Creative Software Design

7 – Standard Template Library

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Fall 2022

Midterm Exam

- Date & time: **Oct 18, 09:30 - 10:30 am**
- Place: **IT.BT 207**
- Scope: Lecture 2 ~ 7

- **You cannot leave until 30 minutes after the start of the exam** even if you finish the exam earlier.

- That means, **you cannot enter the room after 30 minutes from the start of the exam** (do not be late, never too late!).

- Please bring your **student ID card** to the exam.

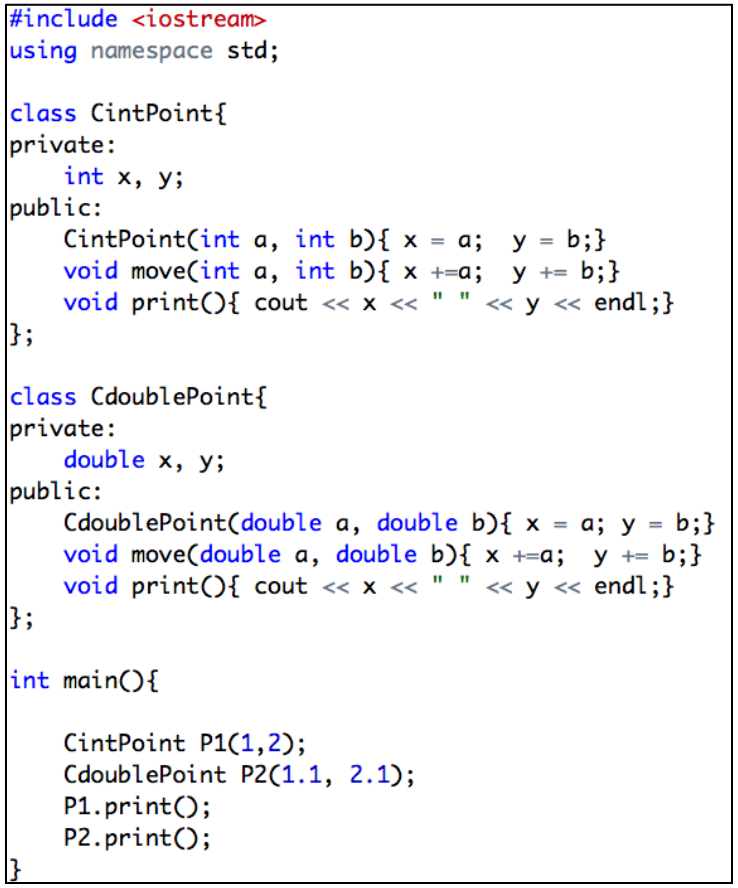
- Problem types: true/false, single choice, multiple choices, short answer, fill-in-blank, ...

Today's Topics

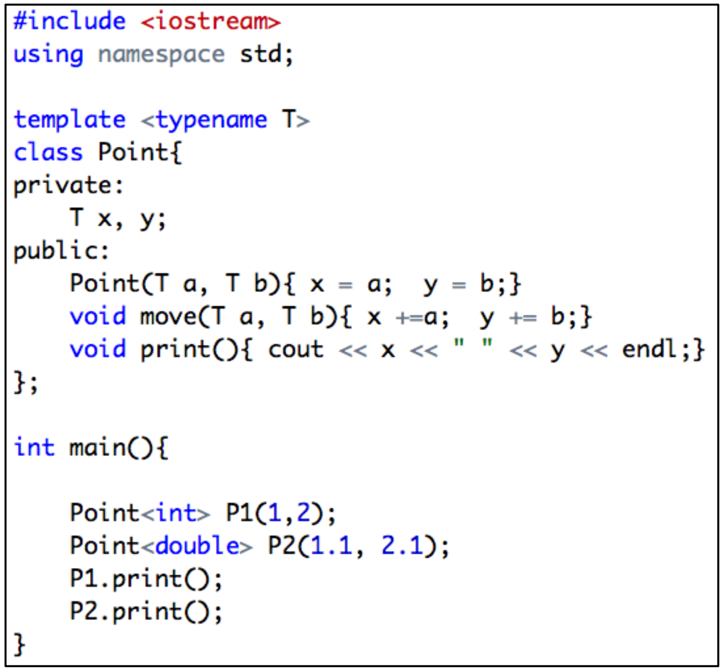
- Intro to C++ Template (briefly)
- STL (Standard Template Library)
- Containters
  - std::vector, std::list
  - std::stack, std::queue
  - std::set, std::map
- Iterator
- Algorithm
- std::string

C++ Template

- Functions and classes can be "templated".
- This allows a function or class to **work on many different data types without being rewritten** for each one.



```cpp
#include <iostream>
using namespace std;

class CintPoint{
private:
    int x, y;
public:
    CintPoint(int a, int b){ x = a;  y = b;}
    void move(int a, int b){ x +=a;  y += b;}
    void print(){ cout << x << " " << y << endl;}
};

class CdoublePoint{
private:
    double x, y;
public:
    CdoublePoint(double a, double b){ x = a; y = b;}
    void move(double a, double b){ x +=a;  y += b;}
    void print(){ cout << x << " " << y << endl;}
};

int main(){

    CintPoint P1(1,2);
    CdoublePoint P2(1.1, 2.1);
    P1.print();
    P2.print();
}
```



```cpp
#include <iostream>
using namespace std;

template <typename T>
class Point{
private:
    T x, y;
public:
    Point(T a, T b){ x = a;  y = b;}
    void move(T a, T b){ x +=a;  y += b;}
    void print(){ cout << x << " " << y << endl;}
};

int main(){

    Point<int> P1(1,2);
    Point<double> P2(1.1, 2.1);
    P1.print();
    P2.print();
}
```

An example of class template

Standard Template Library (STL)

- STL defines powerful, template-based, reusable components.
- A collection of useful template for handling various kinds of data structure and algorithms
  - Containers: data structures that store objects of any type
  - Iterators: used to manipulate container elements
  - Algorithms: operations on containers for searching, sorting and many others

Containers

- Sequential container, Container adaptor, Associative container

- Sequential container
  - Elements are accessed by their "position" in the sequence.
  - **std::vector** - fast insertion at end, random access
  - **std::list** - fast insertion anywhere, sequential access
  - **std::deque** (double-ended queue) - fast insertion at either end, random access

accessing any element in the container has the same cost as any other element

increasing cost associated with an elements position in the container (e.g. accessing the 5th element is 5 times the cost of accessing the first element)

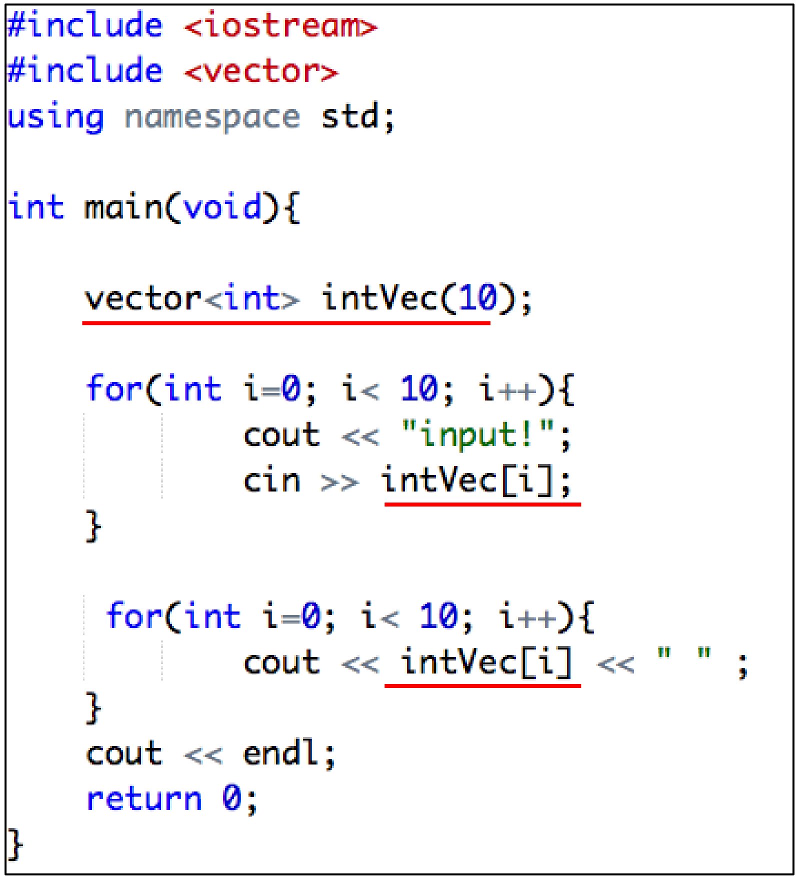
- Container adapter
  - "Adapting" the interface of underlying container to provide the desired behavior.
  - **std::stack** - Last In First Out (based on std::deque by default)
  - **std::queue** - First In First Out (based on std::deque by default)

Containers

- Associative container
  - Elements are **referenced by their key** and not by their absolute position in the container, and always **sorted by keys**.
  - **std::map** - a mapping from one type (key) to another type (value) (each key in the container is unique)
  - **std::set** - stores data as key (each key in the container is unique), fast adding or deleting elements, querying for membership…

