CSCI 104
C++ STL; Iterators, Maps, Sets

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Container Classes

- ArrayLists, LinkedList, Deques, etc. are classes used simply for storing (or contain) other items
- C++ Standard Template Library provides implementations of all of these containers
  - DynamicArrayList => C++: std::vector<T>
  - LinkedList => C++: std::list<T>
  - Deques => C++: std::deque<T>
  - Sets => C++: std::set<T>
  - Maps => C++: std::map<K,V>
- Question:
  - Consider the get() method. What is its time complexity for…
  - ArrayList => O(____)
  - LinkedList => O(____)
  - Deques => O(____)

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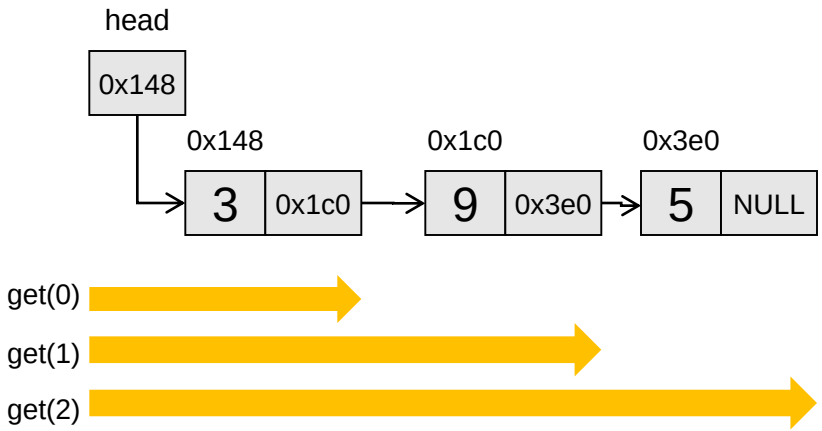
  - Deques => C++: std::deque<T>
  - Sets => C++: std::set<T>
  - Maps => C++: std::map<K,V>
- Question:
  - Consider the at() method. What is its time complexity for…
  - ArrayList => O(1) // contiguous memory, so just go to location
  - LinkedList => O(n) // must traverse the list to location i
  - Deques => O(1)

Iteration

- Consider how you iterate over all the elements in a list
  - Use a for loop and get() or operator[]
- For an array list this is fine since each call to at() is O(1)
- For a linked list, calling get(i) requires taking i steps through the linked list
  - 0^{th} call = 0 steps
  - 1^{st} call = 1 step
  - 2^{nd} call = 2 steps
  - $0+1+2+\ldots+n-2+n-1 = O(n^2)$
- You are re-walking over the linked list a lot of the time

