Introduction to the C++ Standard Library.

For : COP 3330.
Object oriented Programming (Using C++)
http://www.compgeom.com/~piyush/teach/3330

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The C++ Standard Library

- Provides the ability to use:
  - String Types
  - Data Structures (linked list, dynamic arrays, priority queues, binary trees etc)
  - Algorithms (Sorting and Searching…)
  - IO
  - Classes for internationalization support.

The C++ Standard Library

- Not very homogeneous:
  - String classes are safe and convenient to use (almost self explanatory).
  - The Standard Template Library (STL) optimizes for performance and is not required to check for errors. To use it well, you need to understand the concepts and apply them carefully.

C++ Standard Library

- Containers
  - Objects that hold/contain other objects.
  - Examples: vector, string
- Algorithms
  - Work on the containers
  - Examples: sort, search
- Iterators
  - Provide pointer like interface to containers.

Other components

- Allocators: Provide memory management for containers. Can be customized.
- Adaptors: A mechanism to make one thing act like another. Example: Stack.
- Function objects: A **function object or a functor**, is a construct allowing an object to be invoked or called as if it were an ordinary function.

Containers

- Of course: Contain objects/built in types.
  - More powerful than arrays.
  - Grow (and shrink?) dynamically
  - Manage their own memory
  - Keep track of their size
  - Allow optimal algorithmic operations like scan, sorts etc.

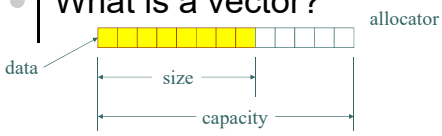
Containers

- Standard STL sequence Containers:
  - vector, string, deque and list
    - bitset, queue
    - valarray, priority_queue

Containers

- Prefer sequential containers to arrays.
- Use vector by default
- Use list when there are a lot of insertions/deletions in the middle of the sequence.
- Use deque when there is a lot of insertion at the beginning or the end of the sequence.

What is a vector?



- A contiguous array of elements
- The first "size" elements are constructed (initialized)
- The last "capacity - size" elements are uninitialized
- Four data members
  - data pointer
  - size
  - capacity
  - allocator

or equivalent

Sample data layout: Internals.

Vector Interface

```
template <class T, class Allocator = allocator<T> >
class vector {
public:
    ...
    explicit   vector(const Allocator& = Allocator());
    explicit   vector(size_type n, const T& value = T(),
                      const Allocator& = Allocator());
    ...
    void    reserve(size_type n);
    ...
    void    resize(size_type sz, const T& c = T());
    ...
    void    push_back(const T& x);
    void    pop_back();
    ...
    iterator insert(iterator position, const T& x);
    void      insert(iterator position, size_type n, const T& x);
    ...
    iterator erase(iterator position);
    iterator erase(iterator first, iterator last);
    ...
    void      clear();
};
```

Vectors

#include <vector>

- template <class T, class Allocator = allocator<T> > class vector { …}
- A default allocator is provided.
- T is the type of the object stored in the vector.
- Constructors for vector:
  - vector<int> ivec1;
  - vector<int> ivec2(3,9);
  - vector<int> ivec3(ivec2);

Containers : is empty?

- Always use:
  - if(icontainer.empty()) …
  - Instead of if(icontainer.size() == 0)
- For some containers, calculating size takes linear time.

An example usage

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

using namespace std;

int main() {
  vector<int> vec(10); // Creates a vector

  // Initializes the vector
  for(int i=0; i < vec.size(); i++) {
    vec[i] = rand() % 10;
    cout << " vec[" << i << "]="
         << vec[i] << endl;
  };
  return 0;
}
```

```
pk@linprog4:~>./a.out
 vec[0]=3
 vec[1]=6
 vec[2]=7
 vec[3]=5
 vec[4]=3
 vec[5]=5
 vec[6]=6
 vec[7]=2
 vec[8]=9
 vec[9]=1
```

An example usage

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

using namespace std;

int main() {

  vector<int> ivec;
  cout << ivec[0]; //error
  vector<int> ivec2(10);
  // subscripts available: 0..9
  cout << ivec[10]; // error

  return 0;
}
```

```
pk@linprog4:~>./a.out
Segmentation fault (core dumped)
```

Make this your friend…

Iterators

- Browsers for containers.
- Allows restricted access to objects stored in a container.
- Can be a class, data structure or an Abstract Data Type.

