C++ Overview (2)

COS320
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Topics

- Last time
  - Heap memory allocation
  - References
  - Classes
  - Inheritance
- Today
  - Operator overloading
  - I/O streams
  - Templates
  - STL
  - C++11

Operator Overloading

- A new meaning can be defined when one operand of an operator is a user-defined (class) type
- Member vs. nonmember operators
  - Class member operator
    - ex) `T T::operator+(const T& rhs)`
    - ex) `T T::operator+(int num)`
    - Pros: can access private data member w/o friend declaration
  - Nonmember (global) operator
    - ex) `T operator+(const T& lhs, const T& rhs)`
    - ex) `T operator+(int num, const T& rhs)`
    - Pros: we can define operators when type of lhs is not modifiable (ex. ostream) or primitive (ex. int)
- Operators are just functions – these are valid
  - ex) `lhs.operator+(rhs)`
  - ex) `operator+(lhs, rhs)`

Complex Number Class

```
class Complex {
  double re, im;

public:
  Complex(double re=0, double im=0) : re(re), im(im) {}

  friend Complex operator +(const Complex &lhs, const Complex &rhs);
  …

  // Assignment operators
  const Complex &operator+=(const Complex &rhs) {
    re += rhs.re;
    im += rhs.im;
    return *this;
  }
  …
};

// Binary arithmetic & relational operators
Complex operator +(const Complex &lhs, const Complex &rhs) {
  return Complex(lhs.re+rhs.re, lhs.im+rhs.im);
}
Complex operator ==(const Complex &lhs, const Complex &rhs) { … }
Complex operator <(const Complex &lhs, const Complex &rhs) { … }
```

Complex Number Class

```
class Complex {
public:
  // Unary operators
  Complex operator-() const { return Complex(-re, im); }
  const Complex &operator++() { // Prefix
    ++re;
    return *this;
  }
  Complex operator++(int) { // Postfix (int arg is dummy)
    Complex tmp = *this;
    ++re;
    return tmp;
  }

  // I/O operators
  ostream &operator<<(ostream &out, const Complex &c) { c.print(out); return out; }
  istream &operator>>(istream &in, Complex &c) { … }

  void print(ostream &out=cout) const;
};
```

Complex Number Class

```
Complex c1(3, 5), c2(2, 7);

Complex c3 = c1 + c2; // operator+

bool isEqual = c1 == c2; // operator==
bool isLess = c1 < c2; // operator<

c1 += c2; // operator+=

Complex c4 = -c3; // operator- (unary)
++c4; //operator++ (prefix)
c4++; // operator++ (postfix)

// cout << thing is similar to printf("..", thing);
std::cout << c4; // operator<<
```

More Operator Overloading

- I/O operators
  - `ostream &operator <<(const T& t)`
  - Now we can do `std::cout << t;`
- Type casting operators
  - `operator double() const`
  - `operator int() const`
- Subscripting operator
  - You may need to overload these if you make your own vector class
  - `const ElemT &operator[](int index) const`
  - `ElemT &operator[](int index)`
- Operator overloading should be used judiciously

from [1]

Templates

- Specifies a class or a function that is the same for several types
- Evaluated in compile time, not run time

- e.g., vector template in STL defines a class of vectors that can be
- instantiated for any particular type
  - `vector<int>`
  - `vector<string>`
  - `vector<vector<int>>`

- Templates vs. inheritance:
  - Use inheritance when behaviors are different for different types
    - ex) Drawing different Shapes is different
  - Use template when behaviors are the same, regardless of types
    - ex) Accessing the n-th element of a vector is the same, no matter what type the vector is

Class Templates

from [1]

```
// vector class example
// This is just for demonstration. Use std::vector instead in your code.
template <typename T>
class vector {
  T *array; // pointer to array
  int size; // number of elements

public:
  vector(int n=1) { array = new T[size = n]; }
  T& operator [](int n) { return array[n]; }
  const T& operator[](int n) const { return array[n]; }
};

vector<int> iv(100); // vector of ints
vector<Complex> cv(20); // vector of Complexes
vector<vector<int>> vvi(10); // vector of vector of ints
```

