CSE 333
Lecture 9 - intro to C++

Hal Perkins
Department of Computer Science & Engineering
University of Washington
Administrivia

New exercise posted yesterday afternoon, due Monday before class

- Read a directory and open/copy text files found there
- Good warmup for …

HW2

- Writeup posted now, starter files will be pushed to repos this afternoon. Will send email once that’s done.
- Short demo today (maybe right now?)
Today’s goals

An introduction to C++
- some shortcomings of C that C++ addresses
- give you a perspective on how to learn C++
- kick the tires and write some code

Advice: read related sections in the C++ Primer. It’s hard to learn the “why is it done like this” from reference docs
We had to work hard to mimic encapsulation, abstraction

**encapsulation**: hiding implementation details

- used header file conventions and the “static” specifier to separate private functions from public functions
- cast structures to (void *) to hide implementation-specific details

**abstraction**: associating behavior with encapsulated state

- the functions that operate on a LinkedList were not really tied to the linked list structure
- we passed a linked list to a function, rather than invoking a method on a linked list instance
C++

A major addition is its support for classes & objects!

classes

- public, private, and protected methods and instance variables
- (multiple!) inheritance

polymorphism

**static polymorphism**: multiple functions or methods with the same name, but different argument types (overloading)

  Works for all functions, not just class members

**dynamic (subtype) polymorphism**: derived classes can override methods of parents, and methods will be dispatched correctly
We had to emulate generic data structures

customer passes a (void *) as a payload to a linked list
customer had to pass in function pointers so that the linked list could operate on payloads correctly

comparisons, deallocation, pickling up state, etc.
**C++**

Supports **templates** to facilitate generic data types!

Parametric polymorphism - same idea as Java generics, but different in details - particularly implementation

- to declare that $\mathbf{x}$ is a vector of ints:
  - `vector<int> x;`

- to declare that $\mathbf{x}$ is a vector of floats:
  - `vector<float> x;`

- to declare that $\mathbf{x}$ is a vector of (vectors of floats):
  - `vector<vector<float>> x;`
We had to be careful about namespace collisions

C distinguishes between external and internal linkage

use “static” to prevent a name from being visible outside a source file (as close as C gets to “private”)

otherwise, a name is global -- visible everywhere

we used naming conventions to help avoid collisions in the global namespace

    LLIteratorNext, HTIteratorNext, etc.
C++

Permits a module to define its own namespace!

- the linked list module could define an “LL” namespace
- the hashtable module could define an “HT” namespace
- both modules could define an Iterator class
  - one would be globally named \texttt{LL::Iterator}
  - the other would be globally named \texttt{HT::Iterator}

Classes also allow duplicate names without collisions

Namespaces isolate names in collections of classes and other “global” things (somewhat like Java packages)
C does not provide any standard data structures
we had to implement our own linked list and hash table
as a C programmer, you often re-invent the wheel badly
maybe if you’re clever you’ll use somebody else’s libraries
but, C’s lack of abstraction, encapsulation, and generics means
you’ll probably have to tweak them, or tweak your code to use them
The C++ standard library is rich!

**generic containers**: bitset, queue, list, associative array (including hash table), deque, set, stack, and vector

and iterators for most of these

**a string class**: hides the implementation of strings

**streams**: allows you to stream data to and from objects, consoles, files, strings, and so on

and more...
Error handling is a pain

have to define error codes and return them

customers have to understand error code conventions, and
need to constantly test return values

if \texttt{a()} calls \texttt{b()} calls \texttt{c()}

\texttt{a} depends on \texttt{b} to propagate an error in \texttt{c} back to it
C++

Supports exceptions!
	ry / throw / catch

if used with discipline, can simplify error processing

but, if used carelessly, can complicate memory management

consider: a( ) calls b( ) calls c( )

if c( ) throws an exception that b( ) doesn’t catch, you might not get a chance to clean up resources allocated inside b( )

But much C++ code still needs to work with C & old C++ libraries, so still uses return codes, exit( ), etc.
Some tasks still hurt in C++

Memory management

C++ has no garbage collector

you have to manage memory allocation and deallocation, and track ownership of memory

it’s still possible to have leaks, double frees, and so on

but, there are some things that help

“smart pointers”

classes that encapsulate pointers and track reference counts

deallocate memory when the reference count goes to zero
Some tasks still hurt in C++

C++ doesn’t guarantee type or memory safety

You can still...

- forcibly cast pointers between incompatible types
- walk off the end of an array and smash the stack (or heap)
- have dangling pointers
- conjure up a pointer to an address of your choosing
C++ has many, many features.