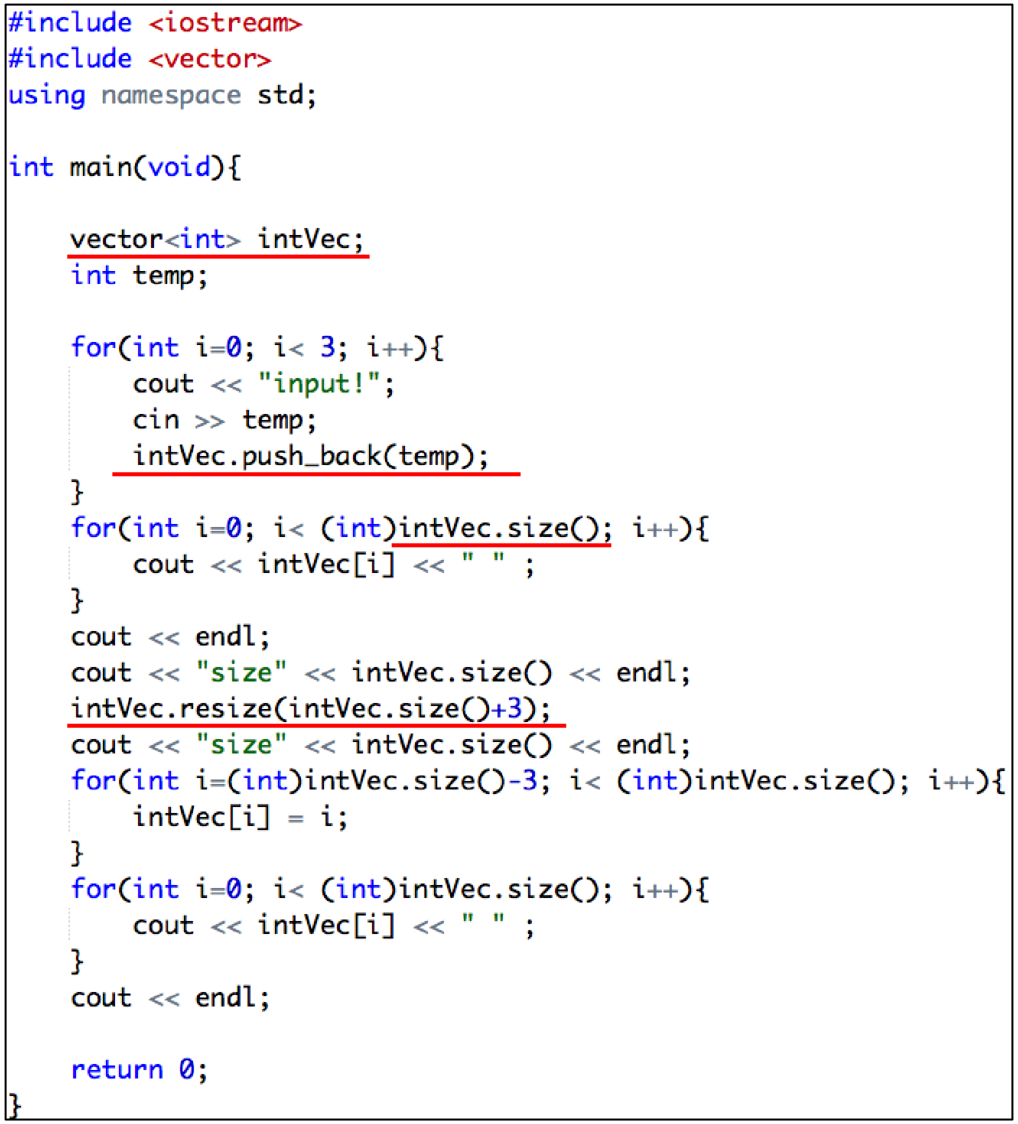
- There are a few more containers in STL, but this course covers only the most popular ones.

std::vector - a resizable array



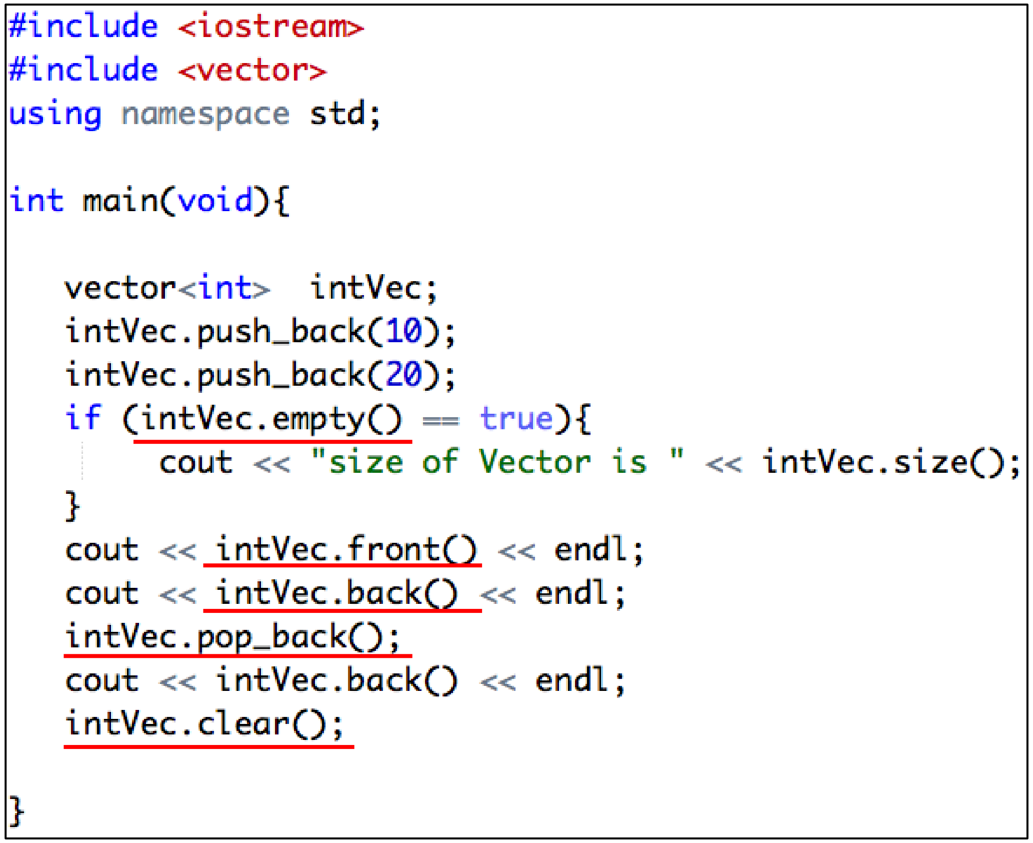
```
#include <iostream>
#include <vector>
using namespace std;

int main(void){

    vector<int> intVec(10);

    for(int i=0; i< 10; i++){
            cout << "input!";
            cin >> intVec[i];
    }

     for(int i=0; i< 10; i++){
            cout << intVec[i] << " " ;
    }
    cout << endl;
    return 0;
}
```

std::vector - a resizable array



```cpp
#include <iostream>
#include <vector>
using namespace std;

int main(void){

    vector<int> intVec;
    int temp;

    for(int i=0; i< 3; i++){
        cout << "input!";
        cin >> temp;
        intVec.push_back(temp);
    }
    for(int i=0; i< (int)intVec.size(); i++){
        cout << intVec[i] << " " ;
    }
    cout << endl;
    cout << "size" << intVec.size() << endl;
    intVec.resize(intVec.size()+3);
    cout << "size" << intVec.size() << endl;
    for(int i=(int)intVec.size()-3; i< (int)intVec.size(); i++){
        intVec[i] = i;
    }
    for(int i=0; i< (int)intVec.size(); i++){
        cout << intVec[i] << " " ;
    }
    cout << endl;

    return 0;
}
```

std::vector - a resizable array



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

int main(void){

   vector<int>  intVec;
   intVec.push_back(10);
   intVec.push_back(20);
   if (intVec.empty() == true){
        cout << "size of Vector is " << intVec.size();
   }
   cout << intVec.front() << endl;
   cout << intVec.back() << endl;
   intVec.pop_back();
   cout << intVec.back() << endl;
   intVec.clear();

}
```

std::vector - a resizable array

- You can make a vector of strings or other classes.

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

struct Complex { double real, imag; /* ... */ };

// ...
vector<string> vs;
for (int i = 0; i < 10; ++i) cin >> vs[i];
// vector(size, initial_value)
vector<string> vs2(5, "hello world");

vector<Complex> v1(10);
vector<Complex> v2(10, Complex(1.0, 0.0));
Complex c(0.0, 0.0);
v2.push_back(c);
for (int i = 0; i < v2.size(); ++i) {
  cout << v2[i].real << "+" << v2[i].imag << "i" << endl;
}
```

std::vector - a resizable array

- Sometimes you may want to use a vector of pointers.

```cpp
#include <vector>
using namespace std;

class Student;

vector<Student*> vp(10, NULL);
for (int i = 0; i < vp.size(); ++i) {
  vp[i] = new Student;
}

// After using vp, all elements need to be deleted.

for (int i = 0; i < vp.size(); ++i) delete vp[i];
vp.clear();
```

std::vector

- Element are stored in contiguous storage, like an array.
- Random access (by index): Fast access to any element
- Fast addition/removal of elements at the **end** of the sequence.
- Much more flexible and powerful than array. **From now on, use std::vector instead of array.**
  – https://www.stroustrup.com/bs_faq2.html#arrays

References for STL

- std::vector
  - http://www.cplusplus.com/reference/vector/vector/

- STL containers
  - http://www.cplusplus.com/reference/stl/

- You can find documents for any other STL features in these links.