Iterators

- A replacement for subscripting, for example in case of vectors: v[i]
- Subscripts are not available for all containers but iterators are.
- You can think of an iterator as pointing to an item that is part of a larger container of items.

Iterators

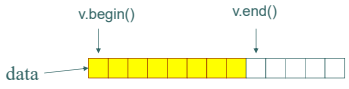
- Container.begin() : All containers support a function called begin, which will return an iterator pointing to the beginning of the container (the first element)
- Container.end() : returns an iterator corresponding to having reached the end of the container. (Not the last element)

Iterators

- Support the following operations:
  - Operator * : Element at the current position (example: (*it)). You can use “->” to access object members directly from the iterator. (Like a pointer)
  - Operator++ : Moves the iterator to the next element. Most iterators will also allow you to use “ - - ” for stepping back one element.
  - Operator == and != : Compare two iterators for whether they represent the same position (not the same element).
  - Operator = : Assigns an iterator.

Iterators

- Vector iterator picture.



- Reason for half-open range:
  - Easy looping
  - Empty containers ➔ begin() == end()

Iterators

- Defining an iterator:
  std::*class_name<template_parameters>*::iterator *name;*
- Example:

```
std::vector<int>::iterator  vit = myvec.begin();
cout << (*vit)  << endl;
```

- Printing all elements of a container.

```
std::container_type<template_parameter>::iterator pos;
for (  pos = container.begin();
       pos != container.end(); ++pos)
      cout << (*pos) << endl;
```

Iterators : Examples

The non-STL way, using subscripts to access data:

```
using namespace std;

vector<int> myIntVector;

// Add some elements to myIntVector
myIntVector.push_back(1);  //adds an element to end of vector.
myIntVector.push_back(4);
myIntVector.push_back(8);

for(int y=0; y<myIntVector.size(); y++) {
    cout<<myIntVector[y]<<" ";  //Should output 1 4 8
}
```

Iterators: Examples

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

int main() {
  using namespace std;
  vector<int> myIntVector;
  // vector<int>::iterator myIntVectorIterator; (use auto instead)

  // Add some elements to myIntVector
  myIntVector.push_back(1);
  myIntVector.push_back(4);
  myIntVector.push_back(8);

  for (auto myIntVectorIterator = myIntVector.begin();
       myIntVectorIterator != myIntVector.end();
       myIntVectorIterator++) {
    cout << *myIntVectorIterator << " ";
    // Should output 1 4 8
  }
}
```

Iterator Types

- Input Iterator : read only, forward moves.
- Output Iterator : write only, forward moves.
- Forward Iterator: Both read/write with (++) support
- Backward: Both read/write with (--) support
- Bi-Directional :Read write and Both ++ or – support.
- Random: Read/Write/Random access. (Almost act like pointers)

Most Common

Iterators

Type of iterator	Example
Input Iterator	istream_iterator
Output Iterator	ostream_iterator, inserter, front_inserter, back inserter
Bi-directional iterator	list, set, multiset, map, multimap
Random access iterator	Vector, deque

Random Access Iterators

- Allow arithmetic
  - it+n
  - The result will be the element corresponding to the nth item after the item pointed to be the current iterator.
  - it – n also allowed
  - (it1 – it2) allowed
    - Example: Type of this operation for vectors is defined by vector<T>::difference_type.

Back to vectors

- Iterator type: Random-access
- Operator [] overloaded

v.size()	Number of elements in vector
v.clear()	Removes all elements
v.pop_back()	Removes last element
v.push_back(elem)	Adds elem at end of vector
v.insert(pos,elem)	Inserts elem at position pos and returns the position of the new element.
v.erase(pos) Another form: v.erase(bpos,epos)	Removes the element at the iterator position pos and returns the position of the next element.

Back to vectors

v.max_size()	Maximum number of elements possible (in entire memory!).
v.capacity()	Returns maximum number of elements without reallocation
v.reserve(new_size)	Increases capacity to new_size.
v.at(idx)	Returns the element with index idx. Throws range error exception if idx is out of range.
v.front() , v.back()	Returns first , last element.
v.resize(new_size)	Changes the size to new_size.

Important facts

- For vectors, the C++ standard states:
  - &v[i] = &v[0] + i