Function Templates

from [2]

```
// Assumes v.size() > 0
// Wouldn't compile if Object does not provide '<'
template <typename Object>
const Object &findMax(const vector<Object> &v) {
  int maxIndex = 0;
  for (int i = 0; i < v.size(); i++) {
    if (v[maxIndex] < v[i])
      maxIndex = i;
  }
  return v[maxIndex];
}


vector<int> vec {2, 7, 4, 3}; // C++11-style vector initialization
int max = findMax<int>(vec);

vector<MyClass> classVec {MyClass, MyClass, MyClass};
// This doesn't compile because MyClass does not have '<' operator
MyClass maxClass = findMax<MyClass>(classVec); (X)
```

Templates

- Templates are classes/functions wannabe, not actual classes/functions
  - Will not even be compiled if not used
- In general, all template implementation (including member functions) should be in header files
  - Templates should be accessible in compile time, not link time
  - There are workarounds to place methods in source files, but this is the simplest
- Code bloat
  - If you use vector template class for 4 different types, compiler will generate 4 different versions of vector class internally

Templates

- Multiple template parameters
  - `map<typename Key, typename Value>`
- Template nontype parameters
  - `template<typename Object, int size> class Buffer { … }`
  - `Buffer<string, 1024> buf;`
- Default template parameters
  - `template <typename Object=char, int size=4096> class Buffer { … }`
  - `Buffer<> buf;`

Function Objects

- Objects to be called as if they were ordinary functions
- Also called functors
- C++ equivalent of C function pointers
- Lots of predefined function objects in STL <functional> header

Function Objects

```
// Object type should have weight() method to compile
template <typename Object>
class LessThanByWeight {
public:
  bool operator()(const Object &lhs, const Object &rhs) const {
    return lhs.weight() < rhs.weight();
  }
};

template <typename Object, typename Commparator>
const Object &findMax(const vector<Object> &v, Comparator lessThan) {
  int maxIndex = 0;
  for (int i = 0; i < v.size(); i++) {
    if (lessThan(v[maxIndex], v[i])) maxIndex = i;
  }
  return v[maxIndex];
}

vector<SomeObject> vec { ... };
SomeObject &maxObj = findMax(vec, LessThanByWeight<SomeObject>());

// Template parameters can take function objects too
std::priority_queue<int, std::vector<int>, LessThanByWeight>> myQueue;
```

Template Specialization

- Override the default template implementation to handle a particular type in a different way

- Example
  - For this struct template
    `template <typename T1, typename T2> void foo() { … }`
  - Full template specialization
    - `template<> void foo<int, bool>() { … }`
  - Partial template specialization
    - `template<typename T2> void foo<int, T2>() { … }`
    - `template<typename T> void foo<T, T*>() { … }`

Template Specialization

```
template<typename T> string tostr(T t) {
  stringstream ss;
  ss << t;
  return ss.str();
}

template<> string tostr<bool>(bool val) {
  return val ? "true" : "false";
}

template<> string tostr<float>(float val) {
  char buf[64];
  snprintf(buf, sizeof(buf), "%.8e", val);
  return string(buf);
}

template<> string tostr<string>(string val) { return val; }
```

Template Metaprogramming (TMP)

- Uses of the C++ template system to perform computation at compile-time
- We are not going to cover this in detail

```
template <int n>
struct factorial {
  enum { value = n * factorial<n-1>::value };
};

template <>
struct factorial<0> {
  enum { value = 1 };
};

// Usage examples:
// factorial<0>::value would yield 1;
// factorial<4>::value would yield 24.
```

I/O Streams

- << : output operator
- >> : input operator

- Properties from [1]
  - Very low precedence
  - Left-associative, so these two are the same
    - `cout << e1 << e2 << e3`
    - `(((cout << e1) << e2) << e3)`
  - Takes a reference to iostream and data item
  - Returns the reference so can use same iostream for next expression

- I/O streams
  - istream: input stream
  - ostream: output stream
  - iostream: input/output stream

I/O Streams

- Predefined streams in <iostream> header
  - istream cin – standard input stream (stdin)
  - ostream cout – standard output stream (stdout)
  - ostream cerr – standard error stream (stderr)

- `cout << "Hello World!" << endl;`
  - They have to be std::cout and std::endl. You can omit 'std::' if you use 'using namespace std;'

- Stream error state
  - Test state: eof(), bad(), fail(), good()
  - Clear state: clear()