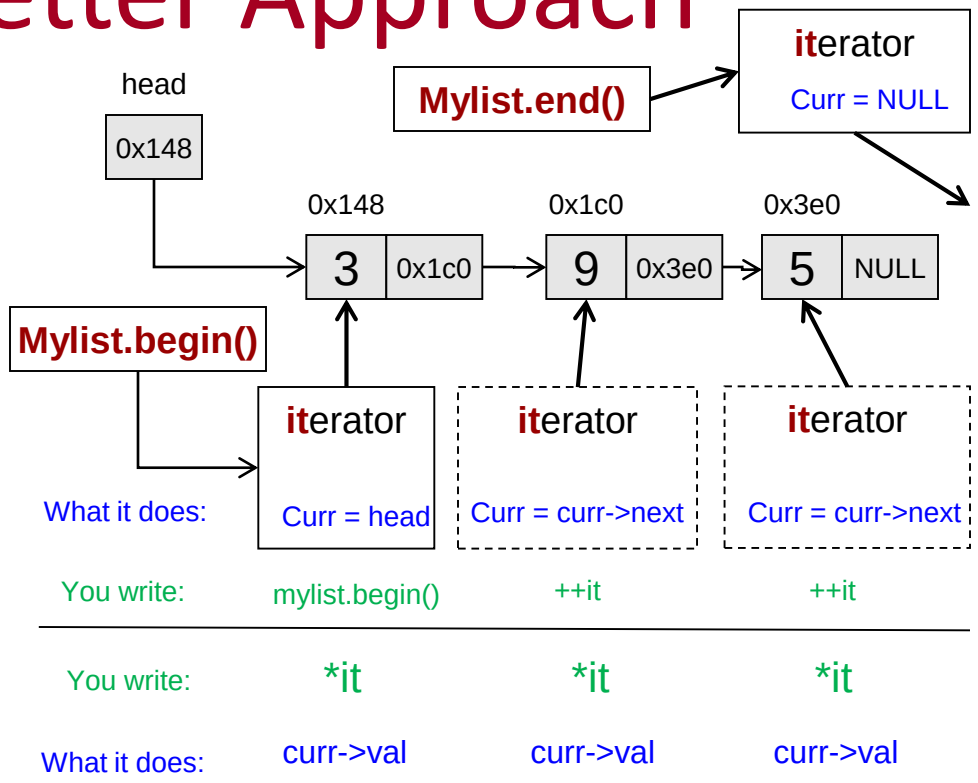
```
ArrayList<int> mylist;
...
for(int i=0; i < mylist.size(); ++i)
{
  cout << mylist.get(i) << endl;
}
```

```
LinkedList<int> mylist;
...
for(int i=0; i < mylist.size(); ++i)
{
  cout << mylist.get(i) << endl;
}
```



Iteration: A Better Approach

- Solution: Don't use get()
- Use an **iterator**
  - an internal state variable (i.e. another pointer) of the class that moves one step in the list at a time as you iterate
- Iterator tracks the internal location of each successive item
- Iterators provide the semantics of a pointer (they look, smell, and act like a pointer to the values in the list
- Assume
  - Mylist.begin() returns an "iterator" to the beginning item
  - Mylist.end() returns an iterator "one-beyond" the last item
  - ++it (preferred) or it++ moves iterator on to the next value




```
LinkedList<int> mylist;
...
iterator it = mylist.begin()
for(it = mylist.begin();
    it !=  mylist.end();
    ++it)
{
  cout << *it << endl;
}
```

Iterators

- A function like 'at' or 'get' gives the programmer the appearance that items are located contiguously in memory (like an array) though in implementation they may not
- Vectors and deques allow us to use array-like indexing (‘myvec[i]’) and finds the correct data “behind-the-scenes”
- To iterate over the whole set of items we could use a counter variable and the array indexing (‘myvec[i]’), but it can be more efficient (based on how STL is actually implemented) to keep an ‘internal’ pointer to the next item and update it appropriately
- C++ STL containers define ‘helper’ classes called **iterators** that help iterate over each item or find an item in the container

Iterators

- Iterators are a new class type defined **in the scope of each container**
  - Type is ***container*::iterator** (vector<int>::iterator is a type)
- Initialize them with *objname*.begin(), check whether they are finished by comparing with *objname*.end(), and move to the next item with ++ operator

```
#include <iostream>
#include <vector>

using namespace std;

int main()
{
  vector<int> my_vec(5); // 5 = init. size
  for(int i=0; i < 5; i++){
    my_vec.push_back(i+50);
  }
  vector<int>::iterator it;
  for(it = my_vec.begin() ; it != my_vec.end(); ++it){
    ...
  }
```

```
// vector.h

template<class T>
class vector
{
  class iterator {

  }

};
```

Iterators

- Iterator variable has same semantics as a pointer to an item in the container
  - Use * to 'dereference' and get the actual item
  - Since you're storing integers in the vector below, the iterator acts and looks like an **int***

```
#include <iostream>
#include <vector>

using namespace std;

int main()
{
  vector<int> my_vec(5); // 5 = init. size
  for(int i=0; i < 5; i++){
    my_vec.push_back(i+50);
  }

  for(vector<int>::iterator it = my_vec.begin() ; it != my_vec.end(); ++it){
    cout << *it;

  }
  cout << endl;
  return 0;
}
```