```
vector < char > vv;
vv.push_back ( 'P' );
vv.push_back ( 'Q' );
vv.push_back ( 'R' );
vv.push_back ( '\0' );
printf("%s\n",&vv[0]);
```

Output : PQR

The swap trick.

- To trim capacity, you can use the following trick:
  - std::vector<T>(v).swap(v);
  - Makes capacity = size.
    - Example: vector<int>(ivec2).swap(ivec2);

Important Facts

- When deleting containers of newed/malloced elements, remember to delete/free them before deleting the container.
- Thread safety of STL containers:
  - Multiple readers are ok
  - Multiple writers to different containers are ok.

What can a container contain?

- Minimal constraint on elements of a container.
  - Operator=
    - a = b; should be valid
  - A copy constructor
    - YourType b(a); should be valid
- Question :
  - Is vector<int&> allowed?
  - Is vector<const int> allowed?

Suggestions

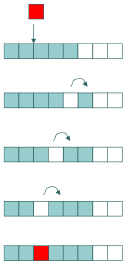
- Prefer vector and string to dynamically allocated arrays.
- Use reserve() to avoid unnecessary reallocations.
- Avoid using vector<bool>

Algorithms

#include <algorithm>

- Methods that act on containers (may or may not change them)
  - Examples: Sorting, searching, reversing etc.
  - Examples:
    - sort(v.begin(), v.end())
    - pos = find(v.begin(), v.end(), 3) // returns an iterator in the container.
    - reverse(v.begin(), v.end())
    - unique(v.begin(), v.end()) // operates on a sorted range to collapse duplicate elements.

Understand Complexity Example: Vector Insert



What happens when the vector is large?

Linear on the number of elements inserted (copy/move construction) plus the number of elements after *position* (moving).

O(num_inserted + num_after_pos)

Intro To The Standard string Class

- C++ has a standard class called "string"
- Strings are simply a sequence of characters
  - Note: This is not a sufficient definition for a "C-string"
  - A "C-string" is an array of characters terminated by a null byte
- Must #include <string> using the standard namespace to get C++ standard string functionality
  - Note: This is different from #include'ing <string.h> which is the header required for "C-string"s
- string variables are used to store names, words, phrases, etc.
- Can be input using ">>" and output using "<<" as other types

Some string Functionality

firstName[5] = 'h'

firstName[6] is undefined unlike C where its '\0'.

- Declaring a string:
  - string lastName;
  - string firstName("Piyush"); //Note: String literal enclosed in double quotes
  - string fullName;
- Assigning a string:
  - lastName = "Kumar"; //The usual assignment operator
- Appending one string on the end of another:
  - fullName = firstName + lastName; //Results in "PiyushKumar"
  - fullName = firstName + " " + lastName; //Results in "Piyush Kumar"
- Accessing individual characters in a string:
  - myChar = firstName[4]; //Results in 's' (no bounds checking)
  - myChar = firstName.at(4); //Results in 's' (does bounds checking)
- Appending a character to the end of a string:
  - lastName = lastName + myChar; //Results in "Kumars"
- Determining number of characters in string:
  - myInt = firstName.length(); //Results in 6

string Example #1

```
#include <iostream>
#include <string>
using namespace std;
int main(void)
{
  string first;
  string last("Morgan");

  first = "Drew"; //Would be illegal for C-string
  cout << "Length of " << first << " is: " << first.length() << endl;
  cout << "Length of " << last << " is: " << last.length() << endl;

  first += "Morgan";
  cout << "Length of " << first << " is: " << first.length() << endl;
  cout << "Length of " << last << " is: " << last.length() << endl;

  first.assign("Drew");
  first.append(" ");
  first.append(last);
  cout << "Length of " << first << " is: " << first.length() << endl;
  cout << "Length of " << last << " is: " << last.length() << endl;
  return(0);
}
```

```
Length of Drew is: 4
Length of Morgan is: 6
Length of DrewMorgan is: 10
Length of Morgan is: 6
Length of Drew Morgan is: 11
Length of Morgan is: 6
```

Constructors

"A **constructor** is a kind of member function that initializes an instance of its class."

"A **constructor** has the same name as the class and no return value."

