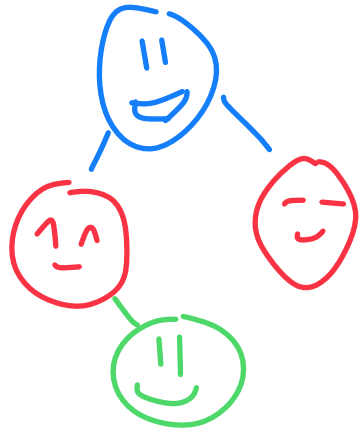
Data Structures

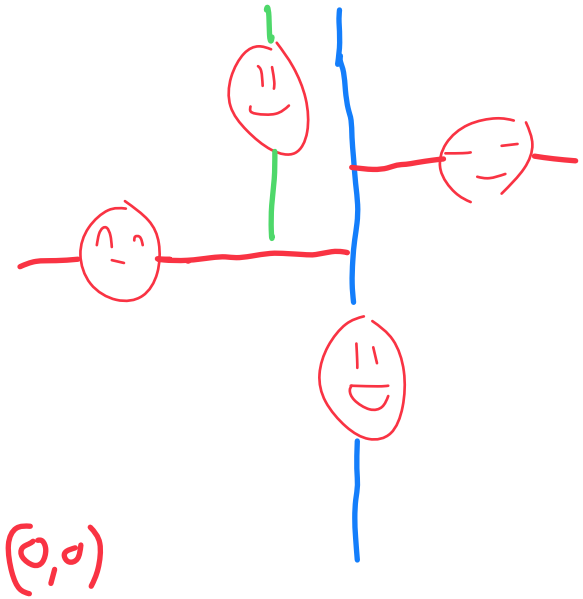
KD Tree (Nearest Neighbor) 2



CS 225

Brad Solomon

October 4, 2024



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A brief reminder of academic integrity

1) Penalties are steep!

2) Homeworks are designed to teach you material!

3) I would rather give extensions than a FAIR letter

Learning Objectives

Review KD Tree Construction

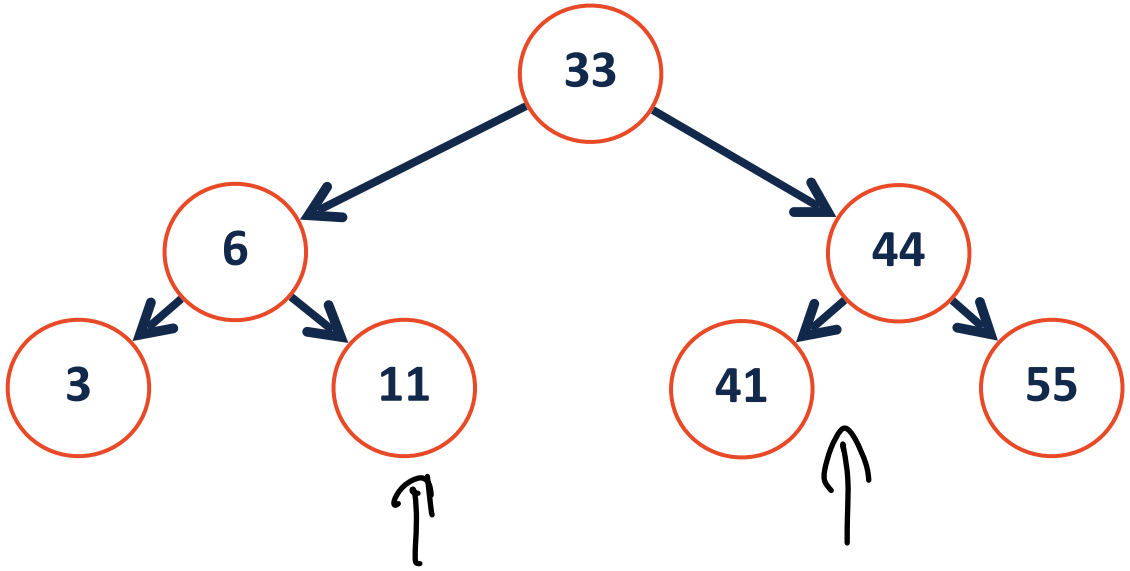
Explore KD Tree Search

Go over C++ concepts for mp_mosaics

Range-based Searches

Consider a collection of points on a 1D line: $\mathbf{p = \{p_1, p_2, \ldots, p_n\}}$

If I want to find all values between [A, B], how could I implement this?



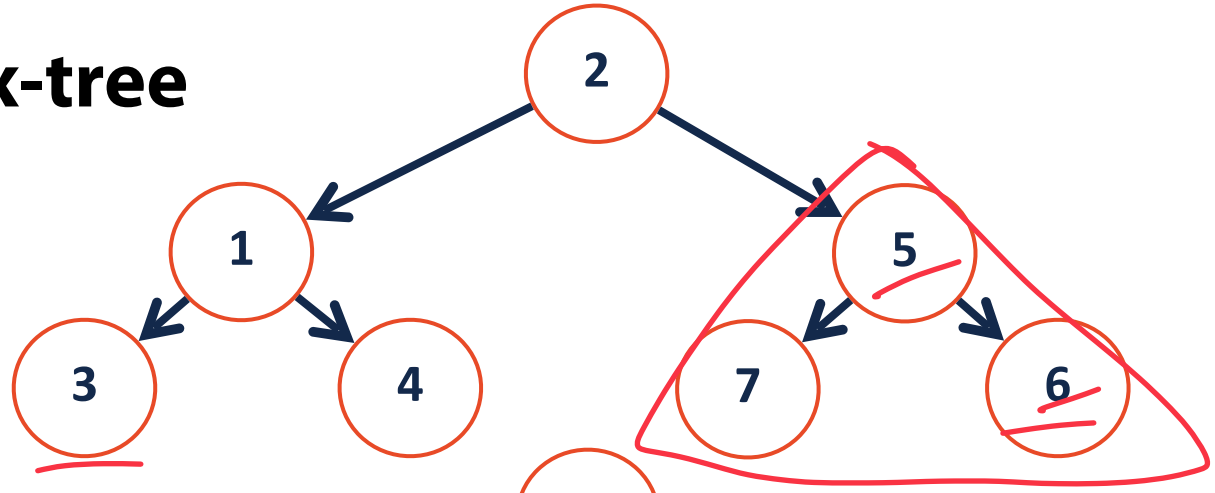

```
1
2 for(auto it = myMap.lower_bound(A); it != myMap.upper_bound(B); ++it){
3
4 // Do Stuff
5 }
```

Range-based Searches

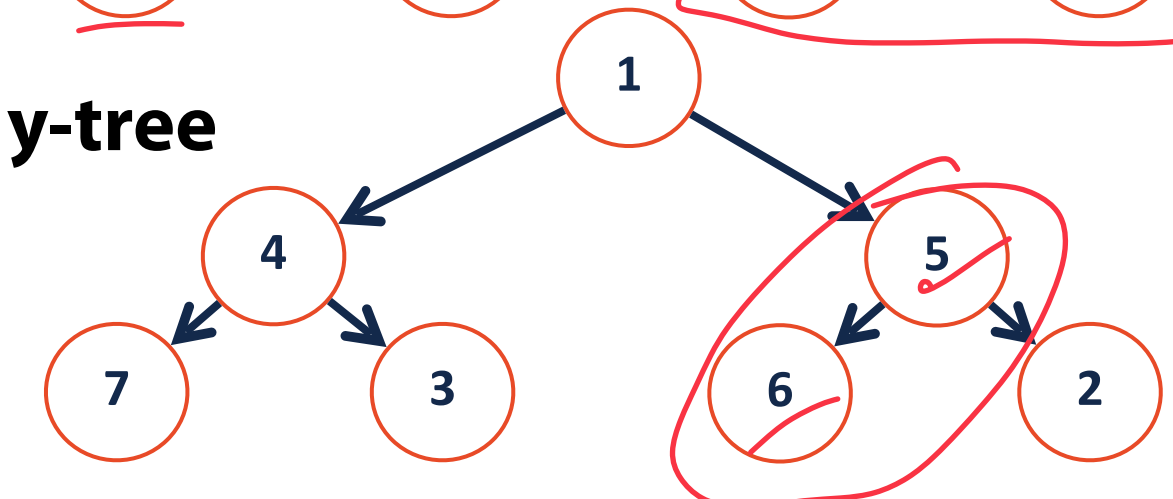
Consider points in 2D: $\mathbf{p = \{p_1, p_2, \ldots, p_n\}}$

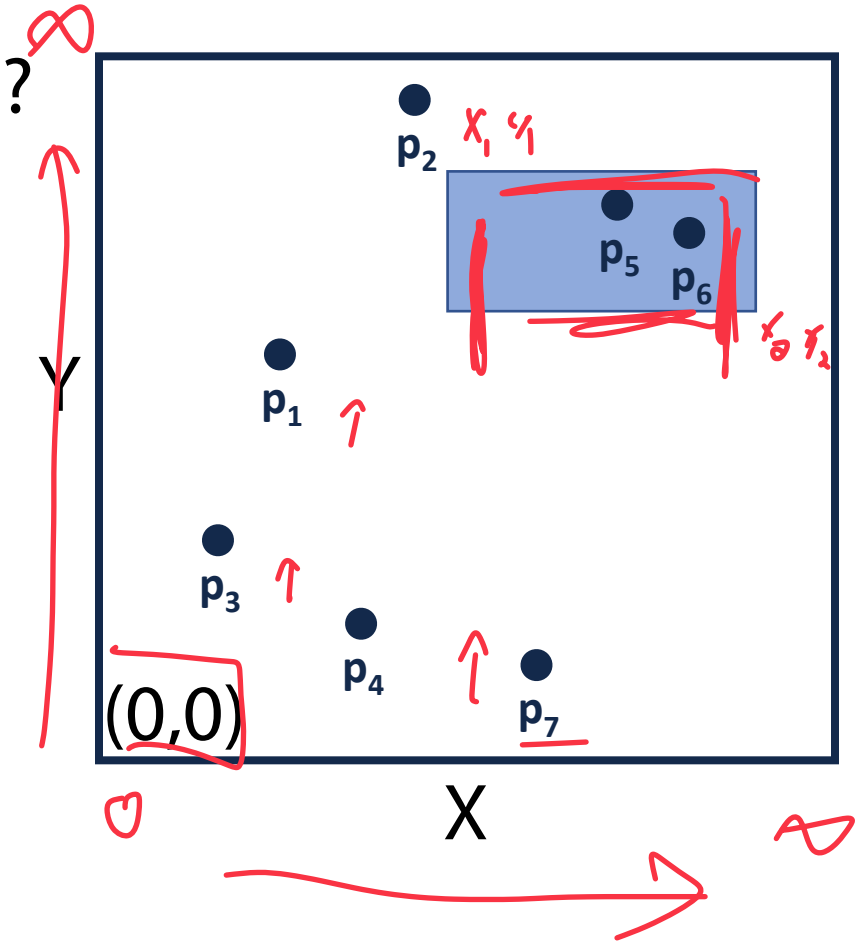
What points in rectangle [$\mathbf{(x_1, y_1)}$, $\mathbf{(x_2, y_2)}$]?

x-tree



y-tree



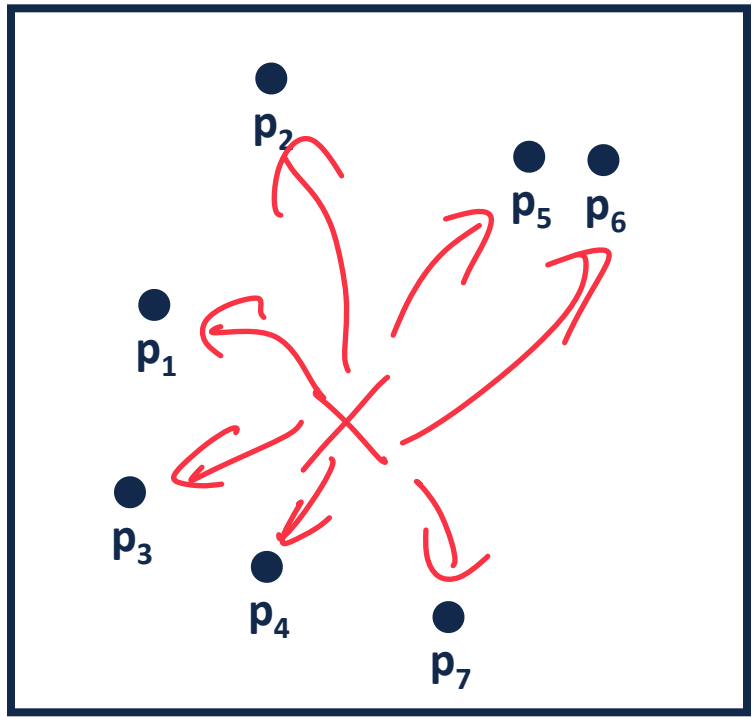


Range-based Searches

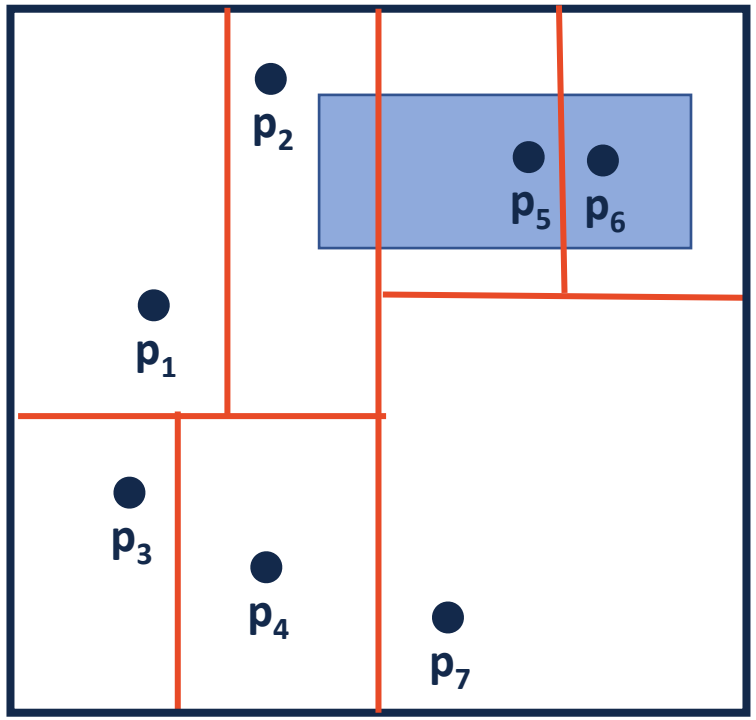
Consider points in 2D: $\mathbf{p = \{p_1, p_2, \ldots, p_n\}}$

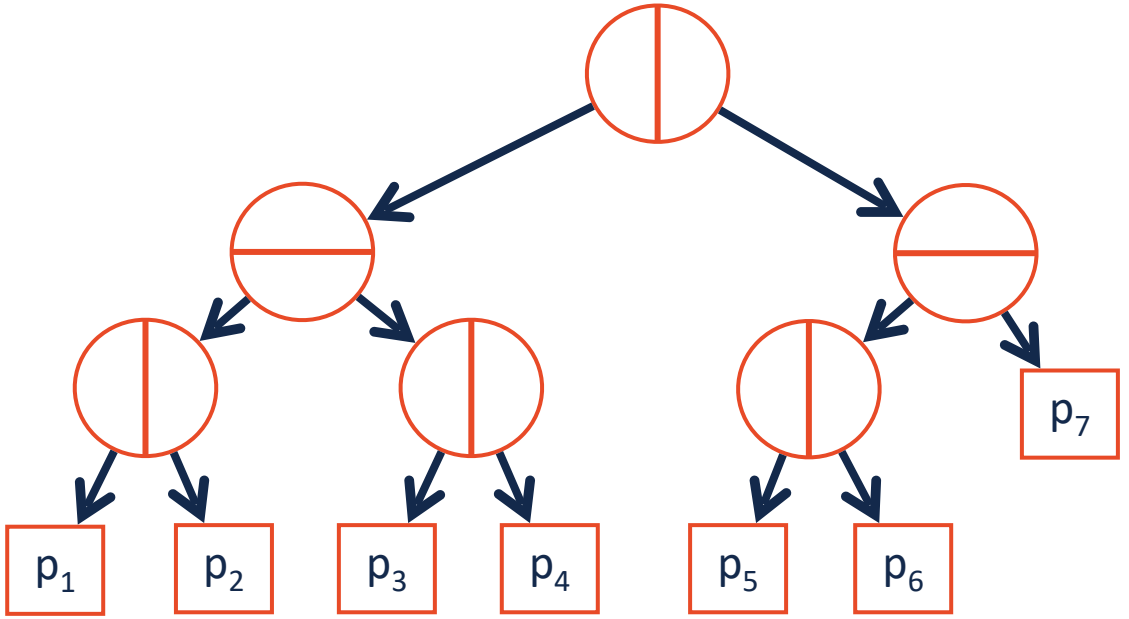
What is nearest point to $\mathbf{(x_1, y_1)}$?