Iterator Tips

- Think of an iterator variable as a ‘pointer’…when you declare it, it points at nothing
- Think of begin() as returning the address of the first item and assigning that to the iterator
- Think of end() as returning the address AFTER the last item (i.e. off the end of the collection or maybe NULL) so that as long as the iterator is less than or not equal, you are safe

C++ STL Algorithms

- Many useful functions defined in <algorithm> library
  - http://www.cplusplus.com/reference/algorithm/sort/
  - http://www.cplusplus.com/reference/algorithm/count/
- All of these functions usually accept iterator(s) to elements in a container

```
#include <iostream>
#include <vector>
#include <cstdlib>
#include <algorithm>
using namespace std;

int main()
{
  vector<int> my_vec(5); // 5 = init. size
  for(int i=0; i < 5; i++){
    my_vec.push_back(rand());
  }
  sort(my_vec.begin(), my_vec.end());
  for(vector<int>::iterator it = my_vec.begin() ; it != my_vec.end(); ++it){
    cout << (*it);

  }
  cout << endl;
  return 0;
}
```

Maps (a.k.a. Dictionaries or Ordered Hashes)

ASSOCIATIVE CONTAINERS

Student Class

```
class Student {
 public:
  Student();
  Student(string myname, int myid);
  ~Student();
  string get_name() { return name; } // get their name
  void add_grade(int score);  // add a grade to their grade list
  int get_grade(int index);   // get their i-th grade
 private:
  string name;
  int id;
  vector<int> grades;
};
```

Creating a List of Students

- How should I store multiple students?
  - Array, Vector, Deque?
- It depends on what we want to do with the student objects and ***HOW we want to access them***
  - Just iterate over all students all the time (i.e. add a test score for all students, find test average over all students, etc.) then use an array or vector
  - If we want to access random (individual) students a lot, this will require searching and finding them in the array/vector…computationally expensive!
  - **O(n) [linear search] or O(log n) [binary search] to find student or test membership**

```
#include <vector>
#include "student.h"
using namespace std;

int main()
{
  vector<student> slist1;
  ...

  unsigned int i;

  // compute average of 0-th score
  double avg = 0;
  for(i=0; i< slist1.size(); i++){
    avg += slist1[i].get_score(0);
  }
  avg = avg / slize1.size();

  // check "Tommy"s score
  int tommy_score= -1;
  for(i=0; i < slist1.size(); i++){
    if(slist1[i].get_name() == "Tommy"){
       tommy_score = slist1[i].get_score(2);
       break;
    }
  }
  cout<< "Tommy's score is: " <<
          tommy_score << endl;
}
```