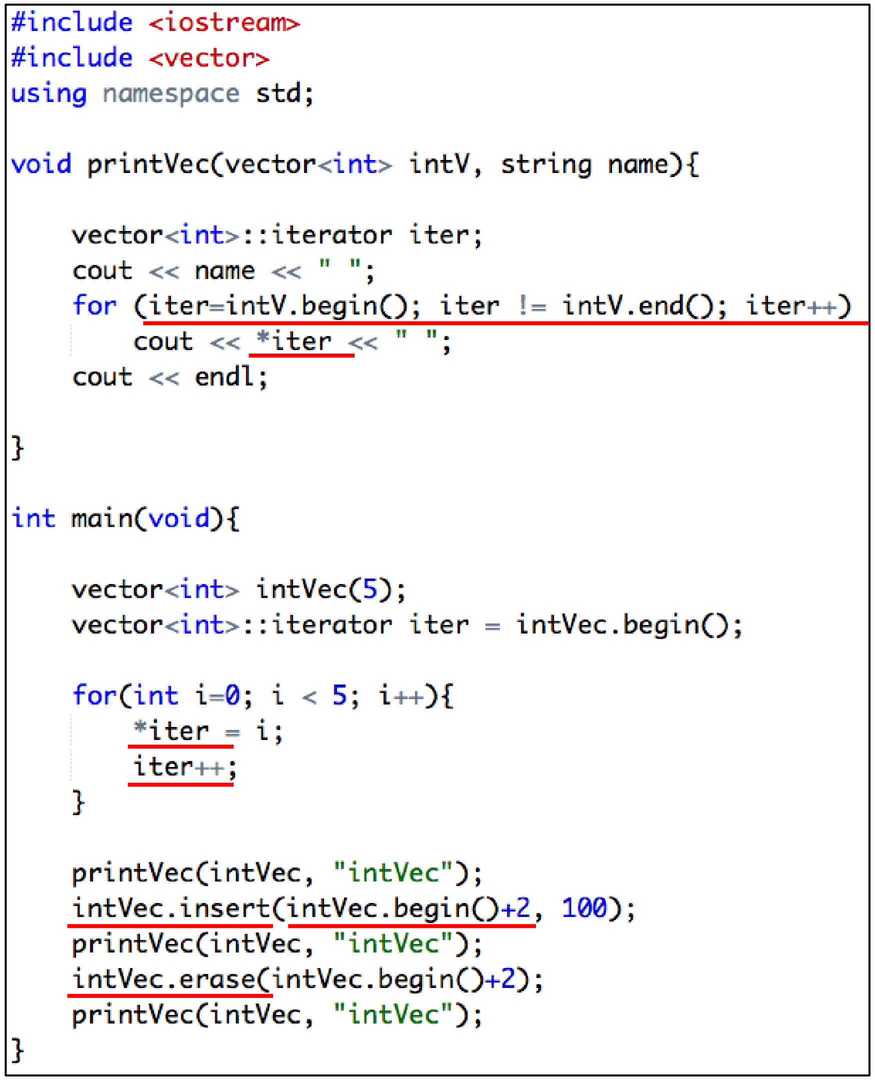
Iterator

- Iterator: a pointer-like object **pointing to** an element in a container.

- Iterators provide **a generalized way** to traverse and access elements stored in a container.
  - can be ++ or -- (move to next or prev element)
  - dereferenced with *
  - compared against another iterator with == or !=

- Iterators are generated by STL container member functions, such as begin() and end().

std::vector with iterator

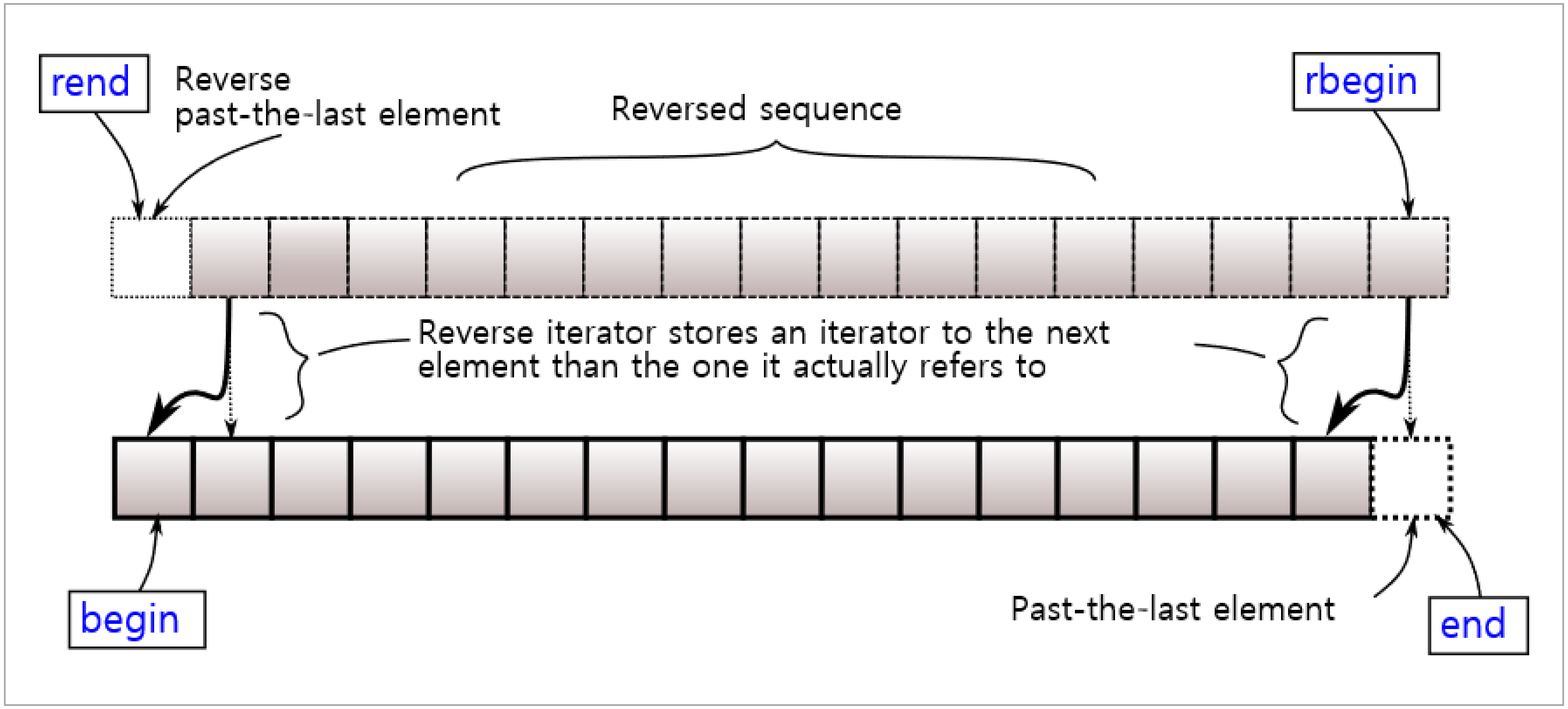


```cpp
#include <iostream>
#include <vector>
using namespace std;

void printVec(vector<int> intV, string name){

    vector<int>::iterator iter;
    cout << name << " ";
    for (iter=intV.begin(); iter != intV.end(); iter++)
        cout << *iter << " ";
    cout << endl;

}

int main(void){

    vector<int> intVec(5);
    vector<int>::iterator iter = intVec.begin();

    for(int i=0; i < 5; i++){
        *iter = i;
        iter++;
    }

    printVec(intVec, "intVec");
    intVec.insert(intVec.begin()+2, 100);
    printVec(intVec, "intVec");
    intVec.erase(intVec.begin()+2);
    printVec(intVec, "intVec");
}
```

std::vector with iterator

```cpp
#include <vector>
#include <iostream>
using namespace std;

int main(void) {
// vector(sz)
vector<int> v(10);
for (int i = 0; i < v.size(); ++i) v[i] = i;

// begin(), end()
for (vector<int>::iterator it = v.begin(); it != v.end(); ++it) {
  cout << " " << *it;
}
// Output:  0 1 2 3 4 5 6 7 8 9

// rbegin(), rend()
for (vector<int>::reverse_iterator it = v.rbegin(); it != v.rend(); ++it) {
  cout << " " << *it;
}
// Output:  9 8 7 6 5 4 3 2 1 0
}
```

Meaning of begin(), end(), rbegin(), rend()


rend
Reverse
past-the-last element
Reversed sequence
rbegin
Reverse iterator stores an iterator to the next element than the one it actually refers to
begin
Past-the-last element
end

Quiz #1

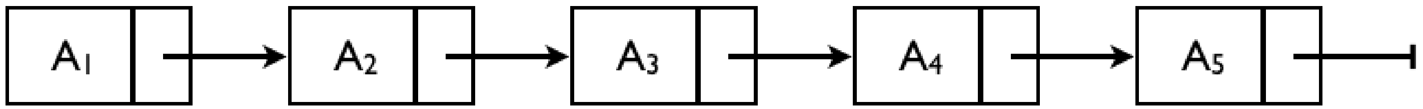
- Go to https://www.slido.com/
- Join #**csd-ys**
- Click "Polls"

- Submit your answer in the following format:
  - **Student ID: Your answer**
  - **e.g. 2017123456: 4)**

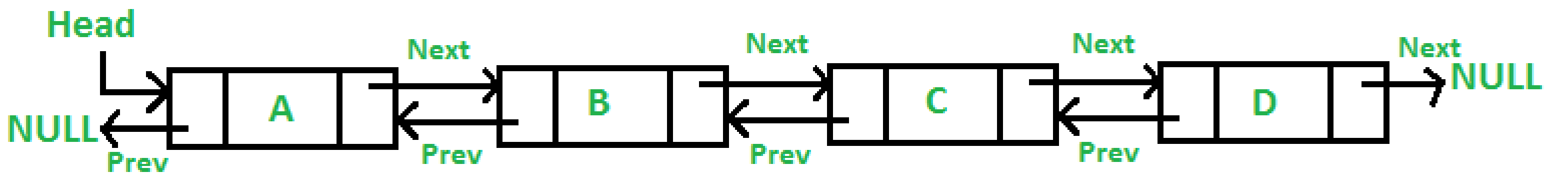
- Note that you must submit all quiz answers **in this format** to be counted as attendance.