Operator overloading

your class can define methods for handling “+”, “->”, etc!

Object constructors, destructors

particularly handy for stack-allocated objects

Reference types

truly pass-by-reference instead of pass-by-value

Advanced OO

multiple inheritance, virtual base classes, dynamic dispatch
How to think about C++

set of styles and ways to use C++

style guides

good styles and robust engineering practices

set of styles and ways to use C
Or...

in the hands of a disciplined programmer, C++ is a powerful weapon

but, if you’re not so disciplined about how you use C++...
Hello, world!

```cpp
#include <iostream>
#include <cstdlib>

int main(int argc, char **argv) {
    std::cout << "Hello, World!" << std::endl;
    return EXIT_SUCCESS;
}
```

text:

Looks simple enough...

compile with g++ instead of gcc:

```
g++ -Wall -g -std=c++11 -o helloworld helloworld.cc
```

let's walk through the program step by step
Hello, world!

```cpp
#include <iostream>
#include <cstdlib>

int main(int argc, char **argv) {
    std::cout << "Hello, World!" << std::endl;
    return EXIT_SUCCESS;
}
```

iostream is part of the C++ standard library

note you don’t include a “.h” when you include C++ standard library headers

but you do for local headers (e.g., #include “ll.h”)

iostream declares stream object instances, including std::cin, std::cout, std::cerr, in the “std” namespace
Hello, world!

```cpp
#include <iostream>
#include <cstdlib>

int main(int argc, char **argv) {
    std::cout << "Hello, World!" << std::endl;
    return EXIT_SUCCESS;
}
```

cstdlib is the C standard library’s stdlib.h header

(nearly) all C standard library functions are available to you

for header `<foo.h>`, you should `#include <cfoo>`

we need it for EXIT_SUCCESS, as usual
Hello, world!

```
#include <iostream>
#include <cstdlib>

int main(int argc, char **argv) {
    std::cout << "Hello, World!" << std::endl;
    return EXIT_SUCCESS;
}
```

std::cout is the “cout” object instance declared by iostream, living within the “std” namespace (C++’s name for stdout)

std::cout is an object of class ostream


used to format and write output to the console

the entire standard library is in namespace std
Hello, world!

```c++
#include <iostream>
#include <cstdlib>

int main(int argc, char **argv) {
    std::cout << "Hello, World!" << std::endl;
    return EXIT_SUCCESS;
}
```

C++ distinguishes between objects and primitive types

- primitive types include all the familiar ones from C
  - char, short, int, unsigned long, float, double, long double, etc.
  - and, C++ defines “bool” as a primitive type (woohoo!)
Hello, world!

```
#include <iostream>
#include <cstdlib>

int main(int argc, char **argv) {
    std::cout << "Hello, World!" << std::endl;
    return EXIT_SUCCESS;
}
```

“<<” is an operator defined by the C++ language

it’s defined by C as well; in C/C++, it bitshifts integers

but, C++ allows **classes** to overload operators

the ostream class overloads “<<”

i.e., it defines methods that are invoked when an ostream is

the LHS of the << operator
Hello, world!

```cpp
#include <iostream>
#include <cstdlib>

int main(int argc, char **argv) {
    std::cout << "Hello, World!" << std::endl;
    return EXIT_SUCCESS;
}
```

ostream has many different methods to handle `<<` the methods differ in the type of the RHS of `<<` if you do `std::cout << "foo";` C++ invokes cout’s method to handle “<<” with RHS “char *”
Hello, world!

```cpp
#include <iostream>
#include <cstdlib>

int main(int argc, char **argv) {
    std::cout << "Hello, World!" << std::endl;
    return EXIT_SUCCESS;
}
```

the ostream class’s methods that handle `"<<"` return (a reference to) themselves

so, when (std::cout << "Hello, World!") is evaluated:

- a method of the std::cout object is invoked
- it buffers the string “Hello, World!” for the console
- and, it returns (a reference to) std::cout
Hello, world!

```cpp
#include <iostream>
#include <cstdlib>

int main(int argc, char **argv) {
    std::cout << "Hello, World!" << std::endl;
    return EXIT_SUCCESS;
}
```

next, a method on std::cout to handle “<<” is invoked

this time, the RHS is `std::endl`

turns out this is a pointer to a “manipulator” function

this manipulator function writes newline to the ostream it is invoked on, and then flushes the ostream’s buffer

so, something is printed on the console at this point
Wow...

```cpp
#include <iostream>
#include <cstdlib>

int main(int argc, char **argv) {
    std::cout << "Hello, World!" << std::endl;
    return EXIT_SUCCESS;
}
```

You should be surprised and scared at this point

C++ makes it easy to hide a significant amount of complexity

it’s powerful, but really dangerous

once you mix together templates, operator overloading, method overloading, generics, and multiple inheritance, it gets really hard to know what’s actually happening!
Refining it a bit...

