## #21: AVL Applications

October 15, 2018 · *Wade Fagen-Ulmschneider*

### AVL – Proof of Runtime

On Friday, we proved an upper-bound on the height of an AVL tree is **2*lg(n)** or **O( lg(n) )**.

| AVL Trees | Red-Black Trees |
|---|---|
| Balanced BST<br><br>Max height: 1.44 * lg(n)<br>*Q: Why is our proof 2*lg(n)?*<br><br>Rotations:<br>- find:<br><br>- insert:<br><br>- remove: | Balanced BST<br>*Functionally equivalent to AVL trees; all key operations runs in O(h) time.*<br><br>Max height: 2 * lg(n)<br><br>Rotations:<br>- find:<br><br>- insert:<br><br>- remove: |

*In CS 225, we learned **AVL trees** because they're intuitive and I'm certain we could have derived them ourselves given enough time. A red-black tree is simply another form of a balanced BST that is also commonly used.*

### Summary of Balanced BSTs:

*(Includes both AVL and Red-Black Trees)*

| Advantages | Disadvantages |
|---|---|
| | |

### Using a Red-Black Tree in C++

C++ provides us a balanced BST as part of the standard library:

```
std::map<K, V> map;
```

The map implements a dictionary ADT. Primary means of access is through the overloaded `operator[]`:

```
V & std::map<K, V>::operator[]( const K & )
```

*This function can be used for both insert and find!*

Removing an element:

```
void std::map<K, V>::erase( const K & );
```

Range-based searching:

```
iterator std::map<K, V>::lower_bound( const K & );
iterator std::map<K, V>::upper_bound( const K & );
```

### Iterators and MP4

Three weeks ago, you saw that you can use an iterator to loop through data:

```
DFS dfs(...);
for ( ImageTraversal::Iterator it = dfs.begin();
      it != dfs.end(); ++it ) {
  std::cout << (*it) << std::endl;
}
```

You will use iterators extensively in MP4, creating them in Part 1 and then utilizing them in Part 2. Given the iterator, you can use the for-each syntax available to you in C++:

```
DFS dfs(...);
for ( const Point & p : dfs ) {
  std::cout << p << std::endl;
}
```

The exact code you might use will have a generic `ImageTraversal`:

```
ImageTraversal & traversal = /* ... */;
for ( const Point & p : traversal ) {
  std::cout << p << std::endl;
}
```

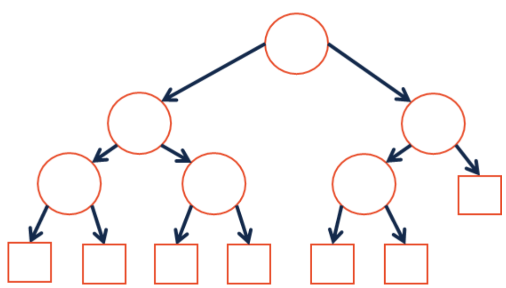
**Running Time of Every Data Structure So Far:**

| | Unsorted Array | Sorted Array | Unsorted List | Sorted List |
|---|---|---|---|---|
| **Find** | | | | |
| **Insert** | | | | |
| **Remove** | | | | |
| **Traverse** | | | | |

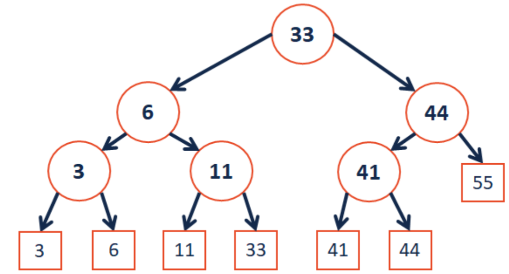
| | Binary Tree | BST | AVL |
|---|---|---|---|
| **Find** | | | |
| **Insert** | | | |
| **Remove** | | | |
| **Traverse** | | | |

**Range-based Searches:**
Q: Consider points in 1D: p = {$p_1, p_2, \ldots, p_n$}.
...what points fall in [11, 42]?


**Tree Construction:**

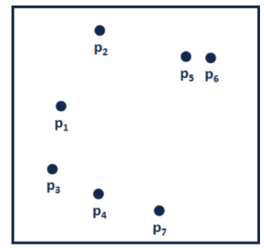


**Range-based Searches:**



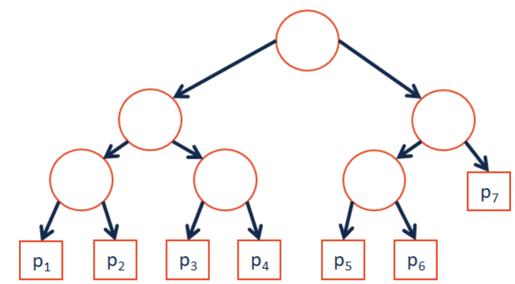

**Running Time:**

**Extending to k-dimensions:**
Consider points in 2D: **p = {$p_1, p_2, \ldots, p_n$}:**




...what points are inside a range (rectangle)?
...what is the nearest point to a query point **q**?

**Tree Construction:**




| CS 225 – Things To Be Doing: |
|---|
| **1.** Programming Exam B starts in 10 days *(grab your time slot!)* |
| **2.** MP4 extra credit +7 due tonight |
| **3.** lab_avl released this week; details on Wednesday |
| **4.** Daily POTDs are ongoing! |