Porter Scobey

http://cs.stmarys.ca/~porter/csc/ref/stl/index_algorithms.html

Stanford 106L, Standard C++ Programming Laboratory

http://web.stanford.edu/class/cs106l/

topcoder's tutorial, Power up C++ with the STL, part I and II

https://www.topcoder.com/community/data-science/data-science-tutorials/power-up-c-with-the-standard-template-library-part-1/

STL Algorithms

<algorithm>, <numeric>, <iterator>, <functional>
<cctype>, <cmath>

C++, a multi-paradigm programming language,
besides being procedural and object-oriented,
is very much ***functional*** with STL

Pei-yih Ting
NTOU CS

Contents

Abstract away some chores

data.txt

```
100
95
92
89
100
...
```

Average = …

Abstract away some chores

Commonly seen procedural piece of codes

low-level mechanical steps

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using namespace std;
int main() {
   ifstream input("data.txt");
   multiset<int> values;

   int currValue;
   while (input >> currValue)
      values.insert(currValue);

   double total = 0.;
   for (multiset<int>::iterator itr = values.begin(); itr != values.end(); ++itr)
      total += *itr;

   cout << "Average = " << total / values.size() << endl;
   return 0;
}
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   copy(istream_iterator<int>(input), istream_iterator<int>(),
         inserter(values, values.begin()));
```

<algorithm>

Average = …

❷ Add the values together

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Functional abstraction

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   copy(istream_iterator<int>(input), istream_iterator<int>(),
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```

map <algorithm>

```
   double total = accumulate(values.begin(), values.end(), 0.0);
```

reduce <numeric>

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- **Functional and Object-oriented styles are not easy to combine.**
- Bjarne Stroustrup's: C++ was designed to allow programmers to **switch** between paradigms as needed. The language is not designed to make it easy for combining different paradigms. Most of Stroustrup's examples regarding OOP touch the STL very little. He creates very distinct layers.

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customized with callable objects
(functions and functors)

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- accumulate is a general-purpose function for **transforming a collection of elements into a single value** (in functional language terms: reduce / collect / convert / join / fold)

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```
int findLess(int smallestSoFar, int current) {
    return current < smallestSoFar ? current : smallestSoFar;   }
int smallest = accumulate(values.begin(), values.end(),
                    <limits>       numeric_limits<int>::max(), findLess);
```

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- **Clarity**:

  With a customized for loop, you would have to read each line in the loop before you understood what the code did.

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  require a predicate function: accepts an element and returns a bool
  e.g. bool **isEven**(int value) { return value %2 == 0; }
  cout << **count_if**(myVec.begin(), myVec.end(), **isEven**);

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- **xxx_n** (generate_n, search_n, …): performs a certain operation n times (on n elements in the container)

  e.g. **fill_n**(myDeque.begin(), 10, 0);

  Two consecutive 3

  vector<int>::iterator it=**search_n**(myV.begin(), myV.end(), 2, 3);

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  If an algorithm demands an Input iterator, it guarantees that the container pointed by the Input iterator is read-only by this algorithm.

Iterator Categories (cont'd)

Input Iterators

```
val = *itr;
++itr;
```

Iterator Categories (cont'd)

Input Iterators	**Output Iterators**
val = *itr; ++itr;	*itr = val; ++itr;

Iterator Categories (cont'd)

Forward Iterators

Input Iterators

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Random-Access Iterators

itr + distance;
itr += distance; std::advance(itr, distance);
itr1 < itr2; std::distance(itr1, itr2); itr2 - itr1;
itr[myIndex]; *(itr + myIndex);

Bidirectional Iterators

--itr;

Forward Iterators

Input Iterators

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Output Iterators

*itr = val;
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Reordering Algorithms

- **sort** // random-access iterators
  - **sort(myVector.begin(), myVector.end());**

    // i.e. vector or deque only, cannot sort list, set or map

    // each element must provide **operator<** or **comparison function**
  - ex.bool compStrLen(const string &one, const string &two) { // or pass by value

    ```
        return one.length() < two.length();
    }
    sort(myVector.begin(), myVector.end(), compStrLen);
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- **stable_sort, partial_sort, partial_sort_copy, is_sorted, nth_element**
- **partition** // bidirectional iterators
  - bool isOdd(int i) { return (i%2)==1; }
    vector<int> myvector;
    for (int i=1; i<10; ++i) myvector.push_back(i); // 1 2 3 4 5 6 7 8 9
    vector<int>::iterator bound =
    std::partition(myvector.begin(), myvector.end(), isOdd);

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- **stable_partition, is_partitioned**

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- **shuffle** (C++11) // random-access iterators
  - unsigned seed = std::chrono::system_clock::now().time_since_epoch().count();
    shuffle(myVec.begin(), myVec.end(), std::default_random_engine(seed));

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- **rotate** // forward iterators
  - **rotate(v.begin(), v.begin()+2, v.end());** // begin, middle, end
    // (0, 1, 2, 3, 4, 5) => (2, 3, 4, 5, 0, 1)

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  - unsigned seed = std::chrono::system_clock::now().time_since_epoch().count();
    shuffle(myVec.begin(), myVec.end(), std::default_random_engine(seed));
- **rotate** // forward iterators
  - **rotate(v.begin(), v.begin()+2, v.end());** // begin, middle, end
    // (0, 1, **2**, 3, 4, 5) => (2, 3, 4, 5, 0, 1)
- **next_permutation** // bidirectional iterators, operator<
  - int v[] = {1, 4, 2};
    next_permutation(v, v+3); // (1, 4, 2) => (2, 1, 4)

    find next with carry

Reordering Algorithms (cont'd)

- **reverse** // bidirectional iterators
  - **reverse(myVector.begin(), myVector.end());**
- **random_shuffle** // random-access iterators
  - **random_shuffle(myVector.begin(), myVector.end());**
- **shuffle** (C++11) // random-access iterators
  - unsigned seed = std::chrono::system_clock::now().time_since_epoch().count();
    shuffle(myVec.begin(), myVec.end(), std::default_random_engine(seed));
- **rotate** // forward iterators
  - **rotate(v.begin(), v.begin()+2, v.end());** // begin, middle, end
    // (0, 1, 2, 3, 4, 5) => (2, 3, 4, 5, 0, 1)
- **next_permutation** // bidirectional iterators, operator<
  - int v[] = {1, 4, 2};
    next_permutation(v, v+3); // (1, 4, 2) => (2, 1, 4)
    find next with carry
- **prev_permutation**

Other Utilities

- **min(a,b)**
  - return the smaller one of a and b
  - cout << **min(2,1)** << ' ' << **min(3.5, 2.1)** << ' ' << **min('d', 'b')**; //1 2.1 b

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- **max(a,b)**
- **min_element** // forward iterators, operator<
  - return the iterator of the smallest element in range [first, end)
  - ```
    bool myfn(int i, int j) { return i<j; }
    struct { bool operator() (int i,int j) { return i<j; } } myobj;
    int myints[] = {3,7,2,5,6,4,9};
    cout << *min_element(myints,myints+7); // 2, operator<
    cout << *min_element(myints,myints+7,myfn); // 2
    cout << *min_element(myints,myints+7,myobj); // 2
    ```
    ```

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    cout << ***min_element(myints,myints+7,myobj)**; // 2
- **max_element**
- **merge** // **sorted** range, input iterators, operator<
  - int a[] = {10,5,15,25,20}; int b[] = {50,40,30,20,10}; vector<int> c(10);
    sort(a, a+5); sort(b, b+5);
    merge(a, a+5, b, b+5, c.begin());

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  - int a[] = {10,5,15,25,20}; int b[] = {50,40,30,20,10}; vector<int> c(10);
    sort(a, a+5); sort(b, b+5);
    merge(a, a+5, b, b+5, c.begin());
- **inplace_merge(first, middle, last)** // bidirectional iterators
  // [first, middle) + [middle, last)
  // **sorted** ranges, operator<

Other Utilities (cont'd)

- **set_union**

- **set_intersection**

- **bitset**

Other Utilities (cont’d)

- **set_union** // union of 2 **sorted** ranges, input iterators, operator<
- **set_intersection**
- **bitset**

Other Utilities (cont'd)

- **set_union** // union of 2 **sorted** ranges, input iterators, operator<
  - return an output iterator that is the end of the constructed sorted ranges
  - int a[] = {10,5,15,25,20}; int b[] = {50,40,30,20,10}; vector<int> c(10);

    ```
    sort(a, a+5); sort(b, b+5);                 // 5 10 15 20 25 30 40 50 0 0
    vector<int>::iterator endIter = set_union(a, a+5, b, b+5, c.begin());
    cout << *(endIter-1) << endl; // 50
    c.resize(endIter-c.begin());     // 5 10 15 20 25 30 40 50
    ```
- **set_intersection**
- **bitset**

Other Utilities (cont'd)

- **set_union** // union of 2 **sorted** ranges, input iterators, operator<
  - return an output iterator that is the end of the constructed sorted ranges
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    int a[] = {10,5,15,25,20}; int b[] = {50,40,30,20,10}; vector<int> c(10);
    sort(a, a+5); sort(b, b+5);                    // 5 10 15 20 25 30 40 50 0 0
    vector<int>::iterator endIter = set_union(a, a+5, b, b+5, c.begin());
    cout << *(endIter-1) << endl; // 50
    c.resize(endIter-c.begin());    // 5 10 15 20 25 30 40 50
    ```
- **set_intersection** // intersection of 2 **sorted** ranges, input iterators, operator<
- **bitset**
    ```

Other Utilities (cont’d)

- **set_union** // union of 2 **sorted** ranges, input iterators, operator<
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    sort(a, a+5); sort(b, b+5); // 5 10 15 20 25 30 40 50 0 0
    vector<int>::iterator endIter = **set_union(a, a+5, b, b+5, c.begin());**
    cout << *(endIter-1) << endl; // 50
    c.resize(endIter-c.begin()); // 5 10 15 20 25 30 40 50
- **set_intersection** // intersection of 2 **sorted** ranges, input iterators, operator<
  - vector<int>::iterator endIter = **set_intersection(a, a+5, b, b+5, c.begin());**
    cout << *(endIter-1) << endl; // 20 // 10 20 0 0 0 0 0 0 0 0
    c.resize(endIter-c.begin()); // 10 20
- **bitset**

Other Utilities (cont'd)

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    cout << *(endIter-1) << endl; // 50
    c.resize(endIter-c.begin()); // 5 10 15 20 25 30 40 50
- **set_intersection** // intersection of 2 **sorted** ranges, input iterators, operator<
  - vector<int>::iterator endIter = **set_intersection(a, a+5, b, b+5, c.begin());**
    cout << *(endIter-1) << endl; // 20 // 10 20 0 0 0 0 0 0 0 0
    c.resize(endIter-c.begin()); // 10 20
- **bitset**
  - bitset<5> foo(string("01011"));
    foo[0] = 0; /* LSB 01010 */ foo[1] = foo[0]; /* 01000 */
    foo.flip(1); /* 01010 */ foo.flip(); /* 10101 */
    cout << foo << ' ' << boolalpha << foo.test(3) << ' ' << foo.count() // 10101 false 3

Max Heap

- Maintain a max heap in a vector or deque
  - creation (heapify): **make_heap** // random-access iterators, **operator<**
  - extract maximum: **pop_heap**
    - does not remove maximum element from the container
    - move the maximum to the end of the range, use v.pop_back() to remove it
    - does not return anything, use v.front() beforehand or use v.back() afterward
  - insert element: **push_heap**

    1. v.push_back() to append the element, 2. push_heap() to sift-up
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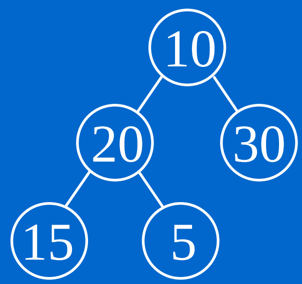
```
int myints[] = {10,20,30,15, 5};
vector<int> v(myints,myints+5);
```



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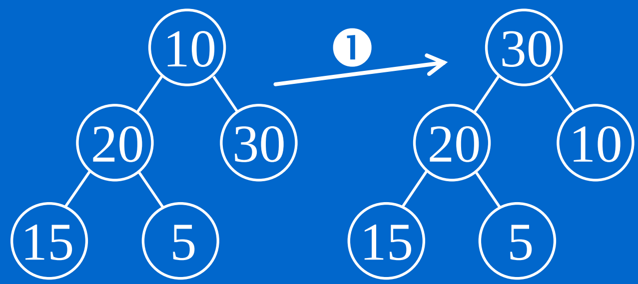
30 20 10 15 5




```
int myints[] = {10,20,30,15, 5};
vector<int> v(myints,myints+5);
❶ make_heap(v.begin(),v.end());
```

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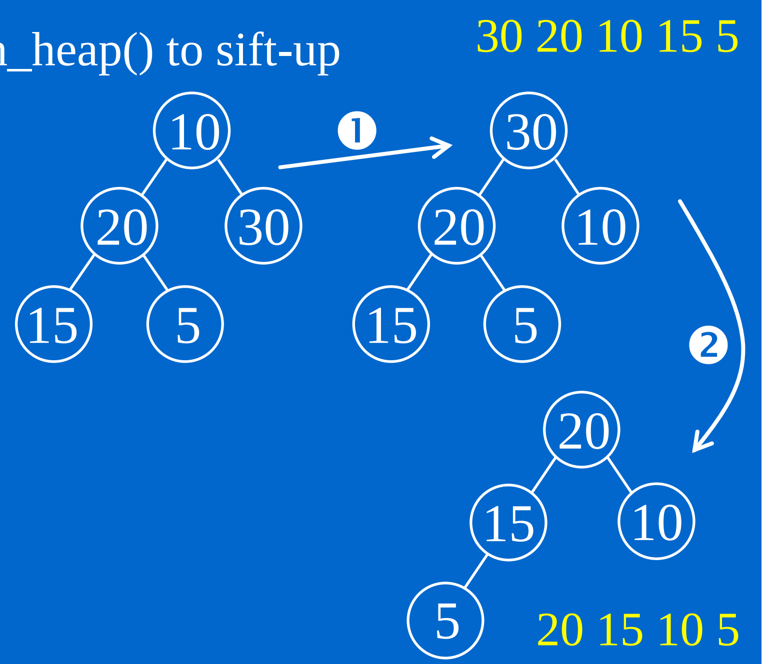
```
   int myints[] = {10,20,30,15, 5};
   vector<int> v(myints,myints+5);
❶ make_heap(v.begin(),v.end());
   cout << v.front() << endl; // 30
❷ pop_heap(v.begin(),v.end()); v.pop_back();
```



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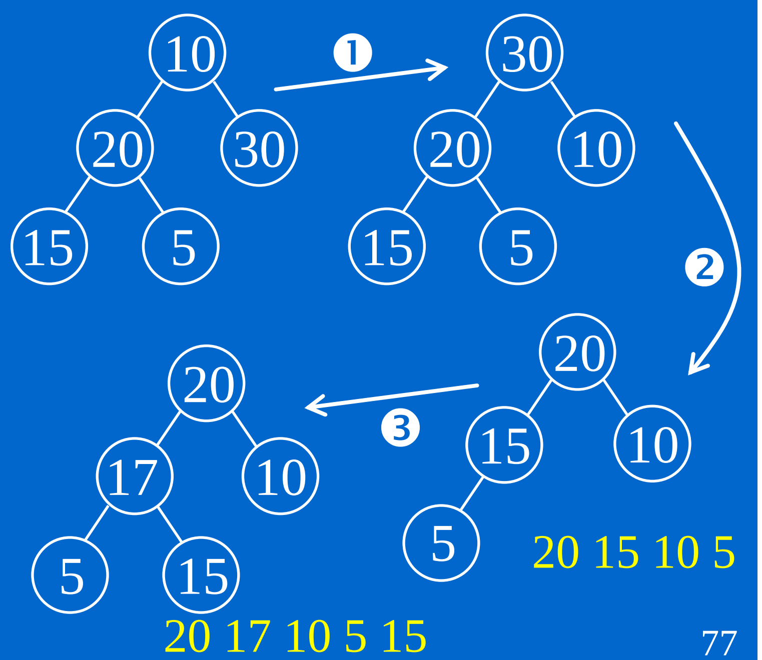
```
   int myints[] = {10,20,30,15, 5};
   vector<int> v(myints,myints+5);
❶ make_heap(v.begin(),v.end());
   cout << v.front() << endl; // 30
❷ pop_heap(v.begin(),v.end()); v.pop_back();
❸ v.push_back(17); push_heap(v.begin(),v.end())
```



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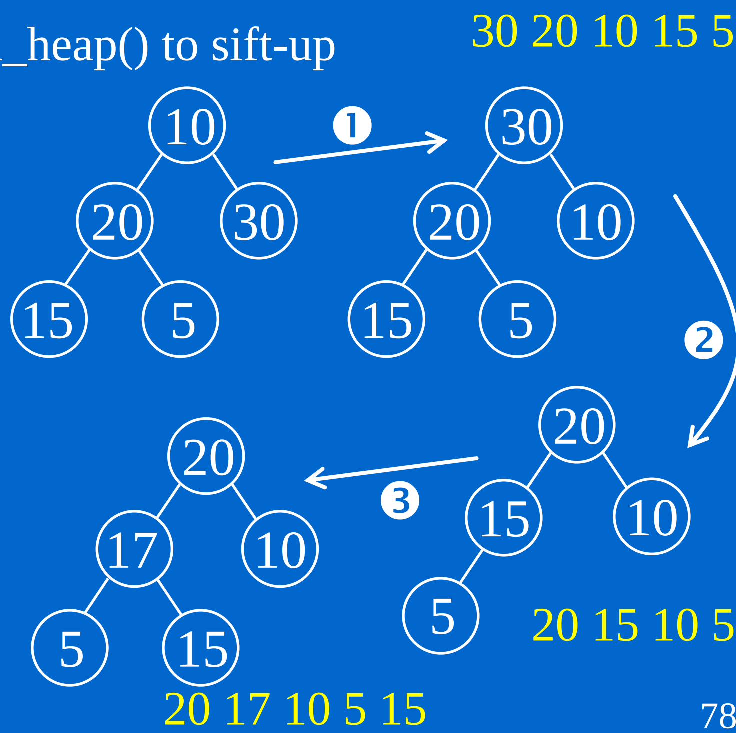
❷ pop_heap(v.begin(),v.end()); v.pop_back();
❸ v.push_back(17); push_heap(v.begin(),v.end())
   sort_heap(v.begin(),v.end());  // no longer a heap
```