Concept of Linked List

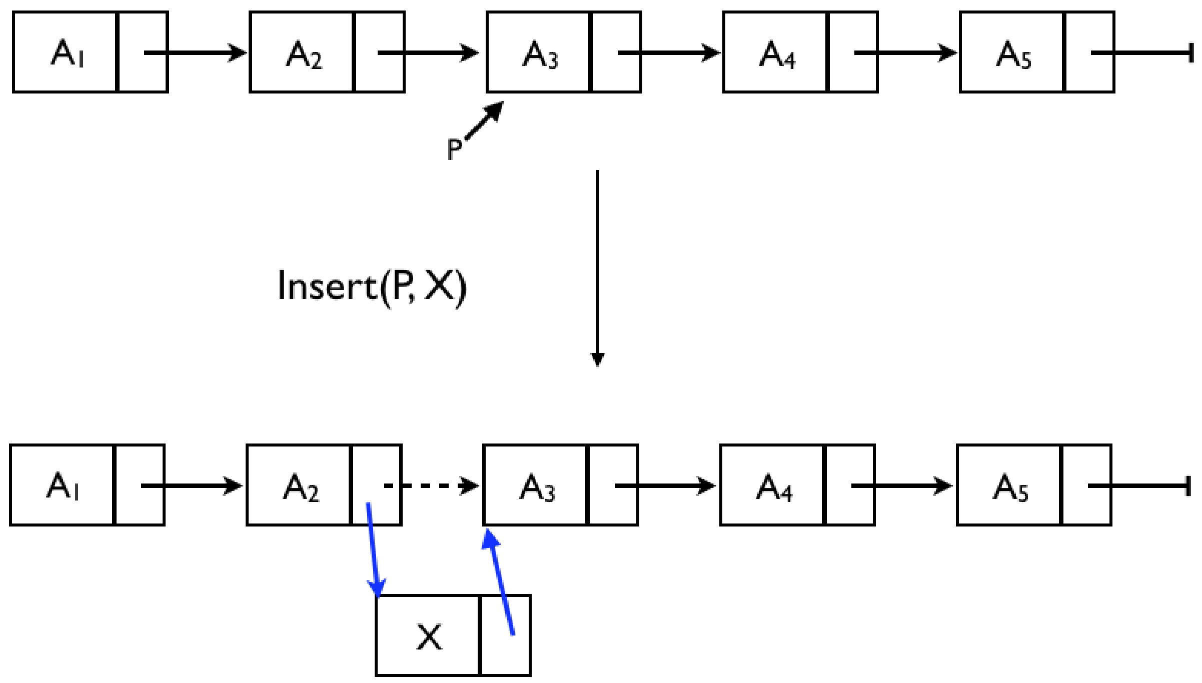
- Singly linked list: A node consists of the data and a link to the next node.

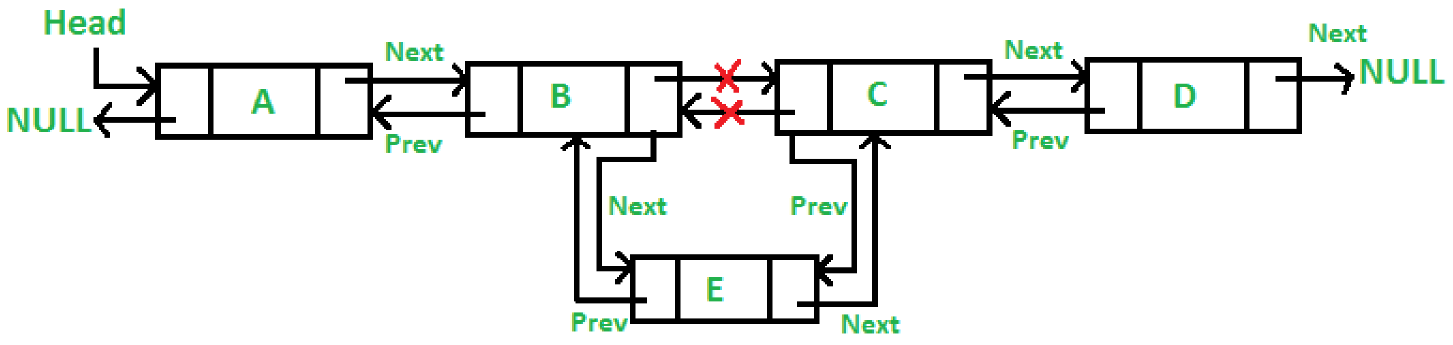


- Doubly linked list: with links to prev. & next node.

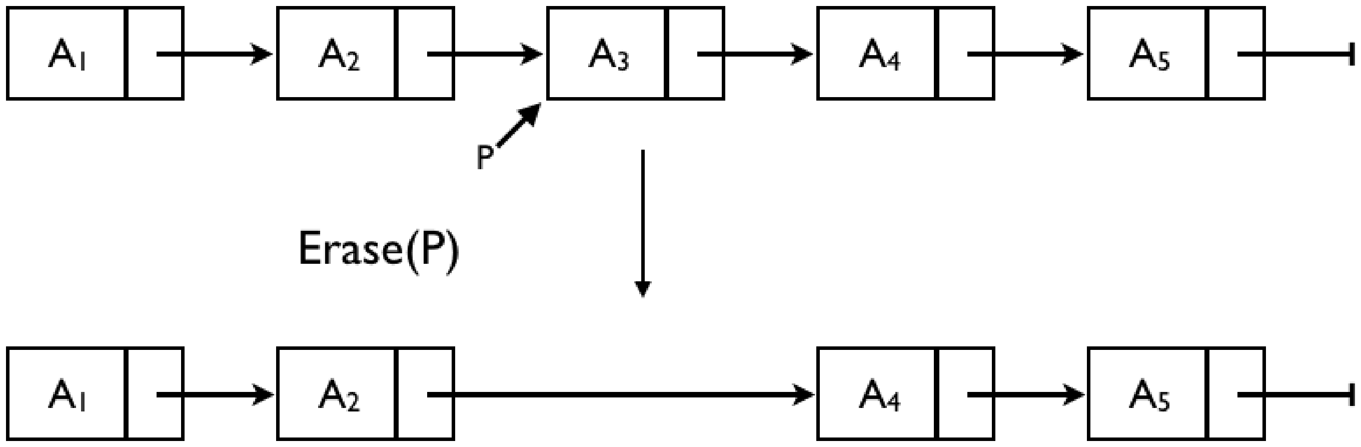


Concept of Linked List: insert





Concept of Linked List: erase



std::list

- Implemented as a doubly-linked list.
  - Non-contiguous storage.
- Sequential access
  - One should iterate from a known position (like begin() or end()) to access to some element.
- Fast addition/removal of elements **anywhere** in the container.

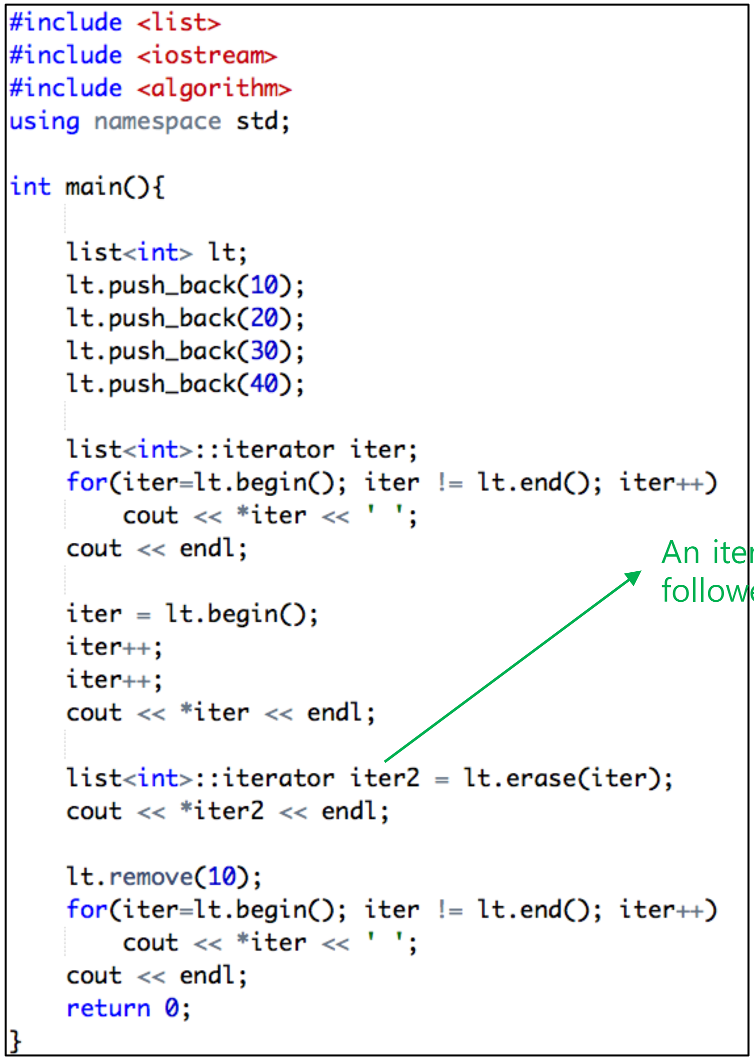
std::list – an insert and erase example

```cpp
void printList(list<int> intV){

    list<int>::iterator iter;
    for (iter = intV.begin(); iter != intV.end(); iter++){
        cout << *iter << " ";
    }
    cout << endl;
}

int main(){

    list<int> intL(5);
    list<int>::iterator iter = intL.begin() ;
    for (int i=0; i < 5; i++){
        *iter = i;
        iter++;
    }
    printList(intL);

    iter = intL.begin();
    iter++;
    iter = intL.insert(iter, 100);
    printList(intL);

    iter++; iter++;
    cout << *iter << endl;
    intL.erase(iter);
    printList(intL);

    return 0;
}
```

An iterator that points to the first of the newly inserted elements.