```
string()                              // empty string
string(string s)                      // copy of s
string(string s, int start)           // substring start, end
string(string s, int start, int len)  // substring
string(char* a)                       // copy of C-string
string(int cnt, char c)               // one or more chars
string(char* beg, char* end)          // [beg, end)
```

Additional string Functionality

- Strings can be compared with usual operators
  - >, >= (greater than, greater than/equal to)
  - <, <= (less than, less than/equal to)
  - == (equality)
- Strings also have a member function called "compare"
  - int string::compare(string rhs);
  - Return value is negative if calling string is less than rhs
  - Return value is positive if calling string is greater than rhs
  - Return value is zero if both strings are identical

Other overloaded operators

- = is used to assign a value (char, C-string, or string) to a string.
- += is used to append a string, character, or C-string to a string.
- + is used to concatenate two strings or a string with something else
- << and >> are used for input and output. On input, leading whitespace is skipped, and the input terminates with whitespace or end of file.

When you need a C-string

```
string s = "1234";
s.data() // returns s as a data array, no '\0'.
s.c_str() // returns s as a C-string with '\0'
int i = atoi(s.c_str()); // conversion
// i is now 1234.

char *carray = new char[80];
s.copy(carray, 79); // copies up to 79 char
```

String Operations

```
s.append(s2); // append s2 to s
s.push_back(c); // append a char
s.erase(various); // erases substrings
s.insert(various); // inserts substrings
s.clear(); // removes all contents
s.resize(cnt); // change the size of s to cnt
swap(a, b); // for general containers.
```

String Operations

s.replace(various); // replaces characters

s.size(); or s.length(); // how many characters?

s.max_size(); // maximum number of char?

s.empty(); // is s empty?

s.reserve(cnt); // reserves memory

string Example #2

```
#include <string>
#include <iostream>

using namespace std;

int main(void)
{
  string s1 = "Drew";
  string s3;
  int result;

  s3 = "Bob";
  if (s3 < s1)
    cout << "oper: s3 less than s1";
  if (s3 > s1)
    cout << "oper: s3 greater than s1";
  if (s3 == s1)
    cout << "oper: s3 is equal to s1";
  cout << endl;

  result = s3.compare(s1);
  if (result < 0)
    cout << "comp: s3 less than s1";
  else if (result < 0)
    cout << "comp: s3 greater than s1";
  else
    cout << "comp: s3 is equal to s1";
  cout << endl;

  s3 = "Drew";
  if (s3 < s1)
    cout << "oper: s3 less than s1";
  if (s3 > s1)
    cout << "oper: s3 greater than s1";
  if (s3 == s1)
    cout << "oper: s3 is equal to s1";
  cout << endl;

  result = s3.compare(s1);
  if (result < 0)
    cout << "comp: s3 less than s1";
  else if (result < 0)
    cout << "comp: s3 greater than s1";
  else
    cout << "comp: s3 is equal to s1";
  cout << endl;

  return (0);
}
```

Output

```
oper: s3 less than s1
comp: s3 less than s1
oper: s3 is equal to s1
comp: s3 is equal to s1
```

Even More string Functionality

- Getting a substring of a string:
  - string string::substr(int startPos, int length)
    - Returns the substring starting at "startPos" with length of "length"
- Finding the location of a substring within a string:
  - int string::find(string lookFor);
    - Returns the index where the first instance of "lookFor" was found in the string
    - Returns "string::npos" (which is usually -1) when the substring isn't found
  - int string::find(string lookFor, int startFrom);
    - Returns the index where the first instance of "lookFor" was found, starting the search at the index "startFrom", or "string::npos" when the substring isn't found
- Finding specific characters in a string:
  - int string::find_first_of(string charList, int startFrom);
    - Returns the index of the first instance of any character in "charList", starting the search at the index "startFrom", or "string::npos" if none of the chars are found
  - int string::find_first_not_of(string charList, int startFrom);
    - Returns the index of the first instance of any character NOT in "charList", starting the search at the index "startFrom", or "string::npos" if none of the chars are found

string Example #3