Max Heap

```
#include <queue>
std::priority_queue<int>
push()
empty(), top(), pop()
```

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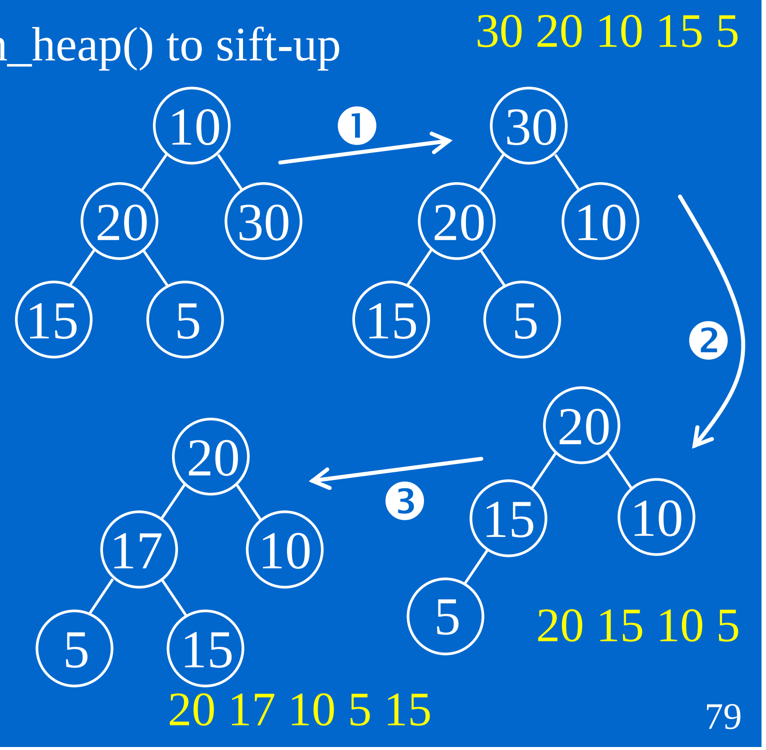

Searching Algorithms

- **InputItr find(InputItr first, InputItr last, const Type& value)**

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  - if (**find(myVec.begin(), myVec.end(), 137)** != myVec.end()) …

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  - return true if found; false otherwise

    if (**binary_search(myVec.begin(), myVec.end(), 137)**) … // found

Searching Algorithms (cont'd)

- **ForwardItr lower_bound(ForwardItr first, ForwardItr last, const Type& value)**

Searching Algorithms (cont'd)

- **ForwardItr lower_bound(ForwardItr first, ForwardItr last, const Type& value)**
  - Find the first element **x ≥ value** in the designated **sorted** range [**first**, **last**)

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- **ForwardItr lower_bound(ForwardItr first, ForwardItr last, const Type& value)**
  - Find the first element **x ≥ value** in the designated **sorted** range [**first**, **last**)
  - itr = **lower_bound(myVec.begin(), myVec.end(), 137);**

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  - return an iterator to the first element satisfying **x ≥ value**

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  - itr = **lower_bound(myVec.begin(), myVec.end(), 137);**
  - return an iterator to the first element satisfying **x ≥ value**
  - if (itr == last) … // all elements in [first, last) satisfy x < value
    else if (*itr == 137) … // 137 is found
    else … // *itr > 137

Searching Algorithms (cont'd)

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  - if (itr == last) …   // all elements in [first, last) satisfy x < value
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Searching Algorithms (cont'd)

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both algorithms are O(log n)

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    e.g. (1,**2**,3,**4**,5) includes (**2**,**4**)

Six Parts of STL

Containers

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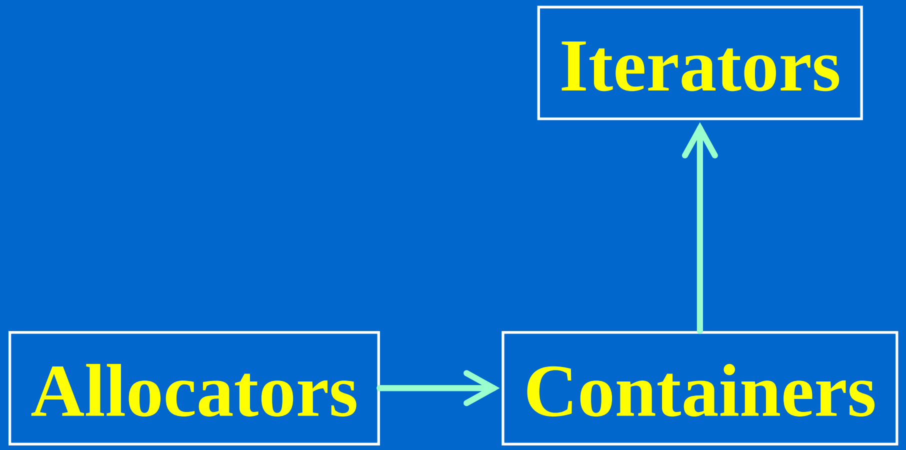

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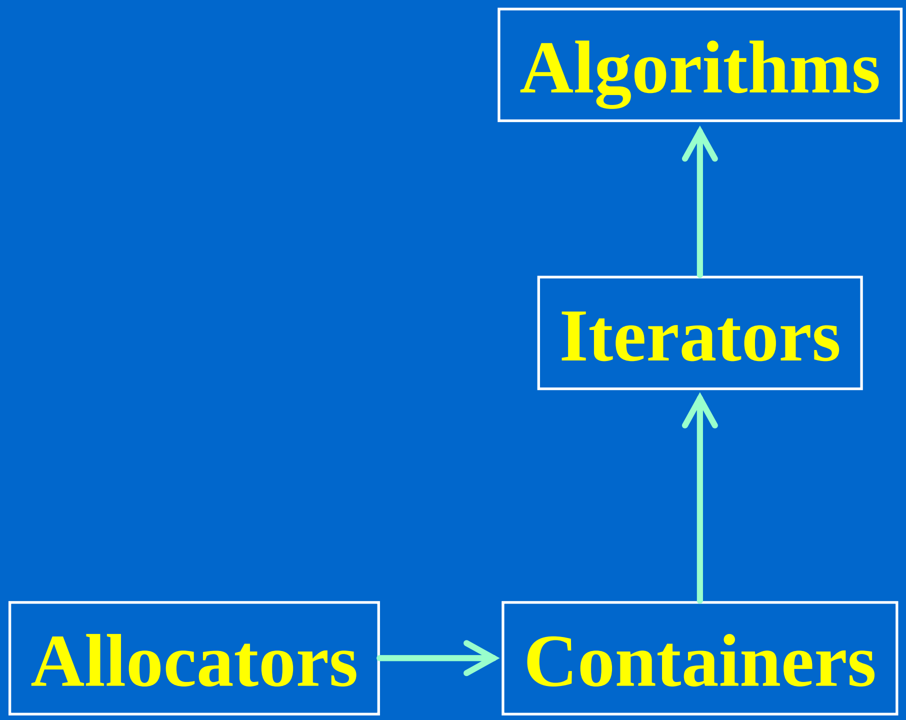

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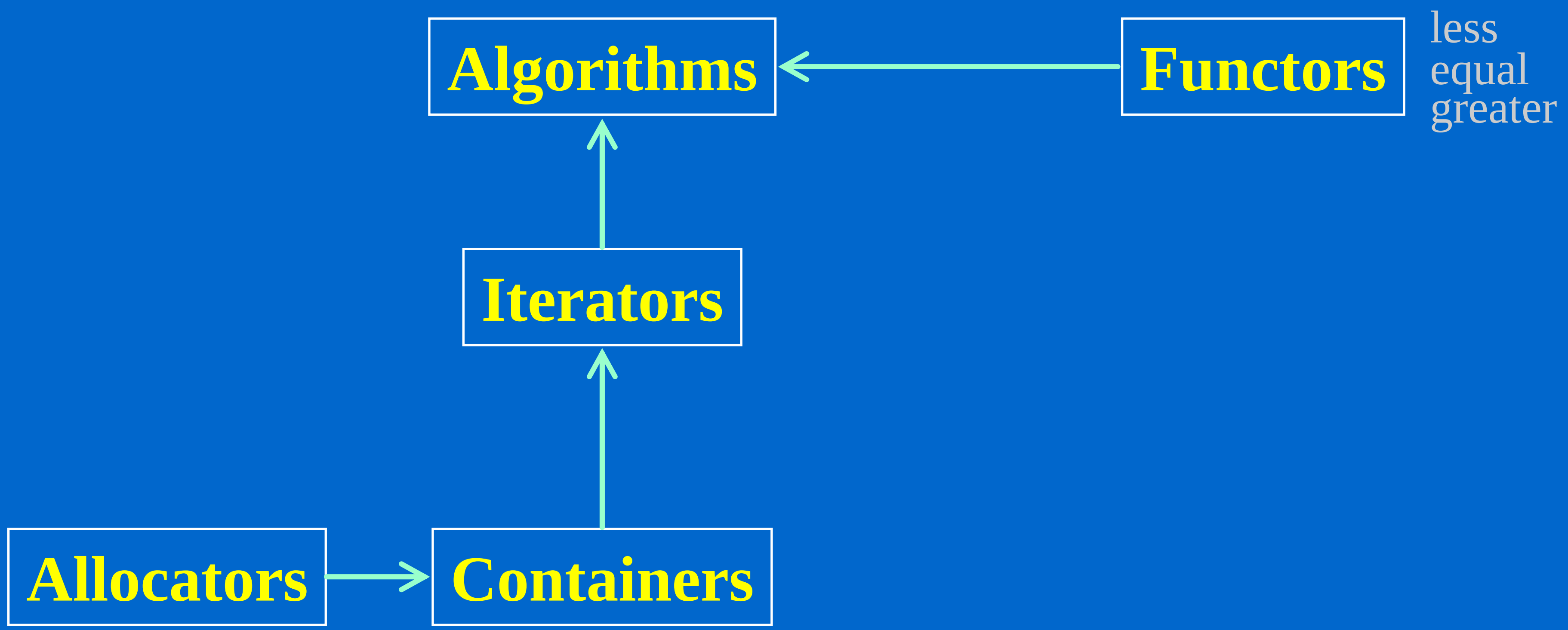

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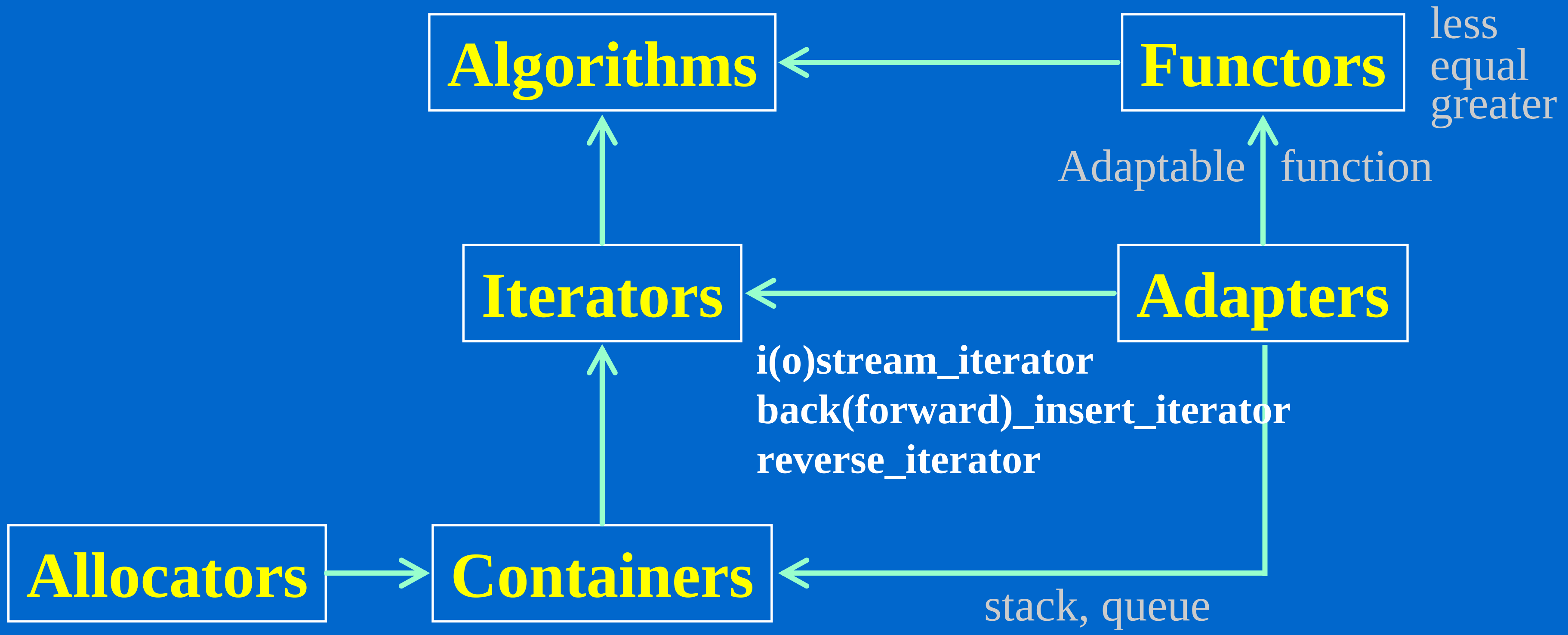

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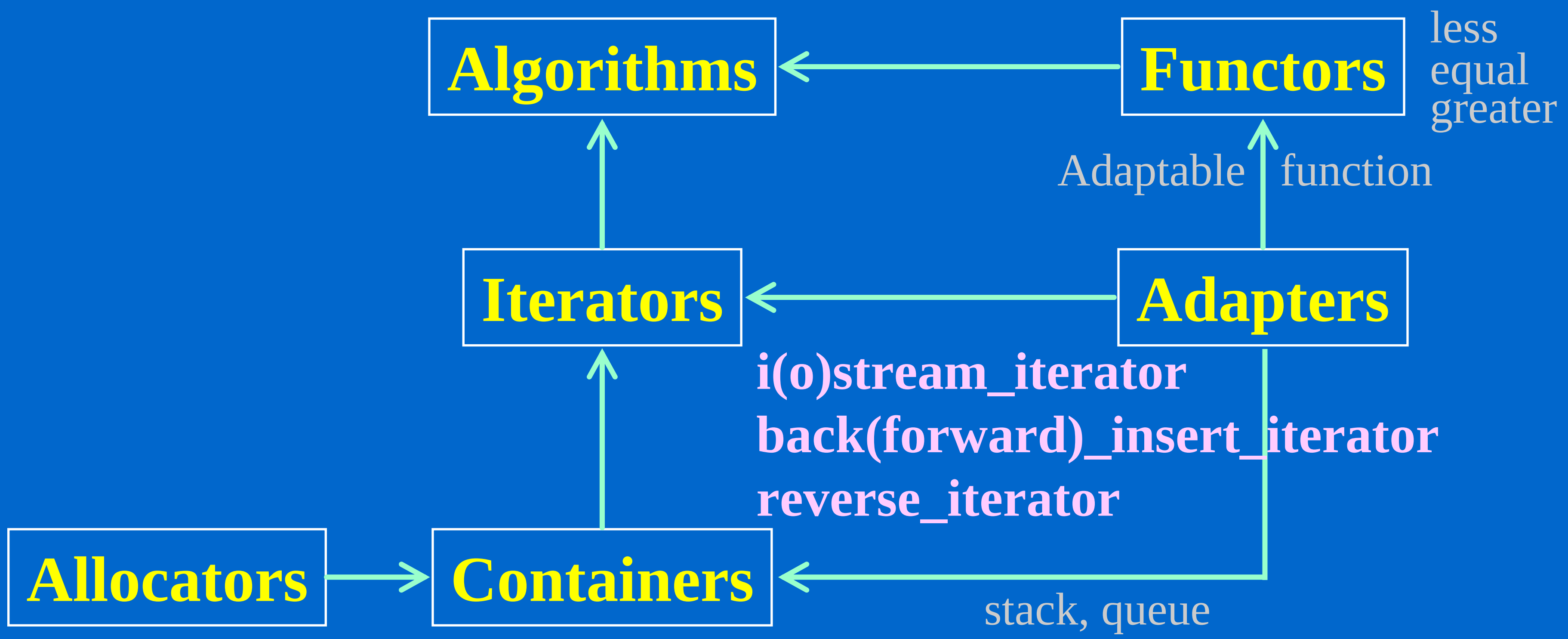