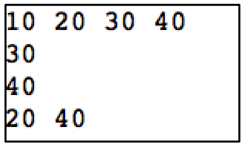
```
0 1 2 3 4
0 100 1 2 3 4
2
0 100 1 3 4
```

std::list – an erase and remove example



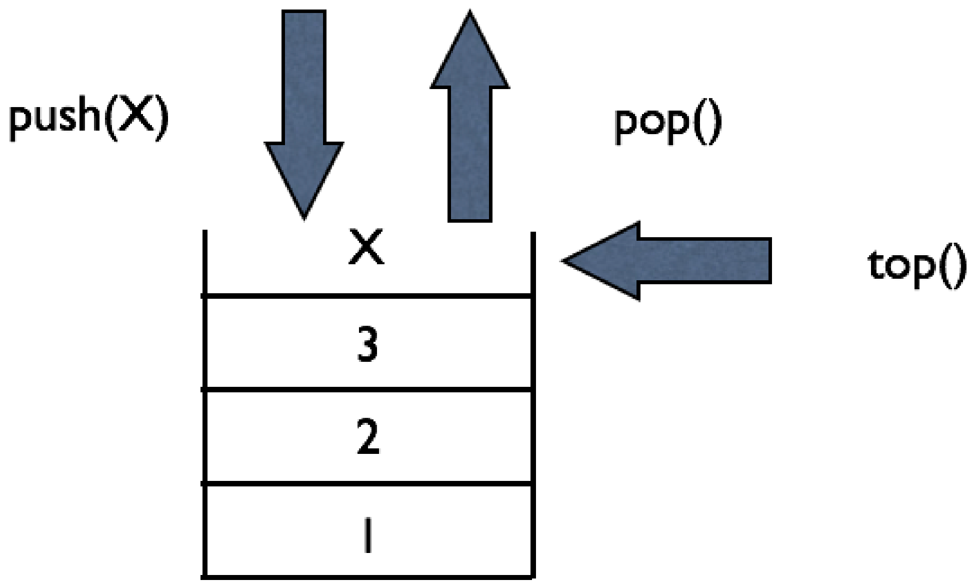
```
#include <list>
#include <iostream>
#include <algorithm>
using namespace std;

int main(){

    list<int> lt;
    lt.push_back(10);
    lt.push_back(20);
    lt.push_back(30);
    lt.push_back(40);

    list<int>::iterator iter;
    for(iter=lt.begin(); iter != lt.end(); iter++)
        cout << *iter << ' ';
    cout << endl;

    iter = lt.begin();
    iter++;
    iter++;
    cout << *iter << endl;

    list<int>::iterator iter2 = lt.erase(iter);
    cout << *iter2 << endl;

    lt.remove(10);
    for(iter=lt.begin(); iter != lt.end(); iter++)
        cout << *iter << ' ';
    cout << endl;
    return 0;
}
```

An iterator pointing to the new location of the element that followed the last element erased by the function call.