Check every distance



Range-based Searches





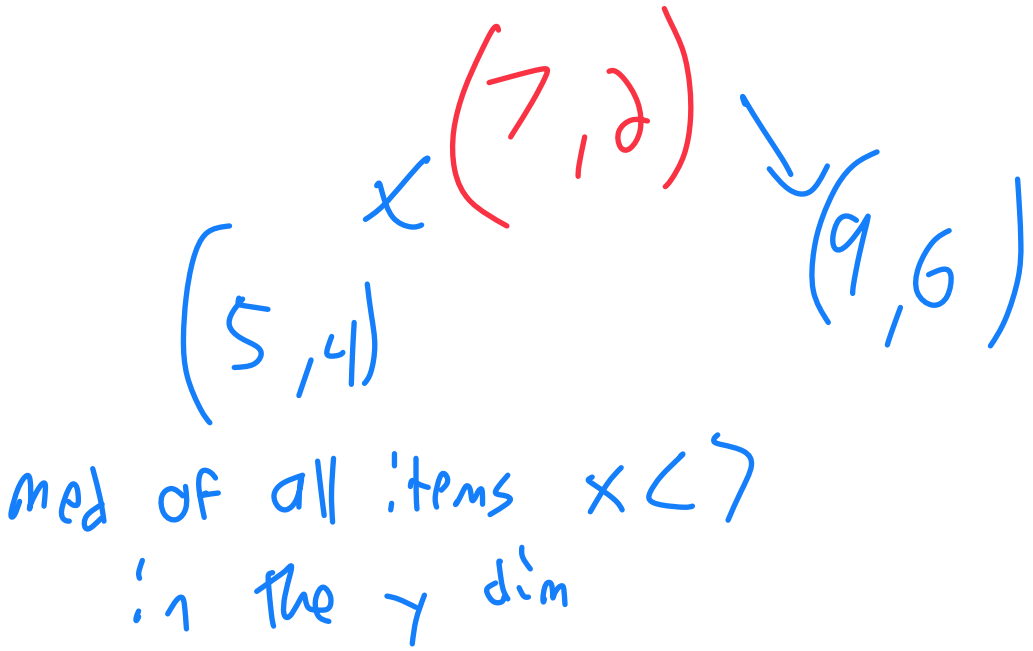
Nearest Neighbor: k-d tree

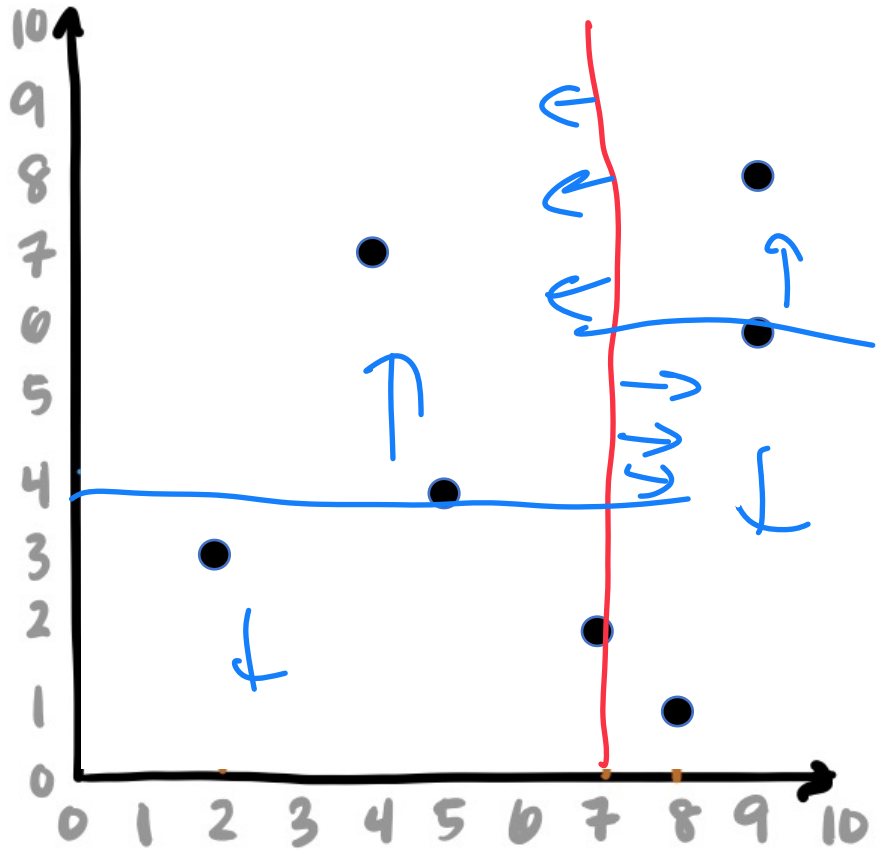
Find medians in all dim

A **k-d tree** is similar but splits on points:

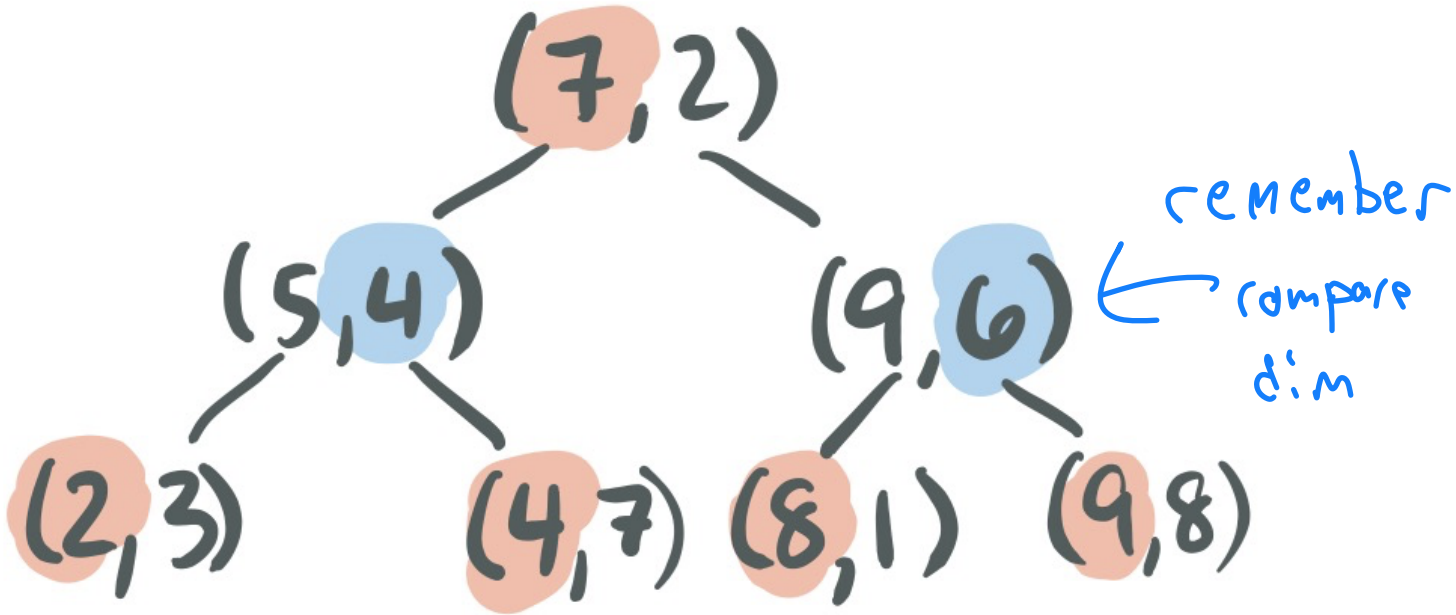
(7,2), (5,4), (9,6), (4,7), (2,3), (8,1), (9,8)