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ostream_iterator<int> myItr(cout, " "); *myItr = 123; myItr++;
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copy(istreambuf_iterator<char>(cin), istreambuf_iterator<char>(),
      ostreambuf_iterator<char>(cout) ); // one line stream copy
istream_iterator<int> itr(cin), endItr;
int x; do x = *itr++, cout << x; while (itr!=endItr);
```

1 2 3 4^Z
1 2 3 4

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Note: **endItr** marks the end, is not attached to any input stream

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vector<int> myVector; // no need to allocate space beforehand
back_insert_iterator<vector<int> > itr(myVector);
for (int i=0; i<10; ++i) *itr++ = i;
int x[] = {10, 11, 12};
reverse_copy(x, x+3, itr);
// reverse_copy(x, x+3, back_insert_iterator<vector<int> >(myVector));
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  vector, deque, list

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set<int> result;
set_union(set1.begin(), set1.end(), set2.begin(), set2.end(),
          inserter(result, result.begin()));
// the 2nd argument is an iterator pointing to the insertion point
// does not make sense for set or map, but is meaningful for vector, deque, or list
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- Summary

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insert_iterator<set<int> > itr = inserter(mySet, mySet.begin());
```

formatted

```
ostream_iterator<int> itr(cout, " "); ostream_iterator<char> itr(cout);
ostream_iterator<double> itr(myStream, "\n");
```

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unformatted	ostreambuf_iterator<char> itr(cout); // Write to cout

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set<int> result;
set_union(set1.begin(), set1.end(), set2.begin(), set2.end(),
          inserter(result, result.begin()));
// the 2nd argument is an iterator pointing to the insertion point
// does not make sense for set or map, but is meaningful for vector, deque, or list
```

- Summary

	back_insert_iterator<vector<int> > itr(myVector); back_insert_iterator<deque<char> > itr = back_inserter(myDeque);
	front_insert_iterator<deque<int> > itr(myIntDeque); front_insert_iterator<deque<char> > itr = front_inserter(myDeque);
	insert_iterator<set<int> > itr(mySet, mySet.begin()); insert_iterator<set<int> > itr = inserter(mySet, mySet.begin());
formatted	ostream_iterator<int> itr(cout, " "); ostream_iterator<char> itr(cout); ostream_iterator<double> itr(myStream, "\n");
formatted	istream_iterator<int> itr(cin); istream_iterator<int> endItr; // Special end of stream value
unformatted	ostreambuf_iterator<char> itr(cout); // Write to cout

unformatted	istreambuf_iterator<char> itr(cin); // Read data from cin
	istreambuf_iterator<char> endItr; // Special end of stream value

Removal Algorithms

- Removal algorithms **do not remove** elements from containers; they only **shuffle down** all elements that need to be erased.
  - They accept range specified by *iterators*, not *containers*, and thus do not know how to erase elements from containers.
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- ex1

```
int x[] = {218, 137, 130, 149, 137, 255};
vector<int> myvec;
copy(x, x+6, back_inserter(myvec));
myvec.erase(remove(myvec.begin(), myvec.end(), 137), myvec.end());
copy(myvec.begin(), myvec.end(), output_iterator<int>(cout, " "));
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Output: **218 130 149 255**

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Note: myvec.erase(myvec.end()) causes runtime error
myvec.erase(myvec.end(), myvec.end()) is fine

empty range

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- ex2

```
string stripPunctuation(string input) {
    input.erase(remove_if(input.begin(), input.end(), ::ispunct), input.end());
    return input;
}
```

Removal Algorithms

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  - They accept range specified by *iterators*, not *containers*, and thus do not know how to erase elements from containers.
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copy(myvec.begin(), myvec.end(), output_iterator<int>(cout, " "));
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- ex2

```
string stripPunctuation(string input) {
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}
```

<cctype>

Removal Algorithms (cont'd)

- **remove_copy, remove_copy_if**
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```
int myints[] = {10,20,30,30,20,10,10,20};    // 10 20 30 30 20 10 10 20
vector<int> myvector(8);                      // must ensure large enough
vector<int>::iterator iter =
remove_copy(myints, myints+8,                                   iter
                    myvector.begin(),          // 10 30 30 10 10 0 0 0
                    20);
myvector.erase(iter, myvector.end());          //  10 30 30 10 10
```

Removal Algorithms (cont'd)

- **remove_copy, remove_copy_if**
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```
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                                                         iter
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```

- **unique_copy**
  - returns an iterator pointing to the end of the copied range, which contains no consecutive duplicates.

Removal Algorithms (cont'd)

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```
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vector<int>::iterator iter =
remove_copy(myints, myints+8,                  iter
            myvector.begin(),                 // 10 30 30 10 10 0 0 0
            20);
myvector.erase(iter, myvector.end());         //  10 30 30 10 10
```

- **unique_copy**
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```
int myints[] = {10,20,20,20,30,30,20,20,10};
vector<int> myvector(9);                              // 0  0  0  0  0  0  0  0  0
vector<int>::iterator iter =                                       iter
unique_copy(myints, myints+9, myvector.begin());  // 10 20 30 20 10 0  0  0  0
```

Functional Thinking

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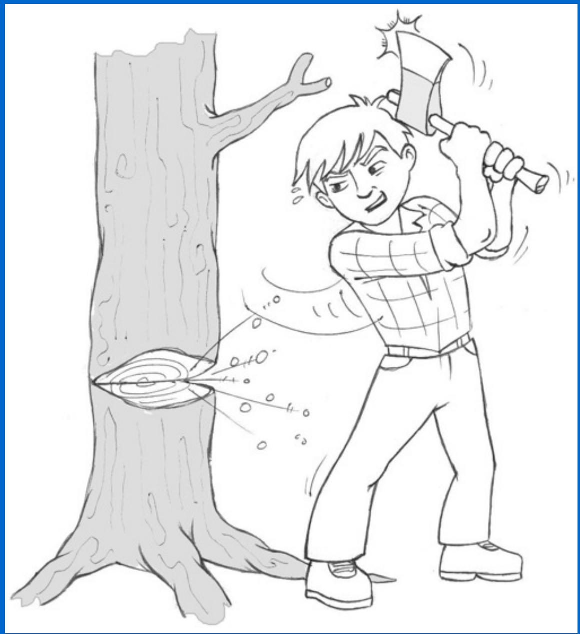

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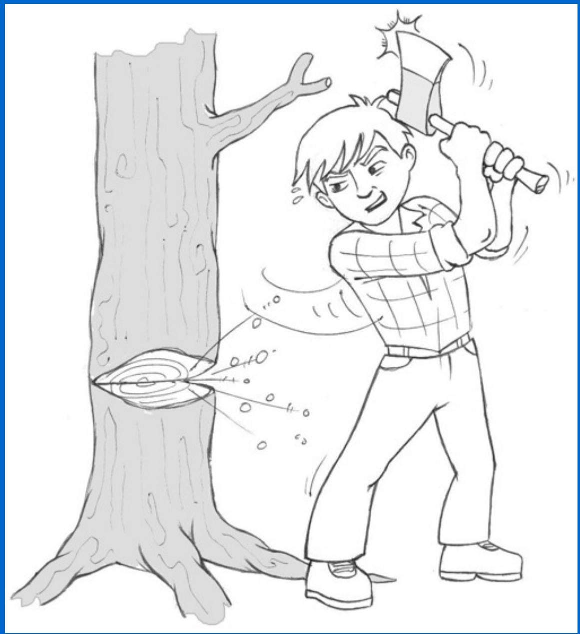

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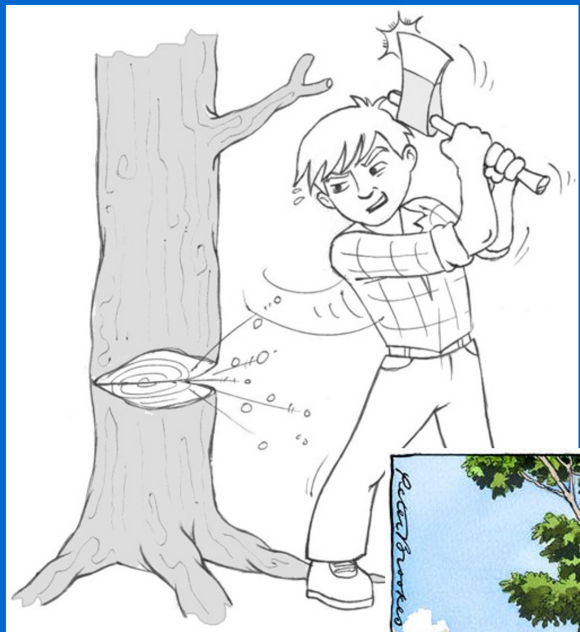

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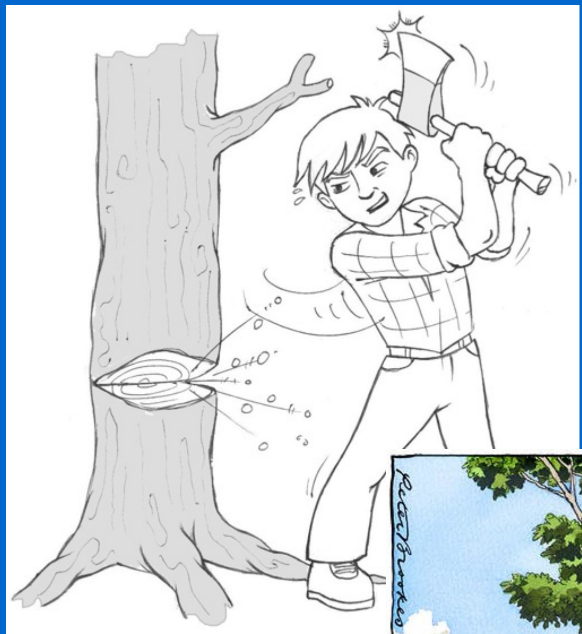

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Paradigm shift!!!

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    Stop thinking of low-level details of implementation and start focusing on the problem domain and on the results across steps (gradual transformation of input data toward the results)

Functional Thinking (cont'd)

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  FP makes codes understandable by removing moving parts.

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  Languages adopting FP paradigms: Perl, PHP, Ruby on Rail, JavaScript, Python, R, C#, and C++

Again, why going FP?

- **Cloud computing**: **Google Map/Reduce**

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Inherent **immutability** of Functional programming is a very good starting point for exploiting H/W parallelism.

Map / Filter / Reduce

STL | **Functional Language**

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- transform() --- **map** in Scala or Closure
  copy()
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  sort()
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  count()
  equal()
  search()
  selection()
  min_element()

  convert

  collect in Java8

  inject, join in Groovy

  fold in Functional Java

Mapping algorithms

- **transform**: applies a function to a range of elements and stores the result in the specified destination range

```
string  convertToLowerCase(string text) {
    transform(text.begin(), text.end(), text.begin(), ::tolower);
    return text;
}
```

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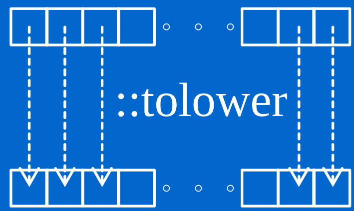

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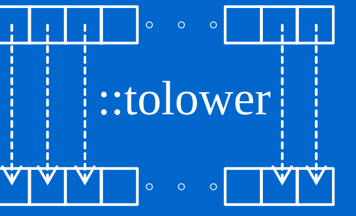
inplace



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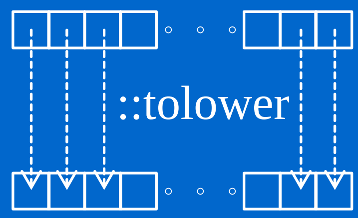


```
int toInt(int ch) { return ch>='a' ? ch - 'a' : ch - 'A' ; }
string  convertToInteger(string text, vector<int> &dest) {
   transform(text.begin(), text.end(), back_inserter(dest), toInt);
   return text;
}
```

the result could be another type

Mapping algorithms

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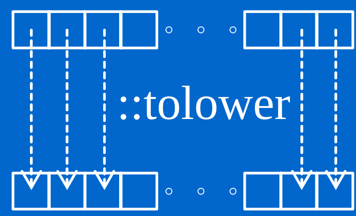


```
int toInt(int ch) { return ch>='a' ? ch - 'a' : ch - 'A' ; }
string  convertToInteger(string text, vector<int> &dest) {
    transform(text.begin(), text.end(), back_inserter(dest), toInt);
    return text;
}
```

the result could be another type

- **for_each**: applies a function to a range of elements

```
void toLower(int &ch) { ch = ch<='Z' ? ch - 'A' + 'a' : ch; }
string  convertToLowerCase(string text) {
    for_each(text.begin(), text.end(), toLower);
    return text;
}
```

the result is of the same type

Mapping algorithms (cont'd)

- **replace**(ForwardItr start, ForwardItr end,
  const Type & toReplace, const Type& replaceWith)

Mapping algorithms (cont'd)

- **replace**(ForwardItr start, ForwardItr end,
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```
int myints[] = {10, 20, 30, 30, 20, 10, 10, 20};
vector<int> myvector(myints, myints+8);              // 10 20 30 30 20 10 10 20
replace(myvector.begin(), myvector.end(), 20, 99);  // 10 99 30 30 99 10 10 99
```

Mapping algorithms (cont'd)

- **replace**(ForwardItr start, ForwardItr end,
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```
int myints[] = {10, 20, 30, 30, 20, 10, 10, 20};
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- **replace_if**(ForwardItr start, ForwardItr end,
  Predicate fn, const Type& replaceWith)

Mapping algorithms (cont'd)

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```

- **replace_if**(ForwardItr start, ForwardItr end,
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```
bool isOdd (int i) { return ((i%2)==1); }
int myints[] = {10, 11, 30, 30, 13, 10};
vector<int> myvector(myints, myints+8);                  // 10 11 30 30 13 10
replace_if(myvector.begin(), myvector.end(), isOdd, 0); // 10  0 30 30  0 10
```

Mapping algorithms (cont'd)

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```
int myints[] = {10, 20, 30, 30, 20, 10, 10, 20};
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vector<int> myvector(myints, myints+8);                   // 10 11 30 30 13 10
replace_if(myvector.begin(), myvector.end(), isOdd, 0); // 10  0 30 30  0 10
```

- **generate**(ForwardItr start, ForwardItr end, Generator fn)

Mapping algorithms (cont'd)

- **replace**(ForwardItr start, ForwardItr end,
  const Type & toReplace, const Type& replaceWith)

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int myints[] = {10, 20, 30, 30, 20, 10, 10, 20};
vector<int> myvector(myints, myints+8);               // 10 20 30 30 20 10 10 20
replace(myvector.begin(), myvector.end(), 20, 99); // 10 99 30 30 99 10 10 99
```

- **replace_if**(ForwardItr start, ForwardItr end,
  Predicate fn, const Type& replaceWith)

```
bool isOdd (int i) { return ((i%2)==1); }
int myints[] = {10, 11, 30, 30, 13, 10};
vector<int> myvector(myints, myints+8);                    // 10 11 30 30 13 10
replace_if(myvector.begin(), myvector.end(), isOdd, 0); // 10   0 30 30   0 10
```

- **generate**(ForwardItr start, ForwardItr end, Generator fn)

```
int randomNumber() { return (std::rand()%100); }
srand(unsigned(std::time(0)));   vector<int> myvector(8);
generate(myvector.begin(), myvector.end(), randomNumber);
```

Mapping algorithms (cont'd)

- **replace**(ForwardItr start, ForwardItr end,
  const Type & toReplace, const Type& replaceWith)

```
int myints[] = {10, 20, 30, 30, 20, 10, 10, 20};
vector<int> myvector(myints, myints+8);              // 10 20 30 30 20 10 10 20
replace(myvector.begin(), myvector.end(), 20, 99); // 10 99 30 30 99 10 10 99
```

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```

- **generate_n**(OutputItr start, size_t n, Generator fn)

for_each

```
#include <iostream>
#include <algorithm>
using namespace std;
template <class T>
class print {
public:
    print(ostream &os)
        : m_os(os), m_count(0) {}
    void operator()(const T &t) {
        m_os << t << ' ';
        ++m_count;
    }
    int count() { return m_count; }
private:
    ostream &m_os;
    int m_count;
};
```