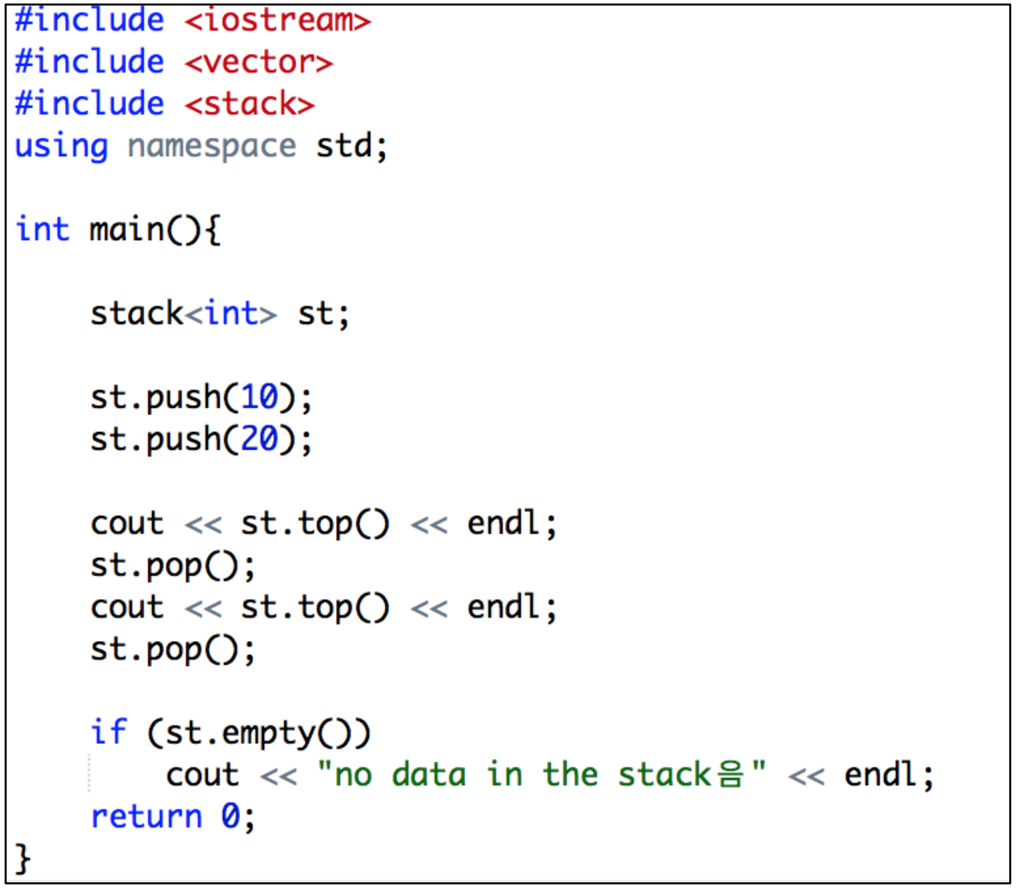


```
10 20 30 40
30
40
20 40
```

Concept of Stack : Last In First Out

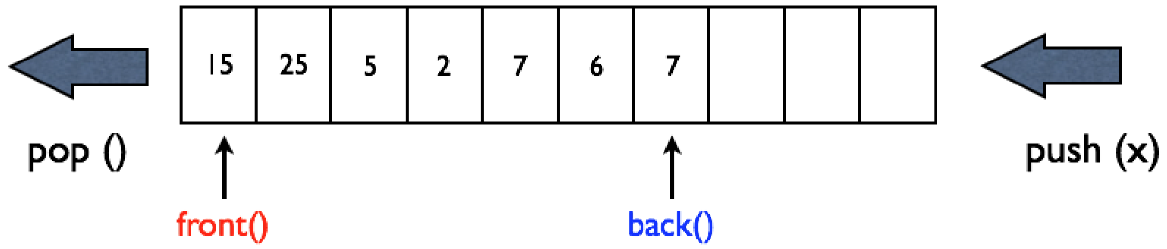


std::stack - example

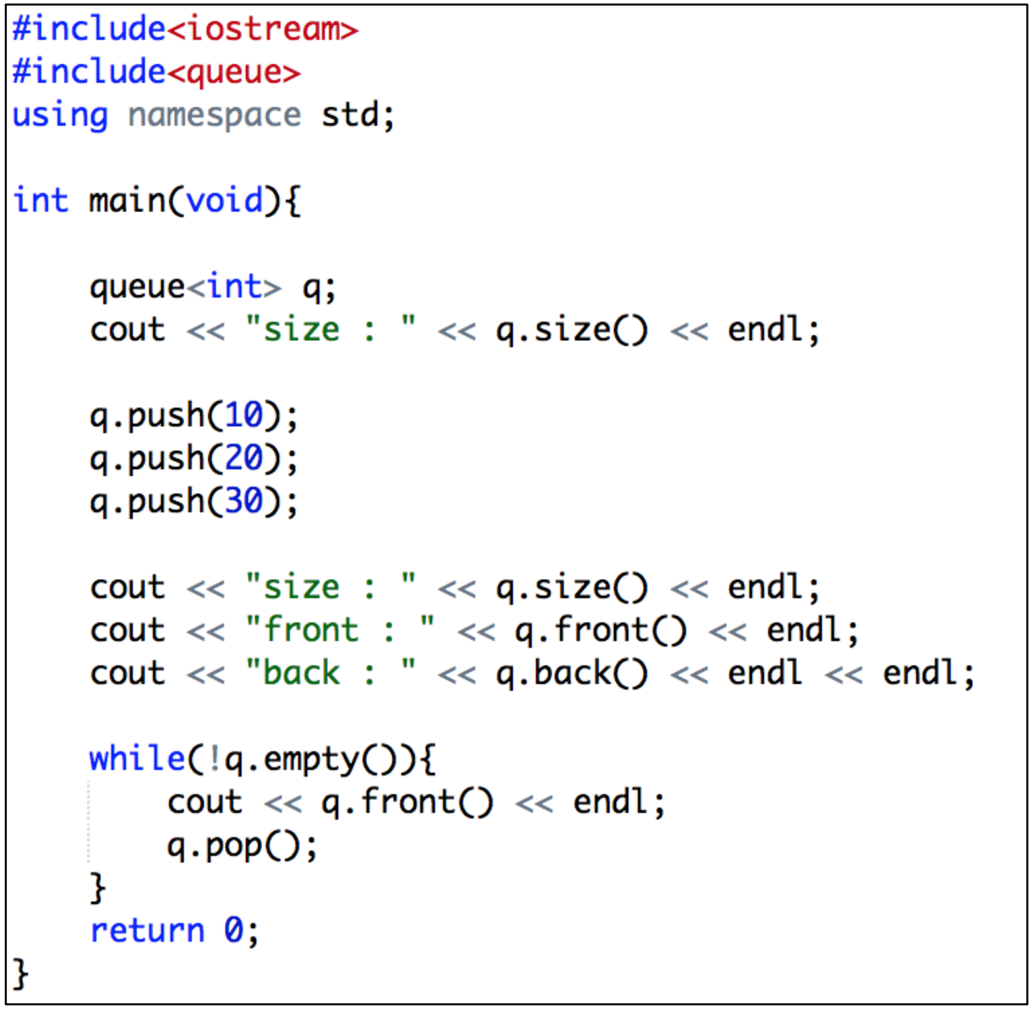


```
#include <iostream>
#include <vector>
#include <stack>
using namespace std;

int main(){

    stack<int> st;

    st.push(10);
    st.push(20);

    cout << st.top() << endl;
    st.pop();
    cout << st.top() << endl;
    st.pop();

    if (st.empty())
        cout << "no data in the stack음" << endl;
    return 0;
}
```

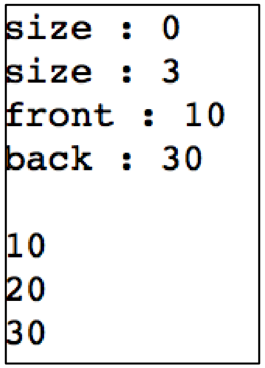
Concept of Queue : First In First Out



std::queue - example



```
#include<iostream>
#include<queue>
using namespace std;

int main(void){

    queue<int> q;
    cout << "size : " << q.size() << endl;

    q.push(10);
    q.push(20);
    q.push(30);

    cout << "size : " << q.size() << endl;
    cout << "front : " << q.front() << endl;
    cout << "back : " << q.back() << endl << endl;

    while(!q.empty()){
        cout << q.front() << endl;
        q.pop();
    }
    return 0;
}
```



```
size : 0
size : 3
front : 10
back : 30

10
20
30
```

Table for STL Sequential Containers

	vector	**list**	**stack**	**queue**	**deque**
Random access	operator[] at()	-	-	-	operator[] at()

Sequential access	front()
	back()
		front()
		back()
			top()	front()
				back()
					front()
					back()

Iterators	begin(), end()
	rbegin(), rend()
		begin(), end()
		rbegin(), rend()
			-	-	begin(), end()
					rbegin(), rend()

Adding elements	push_back()
	insert()
		push_front()
		push_back()
		insert()
			push()	push()	push_front()
					push_back()
					insert()

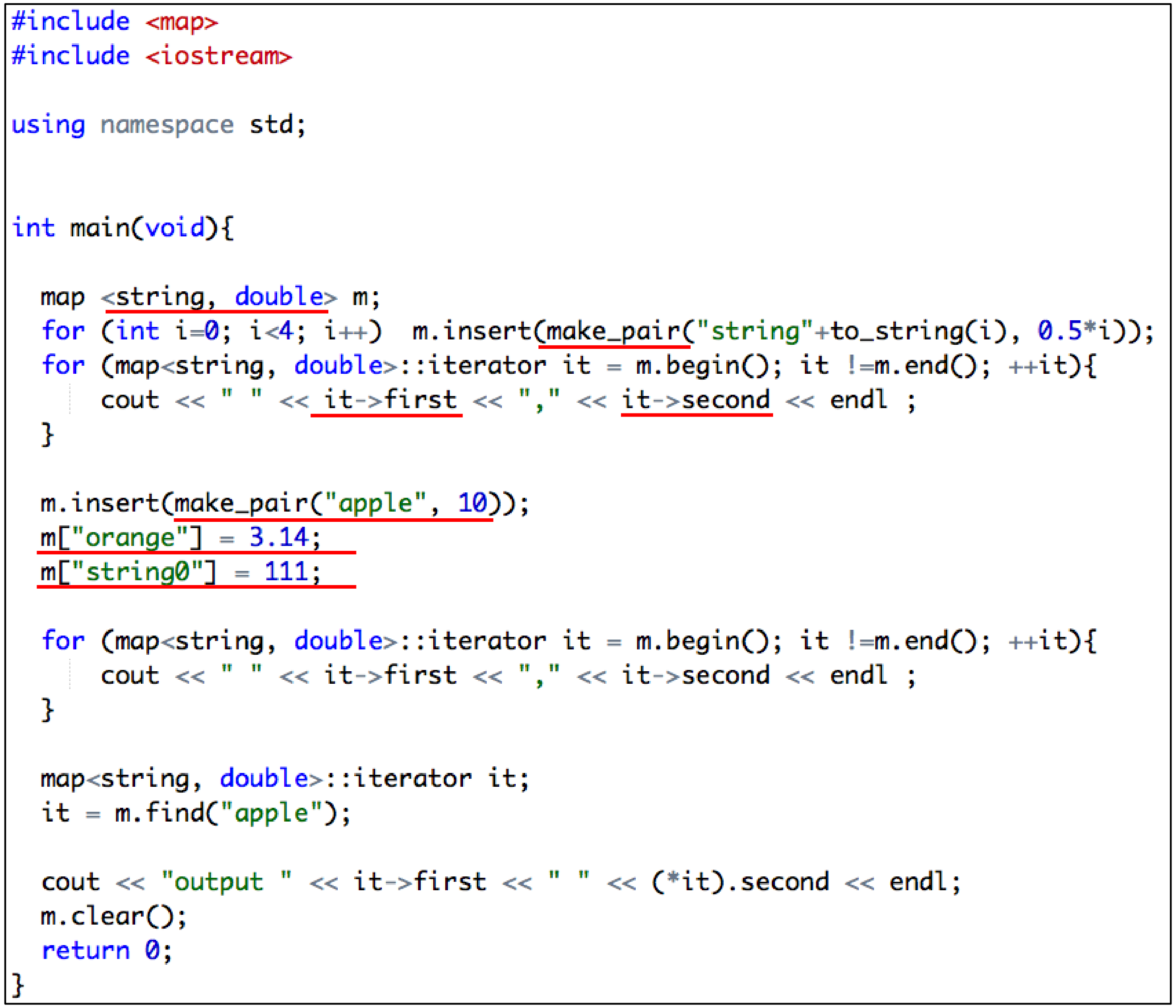
Deleting elements	pop_back()
	erase()
	clear()
		pop_front()
		pop_back()
		erase()
		clear()
			pop()	pop()	pop_front()
					pop_back()
					erase()
					clear()

Adjusting size	resize()
	reserve()
		resize()	-	-	resize()

std::map

- Contains **key-value pairs** with **unique keys**.
- Associative: Elements are referenced by their key, and always sorted by keys.
- Accessing with keys is efficient.

std::map - example



```
#include <map>
#include <iostream>

using namespace std;


int main(void){

  map <string, double> m;
  for (int i=0; i<4; i++)  m.insert(make_pair("string"+to_string(i), 0.5*i));
  for (map<string, double>::iterator it = m.begin(); it !=m.end(); ++it){
      cout << " " << it->first << "," << it->second << endl ;
  }

  m.insert(make_pair("apple", 10));
  m["orange"] = 3.14;
  m["string0"] = 111;

  for (map<string, double>::iterator it = m.begin(); it !=m.end(); ++it){
      cout << " " << it->first << "," << it->second << endl ;
  }

  map<string, double>::iterator it;
  it = m.find("apple");

  cout << "output " << it->first << " " << (*it).second << endl;
  m.clear();
  return 0;
}
```

std::set

- Contains **unique keys**.
- Associative: Elements are referenced by their key, and always sorted by keys.
- Accessing with keys is efficient.

