest points in increasingly larger regions, till the nearest node from sibling of the current node is farther than farthest of the current k-neighbors. You have to implement two algorithms from the following paper:

- Dasgupta, Sanjoy, and Yoav Freund. "Random projection trees and low dimensional manifolds." In *Proceedings of the fortieth annual ACM symposium on Theory of computing*, pp. 537-546. 2008.

Available at Link: https://cseweb.ucsd.edu/~dasgupta/papers/rptree-stoc.pdf

The algorithms are: kd-tree (left in figure) and RP-tree (right in figure). The following figure show the regions for both these trees.



The following are the different algorithms from the paper:

procedure MAKETREE(S)
 if $|S| < MinSize$ **return** $(Leaf)$
 $Rule \leftarrow$ CHOOSERULE(S)
 $LeftTree \leftarrow$ MAKETREE($\{x \in S : Rule(x) = \text{true}\}$)
 $RightTree \leftarrow$ MAKETREE($\{x \in S : Rule(x) = \text{false}\}$)
 return $([Rule, LeftTree, RightTree])$

The k-d tree CHOOSERULE picks a coordinate direction (typically the coordinate with largest spread) and then splits the data on its median value for that coordinate.

procedure CHOOSERULE(S)
 comment: k-d tree version

 choose a coordinate direction i
 $Rule(x) := x_i \leq \text{median}(\{z_i : z \in S\})$
 return $(Rule)$

procedure CHOOSERULE(S)
 comment: RPTree-Max version

 choose a random unit direction $v \in \mathbb{R}^D$
 pick any $x \in S$; let $y \in S$ be the farthest point from it
 choose δ uniformly at random in $[-1, 1] \cdot 6\|x - y\|/\sqrt{D}$
 $Rule(x) := x \cdot v \leq (\text{median}(\{z \cdot v : z \in S\}) + \delta)$
 return $(Rule)$

Here, S is the set of vectors at the current node. D is the dimension of the vector.

The base class `TreeIndex` defines the basic functionalities of an index. Since an index is a large data structure, there should be one copy of it which should store all the data to be searched. Hence, the class `TreeIndex` should be a singleton class. There should be two derive classes `KDTreeIndex` and `RPTreeIndex`.

Further, any concrete ANN index should have the following properties / function:

- **GetInstance:** a static method which generates a new instance of an index or return the existing instance. Also, implement the constructors. **[10 marks]**
- **AddData / RemoveData:** add or remove data from the `VectorDataset` in the current index. **[10 marks]**
- **MakeTree:** create the tree data structure, which is used to the store the vectors in a hierarchy. Implement the **ChooseRule** function. **[30 marks]**
- **Search:** given a test point, find the k-nearest neighbors. **[20 marks]**

Write your code in a header file TreeIndex.h and functions in source code file TreeIndex.cpp. Submit both the files to moodle.

You can use the following code structure and add the necessary functions:

```
class TreeIndex {
protected:
  TreeIndex() {}
  ~TreeIndex() {}

public:
  static TreeIndex& GetInstance();
};

class KDTreeIndex : public TreeIndex {
public:
  static KDTreeIndex& GetInstance();
private:
  KDTreeIndex() {}
  ~KDTreeIndex() {}
};


class RPTreeIndex : public TreeIndex {
public:
  static RPTreeIndex& GetInstance();
private:
  RPTreeIndex() {}
  ~RPTreeIndex() {}
};
```