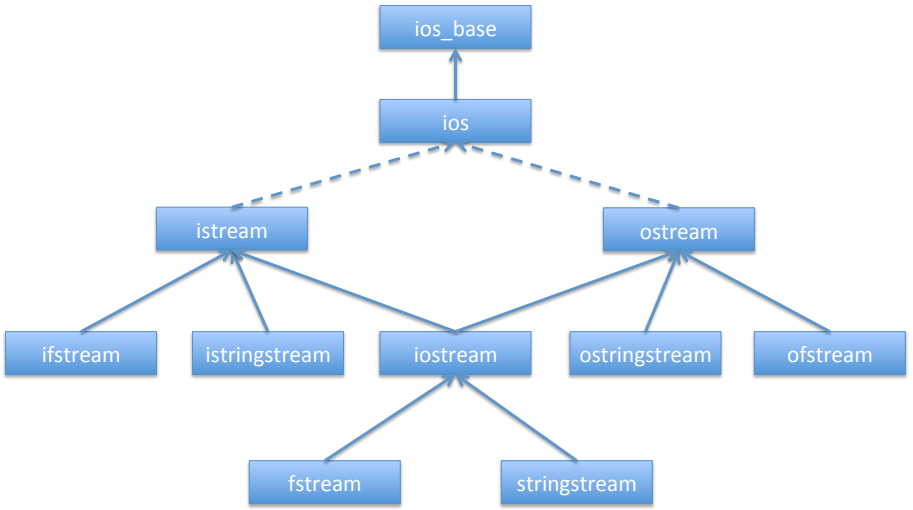
I/O Streams

- File I/O streams
  - declared in <fstream>
  - ifstream: input file stream
  - ofstream: output file stream
  - fstream: input/output file stream

- String I/O streams (You can use strings like streams)
  - declared in <sstream>
  - istringstream: input string stream
  - ostringstream: output string stream
  - stringstream: input/output string stream

- Headers
  - <iostream> - istream, ostream, cout, cin, …
  - <fstream> - ifstream, ofstream, fstream, …
  - <sstream> - istringstream, ostringstream, stringstream, …

I/O Stream Class Hierarchy



I/O Stream Class Hierarchy

- Multiple inheritance and typedefs

```
template<class CharT, class Traits=std::char_traits<CharT>>
class basic_ios : public ios_base { … }

typedef basic_ios<char> ios;
typedef basic_ios<wchar_t> wios;

template<class CharT, class Traits=std::char_traits<CharT>>
class basic_ostream : virtual public std::basic_ios<CharT, Traits> { … }

typedef basic_ostream<char> ostream;
typedef basic_ostream<wchar_t> wostream;

template<typename CharT, typename Traits=std::char_traits<CharT>>
class basic_iostream : public basic_istream<CharT, Traits>, public
basic_ostream<CharT, Traits> { … }

typedef basic_iostream<char> iostream;
typedef basic_iostream<wchar_t> wiostream;
…
```

Stream Manipulators

- Stream format manipulators
  - setw, setprecision, setfill, setw
  - left, right, internal
  - dec, hex, oct
  - showbase, showpos, showpoint
    - noshowbase, noshowpos, noshowpoint
  - fixed, scientific
  - boolalpha, skipws, uppercase
    - noboolalpha, noskipws, nouppercase
  - …
- Stream input manipulators
  - ws
- Stream output manipulators
  - endl, flush
    - endl outputs a newline and flushes the stream

Output Example

from [2]

```
class Person {
public:
  Person(const string &name, double salary=0.0) : name(name), salary(salary) {}
  void print(ostream &out=cout) const {
    out << left << setw(15) << name << " " << right << fixed << setprecision(2)
        << setw(12) << salary;
  }
  …
};

ostream &operator<<(ostream &out, const Person &p) {
  p.print(out);
  return out;
}

// In some function
vector<Person> arr;
arr.push_back(Person("Pat", 40000.11));
arr.push_back(Person("Sandy", 125443.10));
for (int i = 0; I < arr.size(); i++)
  cout << arr[i] << endl;
```