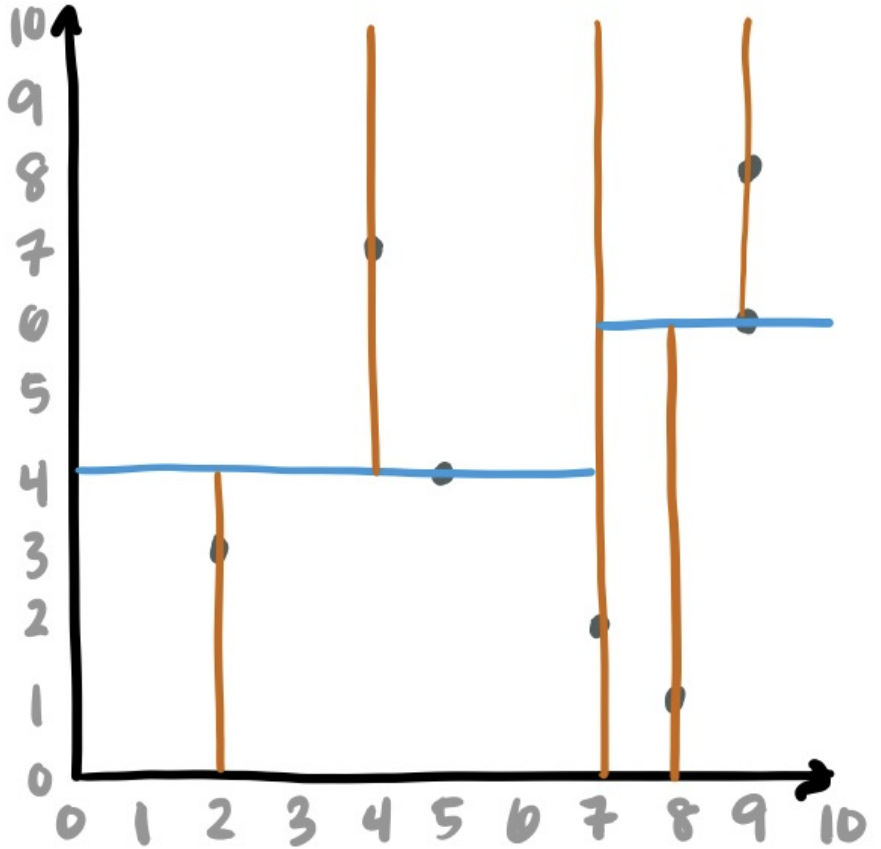
Median of all items in X dim





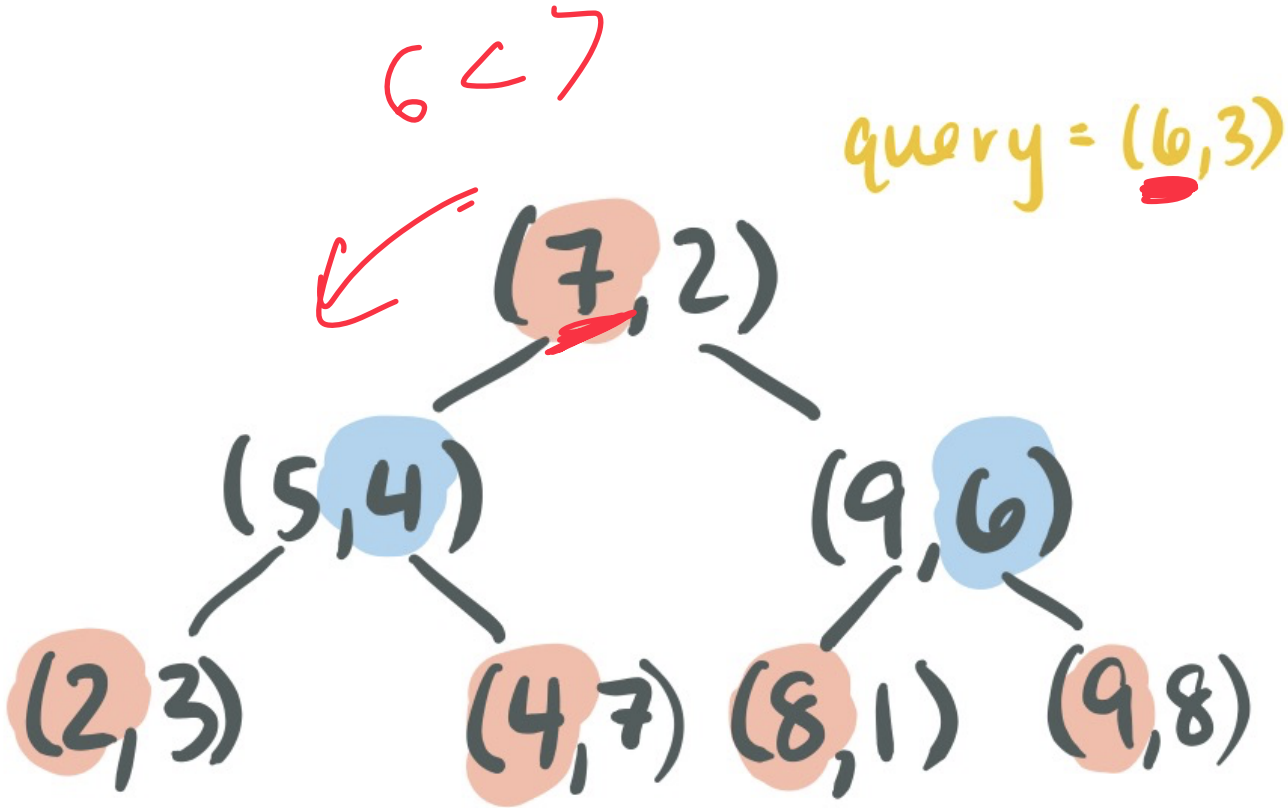
Nearest Neighbor: k-d tree

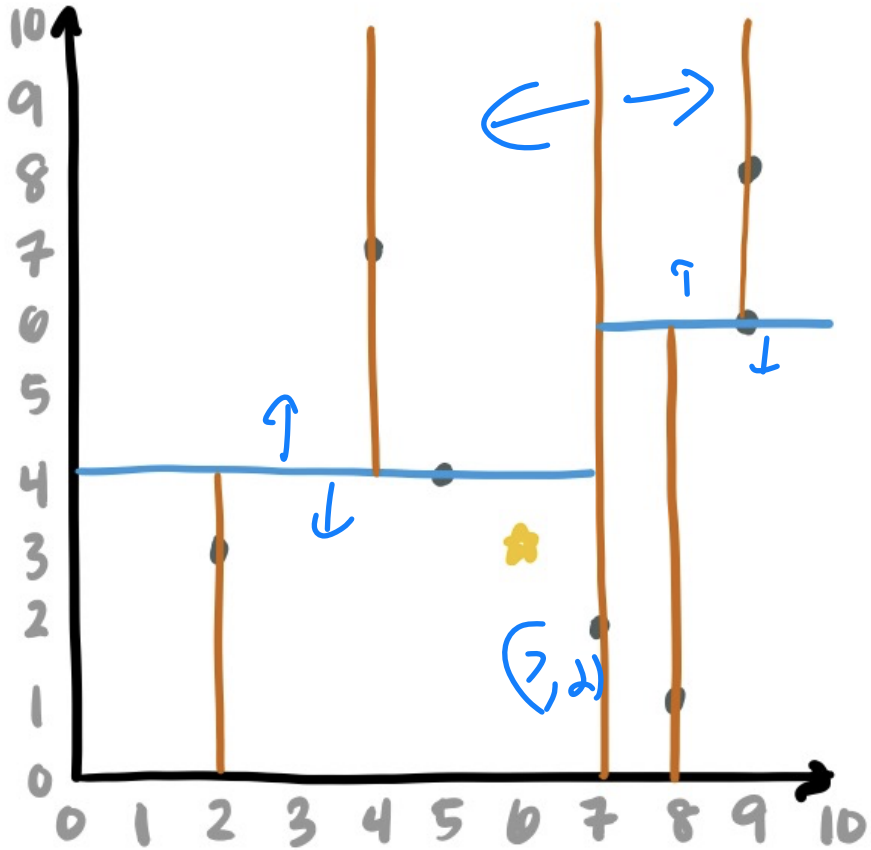




Nearest Neighbor: k-d tree

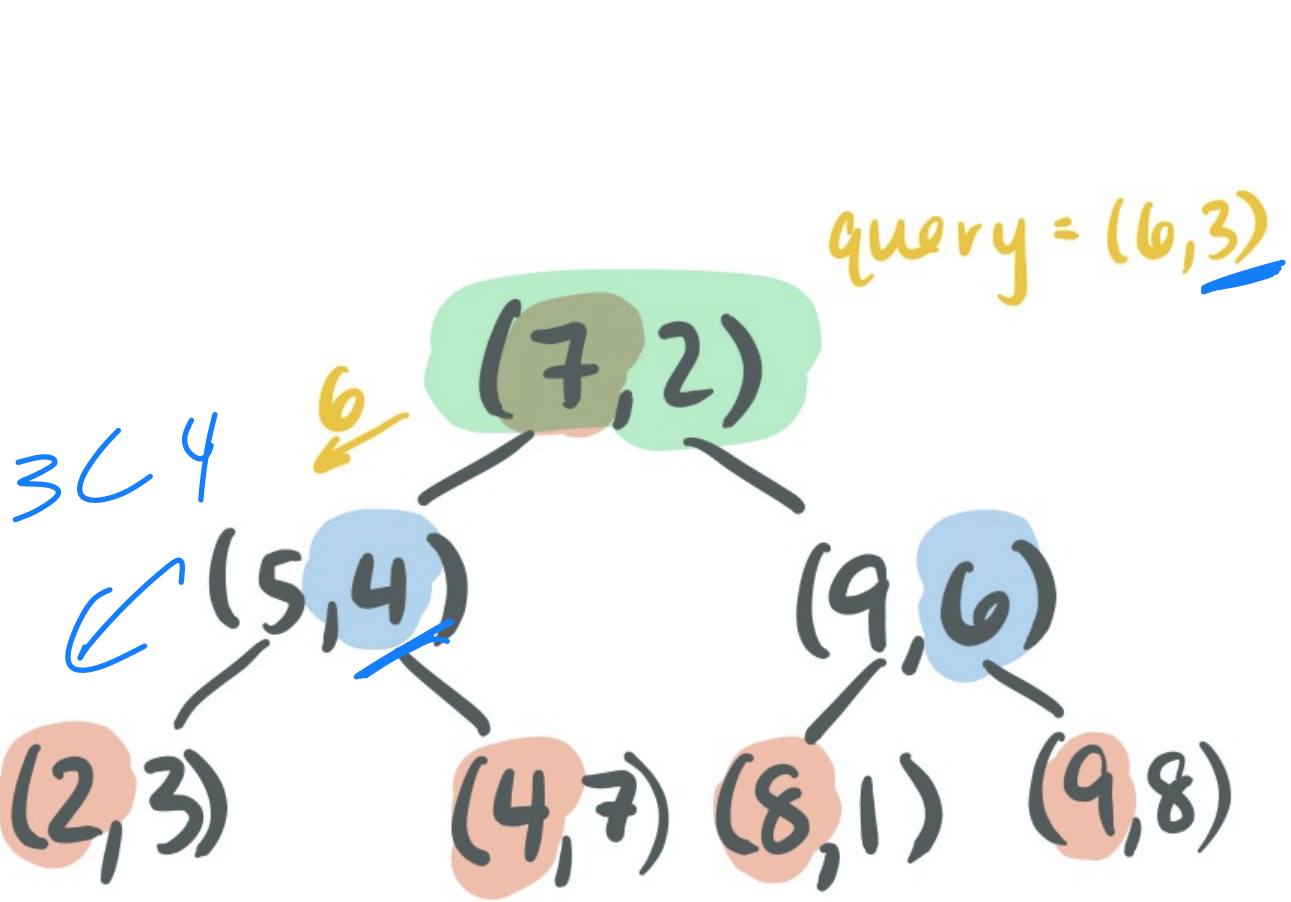
Search by comparing query and node in single dimension

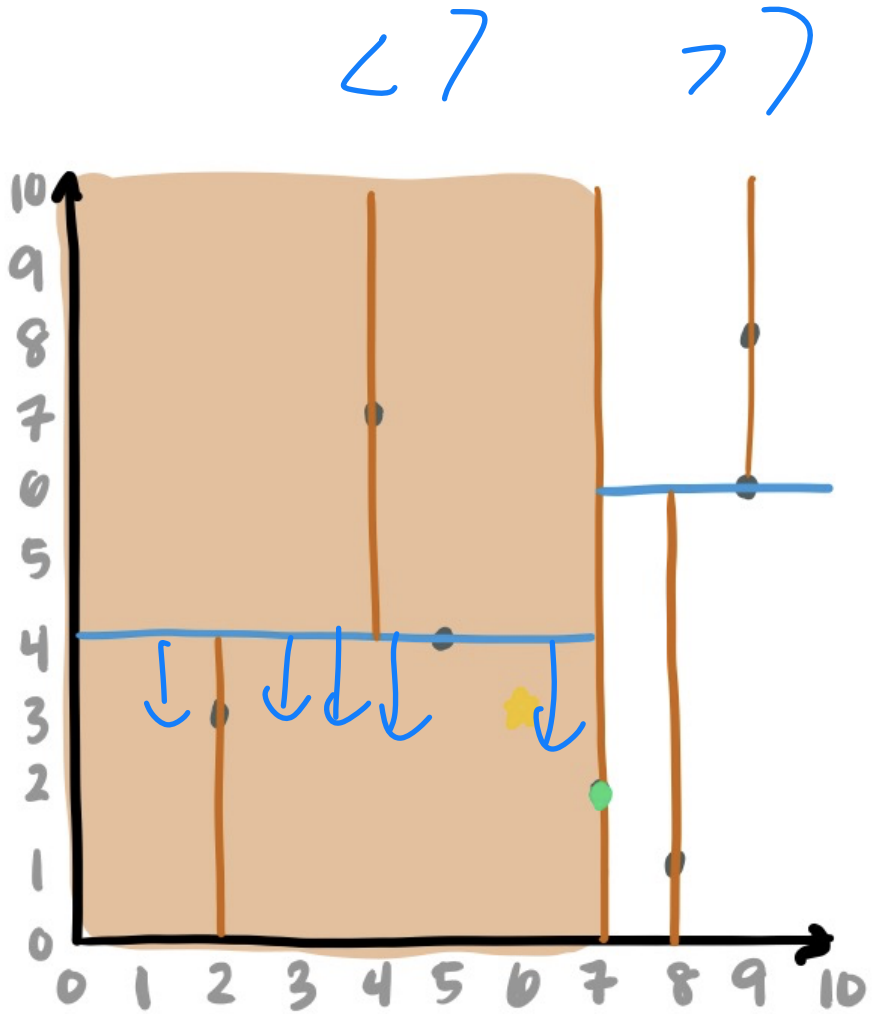




Nearest Neighbor: k-d tree

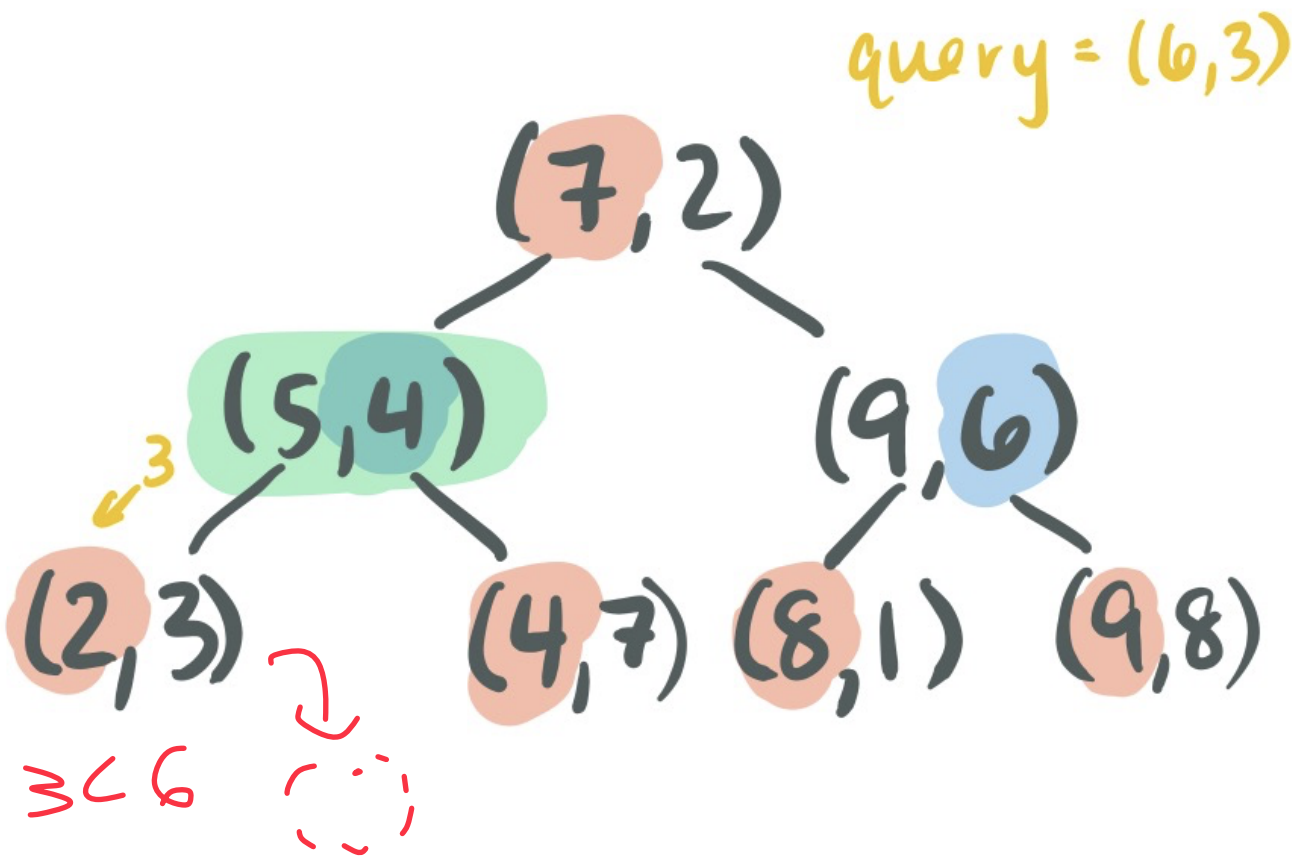
Search by comparing query and node in single dimension