```
int main()
{
    int array[] = {1, 4, 2, 8, 5, 7};
    const int n = sizeof(array) / sizeof(int);

    print<int> f =
        for_each(array, array+n, print<int>(cout));
    cout << endl << f.count()
            << " objects printed." << endl;

    return 0;
}
```

STL Abstractions

- **Containers** abstract away the differences of underlying basic types: the same vector implementation is used for **int**s or **string**s. An algorithm that handles elements in a vector does not concern the actual type stored in that vector.

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Algorithms (customized with the **plugged-in function objects**) are abstract mechanisms that focus on solving the general structure of a problem instead of the particular container or the specific data type in the container.

Things to Remember

when using STL algorithms

- *Prefer a **member function** to a similarly named algorithm for performing a given task*

  e.g. std::set::lower_bound() vs. std::lower_bound()

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  - e.g. int data[] = {5,4,2,3,1}; sort(data, data+5);
- *You can generally use a **more powerful iterator** in place of a less powerful one, if it is more convenient or "natural" to do so.*
  - e.g. replace_n() requires output iterator, the ostream_iterator suffices, but the bidirectional iterator of list/set/map is also good, let along the random-access iterator of vector/deque

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  e.g. replace_n() requires output iterator, the ostream_iterator suffices, but the bidirectional iterator of list/set/map is also good, let along the random-access iterator of vector/deque

- *Ensure a **container's size is large enough** to accept all components being transferred into it.*

  e.g. vector<int> v; back_insert_iterator<vector<int> > iter(v);

Palindrome

- A palindrome is a word or phrase that is the same when read forwards or backwards, such as “racecar” or “Malayalam.”, ignoring spaces, punctuation, and capitalization.

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- Procedural way

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bool IsPalindrome(string input) {
    for (int k=0; k<input.size()/2; ++k)
        if (input[k]!=input[input.length()-1-k])
            return false;
    return true;
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- 1st STL version

```
bool IsPalindrome(string input) {
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string reversed;
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             input.end(),
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return reversed == input;
```

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}
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```
string reversed;
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                  input.end(),
                  reversed);
return reversed == input;
```

plain, narrative, but less efficient

Palindrome (cont'd)

- 2nd STL version: use **reverse_iterator** and **equal**

```
bool IsPalindrome(string input) {
    return equal(input.begin(), input.begin()+input.size()/2, input.rbegin());
}
```

Palindrome (cont'd)

- 2nd STL version: use **reverse_iterator** and **equal**

```
bool IsPalindrome(string input) {
    return equal(input.begin(), input.begin()+input.size()/2, input.rbegin());
}
```

- More: stripping out everything except alphabetic char

```
#include <cctype> // isalpha()
#include <algorithm> // remove_if(), equal()
bool  IsNotAlpha(char ch) {
    return !isalpha(ch);
}
bool IsPalindrome(string input) {
    input.erase(remove_if(input.begin(), input.end(), IsNotAlpha), input.end());
    return equal(input.begin(), input.begin()+input.size()/2, input.rbegin());
}
```

Word Palindrome

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```
bool  IsNotAlphaOrSpace(char ch) { return !isalpha(ch) && !isspace(ch); }
bool IsWordPalindrome(string input)
{
    input.erase(remove_if(input.begin(), input.end(), IsNotAlphaOrSpace),
                  input.end());
    transform(input.begin(), input.end(), input.begin(), ::toupper);
    stringstream tokenizer(input);
    vector<string> tokens;
    tokens.insert(tokens.begin(),  istream_iterator<string>(tokenizer),
                                   istream_iterator<string>());
    return equal(tokens.begin(), tokens.begin()+tokens.size()/2, tokens.rbegin());
}
```

Word Palindrome

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    vector<string> tokens;
    tokens.insert(tokens.begin(),  istream_iterator<string>(tokenizer),
                                            istream_iterator<string>());
    return equal(tokens.begin(), tokens.begin()+tokens.size()/2, tokens.rbegin());
}
```

Clang or GNU g++ has tolower()/toupper() in <locale> header also

<cctype>

int isalnum(int c)	Check if character is alphanumeric
int isalpha(int c)	Check if character is alphabetic
int isblank(int c)	Check if character is blank (C++11)
int iscntrl(int c)	Check if character is a control character
int isdigit(int c)	Check if character is decimal digit
int isgraph(int c)	Check if character has graphical representation
int islower(int c)	Check if character is lowercase letter
int isprint(int c)	Check if character is printable
int ispunct(int c)	Check if character is a punctuation character
int isspace(int c)	Check if character is a white-space
int isupper(int c)	Check if character is uppercase letter
int isxdigit(int c)	Check if character is hexadecimal digit
int isalnum(int c)	Check if character is alphanumeric
int isalpha(int c)	Check if character is alphabetic
int tolower(int c)	Convert uppercase letter to lowercase
int toupper(int c)	Convert lowercase letter to uppercase

In C++, a locale-specific **template** version of each function exists in header <locale>

use ::isalnum() to specify isalnum() in cctype

<cmath>

- Trigonometric functions

double cos(double)	Compute cosine
double sin(double)	Compute sine
double tan(double)	Compute tangent
double acos(double)	Compute arc cosine
double asin(double)	Compute arc sine
double atan(double)	Compute arc tangent
double atan2(double)	Compute arc tangent with two parameters

- Hyperbolic functions

double cosh(double)	Compute hyperbolic cosine
double sinh(double)	Compute hyperbolic sine
double tanh(double)	Compute hyperbolic tangent
double acosh(double)	Compute arc hyperbolic cosine (C++11)
double asinh(double)	Compute arc hyperbolic sine (C++11)
double atanh(double)	Compute arc hyperbolic tangent (C++11)

✧ Exponential and logarithmic functions

double exp(double x)	Compute exponential function, e^x
double frexp(double x, int* exp)	Get significand and exponent, x=sign*2^exp
double ldexp(double x, int exp)	x*2^exp
double log(double x)	Compute natural logarithm, w.r.t. Euler number e
double log10(double x)	Compute common logarithm
double modf(double x, double* intpart)	Break into fractional and integral parts
double exp2(double x), exp2l(x)	Compute 2^x (C++11)
double expm1(double x), expm1l(x)	Compute e^x-1 (C++11)
int ilogb(double x)	Integer binary logarithm (C++11)
int ilogb(long double x)	Returns the integral part of the logarithm of |x|, using FLT_RADIX (==2) as base
double log1p(double x)	Compute logarithm plus one, log(x+1) (C++11)
double log2(double x)	Compute binary logarithm (C++11)
double logb(double x)	Compute floating-point base logarithm, log|x| using FLT_RADIX (==2) as base (C++11)
double scalbn(double x, int n)	scalbn(x,n) = x * FLT_RADIX^n (C++11)

- Power functions

double pow(double base, double exp)	Raise to power, base^exp
double sqrt(double x)	Compute square root
double cbrt(double x)	Compute cubic root (C++11)
double hypot(double x, double y)	Compute hypotenuse (C++11)

- Error and gamma functions

double erf(double x)	Compute error function (C++11)
double erfc(double x)	Compute complementary error function (C++11)
double tgamma(double x)	Compute gamma function (C++11)
double lgamma(double x)	Compute log-gamma function (C++11)

- Rounding and remainder: ceil, floor, fmod, trunc, round, lround, llround, rint ,lrint, llrint, rearbyint, remainder, remquo
- Floating-point manipulation: copysign, nan, nextafter, nexttoward
- Minimum, maximum, difference: fdim, fmax, fmin
- Other: fabs, abs, fma
- Classification: fpclassify, isfinite, isinf, isnan, isnormal, signbit
- Comparison: isgreater, isgreaterequal, isless, islessequal, islessgreater, isunordered
- Constants: INFINITY, NAN, HUGE_VAL

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- **Boost** ==> **C++TR1** (Library extension to C++03) ==> **C++11**
  - **smart_ptrs** – manage the lifetime of referred object with reference counting (shared_ptr, shared_array, scoped_ptr, scoped_array, weak_ptr, intrusive_ptr)
  - boost::**lambda**, boost::**function**, boost::**bind** – higher order programming
  - boost::**regex** – regular expression
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Documents of Boost provide excellent in-depth discussions of the design decisions, constraints, and requirements that went into constructing the library.

Magic Square Solver (1/4)

- A "magic square" is a 3x3 grid in which all elements are distinct and all 3 elements in every row, column, and diagonal sum to the same number, e.g.

2	7	6
9	5	1
4	3	8

```
vector<int> magicSquare(9);
for (i=0; i<9; ++i) magicSquare[i]=i+1;
```

```
do {
   ouputConfig(magicSquare);
}
while (next_permutation(magicSquare.begin(), magicSquare.end()));
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2+7+6=15
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- A magic square can be represented as a linear vector of {1,2, …, 9}

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- Use next_permutation() to generate all configurations

```
do {
   ouputConfig(magicSquare);
}
while (next_permutation(magicSquare.begin(), magicSquare.end()));
```

Magic Square Solver (2/4)

- Output a configuration

```
for (i=0; i<3; ++i)
    copy(magicSquare.begin()+3*i, magicSquare.begin()+3*i+3,
             ostream_iterator<int>(cout, " ")), cout << endl;
```

```
const int starts[]  = {0, 3, 6, 0, 1, 2, 2, 0};
const int offsets[] = {1, 1, 1, 3, 3, 3, 2, 4};
for (i=0; i<8; ++i)
    for (sums[i]=0,j=0; j<3; ++j)
        sums[i] += magicSquare[starts[i]+j*offsets[i]];
```

```
if (8==count(sums, sums+8, 15))
    outputConfig(magicSquare);
```

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for (i=0; i<3; ++i)
   copy(magicSquare.begin()+3*i, magicSquare.begin()+3*i+3,
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```

- Use **for loop** to evaluate everyone of the 8 conditions

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const int starts[]  = {0, 3, 6, 0, 1, 2, 2, 0};
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   for (sums[i]=0,j=0; j<3; ++j)
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for (i=0; i<8; ++i)
   for (sums[i]=0,j=0; j<3; ++j)
      sums[i] += magicSquare[starts[i]+j*offsets[i]];
```

- Use **count()** to validate the conjunction of all 8 conditions

```
if (8==count(sums, sums+8, 15))
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```

Magic Square Solver (3/4)

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    - It is necessary to config the predicate with different ways of accumulation.

use a **functor**

```
for (i=0; i<8; ++i)
   sums[i] = accumulate(magicSquare.begin(), magicSquare.end(), 0,
                        Constraint(starts[i],offsets[i]));
```

Magic Square Solver (4/4)

```
class Constraint {
public:
    Constraint(const int start, const int offset)
        : index(0), x1(start), x2(start+offset), x3(start+2*offset) {}
    int operator()(int sum, int value) {
        if (index==x1||index==x2||index==x3)
            sum += value;
        index++;
        return sum;
    }
private:
    int index;
    const int x1, x2, x3;
};
```

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Monoalphabetic Substitution Cipher

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encryption $\Downarrow$

Monoalphabetic Substitution Cipher

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A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z

encryption ⇩

K	V	D	Q	J	W	A	Y	N	E	F	C	L	R	H	U	X	I	O	G	T	Z	P	M	S	B

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encryption ⇩ ⇧ decryption

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encryption ⇓ ⇑ decryption

For example: plaintext “THECOOKIESAREINTHEFRIDGE”
ciphertext “GYJDHHFNJOKIJNRGYJWINQAJ”

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encryption ⇩ ⇧ decryption

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For example: plaintext “THECOOKIESAREINTHEFRIDGE”
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✶ Use **random_shuffle** to generate a map as the encoding codebook and a map as the decoding codebook

```
int encTable[26], decTable[26]; // two direct address tables (DAT)
random_shuffle(encTable, encTable+26);
for (i=0; i<26; i++) decTable[encTable[i]] = i;
```

Substitution Cipher (cont'd)

- Config **transform** with a decryption **functor**, which takes a decoding codebook and maps a ciphertext character to a plaintext character.

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```
class mapping {
public:
   mapping(int table[]): DAT(table) {}
   char operator()(char &source) { return 'A'+DAT[source-'A']; }
private:
   int *DAT;
};
```

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```
transform(plaintext1.begin(), plaintext1.end(),
                back_inserter(ciphertext), mapping(encTable));
```

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```
transform(ciphertext.begin(), ciphertext.end(),
                  back_inserter(plaintext2), mapping(decTable));
```

pair<T1, T2>

- **pair** is a simple, handy, and useful template of data structure used with any STL containers and algorithms.

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```
bool operator<(pair<T1,T2>& rhs) {
    if (first<rhs.first) return true;
    else if ((first==rhs.first)&&(second<rhs.second)) return true;
    else return false; // *this >= rhs
}
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- e.g. multi-field sorting on **pair<sring, pair<int, vector<int> > >**

```
vector<pair<string, pair<int, vector<int> > > v;
… // populate the vector v with data;
sort(v.begin(), v.end());
```

Convenient Aliases

```
typedef vector<int> vi;
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typedef vector<vi> vvi;
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A two-dimensional 10x20 array initialized with 0

```
vvi matrix(10, vi(20, 0))
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typedef vector<int> vi;
typedef vector<vi> vvi;
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#define sz(a) int((a).size())
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#define sz(a) int((a).size())
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#define sz(a) int((a).size())
#define pb push_back
#define all(c) (c).begin(),(c).end()
```

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only for GNU g++

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#define sz(a) int((a).size())
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#define tr(c,i) for(typeof((c).begin() i = (c).begin(); i != (c).end(); i++)
```

