Frequently Asked Questions (General)

Is a point on the boundary of a rectangle considered inside it? Do two rectangles intersect if they have just one point in common?

Yes and yes, consistent with the implementation of `RectHV.java`.

Can I use the `distanceTo()` method in `Point2D` and `RectHV`?

No, you may use only the subset of the methods listed. You should be able to accomplish the same result (more efficiently) with `distanceSquaredTo()`.

Can I use the `X_ORDER()` and `Y_ORDER()` comparators in `Point2D`?

No, you may use only the subset of the methods listed. You should be able to accomplish the same result by calling the methods `x()` and `y()`.

What should I do if a point is inserted twice in the data structure?

The data structure represents a symbol table, so you should replace the old value with the new value.

What should `points()` return if there are no points in the data structure? What should `range()` return if there are no points in the range?

The API says to return an `Iterable<Point2D>`, so you should return an iterable with zero points.

What should `nearest()` return if there are two (or more) nearest points?

The API does not specify, so you may return any nearest point (up to floating-point precision).

I run out of memory when running some of the large sample file. What should I do?

Be sure to ask Java for additional memory.

Frequently Asked Questions (PointST)

In which order should the `points()` method in `PointST` return the points?

The API does not specify the order, so any order is fine.

Frequently Asked Questions (KdTreeST)

What makes `KdTreeST` difficult? How do I make the best use of my time?

Debugging performance errors is one of the biggest challenges. It is very important that you understand and implement the key optimizations described in the assignment specification:

- *Range-search pruning.* Do not search a subtree whose corresponding rectangle does not intersect the query rectangle.
- *Nearest-neighbor pruning.* Do not search a subtree if no point (that could possibly be) in its corresponding rectangle could be closer to the query point than the best candidate point found so far. Nearest-neighbor pruning is most effective when you perform the recursive-call ordering optimization because find a good candidate point early in the search enables you to do more pruning.
- *Nearest-neighbor recursive-call ordering.* When there are two subtrees to explore, choose first the subtree that is on the same side of the splitting line as the query point. This rule implies that if one of the two subtrees contains the query point, you will consider that subtree first.

Do not begin `range()` or `nearest()` until you understand these rules.

I'm nervous about writing recursive search tree code. How do I even start on `KdTreeST.java`?

Use `BST.java` as a guide. The trickiest part is understanding how the `put()` method works. You do not need to include code that involves storing the subtree sizes (since this is used only for ordered symbol table operations).

Will I lose points for a non-recursive implementation of range search?

No. While we recommend using a recursive implementation (both for elegance and as a warmup for nearest-neighbor search), you are free to implement it without using recursion.

What should I do if a point has the same x-coordinate as the point in a node when inserting or searching in a 2d-tree?

Go to the right subtree as specified in the assignment under *Search and insert*.

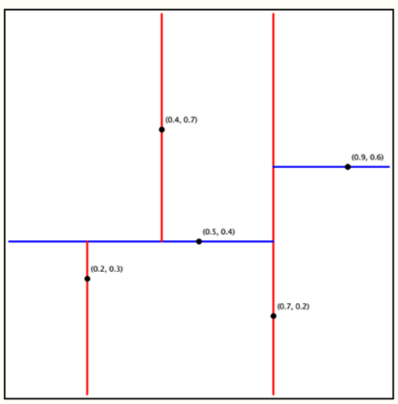
Testing

Testing the bounding boxes. If you include the `RectHV` bounding boxes in the k-d tree nodes, you want to make sure that you got it right. Otherwise, the mistake might not manifest itself until either range search and/or nearest neighbor search. Here are the bounding boxes corresponding to the nodes in `input5.txt`:

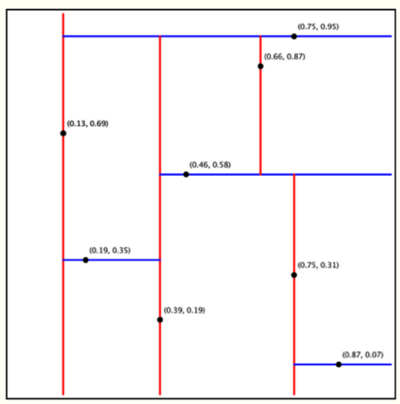
- (0.7, 0.2): [−∞, ∞] × [−∞, ∞]
- (0.5, 0.4): [−∞, 0.7] × [−∞, ∞]
- (0.9, 0.6): [0.7, ∞] × [−∞, ∞]
- (0.2, 0.3): [−∞, 0.7] × [−∞, 0.4]
- (0.4, 0.7): [−∞, 0.7] × [0.4, ∞]

Here, we are following the `toString()` method format of `RectHV` which is [`xmin`, `xmax`] × [`ymin`, `ymax`] instead of (`xmin`, `ymin`) to (`xmax`, `ymax`).