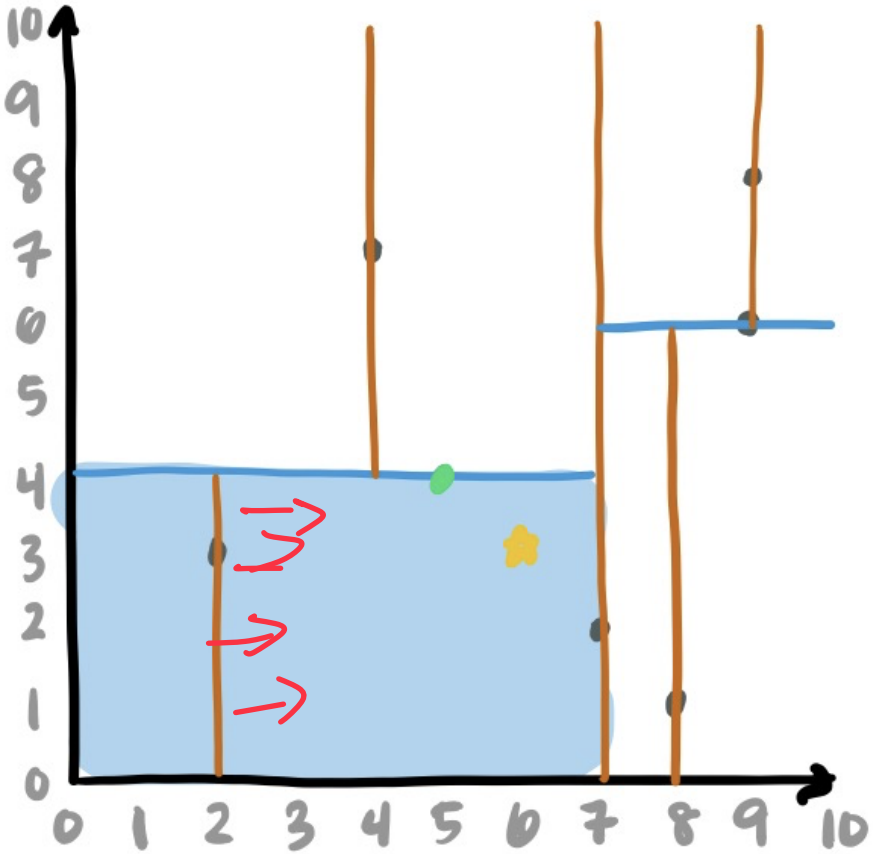




Nearest Neighbor: k-d tree

Search by comparing query and node in single **alternating** dimension

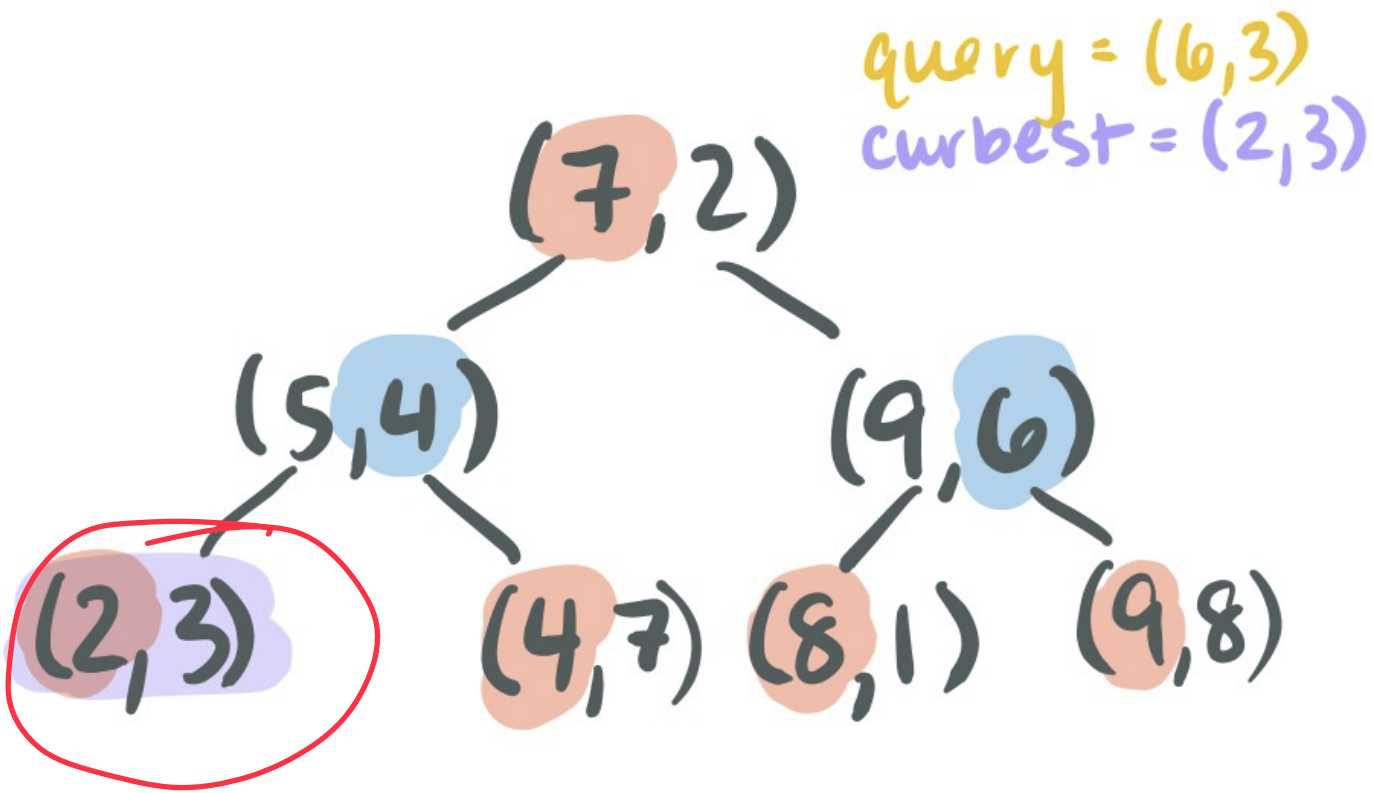


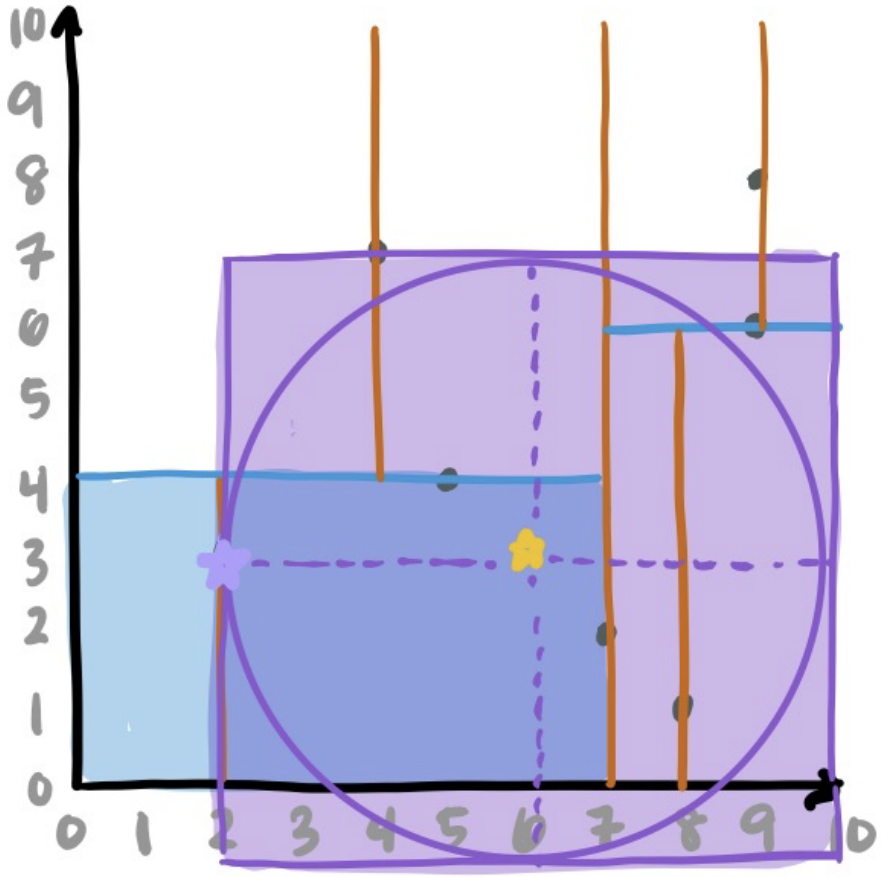


Nearest Neighbor: k-d tree

search radius

Nearest neighbor requires **backtracking**

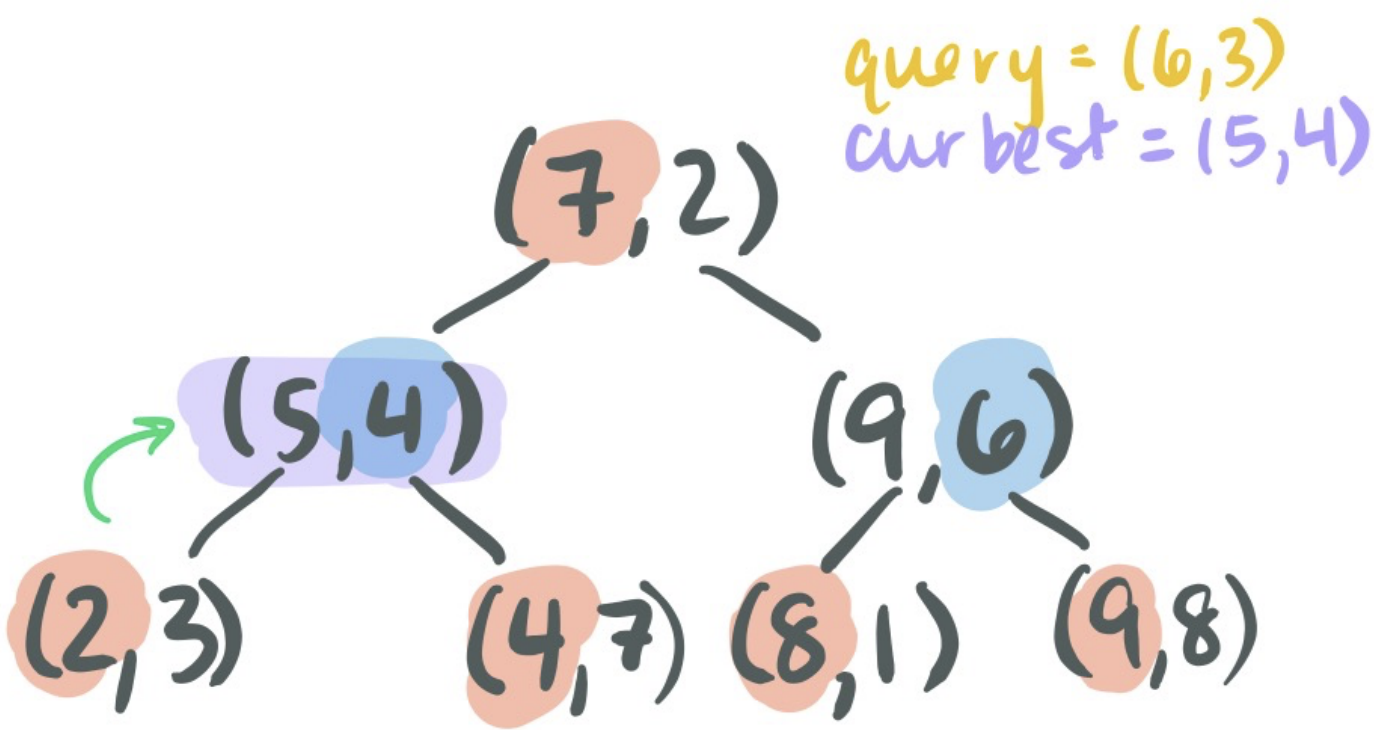


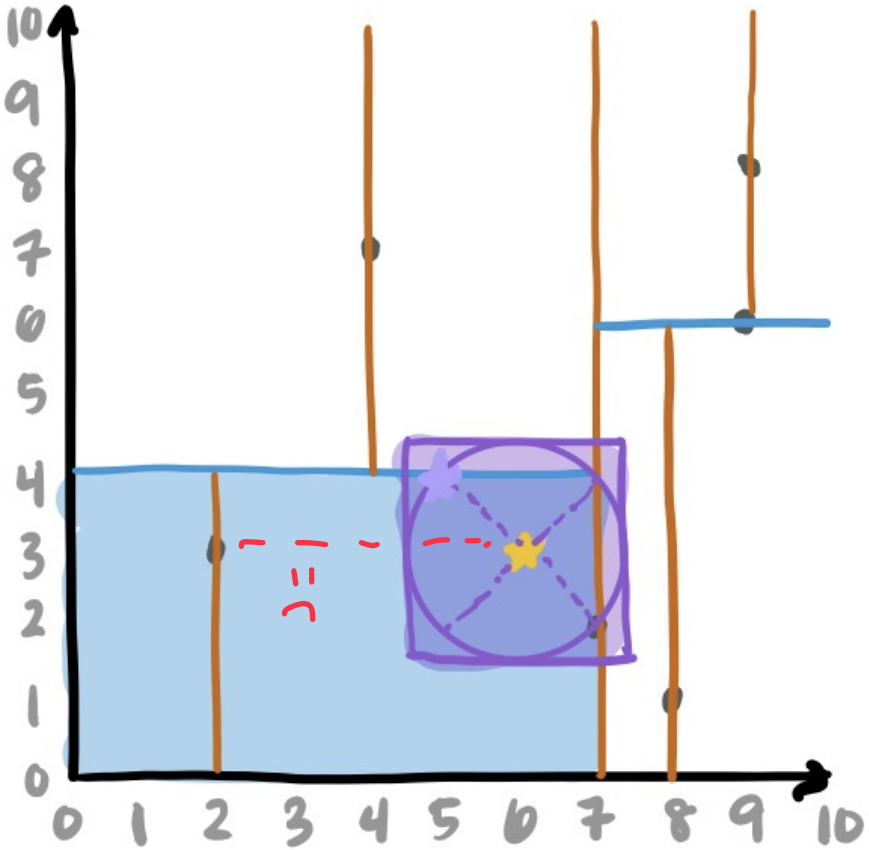


Nearest Neighbor: k-d tree

Backtracking: start recursing backwards -- store "best" possibility as you trace back

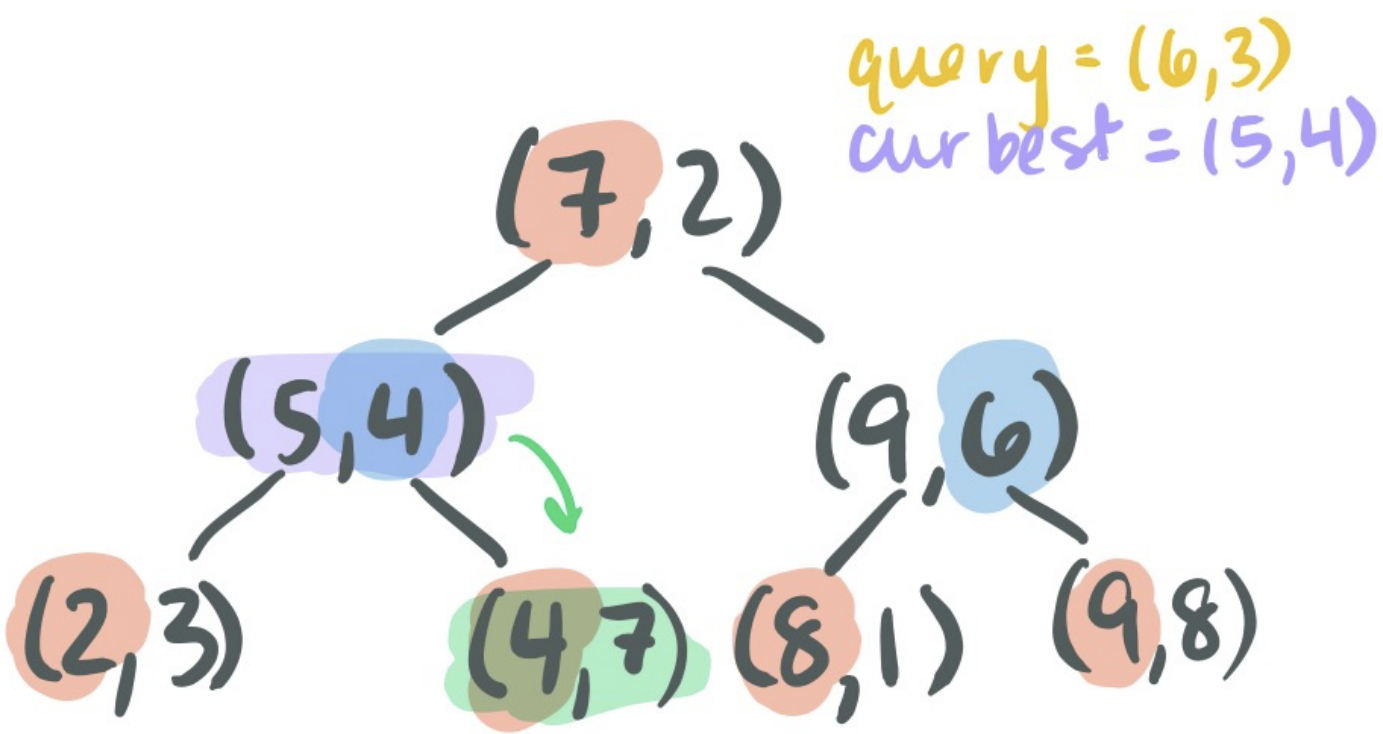
(2,3) or (5,4) better nearest point?