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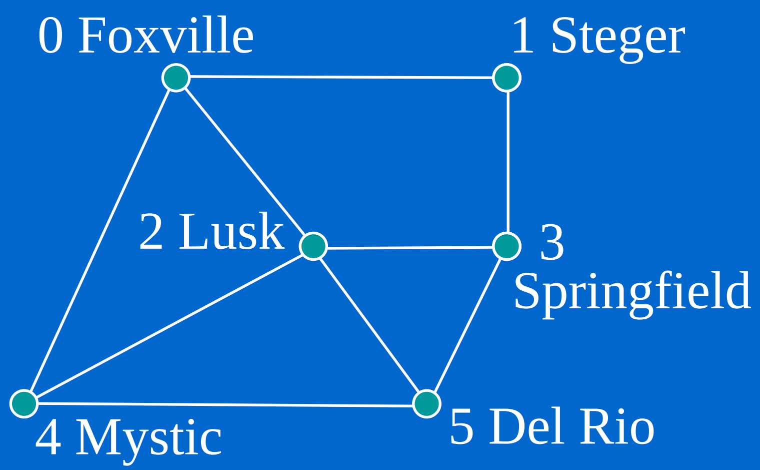
#define has(c,x) ((c).find(x) != (c).end())
#define hasG(c,x) (find(all(c),x) != (c).end())
```

Graph Connectivity - DFS

- Depth-First Search



Graph Connectivity - DFS

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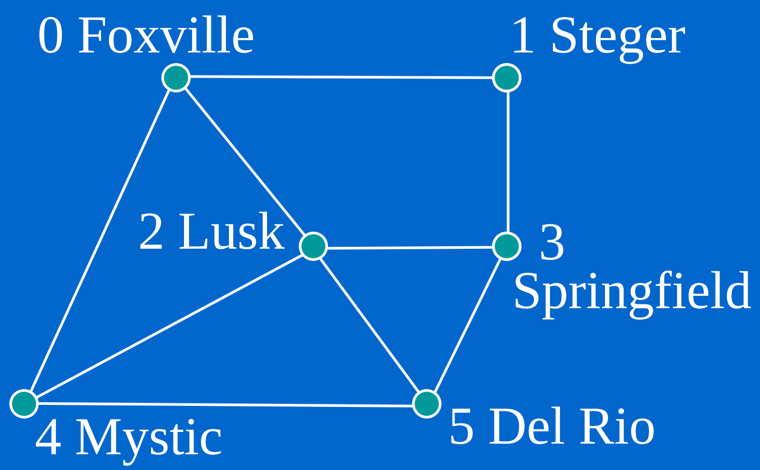
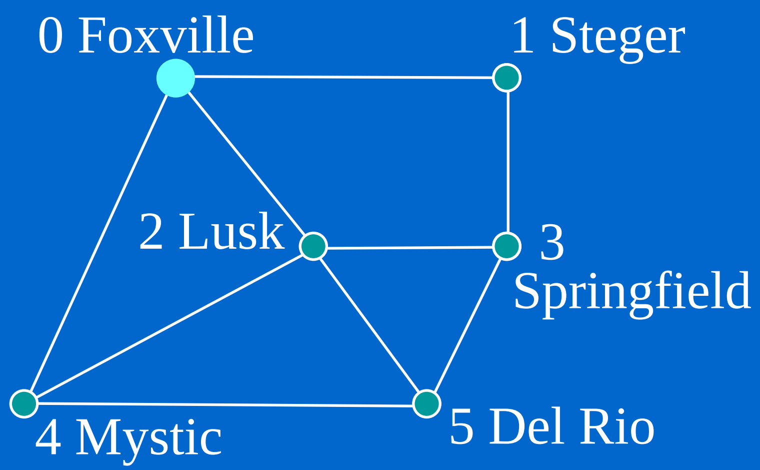


visited

0	1	2	3	4	5
0	0	0	0	0	0

Graph Connectivity - DFS

- Depth-First Search



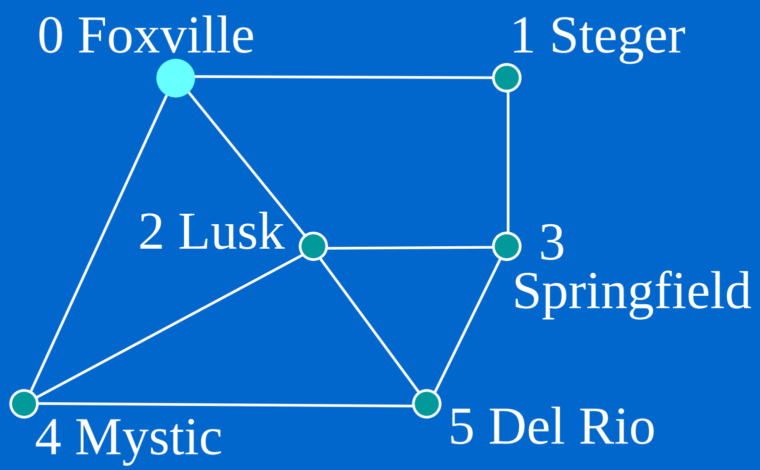
0 .

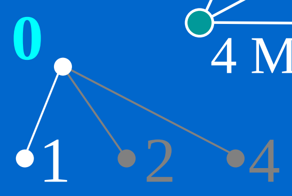
visited

0	1	2	3	4	5
1	0	0	0	0	0

Graph Connectivity - DFS

✧ Depth-First Search



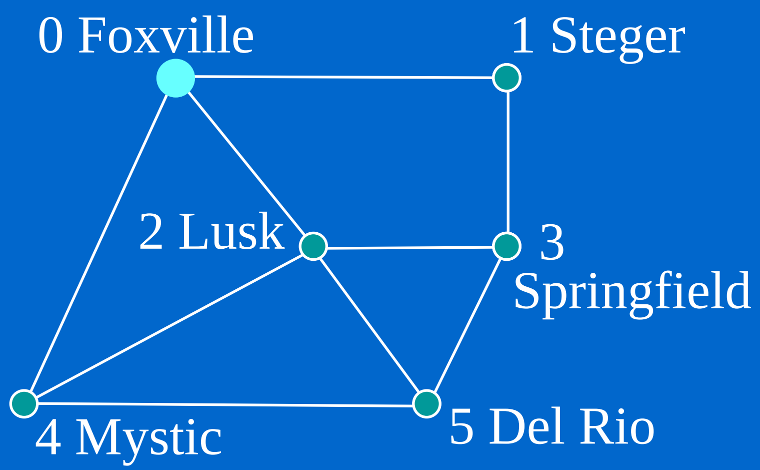


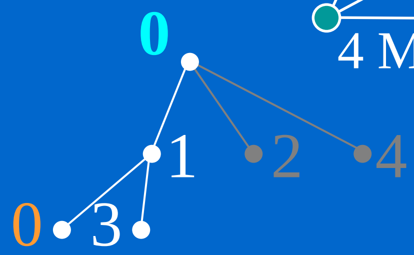
visited

0	1	2	3	4	5
1	1	0	0	0	0

Graph Connectivity - DFS

- Depth-First Search





visited

0	1	2	3	4	5
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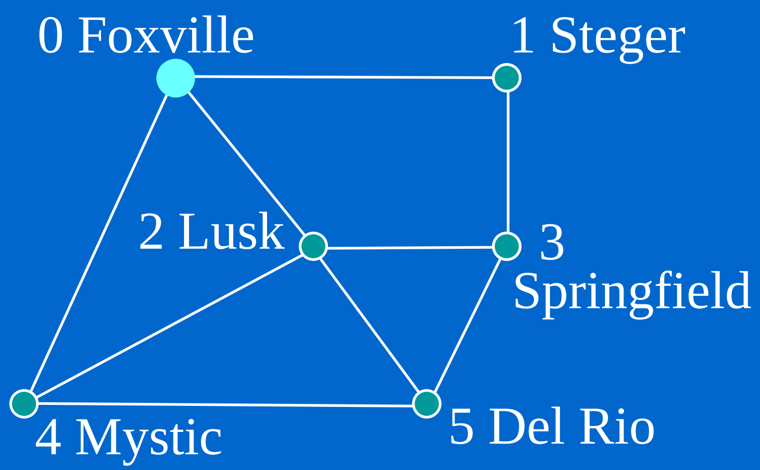

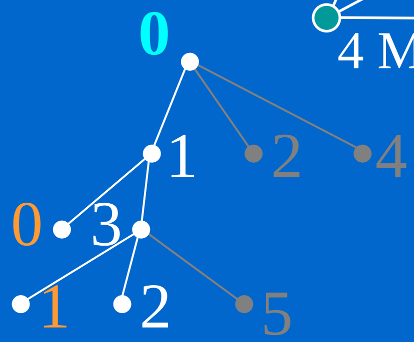

visited

0	1	2	3	4	5
1	1	1	1	0	0

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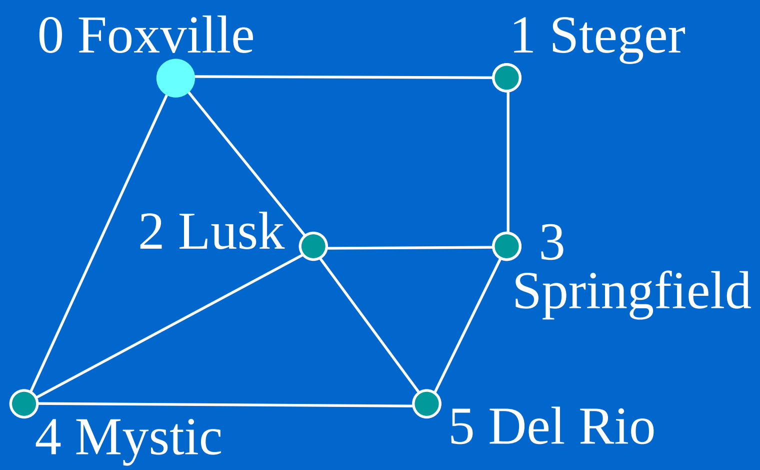

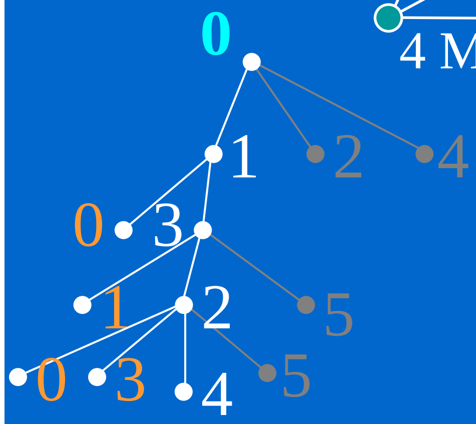

visited

0	1	2	3	4	5
1	**1**	**1**	**1**	**1**	0

Graph Connectivity - DFS

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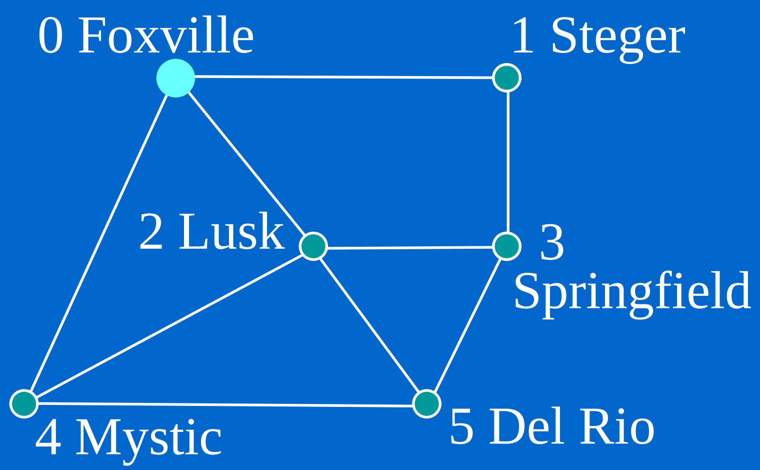

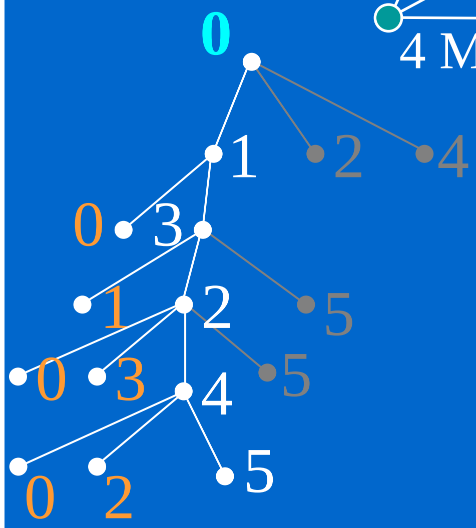

visited

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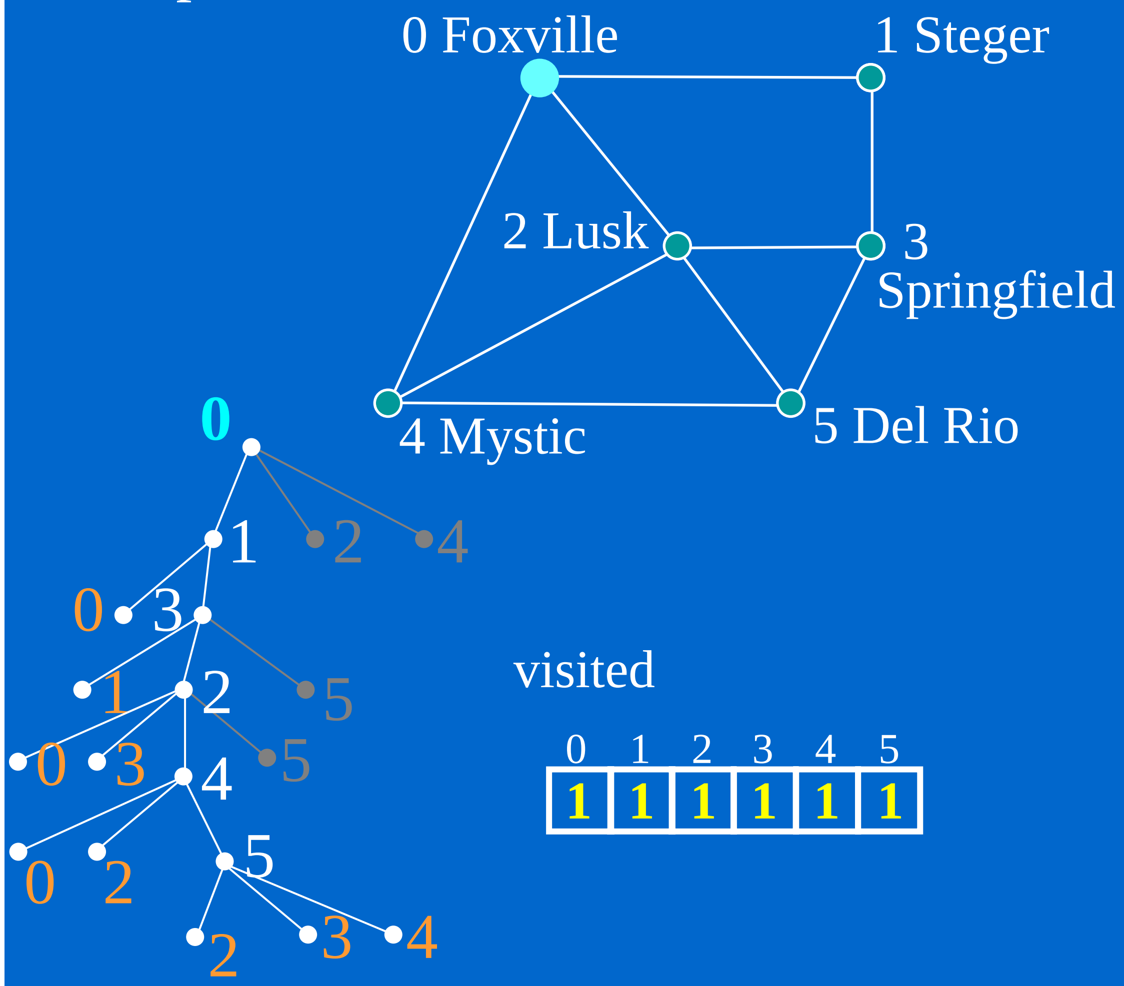

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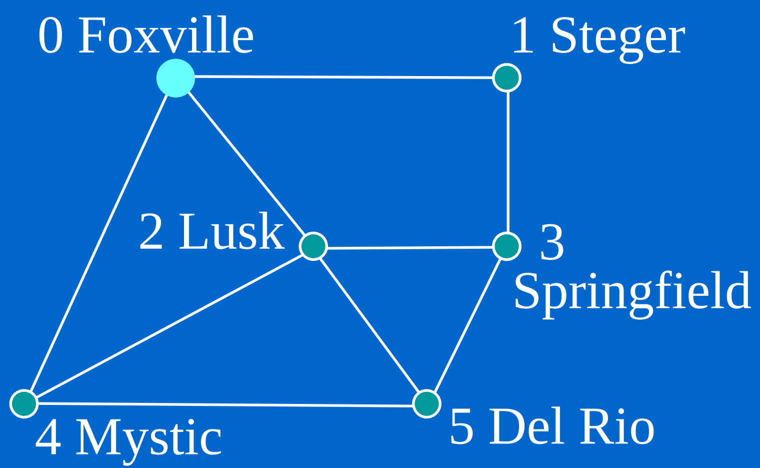

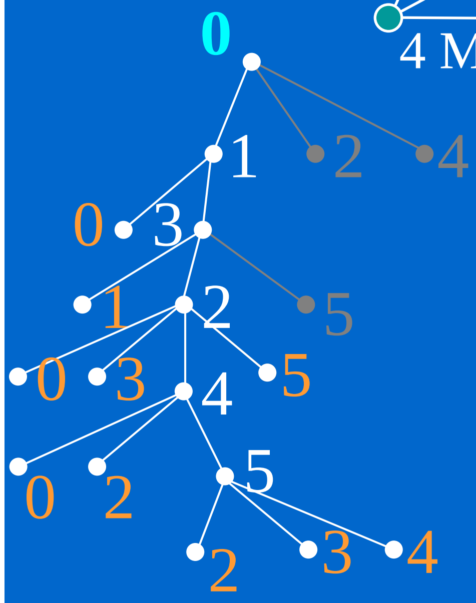

visited

0	1	2	3	4	5
1	1	1	1	1	1

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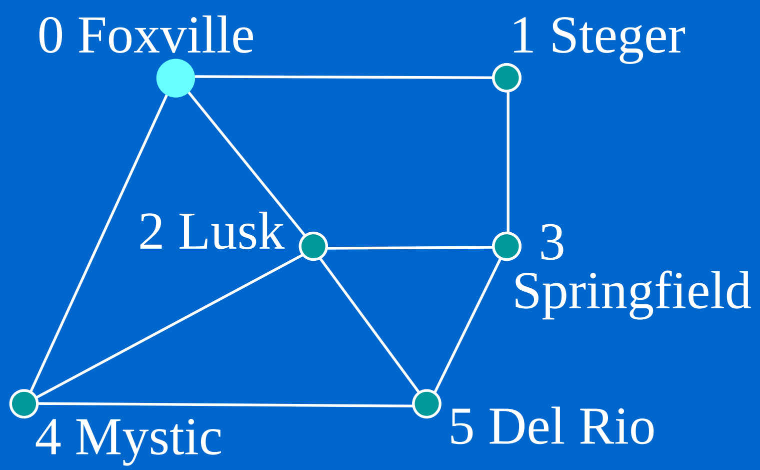

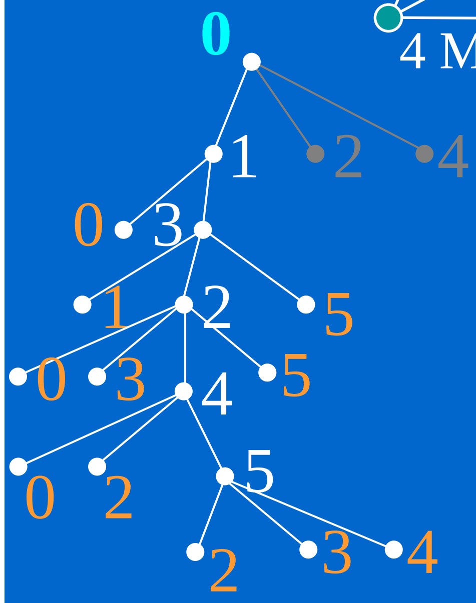

visited

0	1	2	3	4	5
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Graph Connectivity - DFS

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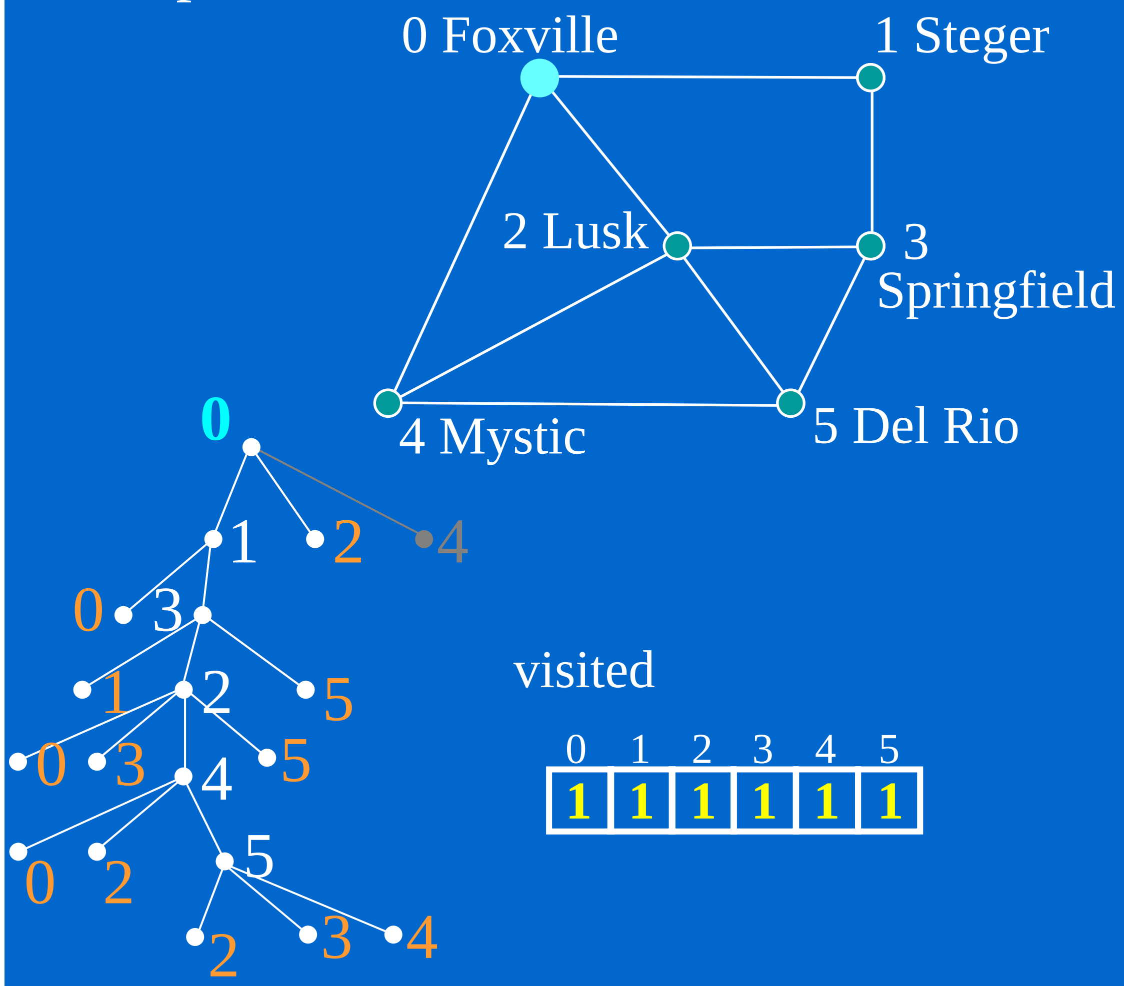

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Graph Connectivity - DFS

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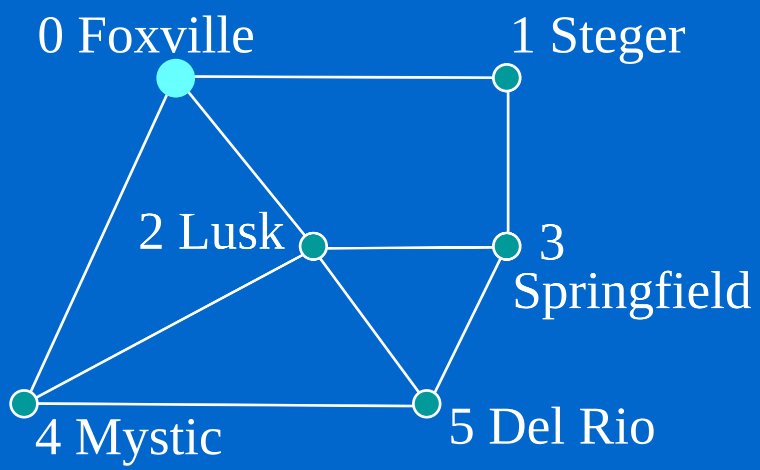
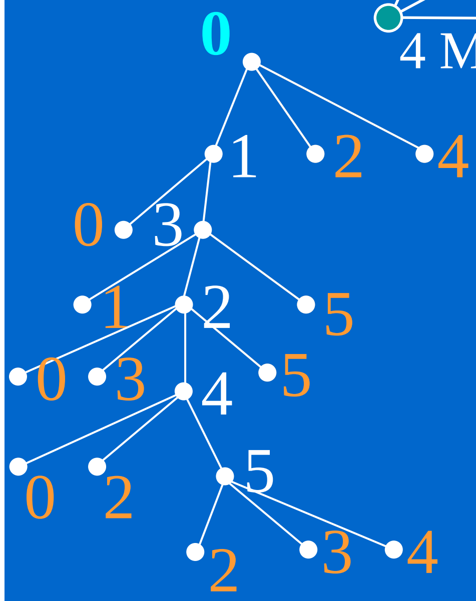


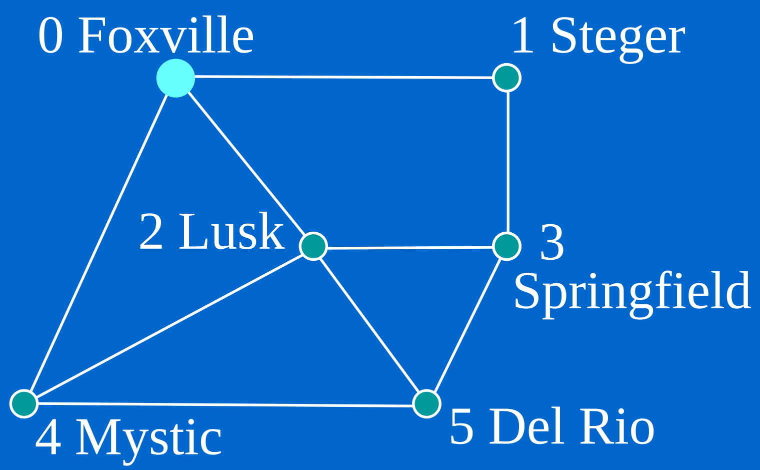


visited

0	1	2	3	4	5
1	1	1	1	1	1

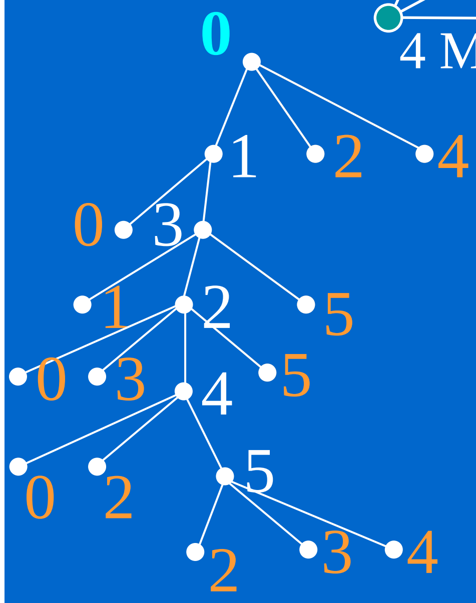
Graph Connectivity - DFS

- Depth-First Search