std::set - example

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

set<int> s;
for (int i = 0; i < 10; ++i) s.insert(i * 10);

for (set<int>::const_iterator it = s.begin(); it != s.end(); ++it) {
  cout << " " << *it; // s: 0 10 20 30 40 50 60 70 80 90
}
cout << s.size();
cout << s.empty();

set<int>::iterator it, it_low, it_up;
it = s.find(123); // it == s.end()
                                 // s: 0 10 20 30 40 50 60 70 80 90
it = s.find(50);                 //                    ^it
s.clear();                       // s:
```

Quiz #2

- Go to https://www.slido.com/
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- Click "Polls"

- Submit your answer in the following format:
  - **Student ID: Your answer**
  - **e.g. 2017123456: 4)**

- Note that you must submit all quiz answers **in this format** to be counted as attendance.

Iterator again

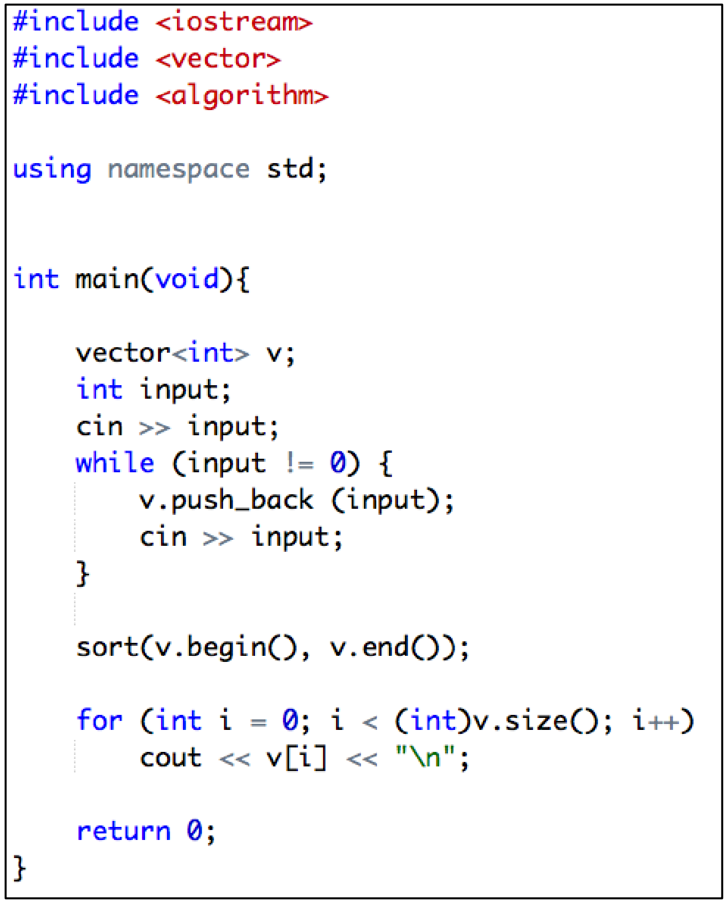
- Iterators provide **a generalized way** to traverse and access elements stored in a container (regardless of the container type).
- Iterators serve as **an interface** for various kinds of containers.
- Passing and returning iterators makes an algorithms more generic, because the algorithms will work for **any** containers.

Algorithm

- Many useful algorithms are available
  - sort
  - min, max, min_element, max_element
  - binary_search

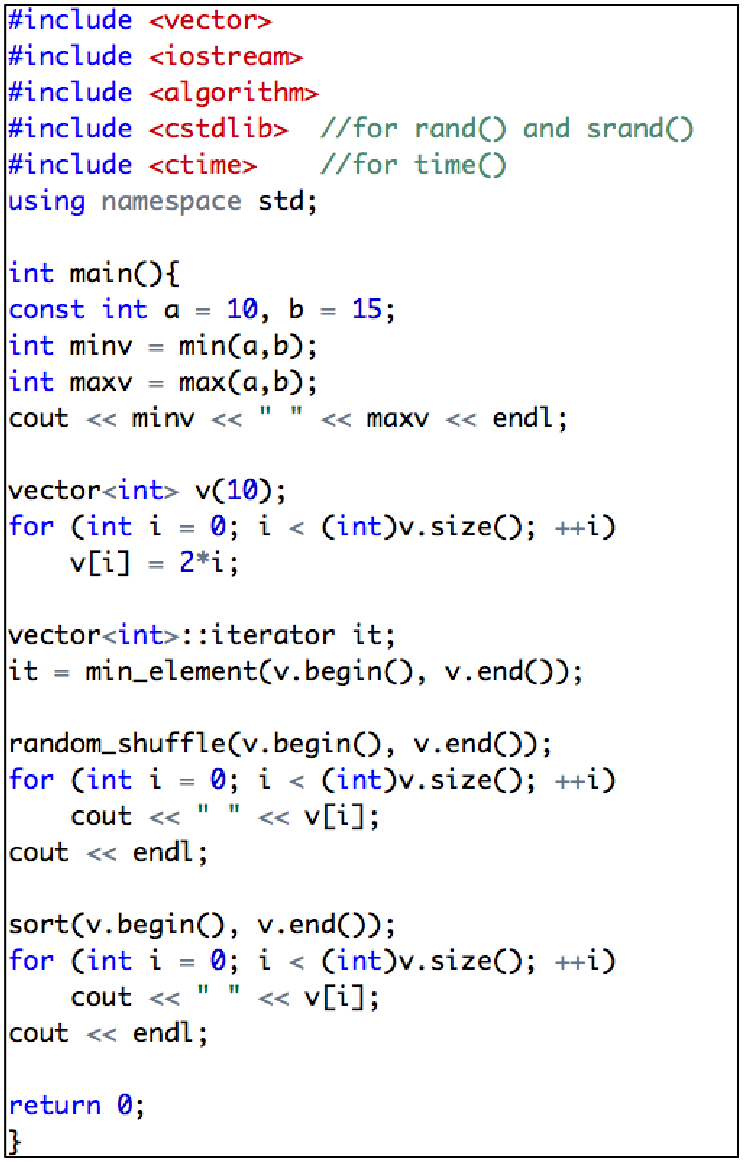
std::sort

void sort(RandomAccessIterator first, RandomAccessIterator last);
Void sort(RandomAccessIterator first, RandomAccessIterator last, Compare comp)



```cpp
#include <iostream>
#include <vector>
#include <algorithm>

using namespace std;


int main(void){

    vector<int> v;
    int input;
    cin >> input;
    while (input != 0) {
        v.push_back (input);
        cin >> input;
    }

    sort(v.begin(), v.end());

    for (int i = 0; i < (int)v.size(); i++)
        cout << v[i] << "\n";

    return 0;
}
```

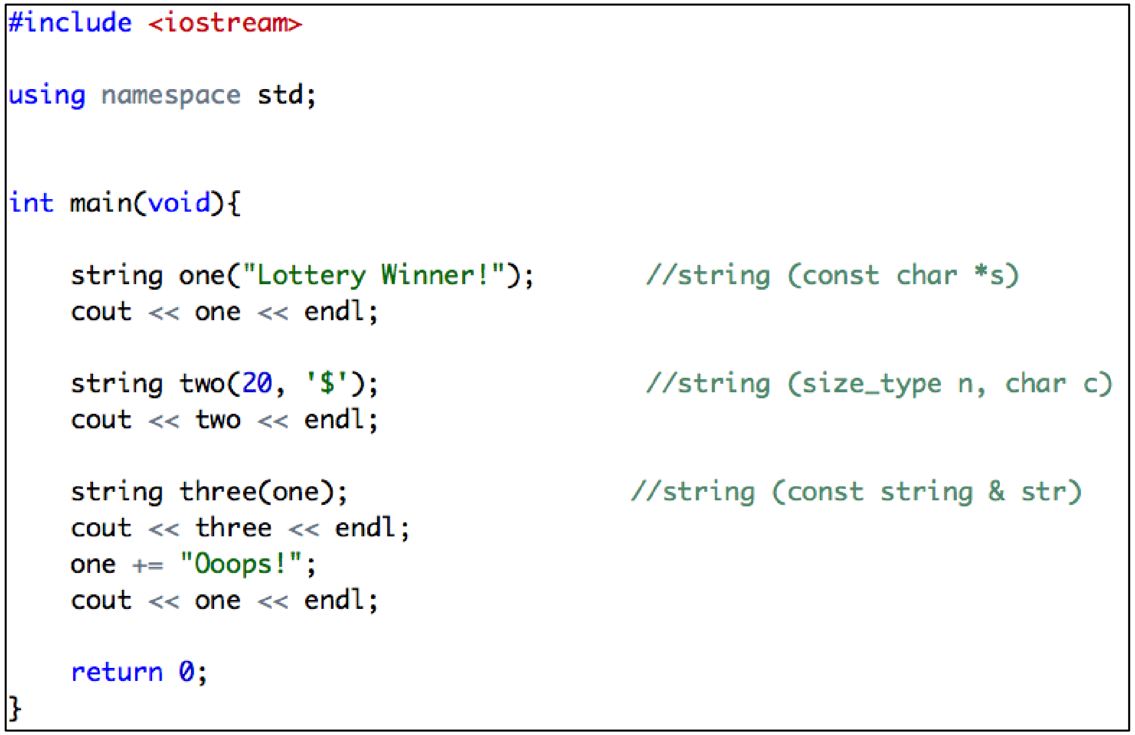
std::min, std::max, std::min_element, std::max_element



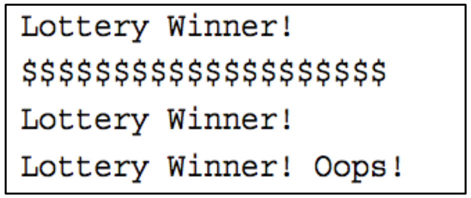
```
#include <vector>
#include <iostream>
#include <algorithm>
#include <cstdlib>   //for rand() and srand()
#include <ctime>     //for time()
using namespace std;

int main(){
const int a = 10, b = 15;
int minv = min(a,b);
int maxv = max(a,b);
cout << minv << " " << maxv << endl;

vector<int> v(10);
for (int i = 0; i < (int)v.size(); ++i)
    v[i] = 2*i;

vector<int>::iterator it;
it = min_element(v.begin(), v.end());

random_shuffle(v.begin(), v.end());
for (int i = 0; i < (int)v.size(); ++i)
    cout << " " << v[i];
cout << endl;

sort(v.begin(), v.end());
for (int i = 0; i < (int)v.size(); ++i)
    cout << " " << v[i];
cout << endl;

return 0;
}
```

std::string - constructor

- In C++, STL provides a powerful string class.