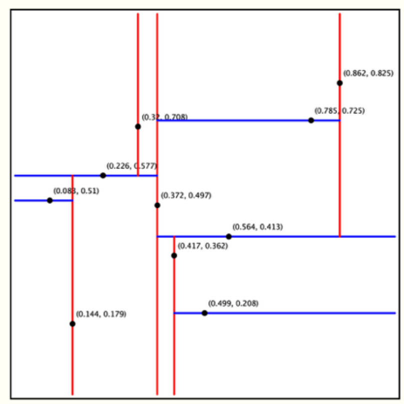
Testing `put()` and `points()` in `KdTreeST`. The client `KdTreeVisualizer.java` reads a sequence of points from a file and draws the corresponding k-d tree. It does so by reconstruting the k-d tree from the level-order traversal returned by `points()`. Note that it assumes all points are inside the unit square.



input5.txt



input8.txt



input10.txt

Testing `range()` and `nearest()` in `KdTreeST`. A good way to test these methods is to perform the same sequence of operations on both the `PointST` and `KdTreeST` data types and identify any discrepancies. The key is to implement a reference solution in which you have confidence. The brute-force implementation `PointST` can serve this purpose in your testing.

- The client `RangeSearchVisualizer.java` reads a sequence of points from a file and draws them to standard drawing. It also highlights the points inside the rectangle that the user selects by dragging the mouse. Specifically, it colors red the points returned by the method `range()` in `PointST` and blue the points returned by the method `range()` in `KdTreeST`.
- The client `NearestNeighborVisualizer.java` reads a sequence of points from a file and draws them to standard drawing. It also highlights the point closest to the mouse. Specifically, it colors red the point returned by the

method `nearest()` in `PointST` and blue the point returned by the method `nearest()` in `KdTreeST`.

Warning: both of these clients will be slow for large inputs because (1) the methods in the brute-force implementation are slow and (2) drawing the points is slow.

Frequently Asked Questions (Timing)

How do I measure the number of calls per second to `nearest()`?

Here is one reasonable approach.

- Read the file `input1M.txt` and insert those 1 million points into the k-d tree.
- Perform m calls to `nearest()` with random points in the unit square.
- Measure the total CPU time t in seconds for the calls to `nearest()`. You can use `Stopwatch`.
- Use m/t as an estimate of the number of calls per second.

To get a reliable estimate, choose m so that the CPU time t is neither negligible (e.g., less than 1 second) or astronomical (e.g., more than 1 hour). When measuring the CPU time, do not include the time to read in the 1 million points or construct the k-d tree.

How do I generate a uniformly random point in the unit square?

Make two calls to `Random.uniform(0.0, 1.0)`—one for the x-coordinate and one for the y-coordinate.

Possible Progress Steps

These are purely suggestions for how you might make progress on `KdTreeST.java`. You do not have to follow these steps.

1. **Implement `PointST`.** This should be straightforward if you use `RedBlackBST` and are familiar with the subset of the `Point2D` and `RectHV` APIs that you may use. After completing this step, you are only about 15% done with the assignment.
2. **Complete the k-d tree worksheet.** There is a set of practice problems in `practice.pdf` for the core k-d tree methods. The answers are in `answers.pdf`.
3. **Node data type.** There are several reasonable ways to represent a node in a 2d-tree. One approach is to include the point, a link to the left/bottom subtree, a link to the right/top subtree, and an axis-aligned rectangle corresponding to the node.

```
private class Node {
   private Point2D p;     // the point
```

```
    private Value val;      // the symbol table maps the point to this value
    private RectHV rect;    // the axis-aligned rectangle corresponding to this node
    private Node lb;        // the left/bottom subtree
    private Node rt;       // the right/top subtree
}
```

4. Writing `KdTreeST`.

- Write `isEmpty()` and `size()`. These should be very easy.
- Write a simplified version of `put()` which does everything except set up the `RectHV` for each node. Write the `get()` and `contains()` method, and use these to test that `put()` was implemented properly. Note that `put()` and `get()` are best implemented by using private helper methods analogous to those found on page 399 and in `BST.java`. We recommend using the orientation (vertical or horizontal) as an argument to these helper methods.

  A common error is to not rely on your base case (or cases). For example, compare the following two `get()` methods for searching in a `BST`:

```
private Value get(Node x, Key key) {
    if (x == null) return null;

    int cmp = key.compareTo(x.key);
    if      (cmp < 0) return get(x.left, key);
    else if (cmp > 0) return get(x.right, key);
    else              return x.val;
}


private Value overlyComplicatedGet(Node x, Key key) {
    if (x == null)
       return null;

    int cmp = key.compareTo(x.key);
    if (cmp < 0) {
        if (x.left == null)
           return null;
        else
           return overlyComplicatedGet(x.left, key);
    }
    else if (cmp > 0) {
        if (x.right == null)
           return null;
        else
           return overlyComplicatedGet(x.right, key);
    }
    else
        return x.val;
}
```

  In the latter method, extraneous null checks are made that would otherwise be caught by the base case. Trust in the base case. Your method may have additional base cases, and code like this becomes harder and harder to read and debug.

- Implement the `points()` method. Use this to check the structure of your k-d tree.
- Add code to `put()` which sets up the `RectHV` for each Node.
- Write the `range()` method. Test your implementation using `RangeSearchVisualizer.java`, which is described in the testing section.
- Write the `nearest()` method. This is the hardest method. We recommend doing it in stages.
    - First, find the nearest neighbor without pruning. That is, always explore both subtrees. Moreover, always explore the left subtree before the right subtree.
    - Next, implementing the pruning rule: if the closest point discovered so far is closer than the distance between the query point and the rectangle corresponding to a node, there is no need to explore that node (or its subtrees).
    - Finally, implement the recursive-call ordering optimization: when there are two subtrees to explore, always choose first the subtree that is on the same side of the splitting line as the query point.

  Test your implementation using `NearestNeighborVisualizer.java`, which is described in the testing section.