```
vvi W;       // global graph
vi visited;
```

```
int w[][6] = {{2,4},{3},{0,4,5},
              {1},{0,2,5},{2,4}};
int wn[6] = {2,1,3,1,3,2};
int i, N = 6;
for (i=0; i<N; i++)
   W.pb(vi(w[i],w[i]+wn[i]));
```

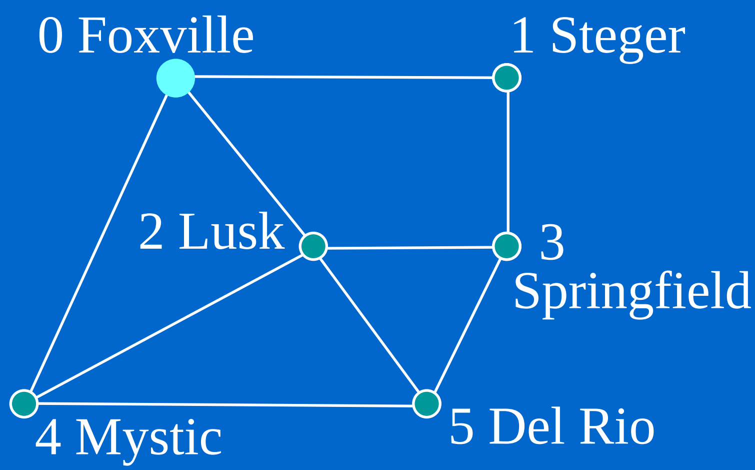


visited

0	1	2	3	4	5
1	1	1	1	1	1

Graph Connectivity - DFS

- Depth-First Search

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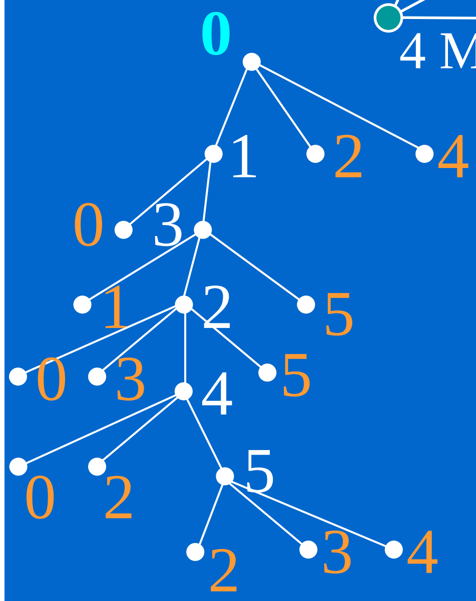


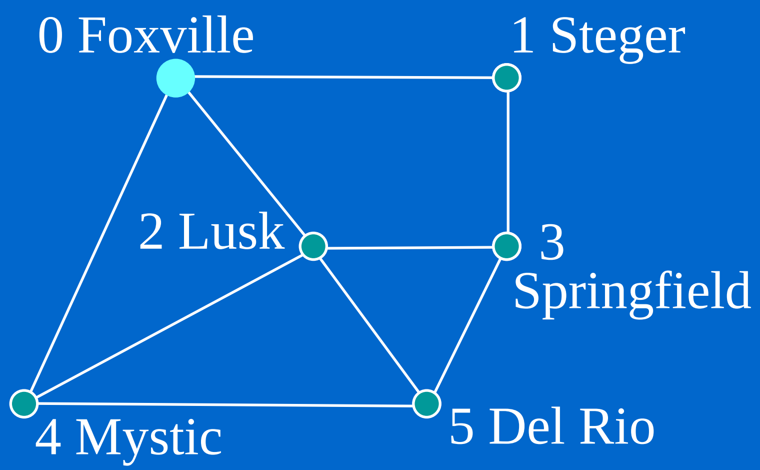
visited

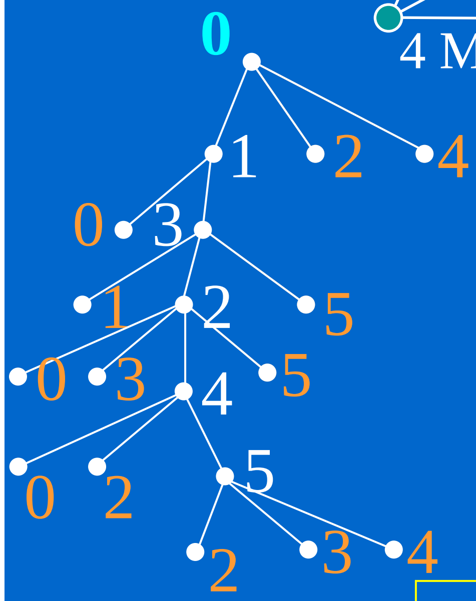
0	1	2	3	4	5
1	1	1	1	1	1

```
void dfs(int i) {
   if (!visited[i]) {
      visited[i] = 1;
      for_each(all(W[i]), dfs);
   }
}
```

Graph Connectivity - DFS

- Depth-First Search






```
vvi W;      // global graph
vi visited;
```

```
int w[][6] = {{2,4},{3},{0,4,5},
              {1},{0,2,5},{2,4}};
int wn[6] = {2,1,3,1,3,2};
int i, N = 6;
for (i=0; i<N; i++)
   W.pb(vi(w[i],w[i]+wn[i]));
```

visited

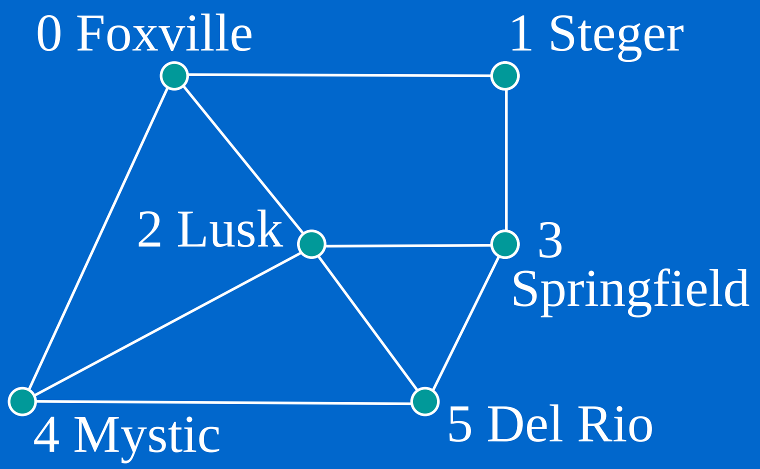
0	1	2	3	4	5
1	1	1	1	1	1

```
void dfs(int i) {
   if (!visited[i]) {
      visited[i] = 1;
      for_each(all(W[i]), dfs);
   }
}
```