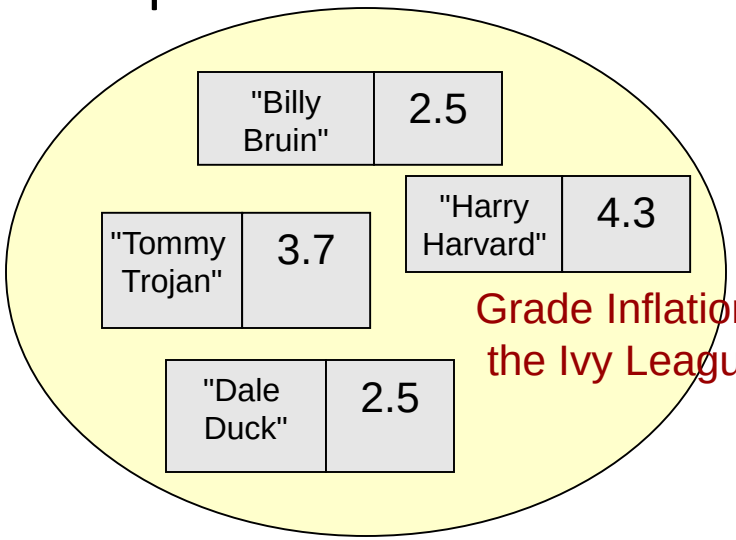
Index and Data Relationships

- Arrays and vectors are indexed with integers 0…N-1 and have no relation to the data
- Could we some how index our data with a meaningful values
  - slist1[“Tommy”].get_score(2)
- YES!!! Associative Containers

```
#include <vector>
#include “student.h”
using namespace std;

int main()
{
  vector<student> slist1;
  ...

  unsigned int i;

  // compute average of 0-th score
  double avg = 0;
  for(i=0; i< slist1.size(); i++){
    avg += slist1[i].get_score(0);
  }
  avg = avg / slize1.size();

  // check “Tommy”s score
  int tommy_score= -1;
  for(i=0; i < slist1.size(); i++){
    if(slist1[i].get_name() == “Tommy”){
       tommy_score = slist1[i].get_score(2);
       break;
    }
  }
  cout<< “Tommy’s score is: “ <<
          tommy_score << endl;
}
```

Maps / Dictionaries

- Stores key,value pairs
  - Example: Map student names to their GPA
- Keys must be unique (can only occur once in the structure)
- No constraints on the values
- No inherent ordering between key,value pairs
  - Can't ask for the 0^{th} item…
- Operations:
  - Insert
  - Remove
  - Find/Lookup



C++ Pair Struct/Class

- C++ library defines a struct 'pair' that is templatized to hold two values (first and second) of different types
  - Types are provided by the template
- C++ map class internally stores its key/values in these ***pair*** objects
- Defined in 'utility' header but if you #include <map> you don't have to include utility
- Can declare a pair as seen in option 1 or call library function "make_pair" to do it

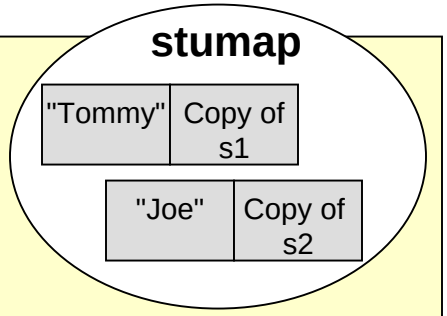
```
template <class T1, class T2>
struct pair {
  T1 first;
  T2 second;
}
```

```
#include <iostream>
#include <utility>
#include <string>
using namespace std;

void func_with_pair_arg(pair<char,double> p)
{   cout << p.first << " " << p.second <<endl;  }

int main()
{
  string mystr = "Bill";
  pair<string, int> p1(mystr, 1);
  cout << p1.first << " " << p1.second <<endl;

  // Option 1: Anonymous pair constructed and passed
  func_with_pair_arg( pair<char,double>('c', 2.3) );

  // Option 2: Same thing as above but w/ less typing
  func_with_pair_arg( make_pair('c', 2.3) );
}
```

```
Bill 1
c  2.3
c  2.3
```

Associative Containers

- C++ STL 'map' class can be used for this purpose
- Maps store (key,value) pairs where:
  - key = index/label to access the associated value
  - Stored value is a copy of actual data
- Other languages refer to these as 'hashes' or 'dictionaries'
- Keys must be unique
  - Just as indexes were unique in an array or list
- Value type should have a default constructor [i.e. Student()]
- Key type must have less-than (<) operator defined for it
  - Use C++ string rather than char array
- **Efficient at finding specified key/value and testing membership ($O(\log_2 n)$)**




```
#include <map>
#include "student.h"
using namespace std;

int main()
{
  map<string,Student> stumap;
  Student s1("Tommy",86328);
  Student s2("Joe",54982);
  ...
  // Option 1:  this will insert an object
  stumap[ "Tommy" ] = s1;
  // Option 2:  using insert()
  stumap.insert( pair<string,Student>("Joe", s2));
  // or stumap.insert( make_pair("Joe", s2) );
  ...
  int tommy_score=stumap["Tommy"].get_score(1);
```