C++’s standard library has a `std::string` class!

- include the `<string>` header to use it
Refining it a bit...

```cpp
#include <iostream>
#include <cstdlib>
#include <string>

using namespace std;

int main(int argc, char **argv) {
    string hello("Hello, World!");
    cout << hello << endl;
    return EXIT_SUCCESS;
}
```

The “using” keyword introduces part of a namespace, or an entire namespace, into the current region:

- `using namespace std;`  -- imports all names from std::
- `using std::cout;`  -- imports only std::cout
Refining it a bit...

```cpp
#include <iostream>
#include <cstdlib>
#include <string>

using namespace std;

int main(int argc, char **argv) {
    string hello("Hello, World!");
    cout << hello << endl;
    return EXIT_SUCCESS;
}
```

We’re instantiating a `std::string` object on the stack passing the C string “Hello, World!” to its constructor method

`hello` is deallocated (and its destructor invoked) when main returns
The C++ string library overloads the `<<` operator as well
defines a function (not an object method) that is invoked when the LHS is an ostream and the RHS is a std::string

http://www.cplusplus.com/reference/string/operator<</
Refining it a bit...

```cpp
#include <iostream>
#include <cstdlib>
#include <string>

using namespace std;

int main(int argc, char **argv) {
    string hello("Hello, World!");
    cout << hello << endl;
    return EXIT_SUCCESS;
}
```

Note the side-effect of using namespace std;

can now refer to std::string by string, std::cout by cout, and std::endl by endl
The string class overloads the “+” operator to create and return a new string that is the concatenation of LHS and RHS.
string assignment

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

int main(int argc, char **argv) {
    string hello("Hello");
    hello = hello + " there";
    cout << hello << endl;
    return EXIT_SUCCESS;
}
```

The string class overloads the “=” operator copies the RHS and replaces the string’s contents with it

so, the full statement (i) “+” creates a string that is the concatenation of hello’s current contents and “ there”, and (ii) “=” creates a copy of the concatenation to store in hello. Without the syntactic sugar it is:

g++ -o concat.cc concat.cc

```cpp
hello.operator=(hello.operator+(" there"));
```
stream manipulators

#include <iostream>
#include <cstdlib>
#include <iomanip>
using namespace std;

int main(int argc, char **argv) {
   cout << "Hi! " << setw(4) << 5 << " " << 5 << endl;
   cout << hex << 16 << " " << 13 << endl;
   cout << dec << 16 << " " << 13 << endl;
   return EXIT_SUCCESS;
}

iomanip defines a set of stream manipulator functions

pass them to a stream to affect formatting

stream manipulators

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

int main(int argc, char **argv) {
    cout << "Hi! " << setw(4) << 5 << " " << 5 << endl;
    cout << hex << 16 << " " << 13 << endl;
    cout << dec << 16 << " " << 13 << endl;
    return EXIT_SUCCESS;
}
```

`setw(x)` sets the width of the next field to x
only affects the next thing sent to the output stream
stream manipulators

```cpp
#include <iostream>
#include <cstdlib>
#include <iomanip>

using namespace std;

int main(int argc, char **argv) {
    cout << "Hi! " << setw(4) << 5 << " " << 5 << endl;
    cout << hex << 16 << " " << 13 << endl;
    cout << dec << 16 << " " << 13 << endl;
    return EXIT_SUCCESS;
}
```

`hex` sets the stream to output integers in hexadecimal
stays in effect until you set the stream to some other base
`hex`, `dec`, `oct` are your choices
You can still use printf, though

C is (roughly) a subset of C++

Can mix C and C++ idioms if needed to work with existing code, but avoid mixing if you can - use C++(11)
Reading

```cpp
#include <iostream>
#include <cstdlib>

using namespace std;

int main(int argc, char **argv) {
    int num;
    cout << "Type a number: ";
    cin >> num;
    cout << "You typed: " << num << endl;
    return EXIT_SUCCESS;
}
```

`std::cin` is an object instance of class `istream`

- supports the `>>` operator for “extraction”

- `cin` also has a `getline()` method
Exercise 1

Write a C++ program that:

uses streams to:

prompts the user to type in 5 floats
prints them out in opposite order
with 4 digits of precision
See you on Monday!