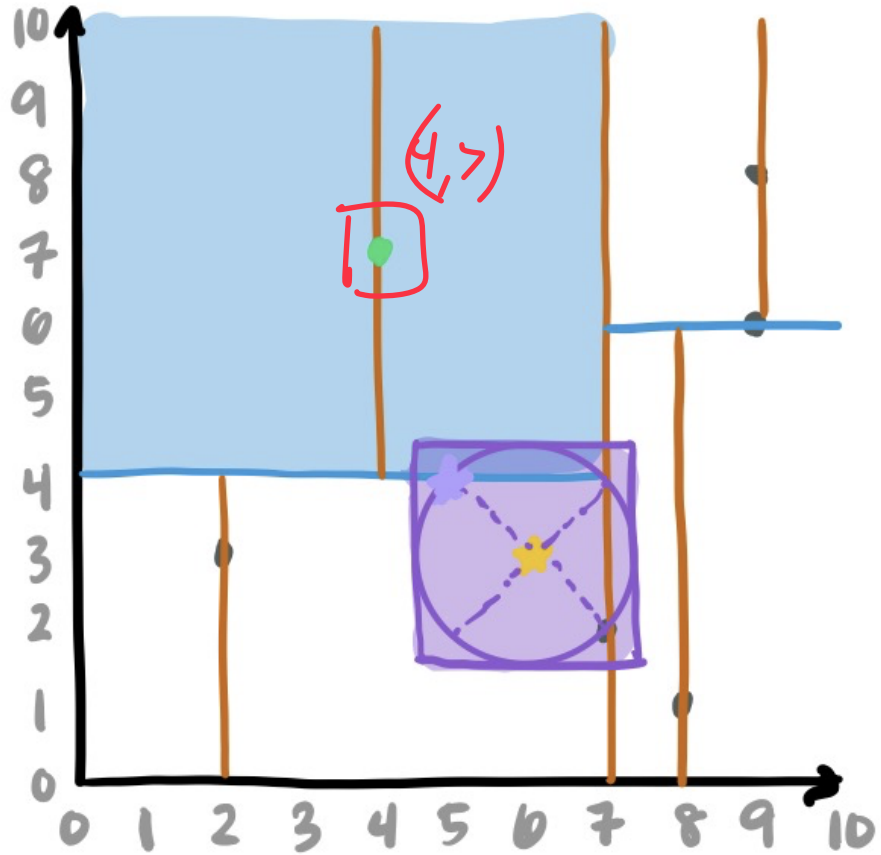




Nearest Neighbor: k-d tree

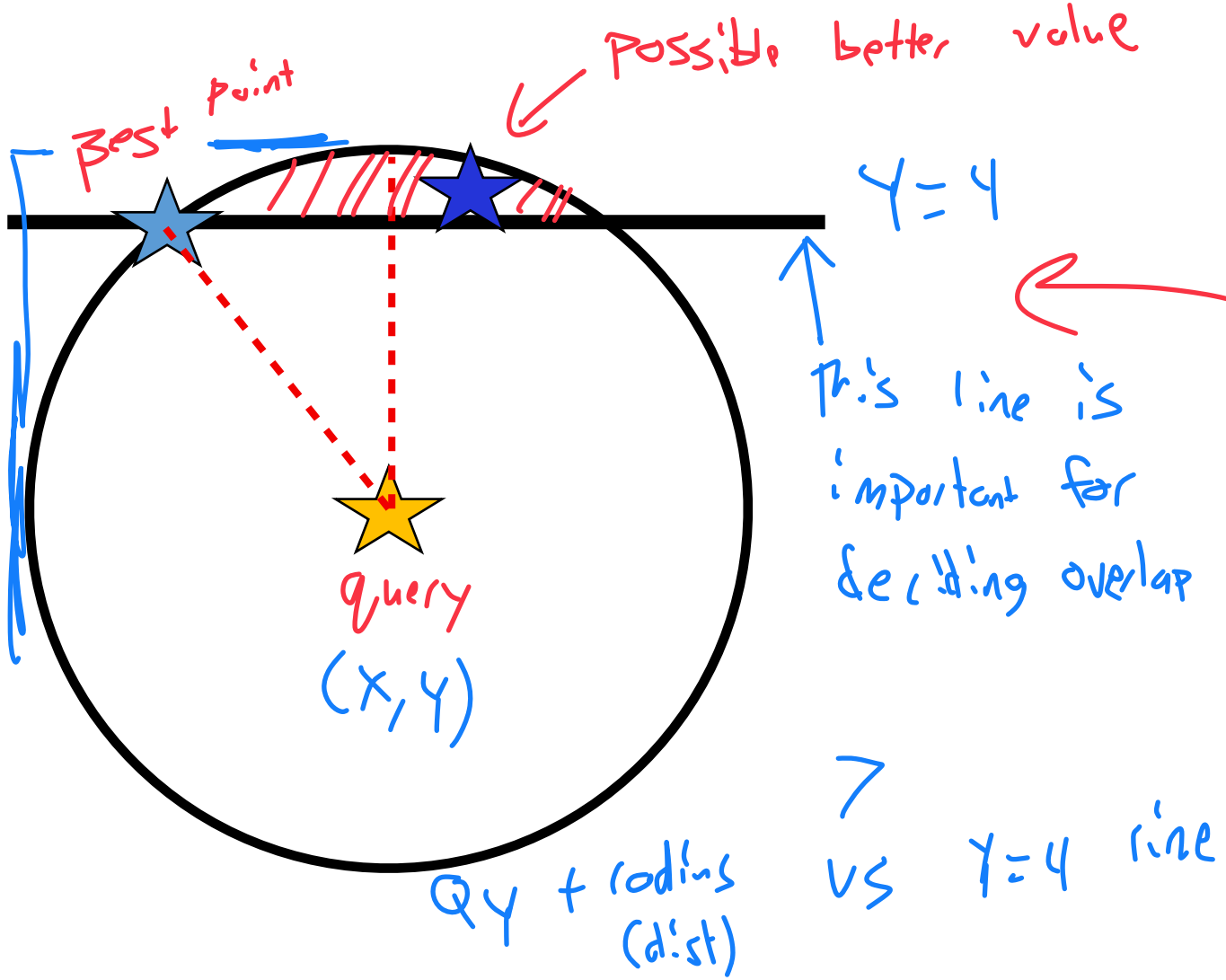
May have to recursively check other branches of tree — **why?**





Nearest Neighbor: k-d tree

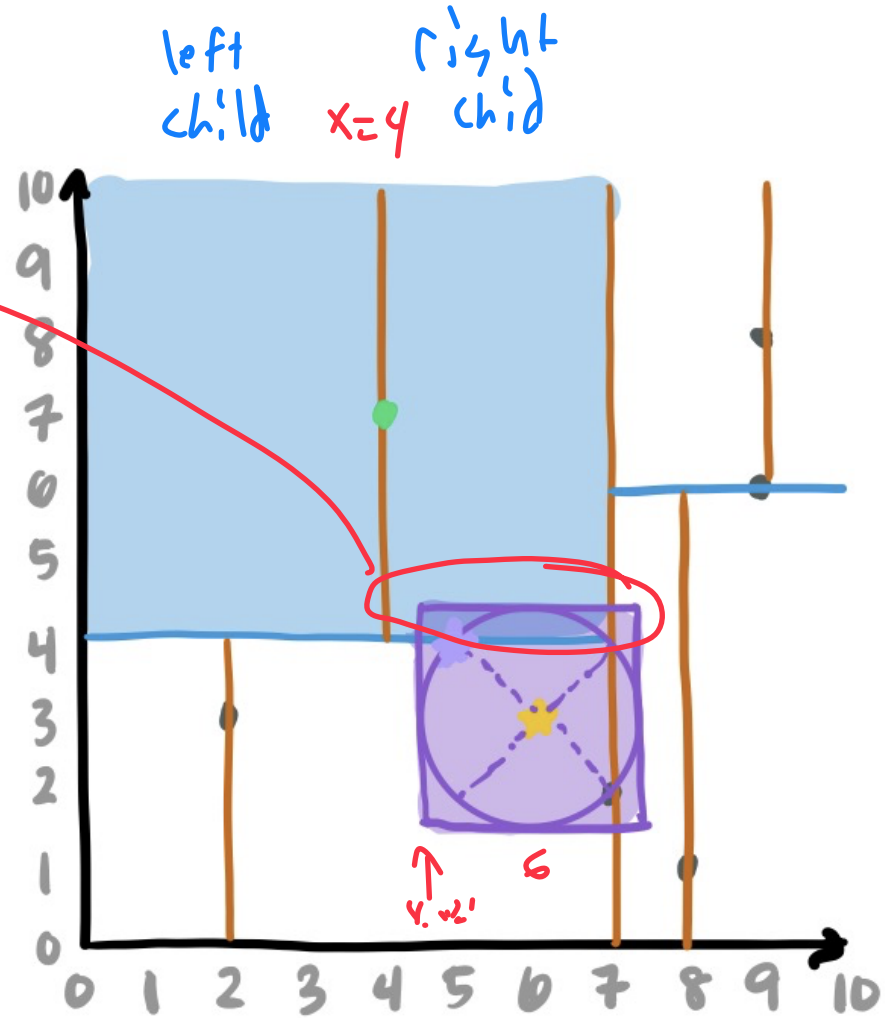
May have to recursively check other branches of tree — **why?**



Y = 4

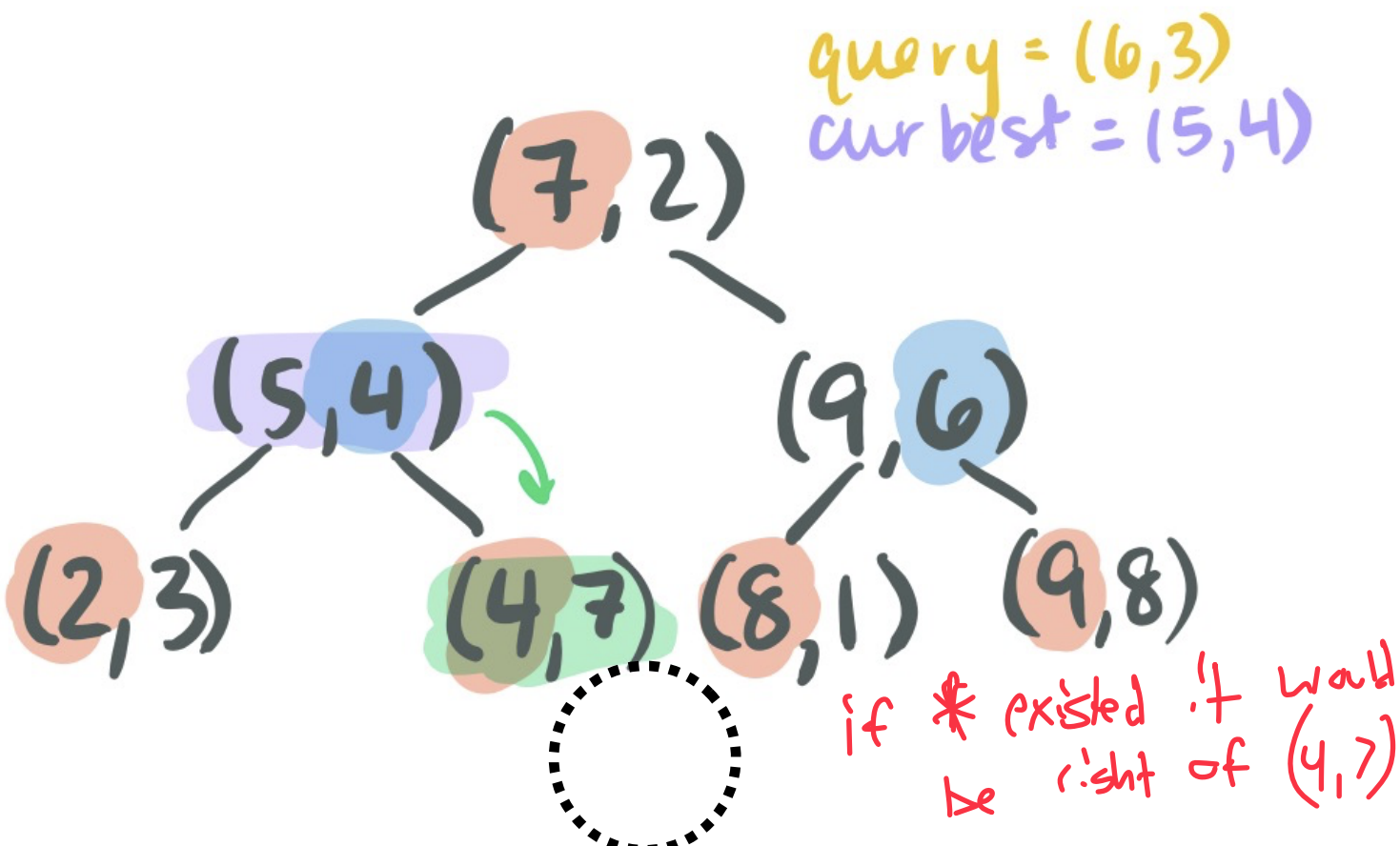
This line is important for deciding overlap