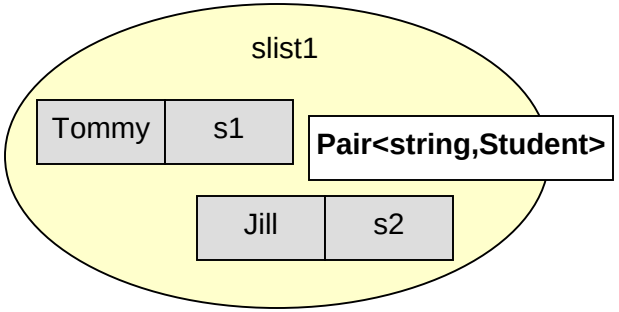
Returns 'Copy of s1' and then you can call Student member functions

```
  stumap.erase( "Joe" );
  cout << "Joe dropped the course..Erased!";
  cout << endl;
}
```

slist1 is a map that associates C++ strings (keys) with Student objects (values)

Maps & Iterators

- Can still iterate over all elements in the map using an iterator object for that map type
- Iterator is a "pointer"/iterator to a pair struct
  - it->first is the key
  - it->second is the value




```
#include <map>
#include "student.h"
using namespace std;

int main()
{
  map<string,student> slist1;
  Student s1("Tommy",86328);
  Student s2("Jill",54982);
  ...
  slist1["Tommy"] = s1;
  slist1[s1.get_name()].add_grade(85);

  slist1["Jill"] = s2
  slist1["Jill"].add_grade(93);
  ...

  map<string,student>::iterator it;
  for(it = slist1.begin(); it!= slist1.end(); ++it){
    cout << "Name/key is " << it->first;
    cout << " and their 0th score is ";
    cout << (it->second).get_score(0);
  }
}
```

Name/key is Tommy and their 0th score is 85
Name/key is Jill and their 0th score is 93

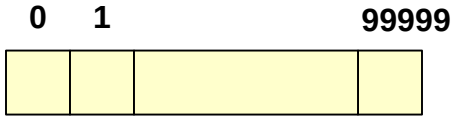
Map Membership [Find()]

- Check/search whether key is in the map object using *find()* function
- Pass a key as an argument
- Find returns an iterator
- If key is IN the map
  - Returns an iterator/pointer to that (key,value) pair
- If key is NOT IN the map
  - Returns an iterator equal to *end()'s* return value

```
#include <map>
#include "student.h"
using namespace std;

int main()
{
  map<string,student> slist1;
  Student s1("Tommy",86328);
  Student s2("Bill",14259);

  slist1["Tommy"] = s1;     // Insert an item
  slist1["Tommy"].add_grade(85);  // Access it


  if(slist1.find("Bill") != slist1.end() ){
    cout << "Bill exists!" << endl;
  }
  else {
    cout << "Bill does not exist" << endl;
    slist1["Bill"] = s2;  // So now add him
  }

  map<string,student>::iterator it = slist1.find(name);
  if( it != slist1.end() ){
    cout << it->first << " got score=" <<
            it->second.get_grade(0) << endl;
  }
}
```

Another User of Maps: Sparse Arrays

- Sparse Array: One where there is a large range of possible indices but only small fraction will be used (e.g. are non-zero, etc.)
- Example 1: Using student ID's to represent students in a course (large 10-digit range, but only 30-40 used)
- Example 2: Count occurrences of zip codes in a user database
  - Option 1: Declare an array of 100,000 elements (00000-99999)
    - Wasteful!!
  - Option 2: Use a map
    - Key = zipcode, Value = occurrences