```
visited = vi(N, 0); dfs(0); // start from vertex 0
if (find(all(visited), 0) == visited.end()) cout << "Connected\n";
```

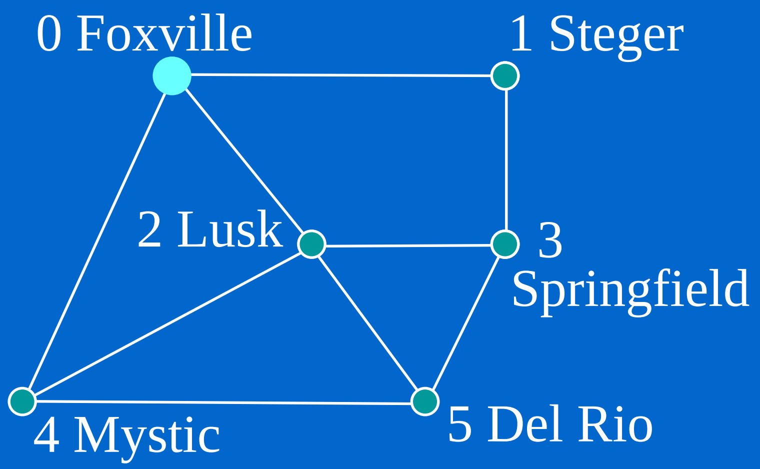
Graph Connectivity - BFS

- Breadth-First Search



Graph Connectivity - BFS

✧ Breadth-First Search



queue

visited

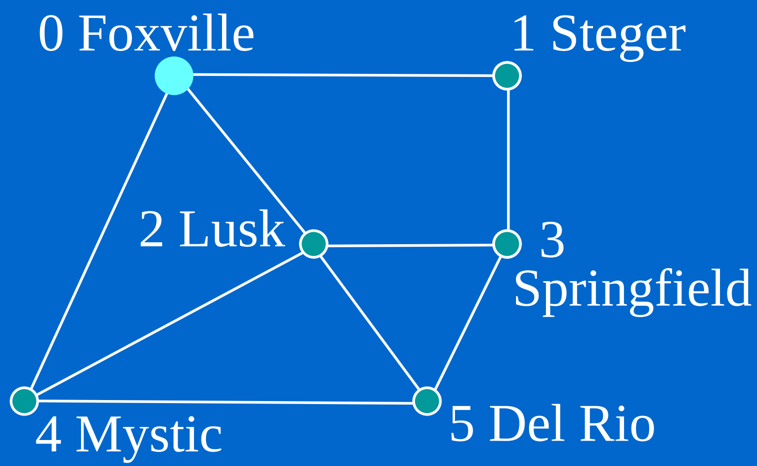
0	1	2	3	4	5
0	0	0	0	0	0

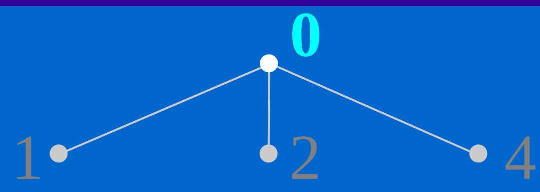
Graph Connectivity - BFS

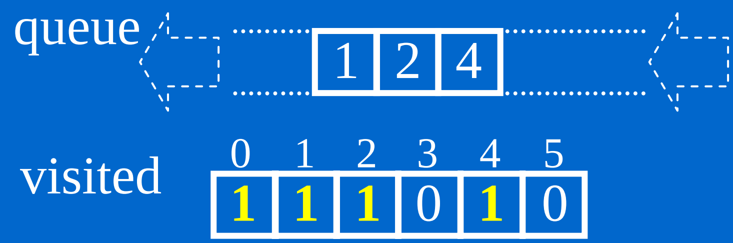
- Breadth-First Search

Graph Connectivity - BFS

✧ Breadth-First Search

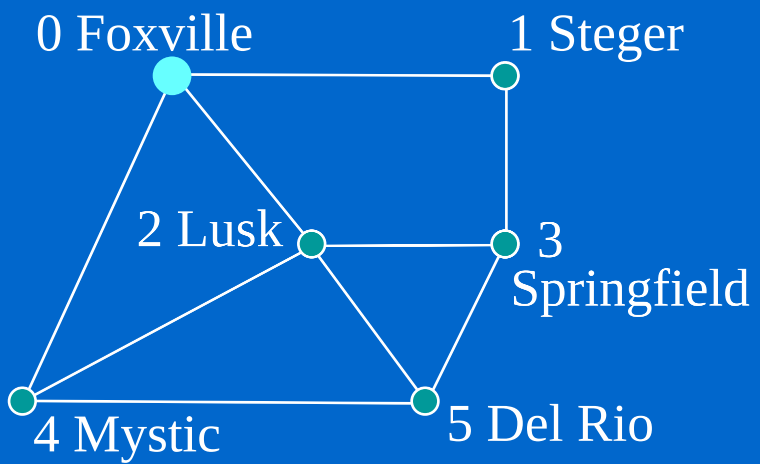


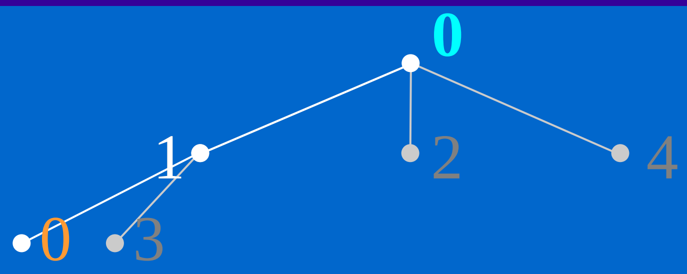




Graph Connectivity - BFS

- Breadth-First Search





queue

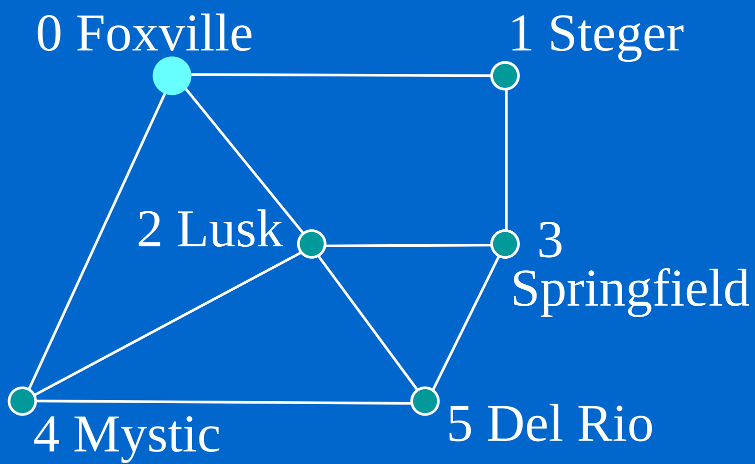
2	4	3

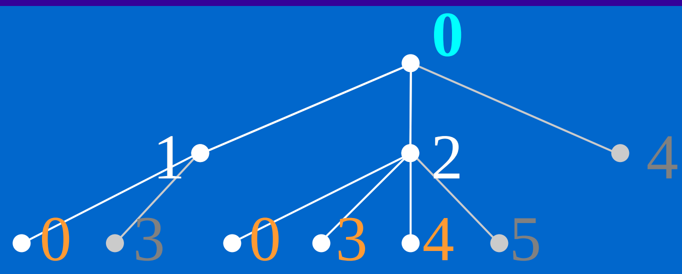
visited

0	1	2	3	4	5
1	1	1	1	1	0

Graph Connectivity - BFS

- Breadth-First Search





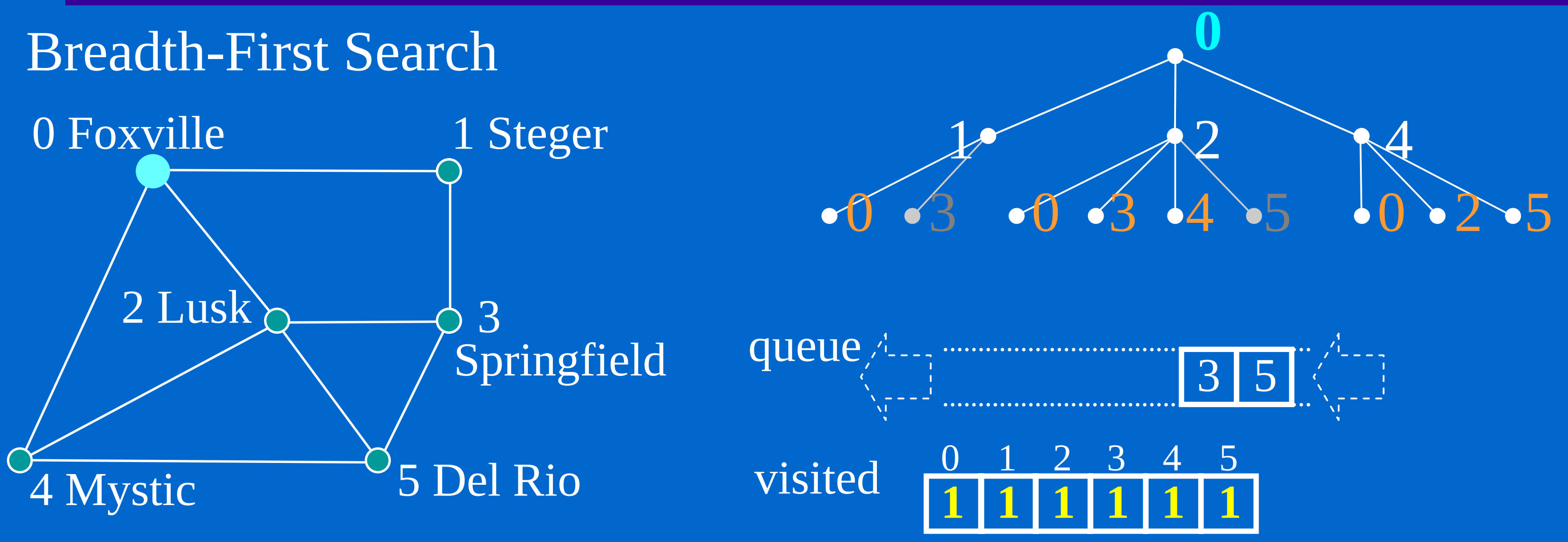
queue

visited

0	1	2	3	4	5
1	1	1	1	1	1

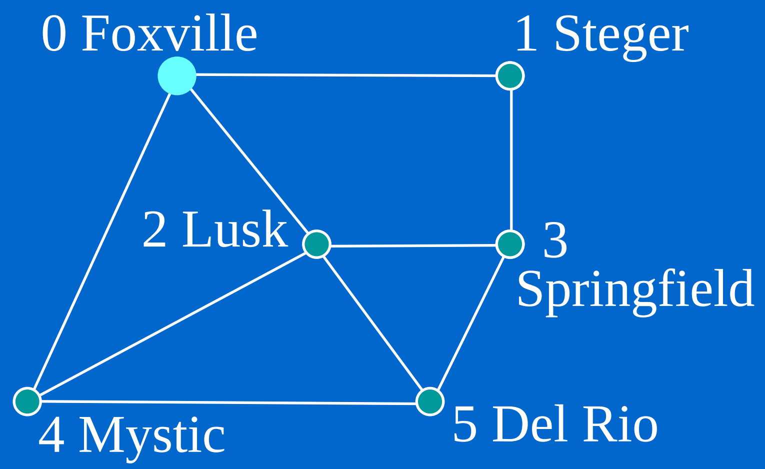
Graph Connectivity - BFS

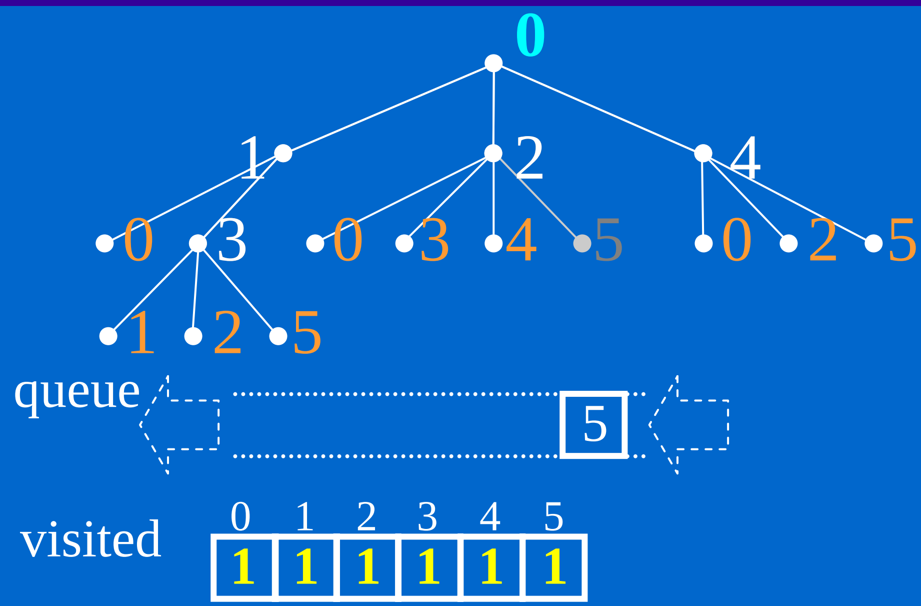
- Breadth-First Search



Graph Connectivity - BFS

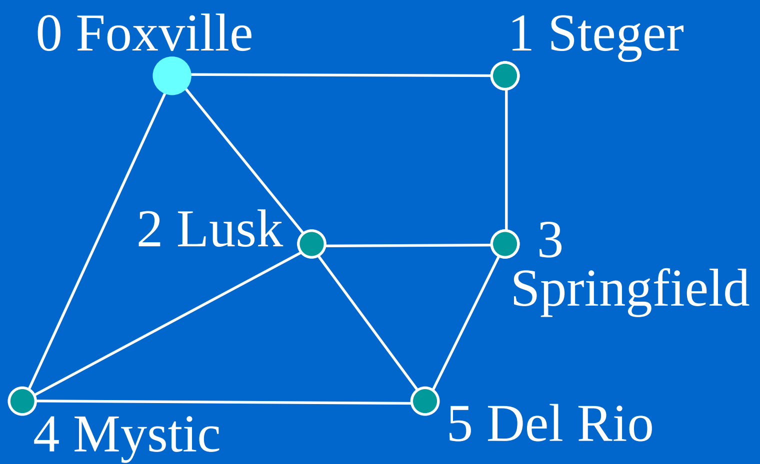
- Breadth-First Search

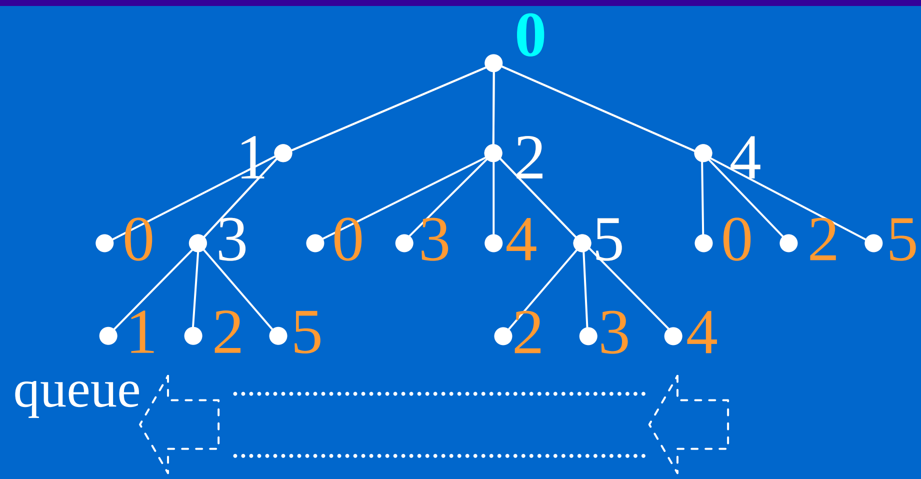




Graph Connectivity - BFS

✧ Breadth-First Search



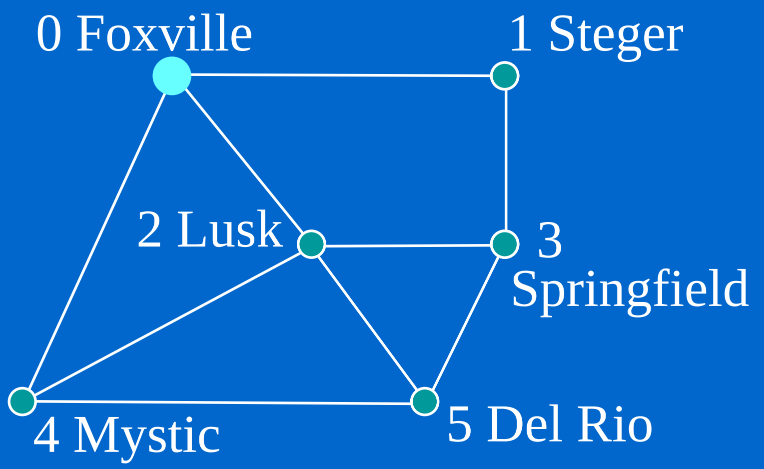


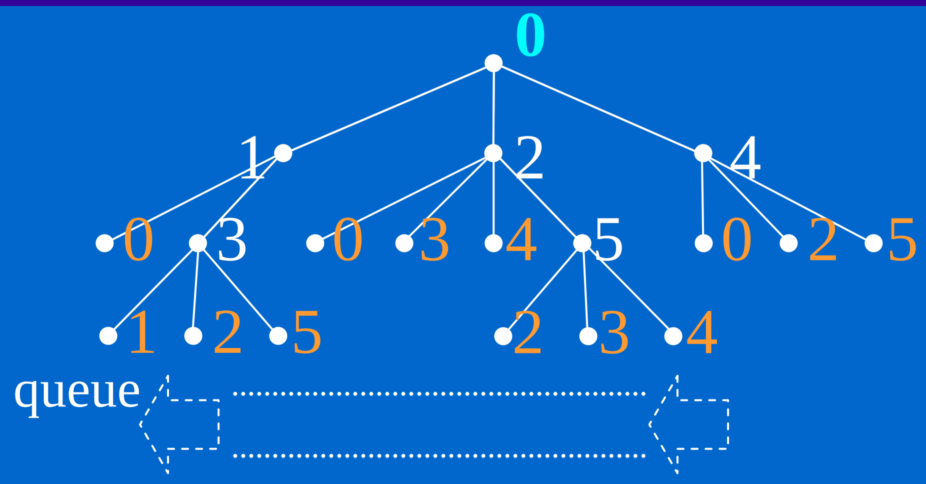
visited

0	1	2	3	4	5
1	1	1	1	1	1

Graph Connectivity - BFS

- Breadth-First Search





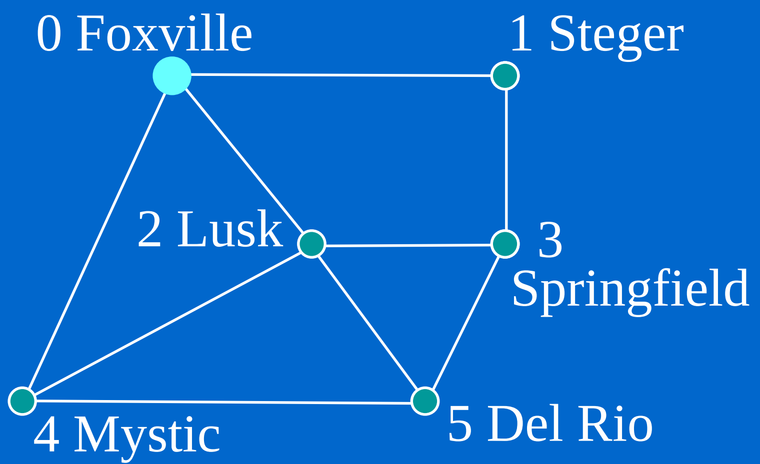
visited

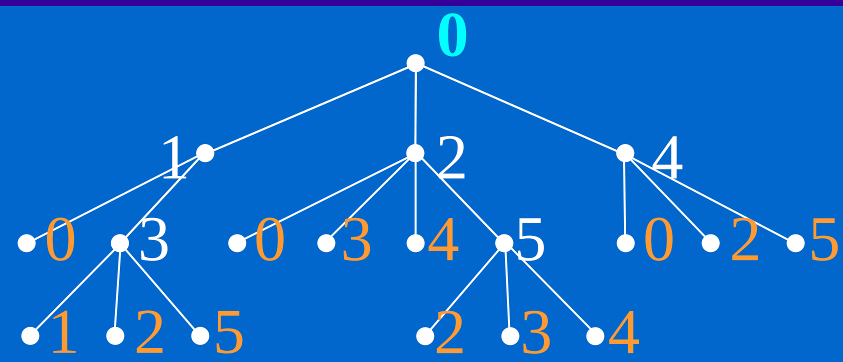
0	1	2	3	4	5
1	1	1	1	1	1