Input Example

from [2]

```
template <typename Object>
void readData(istream &in, vector<Object> &items) {
  items.resize(0);
  Object x;
  string junk; // to skip over bad data

  while (!(in >> x).eof()) {
    if (in.fail()) {
      in.clear();
      in >> junk;
      cerr << "Skipping " << junk << endl;
    } else
      items.push_back();
  }
}

// In some function..
vector<string> vec;
readData<string>(cin, vec);
```

File I/O

- ifstream / ofstream
- Declared in <fstream>

```
// Read each line from input.txt and write it to output.txt

istream& getline(istream &is, string &str); // declared in <iostream>

string line;
ifstream fin("input.txt");
ofstream fout("output.txt");

if (fin.is_open()) {
  while (getline(fin, line))
    fout << line << '\n';
  myfile.close();
} else
  cout << "Unable to open file" << endl;

  return 0;
}
```

StringStream I/O

- Use a string like a stream
- Declared in <stringstream>
- stringstream output is C++ equivalent of C sprintf/snprintf

```
// C-style string generation
char buf[100];
snprintf(buf, 100, "The half of %d is %d", 60, 60/2);
printf("%s", buf);

// C++-style string generation
stringstream ss;
ss << "The half of " << 60 << is << 60/2;
cout << ss.str();
```

Standard Template Library (STL)

- General purpose library of data structures including containers, and algorithms using templates
- Generic: every algorithm works on a variety of containers, including built-in types

- Containers: can contain objects of any type
  - Simple: pair
  - Sequences: vector, list, slist, stack, queue, deque
  - Sorted associative: set, map, multiset, multimap, …
  - Others: priority_queue, bitset, …

- Iterators: generalization of pointer for uniform access to items in a container

Standard Template Library (STL)

- Algorithms
  - Finding and counting
    - find_if, count_if, search, all_of, any_of, find, …
  - Modifying sequence
    - copy, copy_if, swap, replace, fill, generate, remove, reverse, …
  - Sorting
    - sort, stable_sort, nth_element, …
  - Binary search
    - binary_search equal_range, lower_bound, upper_bound, …
  - …
- Function objects
  - Function wrappers
    - function, mem_fn, …
  - Bind
    - bind, is_bind_expression, …
  - Arithmetic / comparisons / logical / bitwise operations
    - plus, minus, equal_to, greater, less, less_equal, logical_and, bit_and, …

Containers

from [2]

```
#include <iostream>
#include <vector>
#include <list>
#include <set>
#include <string>
using namespace std;
int main() {
  vector<int> vec;
  vec.push_back(3); vec.push_back(4);

  list<double> lst;
  lst.push_back(3.14); lst.push_front(6.28);

  set<string> s;
  s.insert("foo"); s.insert("bar"); s.insert("foo");

  multiset<string> ms;
  ms.insert("foo"); ms.insert("bar"); ms.insert("foo");

  print(vec); print(lst); print(s); print(ms);
  return 0;
}
```

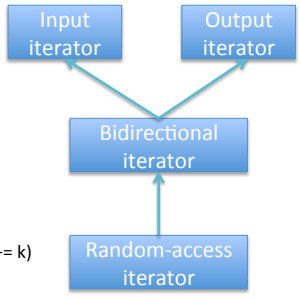
Iterators

```
template <typename Container>
void print(const Container &c, ostream &out=cout) {
  typename Container::const_iterator it;
  for (it = c.begin(); it != c.end(); ++it)
    out << *itr << " ";
  out << endl;
}
```

- begin(): iterator pointing to the first element
- end(): iterator referring to the past-the-end element
- ++it and it++ advance the iterator it to the next location

Iterators

- Have const and non-const forms
  - iterator begin() / iterator end();
  - const_iterator begin() const /const_iterator end() const;
- Reverse iterators
  - rbegin() / rend()
- Dereferencing iterators: *it
  - for map, it->first is key and it->second is value
- Iterator hierarchy
  - Bidirectional iterator
    - Can be incremented or decremented (++it, --it)
    - list, map, …
  - Random access iterator
    - Can access elements at an arbitrary offset position (it += k)
    - vector



Containers

```
#include <iostream>
#include <map>
#include <utility> // std::pair, std::make_pair

using namespace std;

int main() {
  map<string, pair<int, int>> m;
  m["apple"] = pair<int, int>(1, 3);
  m["banana"] = make_pair(2, 4);

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

  return 0;
}
```