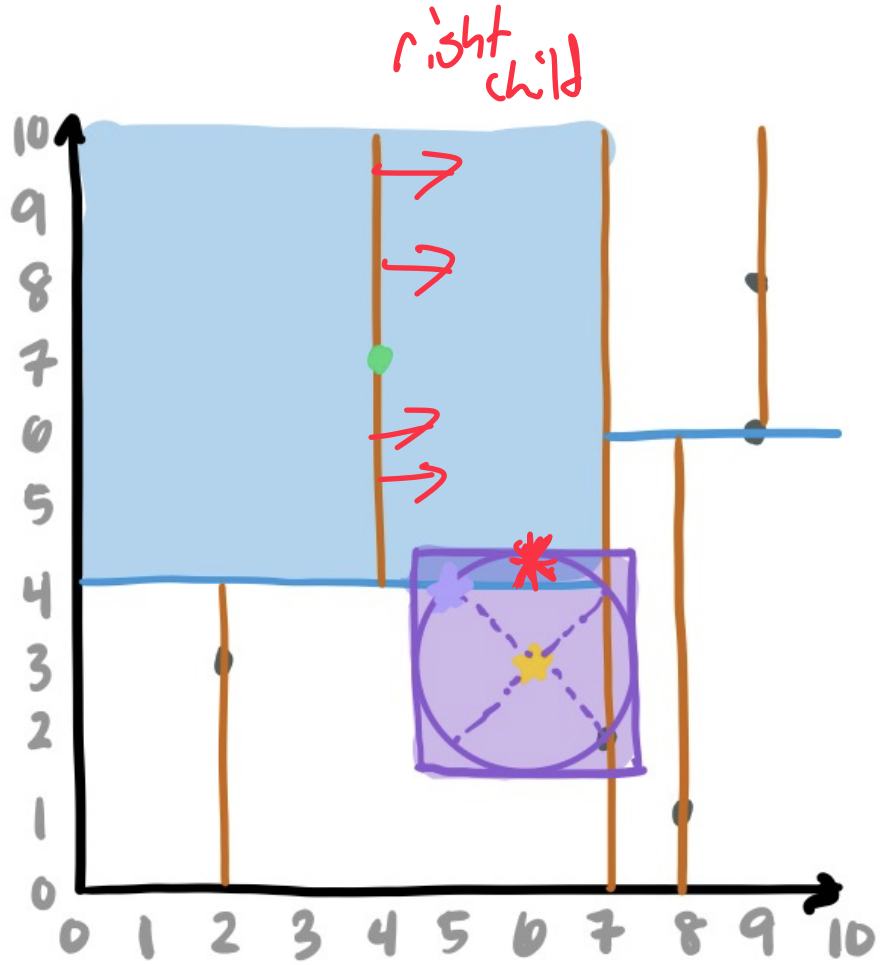
vs Y = 4 line



Nearest Neighbor: k-d tree

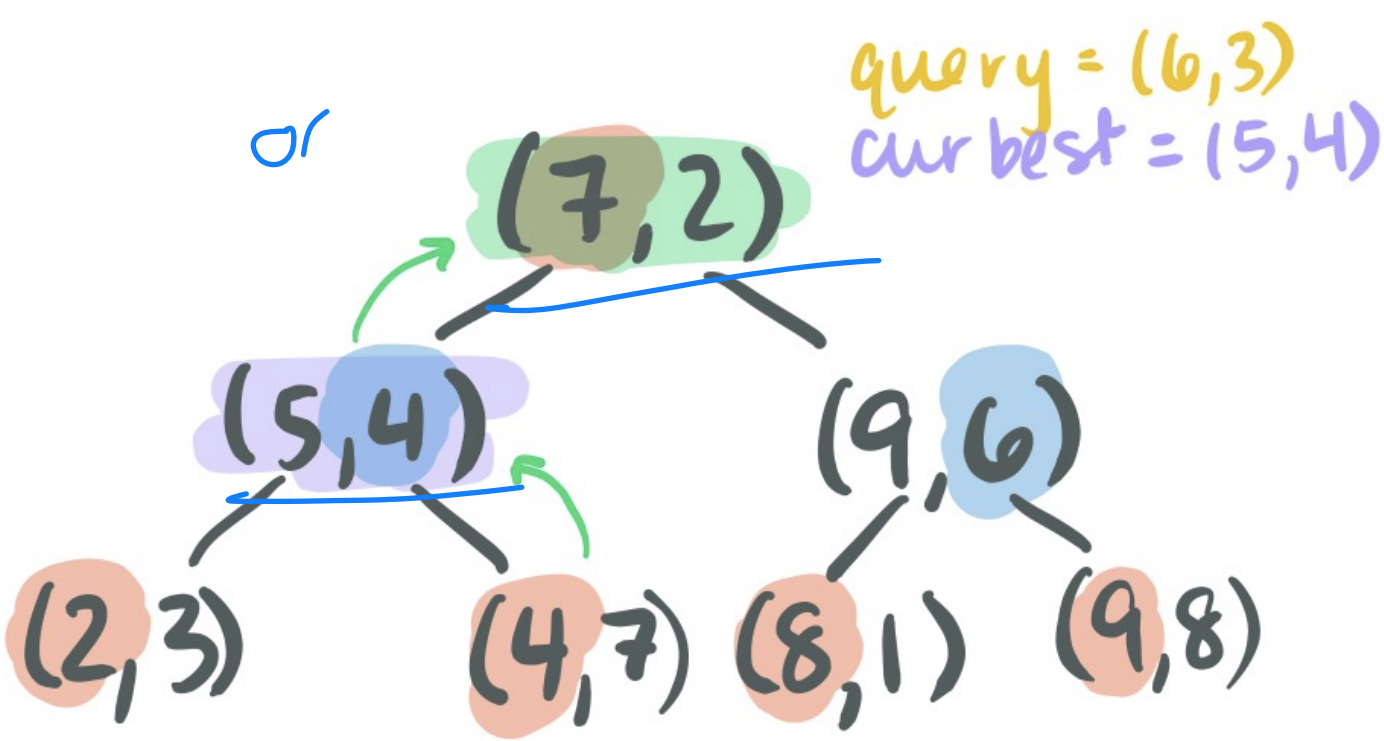
In this instance, there is no right child of (4, 7) so we continue…

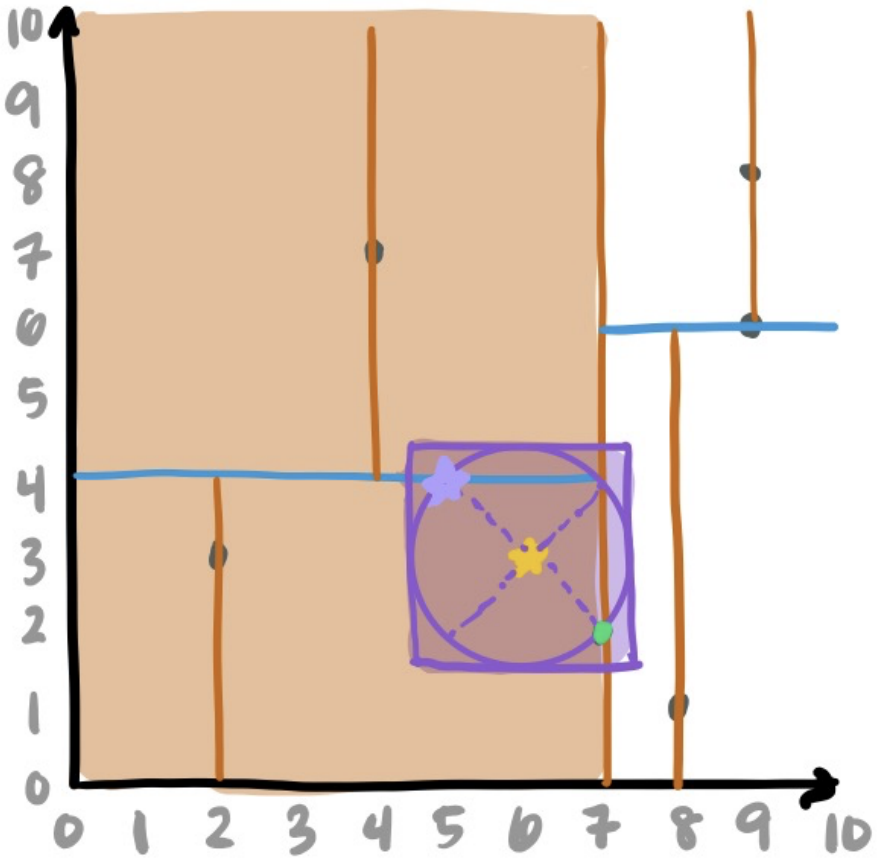




Nearest Neighbor: k-d tree

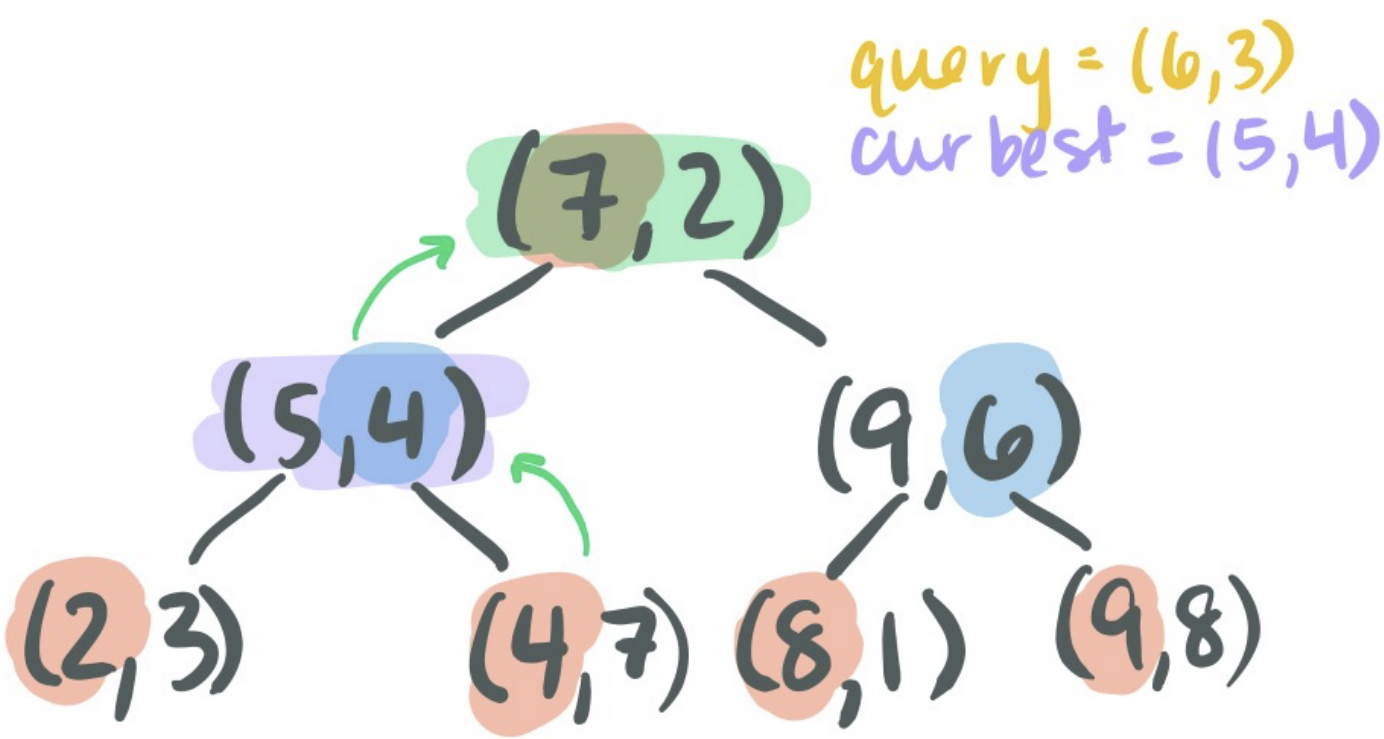
Tie breaking is described in doxygen (`smallerDimVal`)