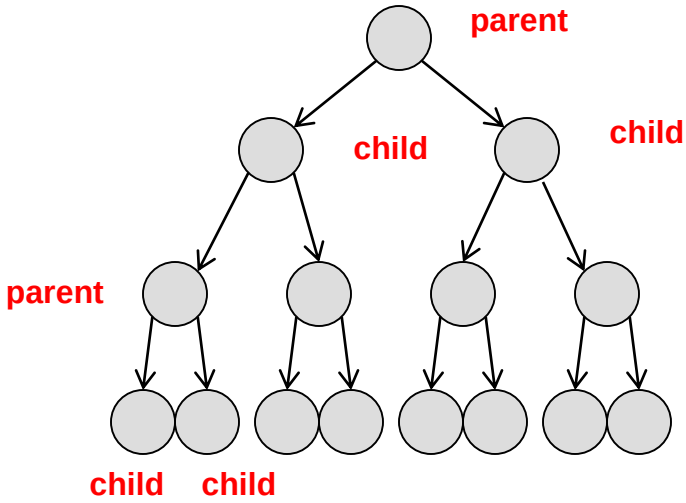
Set Class

- C++ STL "set" class is like a list but each value **can appear just once**
- Think of it as a map that stores just keys (no associated value)
- Keys are unique
- insert() to add a key to the set
- erase() to remove a key from the set
- Very efficient at testing membership (**$O(\log_2 n)$**)
  - Is a specific key in the set or not!
- Key type must have a less-than (<) operator defined for it
  - Use C++ string rather than char array
- Iterators to iterate over all elements in the set
- find() to test membership

```
#include <set>
#include <string>
using namespace std;

int main()
{
  set<string> people;

  people.insert("Tommy");
  string myname = "Jill";
  people.insert(myname);
  people.insert("Johnny");

  for(set<string>::iterator it=people.begin();
      it != people.end();
      ++it){
    cout << "Person: " << *it << endl;
  }
  myname = "Tommy";
  if(people.find(myname) != people.end()){
    cout<< "Tommy is a CS or CECS major!" << endl;
  }
  else {
    cout<< "Tommy is the wrong major!" << endl;
  }
  myname = "Johnny";
  people.erase("Johnny");
}
```

A Deeper Look: Binary Tree

- Data structure where each node has at most 2 children (no loops/cycles in the graph) and at most one parent
- Tree nodes w/o children are called "leaf" nodes
- Depth of binary tree storing N elements? _____



A Deeper Look: Binary Tree

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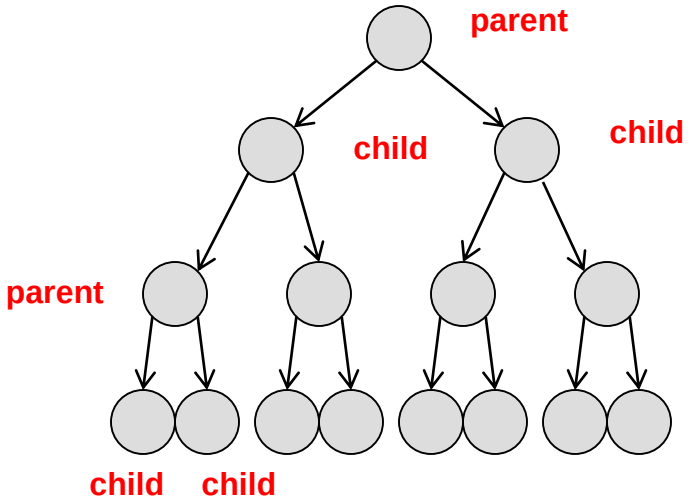
- Tree nodes w/o children are called "leaf" nodes
- Depth of binary tree storing N elements? $\log_2 n$



Binary Search Tree

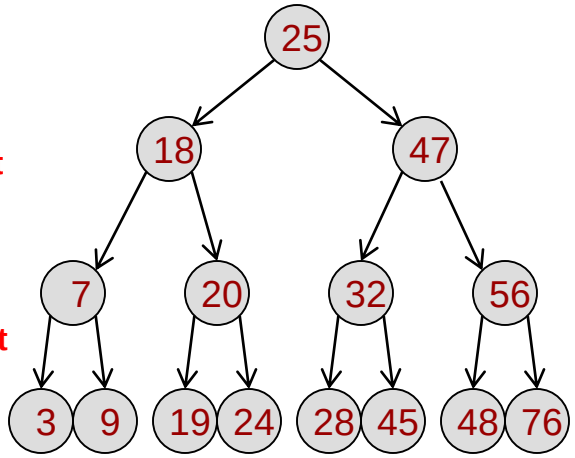
- Tree where all nodes meet the property that:
  - All descendants on the left are less than the parent's value
  - All descendants on the right are greater than the parent's value
- Can find value (or determine it doesn't exit) in log2n time by doing binary search

Q: is 19 in the tree?