```
vi visited(N, 0);
queue<int> Q;
visited[0] = 1; Q.push(0); // start vertex is 0
while (!Q.empty()) {
    i = Q.front(); Q.pop();
    for (vi::iterator it=W[i].begin(); it!=W[i].end(); ++it)
        if (!visited[*it]) visited[*it] = 1, Q.push(*it);
}
if (find(all(visited), 0) == visited.end()) cout << "Connected\n";
```

Graph Connectivity - BFS

✧ Breadth-First Search





visited

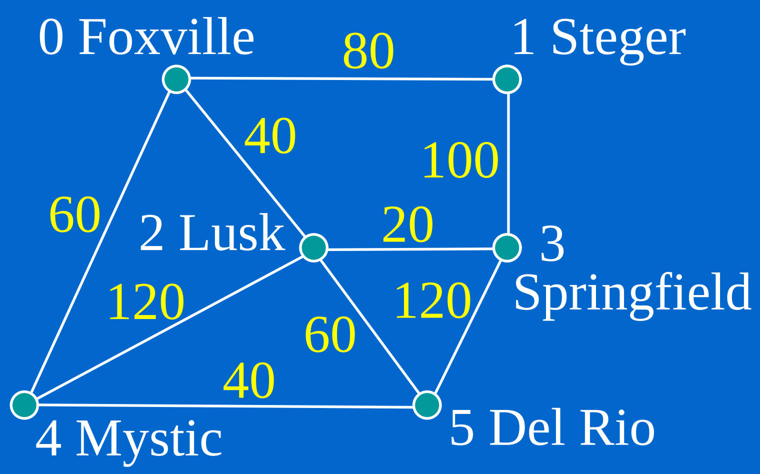
0	1	2	3	4	5
1	1	1	1	1	1

```
vi visited(N, 0);
queue<int> Q;
visited[0] = 1; Q.push(0); // start vertex is 0
while (!Q.empty()) {
   i = Q.front(); Q.pop();
   for (vi::iterator it=W[i].begin(); it!=W[i].end(); ++it)
      if (!visited[*it]) visited[*it] = 1, Q.push(*it);
}
if (find(all(visited), 0) == visited.end()) cout << "Connected\n";
```

tr (W[i], it) // only for g++

Dijkstra’s Shortest Path

```
int i, j, N = 6, w[][6][2] =
    {{{1,80},{2,40},{4,60}},
      {{0,80},{3,100}},
      {{0,40},{3,20},{4,120},{5,60}},
      {{1,100},{2,20},{5,120}},
      {{0,60},{2,120},{5,40}},
      {{2,60},{3,120},{4,40}}};
int wn[6] = {3,2,4,3,3,3};
vvii G; // weighted graph
vii tmp;
```

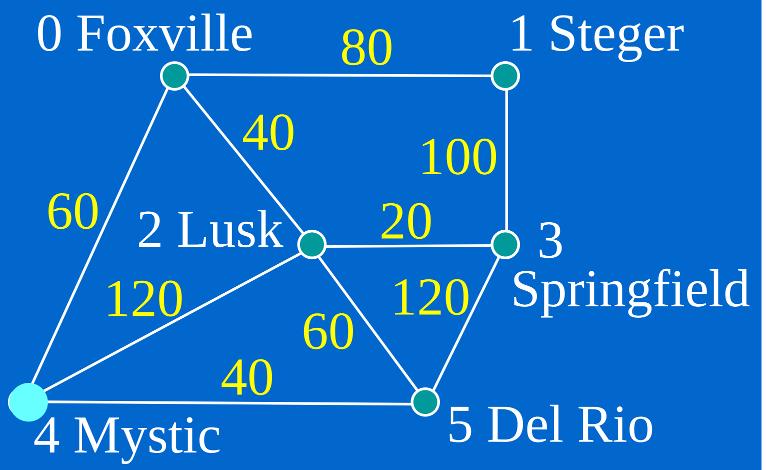



```
for (i=0; i<N; i++) {
    for (j=0; j<wn[i]; j++)
        tmp.push_back(pair<int,int>(w[i][j][0],w[i][j][1]));
    G.push_back(tmp);
}
```

Dijkstra's Shortest Path (cont'd)

- implementation with a **priority_queue**

  vi **D**(N, 0x7fffffff);   // distance from start vertex to each vertex at the moment
  priority_queue<ii,vector<ii>,greater<ii> > **Q**; // min heap

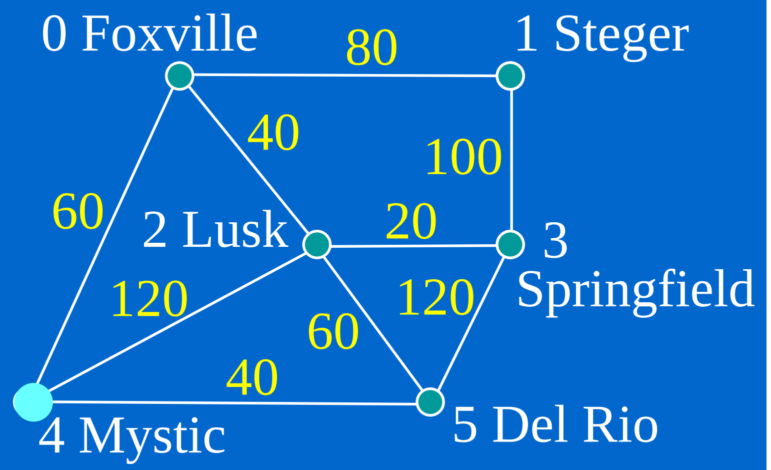


Dijkstra's Shortest Path (cont'd)

✧ implementation with a **priority_queue**

vi **D**(N, 0x7fffffff); // distance from start vertex to each vertex at the moment
priority_queue<ii,vector<ii>,greater<ii> > **Q**; // min heap

D[4] = 0; Q.push(ii(D[4],4)); // start vertex: **4**



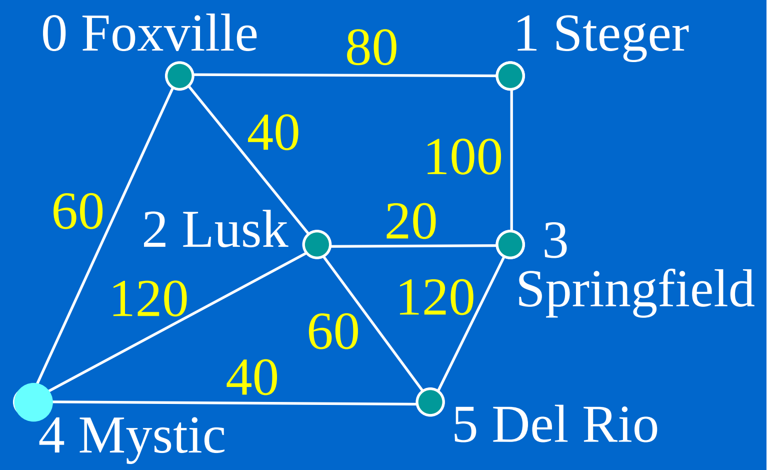
Dijkstra's Shortest Path (cont'd)

- implementation with a **priority_queue**

```
vi D(N, 0x7ffffff);    // distance from start vertex to each vertex at the moment
priority_queue<ii,vector<ii>,greater<ii> > Q; // min heap

D[4] = 0; Q.push(ii(D[4],4)); // start vertex: 4

int v, d, v2, cost;
while (!Q.empty()) {
    ii top = Q.top(); Q.pop(); // min element
    v = top.second, d = top.first;
    if (d <= D[v]) {
        cout << v << ':' << d << endl;
        for (vii::iterator it=G[v].begin(); it!=G[v].end(); ++it) {
            v2 = it->first, cost = it->second;
            if (d + cost < D[v2])
                D[v2] = d + cost, Q.push(ii(D[v2], v2));
        }
    }
}
```



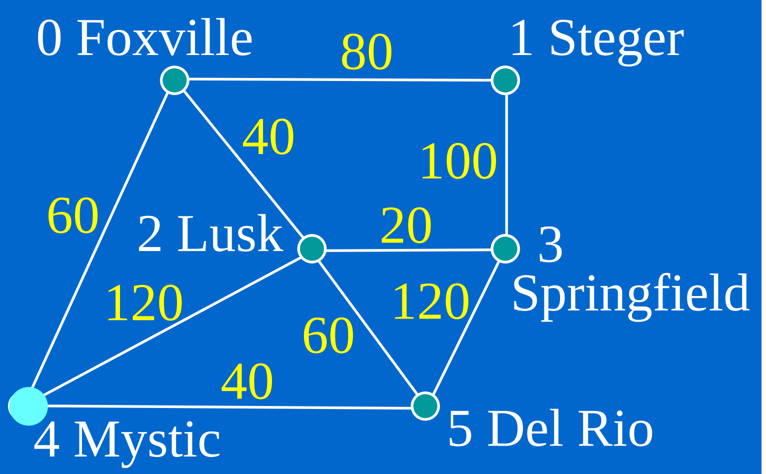
Dijkstra’s Shortest Path (cont’d)

- implementation with a **priority_queue**

```
vi D(N, 0x7ffffff);    // distance from start vertex to each vertex at the moment
priority_queue<ii,vector<ii>,greater<ii> > Q; // min heap

D[4] = 0; Q.push(ii(D[4],4)); // start vertex: 4

int v, d, v2, cost;
while (!Q.empty()) {
    ii top = Q.top(); Q.pop(); // min element
    v = top.second, d = top.first;
    if (d <= D[v]) {
        cout << v << ':' << d << endl;
        for (vii::iterator it=G[v].begin(); it!=G[v].end(); ++it) {
            v2 = it->first, cost = it->second;
            if (d + cost < D[v2])
                D[v2] = d + cost, Q.push(ii(D[v2], v2));
        }
    }
}
```



there could be multiple entries of the same vertex in the priority queue, only the one that has the least distance ever seen is considered

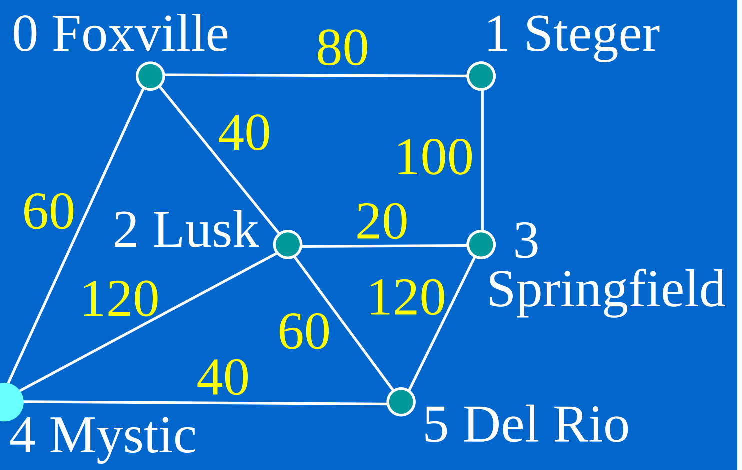
Dijkstra’s Shortest Path (cont’d)

- implementation with a **priority_queue**

```
vi D(N, 0x7ffffff);    // distance from start vertex to each vertex at the moment
priority_queue<ii,vector<ii>,greater<ii> > Q; // min heap

D[4] = 0; Q.push(ii(D[4],4)); // start vertex: 4

int v, d, v2, cost;
while (!Q.empty()) {
    ii top = Q.top(); Q.pop(); // min element
    v = top.second, d = top.first;
    if (d <= D[v]) {
        cout << v << ':' << d << endl;
        for (vii::iterator it=G[v].begin(); it!=G[v].end(); ++it) {
            v2 = it->first, cost = it->second;
            if (d + cost < D[v2])
                D[v2] = d + cost, Q.push(ii(D[v2], v2));
        }
    }
}
```



4:0
5:40
0:60
2:100
3:120
1:140

there could be multiple entries of the same vertex in the priority queue, only the one that has the least distance ever seen is considered

Dijkstra's Shortest Path (cont'd)

- implementation with **set**

```
vi D(N, 0x7fffffff);    // distance from start vertex to each vertex at the moment
set<ii> S;  set<ii>::iterator itS;
```

Dijkstra’s Shortest Path (cont’d)

- implementation with **set**

```
vi D(N, 0x7fffffff);    // distance from start vertex to each vertex at the moment
set<ii> S;  set<ii>::iterator itS;
D[4] = 0; S.insert(ii(D[4],4)); // start vertex: 4
```

Dijkstra's Shortest Path (cont'd)

- implementation with **set**

```
vi D(N, 0x7fffffff);    // distance from start vertex to each vertex at the moment

set<ii> S;  set<ii>::iterator itS;

D[4] = 0; S.insert(ii(D[4],4)); // start vertex: 4

while (!S.empty()) {
    ii top = *(S.begin()); S.erase(S.begin()); // min element
    int v = top.second, d = top.first;
    cout << v << ':' << d << endl;
    for (vii::iterator it=G[v].begin(); it!=G[v].end(); ++it) {
        int v2 = it->first, cost = it->second;
        if (D[v2] > d + cost) { // d==D[v] actually
            if ((D[v2]!=0x7fffffff)&&(itS=S.find(ii(D[v2],v2)))!=S.end()))
                S.erase(itS);
            D[v2] = d + cost; S.insert(ii(D[v2], v2));
        }
    }
}
```

Dijkstra's Shortest Path (cont'd)

- implementation with **set**

```
vi D(N, 0x7fffffff);    // distance from start vertex to each vertex at the moment
set<ii> S;  set<ii>::iterator itS;
D[4] = 0; S.insert(ii(D[4],4)); // start vertex: 4
while (!S.empty()) {
    ii top = *(S.begin()); S.erase(S.begin()); // min element
    int v = top.second, d = top.first;
    cout << v << ':' << d << endl;
    for (vii::iterator it=G[v].begin(); it!=G[v].end(); ++it) {
        int v2 = it->first, cost = it->second;
        if (D[v2] > d + cost) { // d==D[v] actually
            if ((D[v2]!=0x7fffffff)&&(itS=S.find(ii(D[v2],v2)))!=S.end()))
                S.erase(itS);
            D[v2] = d + cost; S.insert(ii(D[v2], v2));
        }
    }
}
```

might be erased earlier

Dijkstra's Shortest Path (cont'd)

- implementation with **set**

```
vi D(N, 0x7ffffff);    // distance from start vertex to each vertex at the moment

set<ii> S;  set<ii>::iterator itS;

D[4] = 0; S.insert(ii(D[4],4)); // start vertex: 4

while (!S.empty()) {
   ii top = *(S.begin()); S.erase(S.begin()); // min element
   int v = top.second, d = top.first;
   cout << v << ':' << d << endl;
   for (vii::iterator it=G[v].begin(); it!=G[v].end(); ++it) {
      int v2 = it->first, cost = it->second;
      if (D[v2] > d + cost) { // d==D[v] actually
         if ((D[v2]!=0x7ffffff)&&(itS=S.find(ii(D[v2],v2)))!=S.end()))
            S.erase(itS);
         D[v2] = d + cost; S.insert(ii(D[v2], v2));
      }
   }
}
```

might be erased earlier

guarantees no duplicated entry with the same vertex in the set

Dijkstra's Shortest Path (cont'd)

- implementation with **set**

```
vi D(N, 0x7ffffff);    // distance from start vertex to each vertex at the moment
set<ii> S;  set<ii>::iterator itS;
D[4] = 0; S.insert(ii(D[4],4)); // start vertex: 4
while (!S.empty()) {
   ii top = *(S.begin()); S.erase(S.begin()); // min element
   int v = top.second, d = top.first;
   cout << v << ':' << d << endl;
   for (vii::iterator it=G[v].begin(); it!=G[v].end(); ++it) {
      int v2 = it->first, cost = it->second;
      if (D[v2] > d + cost) { // d==D[v] actually
         if ((D[v2]!=0x7ffffff)&&(itS=S.find(ii(D[v2],v2)))!=S.end()))
            S.erase(itS);
         D[v2] = d + cost; S.insert(ii(D[v2], v2));
      }
   }
}
```

4:0
5:40
0:60
2:100
3:120
1:140

might be erased earlier

guarantees no duplicated entry with the same vertex in the set

References

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