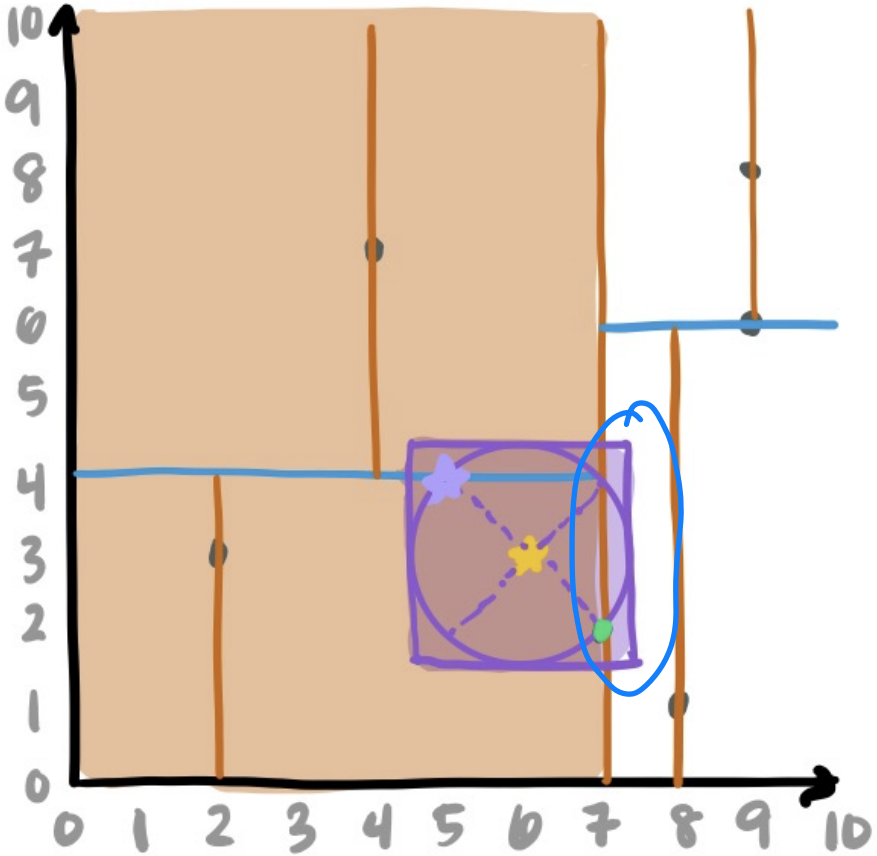




Nearest Neighbor: k-d tree

We've hit root and have a 'best' match — **are we done?**

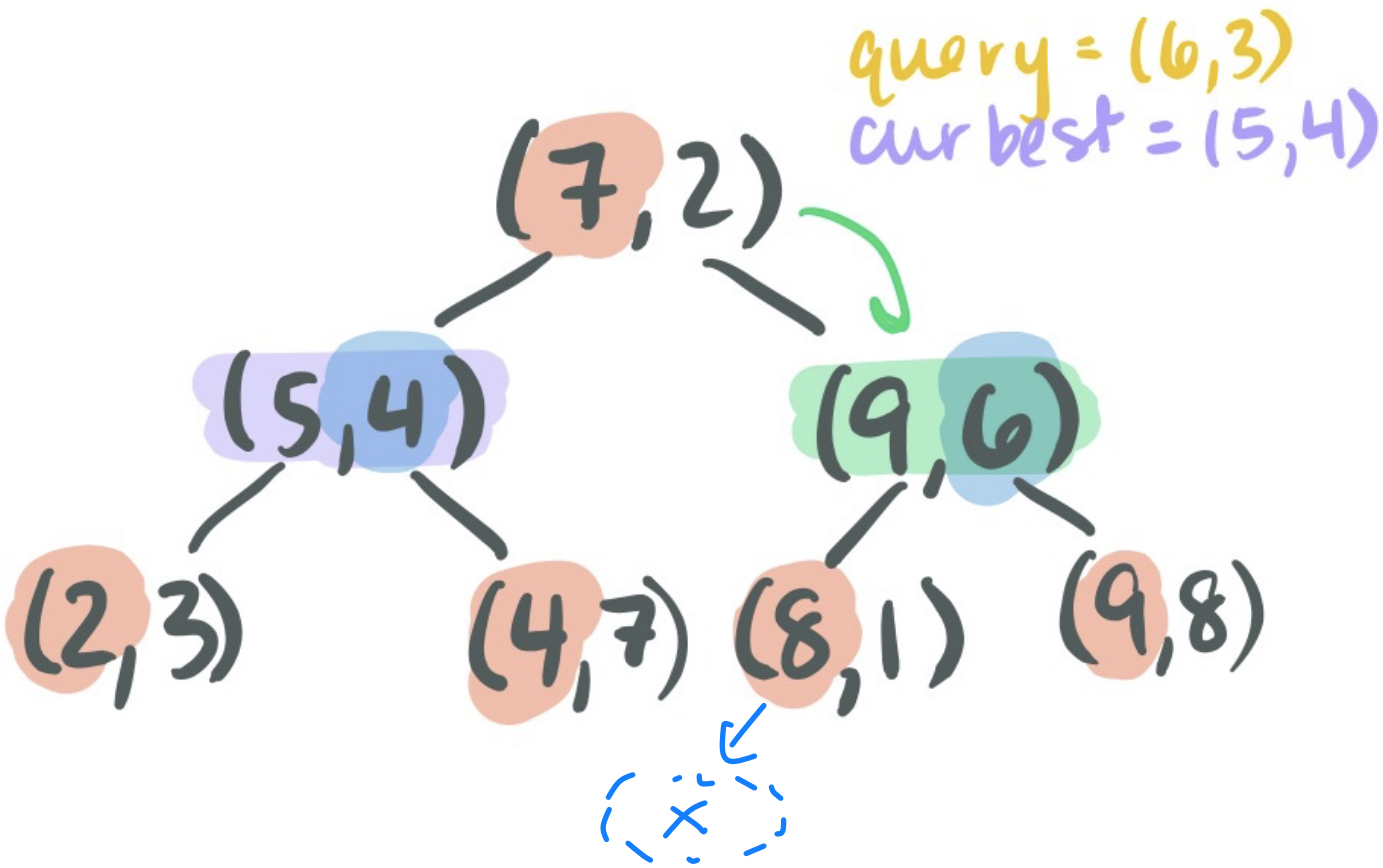


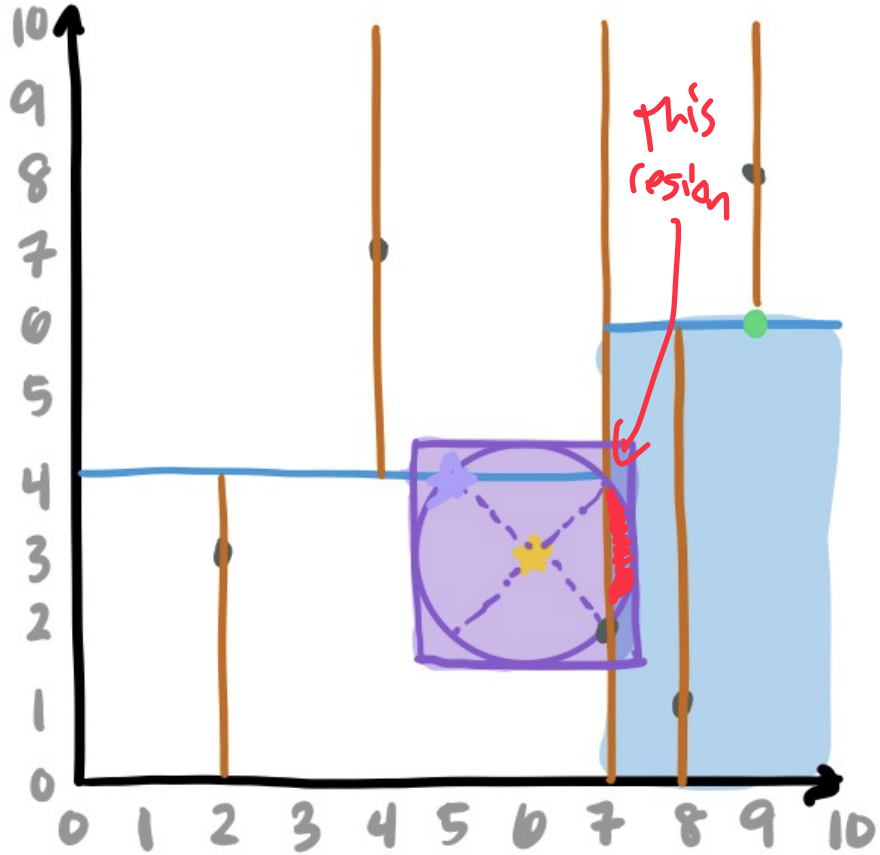


Nearest Neighbor: k-d tree

Why do we need to explore the right subtree?

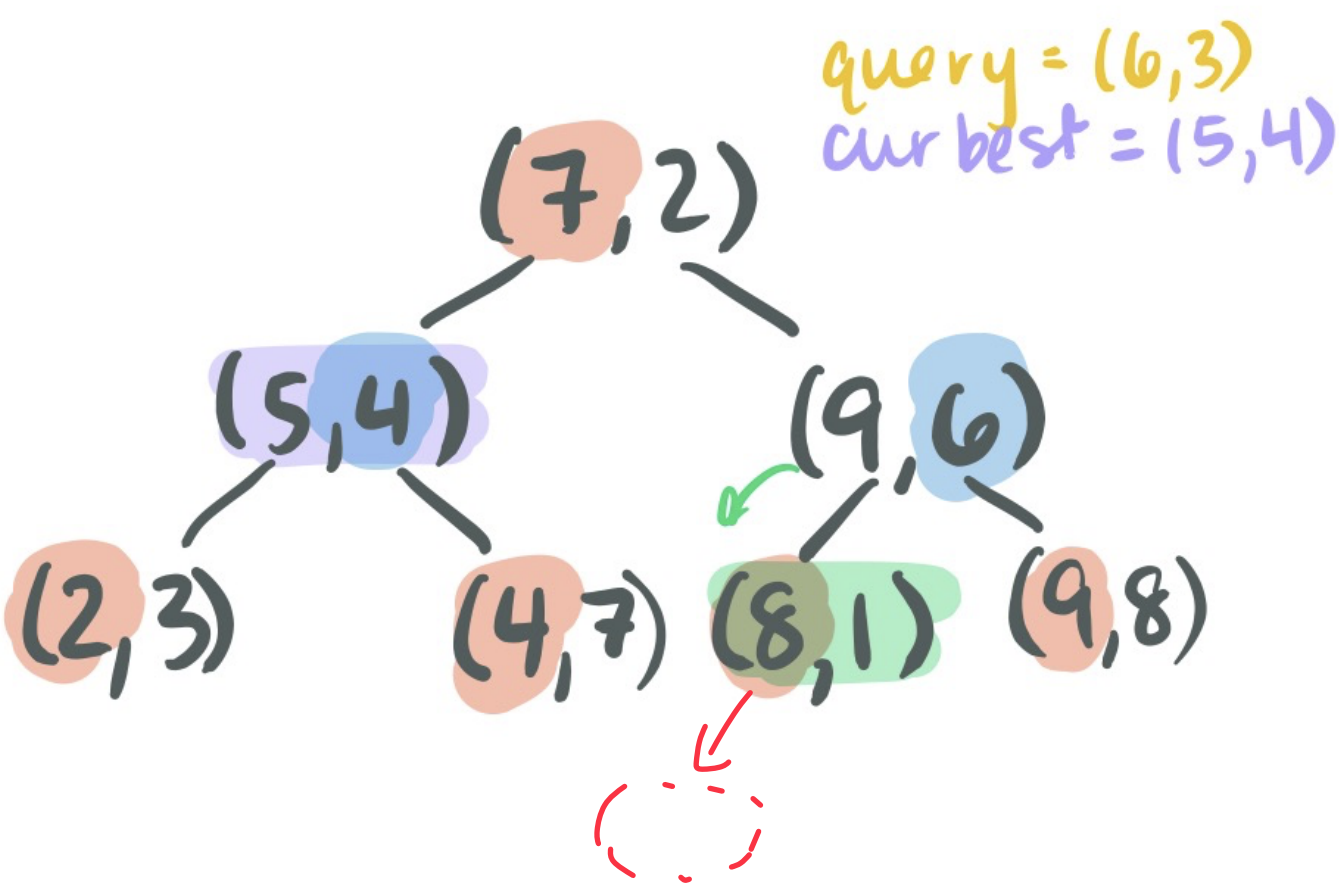
If there existed a point X it could be better!

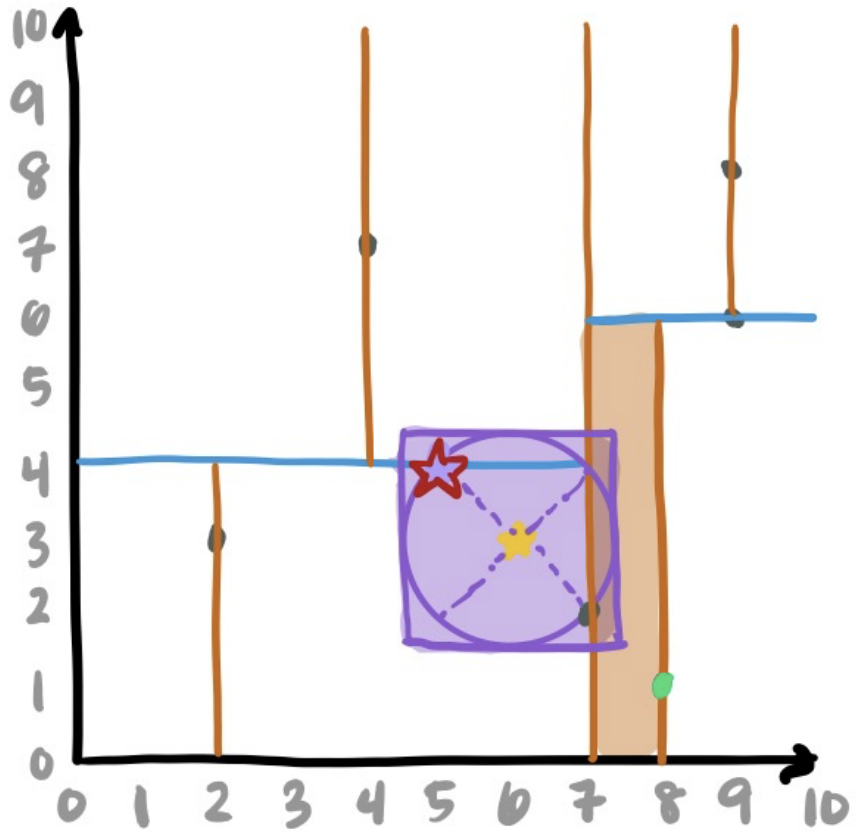




Nearest Neighbor: k-d tree

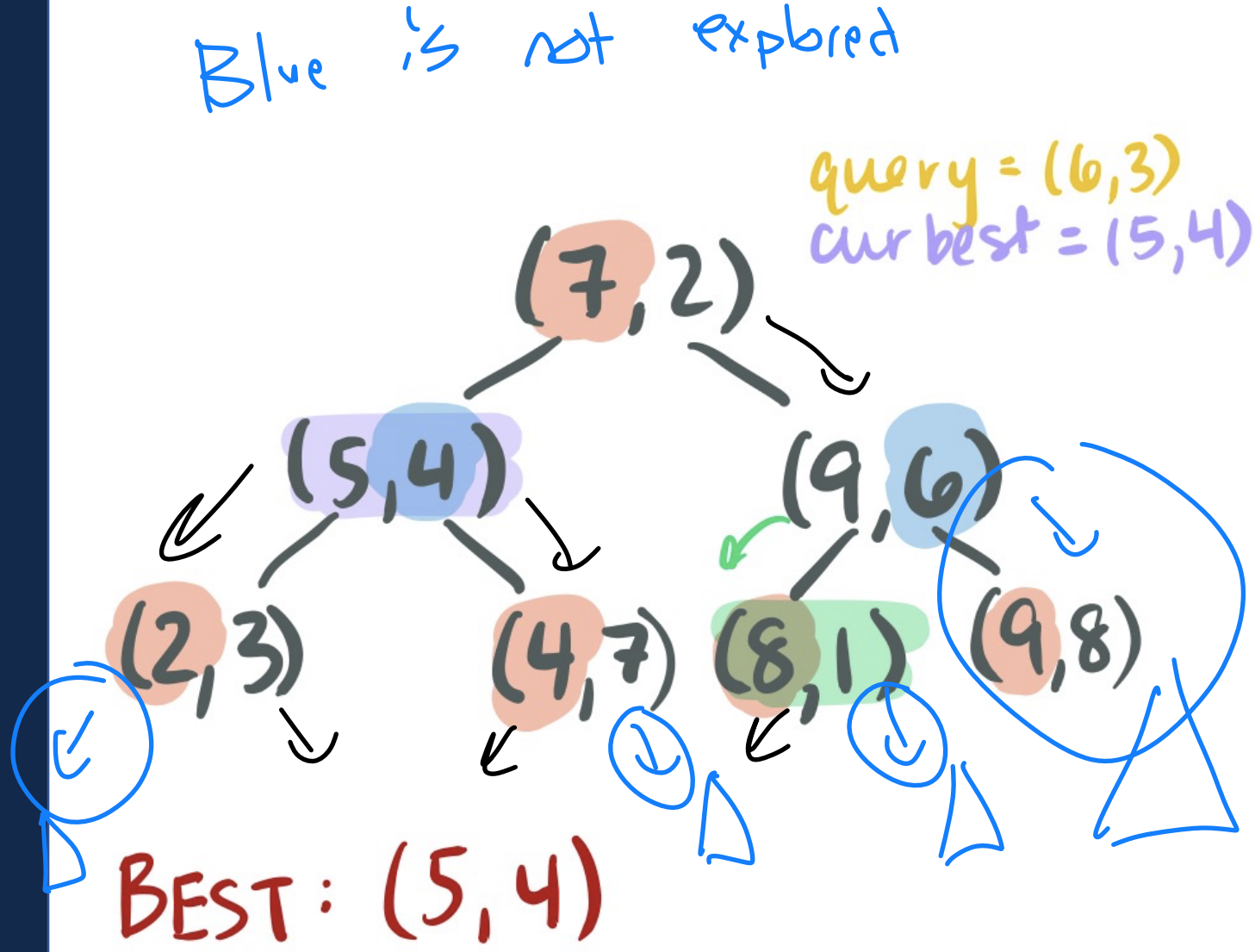
If there was a left child of (8,1), it could have been a better match!

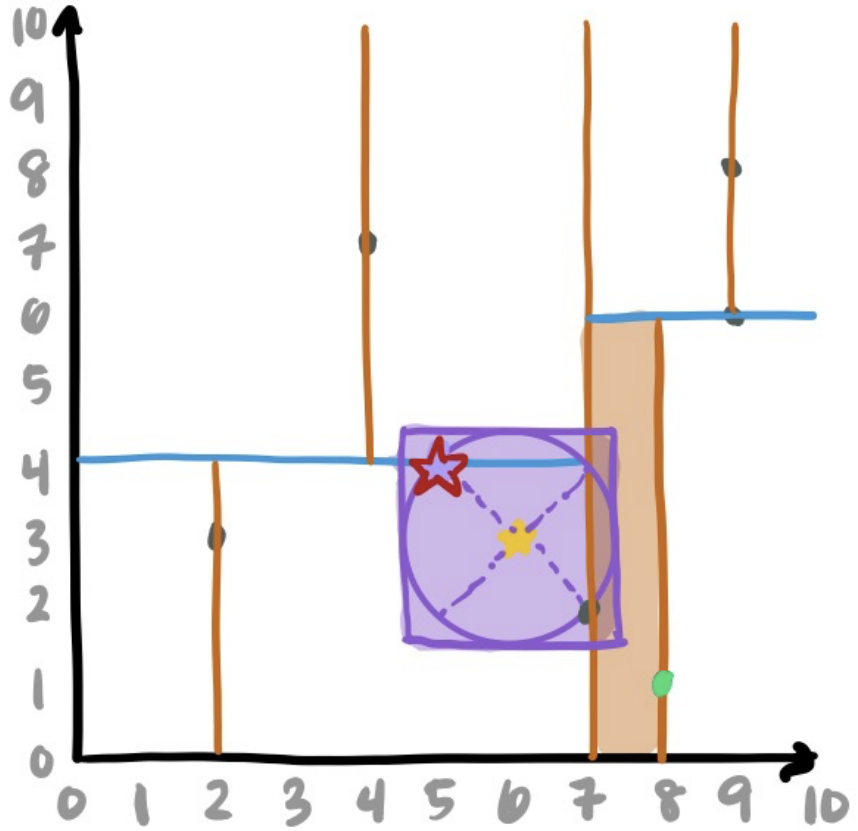




Nearest Neighbor: k-d tree

Having exhaustively explored for better matches, we are done!