19 < 25..left

19 > 18..right

19 < 20..left



Q: is 34 in the tree?

34 > 25..right

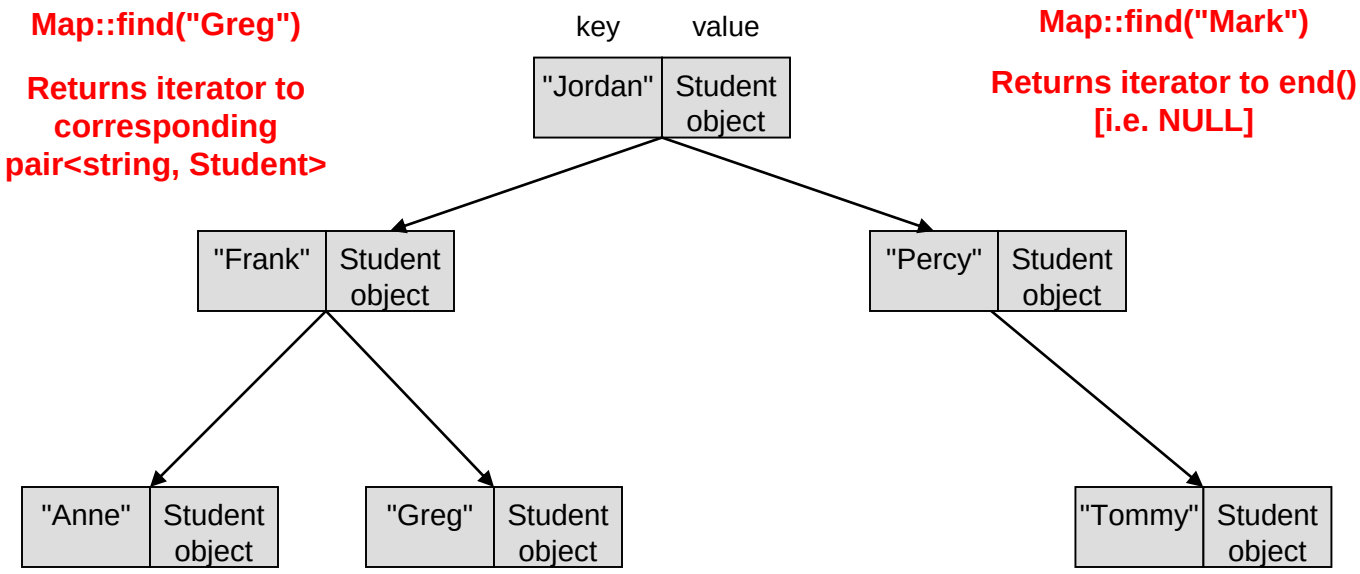
34<47..left

34>32..right

34 != 45 and we're at a leaf node...34 does not exist

Trees & Maps/Sets

- Maps and sets use binary trees internally to store the keys
- This allows logarithmic find/membership test time
- This is why the less-than (<) operator needs to be defined for the data type of the key



Exercise

- Practice using iterators and a map
- $ wget http://ee.usc.edu/~redekopp/cs104/zipmap.tar
- $ tar xvf zipmap.tar
- Edit map_zip.cpp and view the data file zipcodes.txt
  - We have written code to read in all the zipcodes in zipcodes.txt into a vector 'all_zips'
  - Iterate through the zipcodes in 'all_zips' using an **iterator**
  - Create (insert the first time, increment remaining times) a map that stores zip codes as the keys and the number of occurrences as the value
  - The code at the bottom will iterate through your map and print out your results so you can check your work
- Bonus: Lookup the std::algorithm library
  - Look at 'count()' and 'sort()' and see if you can use them to sort the all_zips vector data or count the occurrences of a particular zip code in all_zips (rather than using the map)