Generic Algorithms

from [2]

```
// Sort element in a container
vector<int> v {3, 67, 45, 6, 99};

// sort the whole vector using default operator, which is less(<)
sort(v.begin(), v.end());
// sort only first half using the function object greater<int>
sort(v.begin(), (v.end() - v.begin()) / 2, greater<int>());
```

```
// Find the string with length 9
template <int len>
class StrLength { // Function object
public:
  bool operator()(const string &s) const { return s.length() == len; }
};

vector<string> v {“strawberry”, “apple”, “banana”}
vector<string>::iterator it = find_if(v.begin(), v.end(), StrLength<9>());

// Print the vector to cout
copy(v.begin(), v.end(), ostream_iterator<string>(cout, "\n"));
```

C++11

- C++ standard approved by ISO on August 2011
- Formerly known as C++0x
- Biggest extension since C++98
- Features – we are going to cover only handful of them
  - Initializer lists (for STL containers)
  - Template alias
  - Rvalue references
  - Variadic templates
  - Lambdas
  - auto
  - range-for
  - Smart pointers: shared_ptr / unique_ptr / weak_ptr
  - nullptr
  - …

C++11 Additions

- nullptr — from [1]
  - Type-safe and unambiguous replacement for NULL and 0 pointer values
- auto
  - Infers the type of x from the type of the initializing value
  - `auto x = val;` replaces
  - `VeryLongTypeNameLikeWhatYouOftenSeeInJava x = val;`
- range-for
  - for (v : whatever) … replaces
  - for (…. it = whatever.begin(); it != whatever.end() ++it) …
- Now >> is possible
  - C++03: vector<vector<int> > v;
  - C++11: vector<vector<int>> v;

auto, range-for

```
// C++03
for(std::vector<int>::iterator it = v.begin(); it != v.end(); ++it)
  cout << *it << endl;
for (std::map<int, string>::iterator it = m.begin(); it != m.end();
     ++it)
  cout << it->first << ": " << it->second << endl;

// C++11: using auto
for (auto it = v.begin(); it != v.end(); ++it)
  cout << *it << endl;
for (auto it = m.begin(); it != m.end(); ++it)
  cout << it->first << ": " << it->second << endl;

// C++11: using auto with ranged-for
for (auto &e : v)
  cout << e << endl;
for (auto &kv : m)
  cout << kv.first << ": " << kv.second << endl;
```

C++11 Additions

- Initializer lists for STL containers
  - `std::vector<int> v {34,23};`
  - `std::vector<int> v = {34,23};`
  - `std::map<int, string> m = {{1, "hello"}, {5, "world"}};`
- Smart poniters
  - Helps memory management – you don't need to delete raw pointer manually, which is very error-prone
  - shared_ptr: shared ownership (reference counting)
  - unique_ptr: unique ownership
  - weak_ptr: no ownership

shared_ptr

- Reference-counted ownership of its contained raw pointer
- If the number of users reach 0, deletes the pointer

```
#include <memory>
…

class MyClass {
public:
  ~MyClass() { cout << "~MyClass" << endl; }
};

void func() {
  vector<shared_ptr<MyClass>> vec;
  {
    shared_ptr<MyClass> t(new MyClass());
    vec.push_back(t);
  } // "~MyClass" would have been printed here if 't' was not in 'vec'
  cout << "after the block" << endl;
} // "~MyClass" is printed here; now # of users is 0
```

GDB: The GNU Project Debugger

- Standard debugger for GNU operating system
- Supports many programming languages
  - Ada, C, C++, Objective-C, Free Pascal, Fortran, Java, …
- If you haven't used it, learn it!
  - There are many tutorials on the internet
  - And it's not that difficult after all
- Some important commands
  - b(breakpoint), p(print)
  - u(go up), d(go down) (stack frame)
  - r(run), c(continue), ctrl+c(stop), s(step into), n(step over)
  - And most of all, h(help)

Helpful Sites

- http://en.cppreference.com/w/
- http://www.cplusplus.com/
- http://stackoverflow.com/
- And
- http://www.google.com

References

- [1] Brian Kernighan, COS333 lecture notes, 2013.
- [2] Mark Allen Weiss, C++ for Java Programmers, Pearson Prentice Hall, 2004.