```
#include <string>
#include <iostream>

using namespace std;

int main()
{
  int startPos;
  int len;
  int commaLoc;
  int howLoc;
  int loc;
  int spaceLoc;
  string myStr;
  string myStr2;

  myStr = "Hello, how are you?";
  startPos = 7;
  len = 3;
  myStr2 = myStr.substr(startPos, len);
  cout << "Substr: " << myStr2 << endl;
  commaLoc = myStr.find(",");
  howLoc = myStr.find(myStr2);
  cout << "Comma: " << commaLoc;
  cout << " how: " << howLoc << endl;

  cout << "Spaces:";
  spaceLoc = myStr.find(" ");
  while (spaceLoc != string::npos)
  {
    cout << " " << spaceLoc;
    spaceLoc = myStr.find(" ", spaceLoc + 1);
  }
  cout << endl;

  cout << "Punct and spaces:";
  loc = myStr.find_first_of(" ,?", 0);
  while (loc != string::npos)
  {
    cout << " " << loc;
    loc = myStr.find_first_of(" ,?", loc + 1);
  }
  cout << endl;

  return (0);
}
```

Output

```
Substr: how
Comma: 5 how: 7
Spaces: 6 10 14
Punct and spaces: 5 6 10 14 18
```

string Class Implementation

- The string class uses dynamic memory allocation to be sure segmentation faults don't occur
  - When a string is updated such that it requires more characters than currently allocated, a new, larger array is allocated and the prior contents are copied over as necessary
- Since dynamic allocation is relatively slow, it is not desirable to be re-allocating strings often
  - C++ allows some memory to be "wasted" by often allocating more space than is really needed
  - However, as strings are appended to the end, it is likely that a re-allocation won't be needed every time
  - Occasionally, re-allocation is necessary and is performed, again allocating more memory than necessary
- Note: this is all done *automatically* by the string class (Similar to vectors?)

Some Final string Functionality

- Several member functions are available to get information about a string
  - capacity: The number of characters that can be placed in a string without the inefficiency of re-allocating
  - length: The number of characters currently in the string
- You can manually change the capacity of a string
  - resize: Sets the capacity of a string to be at least a user-defined size
  - This can be useful if you know a string will be at most *n* characters long
    - By resizing the string to capacity *n* only that amount of memory is associated with the string
    - This prevents wasted memory when you know the exact size you need
    - Additionally, it can help prevent numerous re-allocations if you will be appending on to the end of the string, but know the final size ahead of time

Example #4

```
#include <string>
#include <iostream>

using namespace std;

int main(void)
{
  string str;
  string str2;

  cout << "Str: " << str << endl;
  cout << "Length: " << str.length();
  cout << "   Cap: " << str.capacity();
  cout << endl;

  str = "888";
  cout << "Str: " << str << endl;
  cout << "Length: " << str.length();
  cout << "   Cap: " << str.capacity();
  cout << endl;

  str += "-111-";
  cout << "Str: " << str << endl;
  cout << "Length: " << str.length();
  cout << "   Cap: " << str.capacity();
  cout << endl;

  str += "1723-9";
  cout << "Str: " << str << endl;
  cout << "Length: " << str.length();
  cout << "   Cap: " << str.capacity();
  cout << endl;

  str += "abcdefghijklmnopqrstuv";
  cout << "Str: " << str << endl;
  cout << "Length: " << str.length();
  cout << "   Cap: " << str.capacity();
  cout << endl;