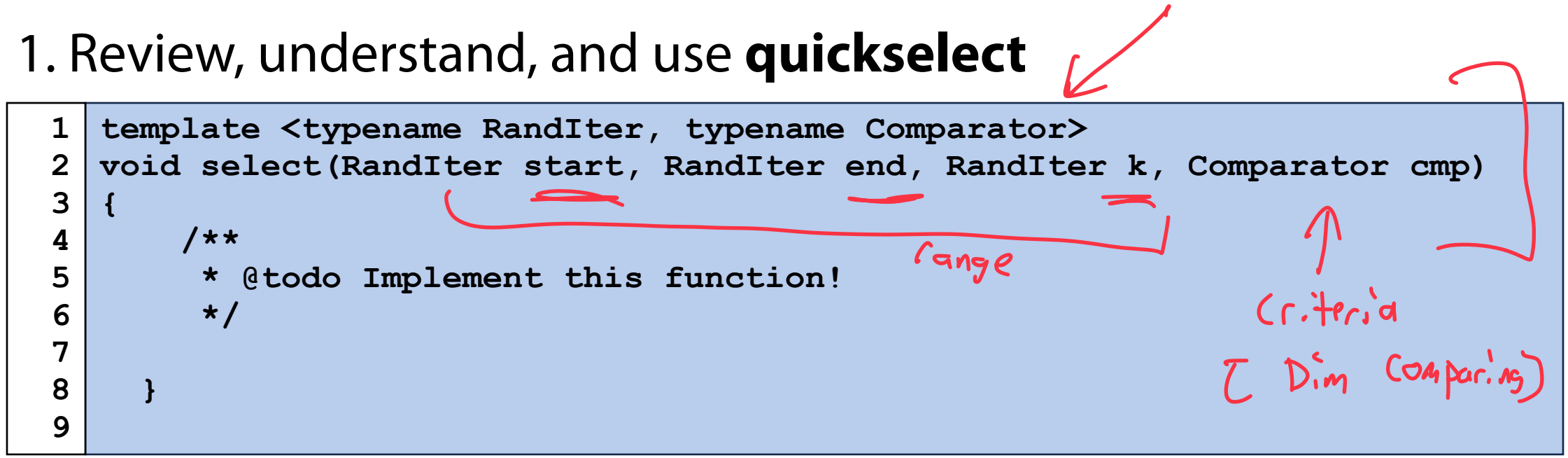




Tips and Tricks for MP_Mosaics

1. Review, understand, and use **quickselect**

```
1  template <typename RandIter, typename Comparator>
2  void select(RandIter start, RandIter end, RandIter k, Comparator cmp)
3  {
4      /**
5       * @todo Implement this function!
6       */
7
8    }
9
```



2. Review, understand, and use **lambda functions**

Understanding ‘randIter’

An iterator is a container giving access in different ways:

Forward ++ preinc
* access
!= not equals

Bidirectional ↗
--

Random Access → Does all bidirection but also fakes being an array
Assume ~O(1)

Implementing quickselect with RandIter

Random Access Iterator lets you:

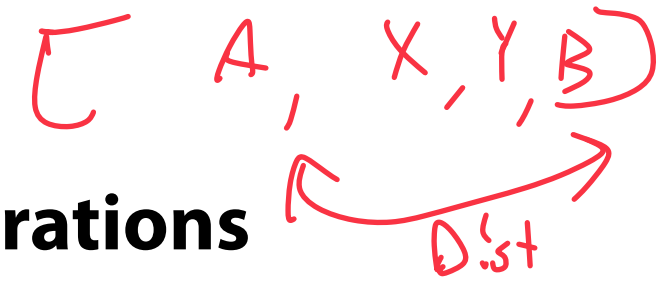
Swap items using std::swap()

```
1  template <typename RandIter, typename Comparator>
2  void BlackBox(RandIter A, RandIter B)
3  {
4
5     std::swap(*A, *B);
6
7
8  }
9
```

Hint: Look at pseudo-code for quickselect!

Implementing quickselect with RandIter

Random Access Iterator lets you:



Access container indices using math operations

```
randIter A;

auto nth = *(A + n);
```

Get distance between two iterators

```
randIter A, B;

A < B;          // True if A is earlier in container than B

A - B;          // The distance between A and B
```

Implementing quickselect with RandIter

Random Access Iterator lets you:

Do most things you'd expect an array to be able to do!

The power of the **Interface!**

https://en.cppreference.com/w/cpp/iterator/random_access_iterator

Tips and Tricks for MP_Mosaics

1. Review, understand, and use **quickselect**

```
1  template <typename RandIter, typename Comparator>
2  void select(RandIter start, RandIter end, RandIter k, Comparator cmp)
3  {
4      /**
5       * @todo Implement this function!
6       */
7
8    }
9
```

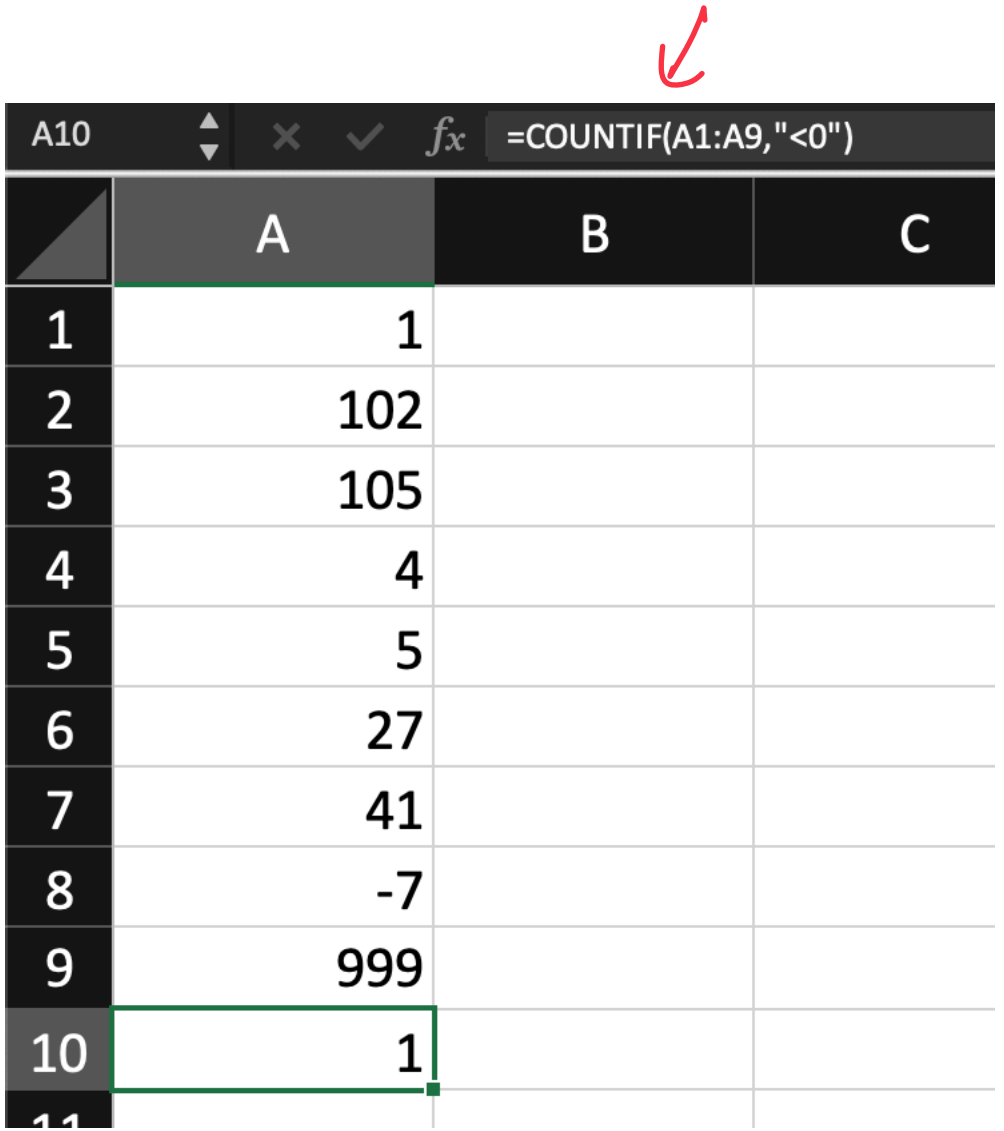
2. Review, understand, and use **lambda functions**

Functions as arguments

Consider the function from Excel
COUNTIF(*range*, *criteria*)

A1:A9 "<0"

Function



Functions as arguments

Countif.hpp

```
10  template <typename Iter, typename Pred>
11  int Countif(Iter begin, Iter end, Pred pred) {
12    int count = 0;
13    auto cur = begin;
14
15    while(cur != end) {
16      if(pred(*cur))
17        ++count;
18      ++cur;
19    }
20
21    return count;
22  }
```

range

iterate over range

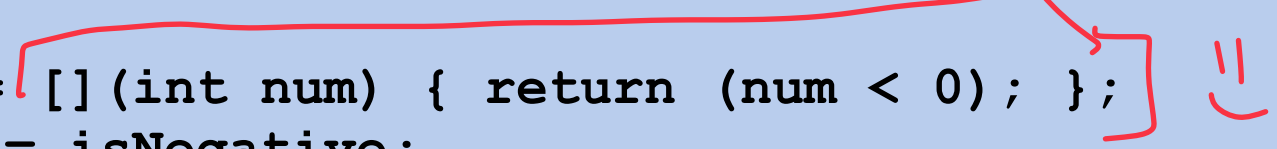
count # times pred is true

Lambda Functions in C++

Here are several ways to write a function as an object

main.cpp

```
1  bool isNegative(int num) { return (num < 0); }
2
3  class IsNegative {
4  public:
5      bool operator() (int num) { return (num < 0); }
6  };
7
8  int main() {
9    std::vector<int> numbers = {1, 102, 105, 4, 5, 27, 41, -7, 999};
10
11   auto isnegl = [](int num) { return (num < 0); };
12   auto isnegfp = isNegative;
13   auto isnegfunctor = IsNegative();
14
15   cout << "There are " << Countif(numbers.begin(), numbers.end(), _______)
16     << " negative numbers" << std::endl;
17
```



Lambda Functions in C++

[ ] ( ) { }

[Capture](Arg List){ Function Body}

Lambda Functions in C++

```
[Capture](Arg List){ Function Body}
```

Capture: Takes the value of object based on when the lambda was defined, NOT the current value of the object!

Arg List: Standard way of inputing into a function

Function Body: Code can use both capture vars and arg vars

Lambda Functions in C++

main.cpp

```
29    int big;
30    std::cout << "How big is big? ";
31    std::cin >> big;
32
33    auto isbig = [big](int num) { return (num >= big); };
34
35
36
37    std::cout << "There are " << Countif(numbers.begin(), numbers.end(), isbig)
38      << " big numbers" << std::endl;
}
```

Lambda Functions in C++

main.cpp

```
29    int big;
30    std::cout << "How big is big? ";
31    std::cin >> big;
32
33    auto isbig = [big](int num) { return (num >= big); };
34
35
36
37    std::cout << "There are " << Countif(numbers.begin(), numbers.end(), isbig)
38      << " big numbers" << std::endl;
      }
```

Useful for mp_mosaics!

KD-Tree will split points in one dimension

When comparing, we need to remember what dimension we are in!

Tips and Tricks for MP_Mosaics

Final tips:

The mp_mosaic writeup is long. **READ IT**

The suggestions in the writeup should be followed carefully

Summary of Balanced BST

Pros:

O(log N) for insert, find, remove

Optimal range queries in 1D

Cons:

O(log N) isn't that great

Large in-memory requirement

Considering hardware limitations

Can we always fit our data in main memory?

Where else can we keep our data?

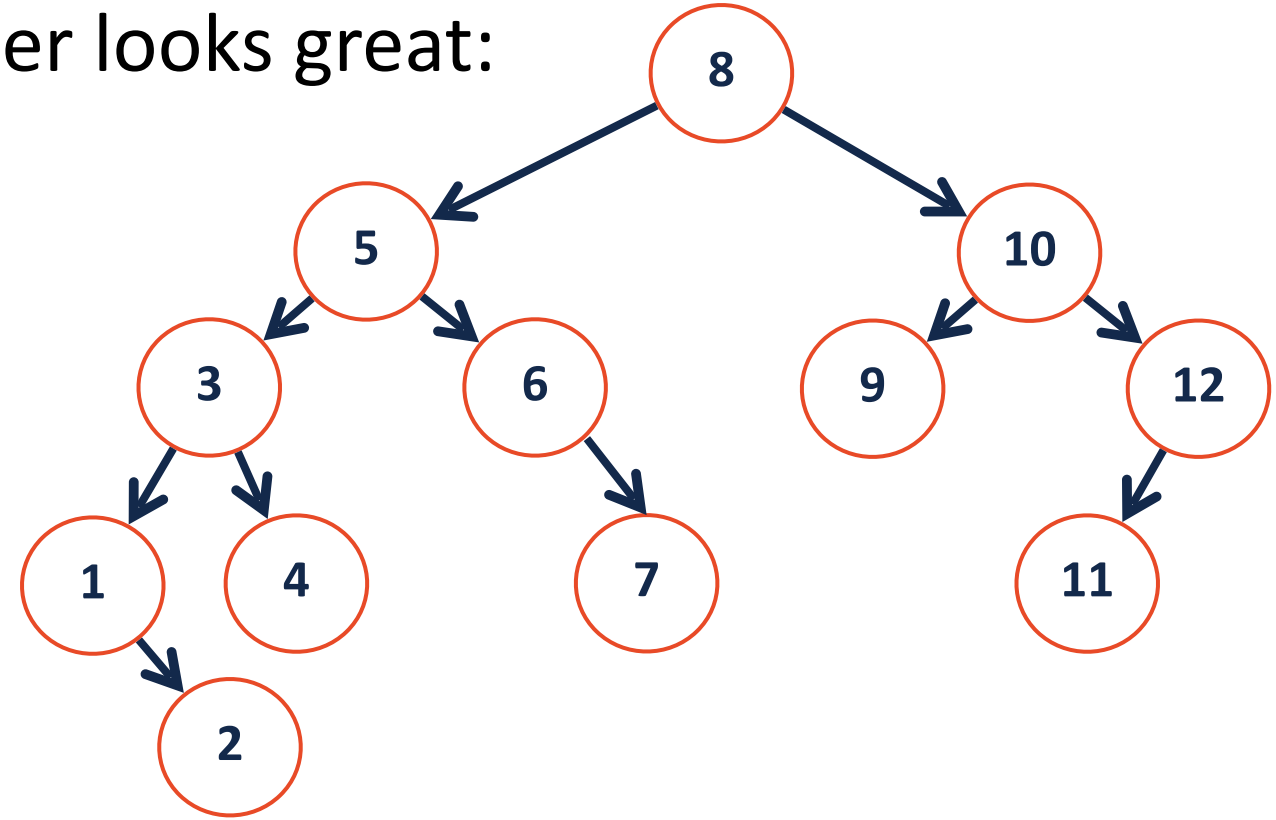
Does this match our assumption that all memory lookups are O(1)?

B-Tree Motivation

In Big-O we have assumed uniform time for all operations, but this isn't always true.

However, seeking data from the cloud may take 40ms+.

…an O(lg(n)) AVL tree no longer looks great:



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