```
#include <iostream>

using namespace std;


int main(void){

    string one("Lottery Winner!");       //string (const char *s)
    cout << one << endl;

    string two(20, '$');                 //string (size_type n, char c)
    cout << two << endl;

    string three(one);                  //string (const string & str)
    cout << three << endl;
    one += "Ooops!";
    cout << one << endl;

    return 0;
}
```

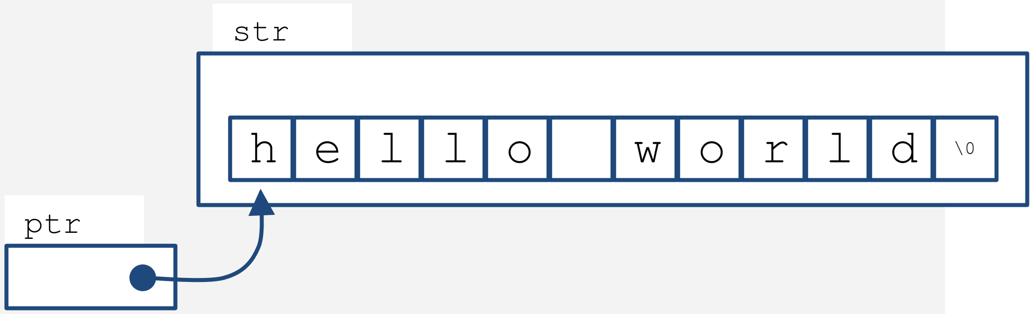


```
Lottery Winner!
$$$$$$$$$$$$$$$$$$$$
Lottery Winner!
Lottery Winner! Oops!
```

(Recall) std::string - c_str()

- Returns a pointer to a null-terminated string array representing the current value of the string object.

```
#include <string>

std::string str = "hello world";
const char* ptr = str.c_str();
printf("%s\n", ptr);

// ...


std::string str1 = str + " - bye world";
assert(str1 == "hello world - bye world");

assert(str.length() > 10);
assert(str[0] == 'h');
str[0] = 'j';
str.resize(5);
assert(str == "jello");

// check out http://www.cplusplus.com/reference/string/string/
// resize(), substr(), find(), etc.
```

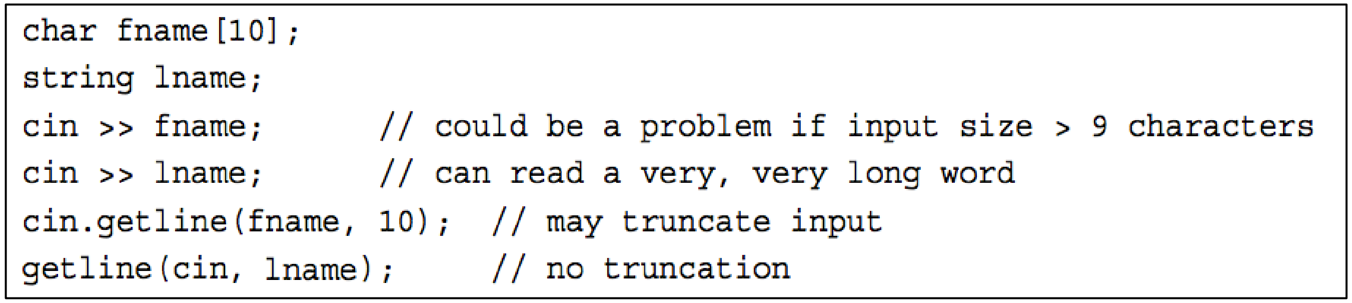


(Recall) std::string - input

```
std::string str;

std::cin >> str; // read a word (separated by a space, tab, enter)

std::getline(cin, str); // read characters until the default
                        // delimiter '\n' is found

std::getline(cin, str, ':'); // read characters until the delimiter
                             // ':' is found
```

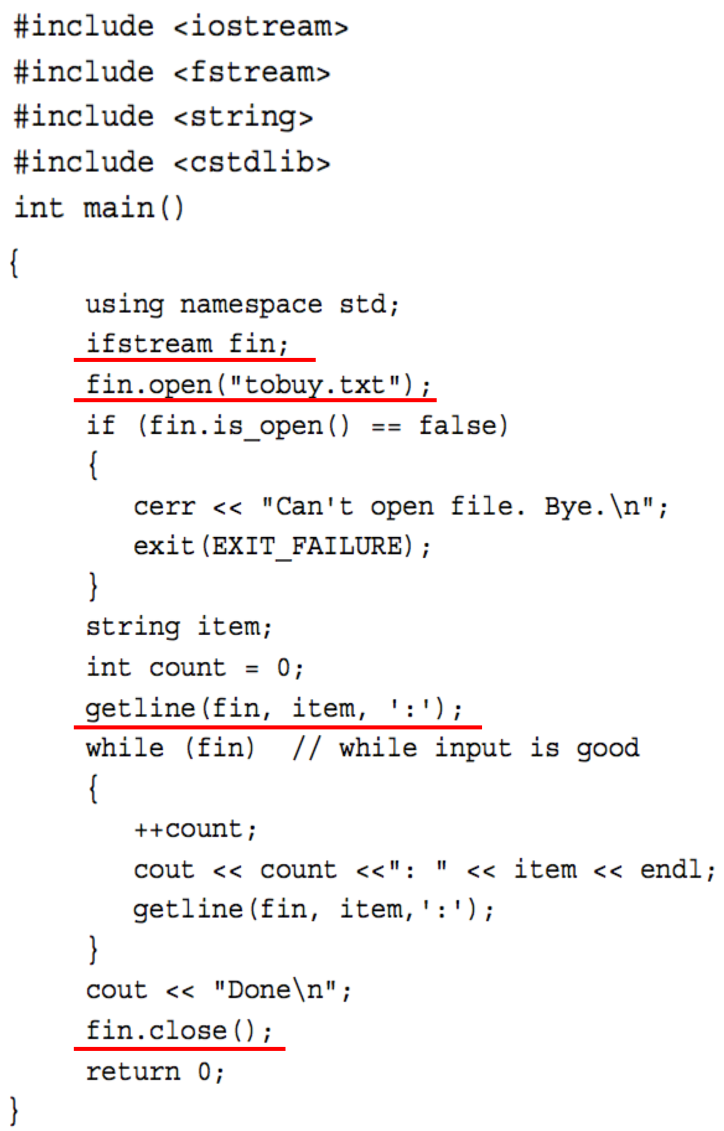
(Recall) std::string - input

- Note that `std::string` automatically resize to the length of target string.



```
char fname[10];
string lname;
cin >> fname;       // could be a problem if input size > 9 characters
cin >> lname;       // can read a very, very long word
cin.getline(fname, 10);  // may truncate input
getline(cin, lname);     // no truncation
```

std::string - input from file



```
#include <iostream>
#include <fstream>
#include <string>
#include <cstdlib>
int main()
{
     using namespace std;
     ifstream fin;
     fin.open("tobuy.txt");
     if (fin.is_open() == false)
     {
        cerr << "Can't open file. Bye.\n";
        exit(EXIT_FAILURE);
     }
     string item;
     int count = 0;
     getline(fin, item, ':');
     while (fin)  // while input is good
     {
        ++count;
        cout << count <<": " << item << endl;
        getline(fin, item,':');
     }
     cout << "Done\n";
     fin.close();
     return 0;
}
```

std::string - find

```
size_t find(const string& str, size_t pos = 0) const;
size_t find(char c, size_t pos = 0) const;
[from http://www.cplusplus.com/]
```

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

int main() {
  string str("There are two needles in this haystack with needles.");
  string str2("needle");
  size_t found;

  if ((found = str.find(str2)) != string::npos) {
    cout << "first 'needle' found at: " << int(found) << endl;
  }
  str.replace(str.find(str2), str2.length(), "preposition");
  cout << str << endl;
  return 0;
}
```

```
first 'needle' found at: 14
There are two prepositions in this haystack with needles.
```

std::string - substr

```
string substr(size_t pos = 0, size_t n = npos) const;
[from http://www.cplusplus.com/]
```

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

int main() {
  string str = "We think in generalities, but we live in details.";
               // quoting Alfred N. Whitehead

  string str2 = str.substr(12, 12);  // "generalities"
  size_t pos = str.find("live");     // position of "live" in str
  string str3 = str.substr(pos);     // get from "live" to the end

  cout << str2 << ' ' << str3 << endl;
}
```

```
generalities live in details.
```

Quiz #3

- Go to https://www.slido.com/
- Join #**csd-ys**
- Click "Polls"

- Submit your answer in the following format:
  - **Student ID: Your answer**
  - **e.g. 2017123456: 4)**

- Note that you must submit all quiz answers **in this format** to be counted as attendance.

Next Time

- Labs for this lecture:
  - Lab1 (next Tue): Assignment 7-1
  - Lab2 (next Thur): Assignment 7-2

- The midterm exam is on Oct 18.
  - **No lecture on Oct 14**
  - **No labs on Oct 18 and Oct 20**

- Next lecture: **Oct 21 (two weeks later**)
  - 8 - Inheritance, Const & Class