  return (0);
}
```

```
Str:
Length: 0   Cap: 0
Str: 888
Length: 3   Cap: 31
Str: 888-111-
Length: 8   Cap: 31
Str: 888-111-1723-9
Length: 14   Cap: 31
Str: 888-111-1723-9abcdefghijklmnopqrstuv
Length: 36   Cap: 63
```

C Vs C++: Strings

C Library Functions	C++ string operators /member functions.
strcpy	=
strcat	+=
strcmp	= =, !=, <, >, <=, >=
strchr, strstr strrchr	.find( ) method .rfind( ) method
strlen	.size( ) or .length( ) methods

Reading text into a string

getline(istream, s); // Reads from istream (e.g., cin or a file) into the string s. Returns a reference to istream that can be used again.

- Reads all characters until a line delimiter or end of file is encountered.
- The line delimiter is extracted but not put into the string
- You can then parse s without worrying about end of line or end of file characters.

Char functions in C/C++

- #include <ctype.h>
- **int** isalnum(**int** c); //non-zero iff c is alphanumeric
- **int** isalpha(**int** c); //non-zero iff c is alphabetic
- **int** isdigit(**int** c); //non-zero iff c a digit: 0 to 9
- **int** islower(**int** c); //non-zero iff c is lower case
- **int** ispunct(**int** c); //non-zero iff c is punctuation
- **int** isspace(**int** c); //non-zero iff c is a space char
- **int** isupper(**int** c); // non-zero iff c is upper case
- **int** isxdigit(**int** c); //non-zero iff c is hexadecimal
- **int** tolower(**int** c); //returns c in lower case
- **int** toupper(**int** c); //returns c in upper case

Using the transform algorithm #include <algorithm>

- Lowercase all characters of a string:

```
transform(s.begin(), s.end(),   // source
          s.begin(),            // destination
          tolower);             // operation
```

- Uppercase all characters:

```
transform(s.begin(), s.end(), s.begin(), toupper);
```

- tolower and toupper are C-string functions. Other functions can also be used.

Using the transform algorithm #include <algorithm>

- What does the following do?
  - If (s == reverse(s.begin(),s.end()))
    cout << “S is a …”;

Project 1 Solution

```
#include <iostream>
#include <string>

/*! \brief function to return the max count of character in a given string.
 *
 *  Description: Takes in a string as input and returns the count of
 *  the char which appears most often in said string.
 *
 */
int get_max_count(const std::string & s)
{
  const unsigned NUM_CHARS = 128;     /* Number of lower case letters (en). */
  unsigned chars[NUM_CHARS] = { 0 };  /* Array of counters; for each lapha. */
  unsigned maxCount = 0;              /* Count of lapha which appears most. */
```

…what does this code do?

Project 1 Solution (cont.)

```
  /* For each char of the string, uptick its associated counter. */
  for (unsigned i = 0; i < s.length(); ++i)
    ++chars[static_cast<unsigned>(s[i])];

  /* Get the count of the char which appears most often. */
  for (unsigned i = 0; i < NUM_CHARS; ++i)
    if (maxCount < chars[i])
      maxCount = chars[i];

  return maxCount;
}
```

Reading assignment: Chapter 3, 9 Including Bitset.

#include <bitset>

Output

```
0 0 0 0 0 0 0 0
1 0 0 0 0 0 1 1
```

- Ordered collection of bits.
- Example program:

```
#include <bitset>
#include <iostream>

using namespace std;

int main() {
      // create a bitset that is 8 bits long
      bitset<8> bs;
      // display that bitset
      for( int i = (int) bs.size()-1; i >= 0; i-- ) { cout << bs[i] << " "; }
      cout << endl;

      // create a bitset out of a number
      bitset<8> bs2( (long) 131 ); // display that bitset, too
      for( int i = (int) bs2.size()-1; i >= 0; i-- ) { cout << bs2[i] << " "; }
      cout << endl;

      return 0;
}
```

bitset operators

- != returns true if the two bitsets are not equal.
- == returns true if the two bitsets are equal.
- &= performs the AND operation on the two bitsets.
- ^= performs the XOR operation on the two bitsets.
- |= performs the OR operation on the two bitsets.
- ~ reverses the bitset (same as calling flip())
- <<= shifts the bitset to the left
- >>= shifts the bitset to the right
- [x] returns a reference to the xth bit in the bitset.

Example

```
#include <bitset>
#include <iostream>

using namespace std;

int main() {
      // create a bitset out of a number
      bitset<8> bs2( (long) 131 );
      cout << "bs2 is " << bs2 << endl;

      // shift the bitset to the left by 4 digits
      bs2 <<= 4;
      cout << "now bs2 is " << bs2 << endl;

      return 0;
}
```

Output?

```
bs2 is 10000011
now bs2 is 00110000
```

Recommended Exercise: 3.23, 3.21, 3.18, 3.15