

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

C

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

C

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 **x** is a vector of ints:
 - ▶ `vector<int> x;`
- to declare that **x** is a vector of floats:
 - ▶ `vector<float> x;`
- to declare that **x** is a vector of (vectors of floats):
 - ▶ `vector<vector<float>> x;`

C

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 `LL::Iterator`
 - ▶ the other would be globally named `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

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

C++

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...

C

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 **a()** calls **b()** calls **c()**
 - ▶ **a** depends on **b** to propagate an error in **c** back to it

C++

Supports exceptions!

- try / 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

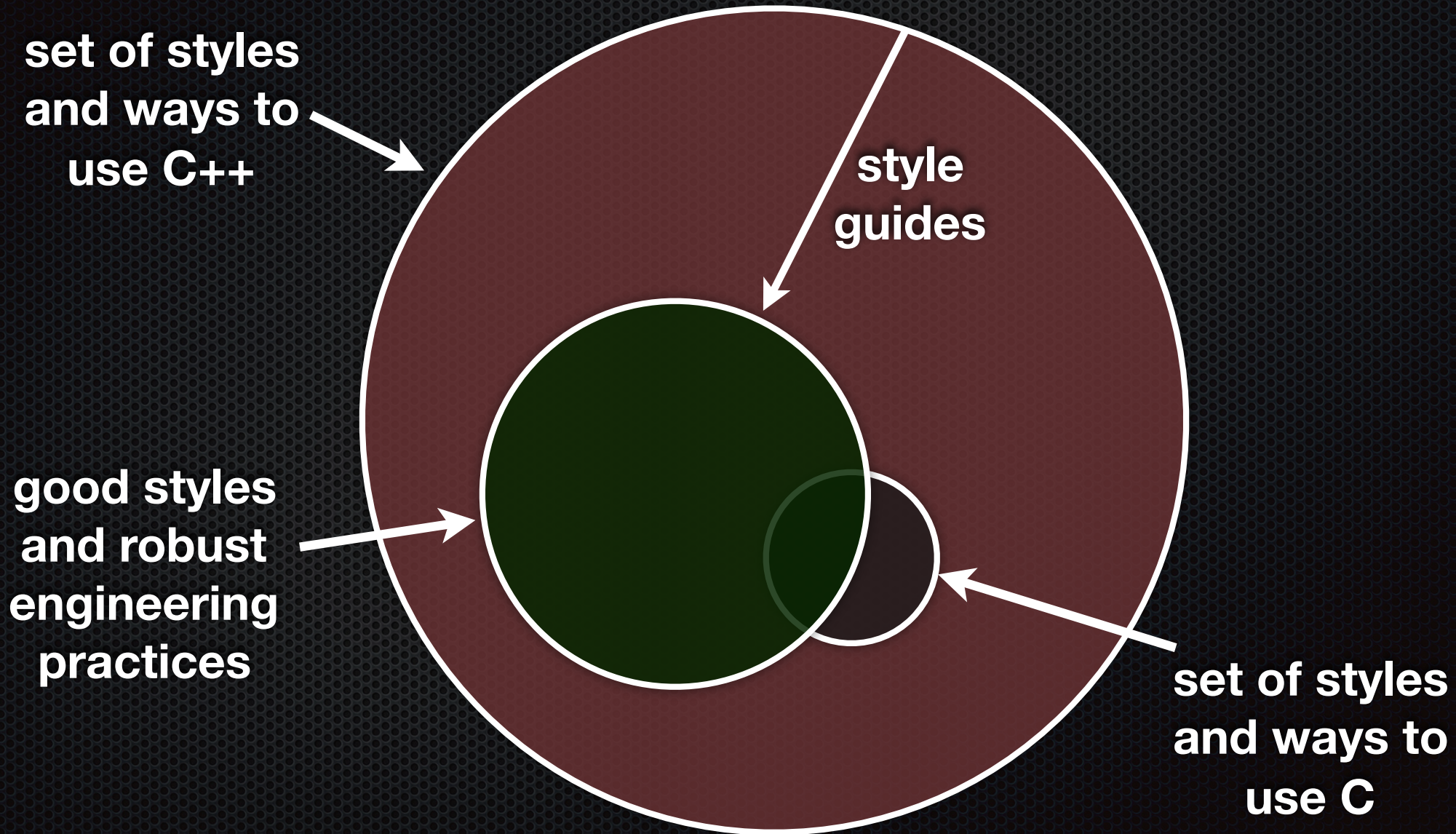
Reference types

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

Advanced OO

- multiple inheritance, virtual base classes, dynamic dispatch

How to think about C++



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!

```
helloworld.cc
#include <iostream>
#include <cstdlib>

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

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!

```
helloworld.cc
#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!

```
helloworld.cc
#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!

```
helloworld.cc
#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
 - ▶ <http://www.cplusplus.com/reference/iostream/ostream/>
- used to format and write output to the console
- the entire standard library is in namespace std

Hello, world!

```
helloworld.cc
#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!

```
helloworld.cc
#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!

```
helloworld.cc
#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!

```
helloworld.cc
#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!

```
helloworld.cc
#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...

```
helloworld.cc
#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...

```
helloworld2.cc
#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;
}
```

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

- include the `<string>` header to use it
- <http://www.cplusplus.com/reference/string/>

Refining it a bit...

```
helloworld2.cc
#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...

```
helloworld2.cc
#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

Refining it a bit...

```
helloworld2.cc
#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 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<](http://www.cplusplus.com/reference/string/operator<</)

Refining it a bit...

```
helloworld2.cc
#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`

string concatenation

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

concat.cc

```
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

- creates and returns a new string that is the concatenation of LHS and RHS

string assignment

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

concat.cc

```
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:
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;
}
```

helloworld3.cc

iomanip defines a set of stream manipulator functions

- pass them to a stream to affect formatting
 - ▶ <http://www.cplusplus.com/reference/iostream/manipulators/>

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;
}
```

helloworld3.cc

setw(x) sets the width of the next field to x

- only affects the next thing sent to the output stream

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;
}
```

helloworld3.cc

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

helloworld4.cc

```
#include <stdio>
#include <stdlib>

int main(int argc, char **argv) {
    printf("hello from C\n");
    return EXIT_SUCCESS;
}
```

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

```
#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;
}
```

helloworld5.cc

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!