C++ Intro

CSE 333 Fall 2022

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Administrivia

- Exercise 7 posted yesterday, due Monday
  - POSIX I/O for directories and reading data from files
  - Read a directory and open/copy text files found there
    - Copy *exactly* and *only* the bytes in the file(s). No extra output, no "formatting", no any other transformations.
  - Good warm-up for…
- Homework 2 due in two weeks (10/27)
  - File system crawler, indexer, and search engine
  - Spec posted now
  - Starter files will be pushed out this afternoon
  - Demo in class today!

Now?

Administrivia (Monday)

- New exercise out today – First C++ program: read a number and print its factors
  - Due Wed. morning

- HW2 – how's it look? Be sure to make good progress this week

If things are starting to get difficult…

- We're starting week 4 of the quarter and for most of us, so far, so good
- But some of us are dealing with unexpected things (illness, personal situations) and maybe the world doesn't yet seem entirely back to "normal" (whatever that is)
- If you're having problems, please reach out to course staff, Allen School Advising, UW Counseling Center, other resources, etc.
  - Say something if you could use some help, or just need to talk – don't bottle it up and hope that it will magically get better
- Try to stay on schedule – don't plan in advance to use late days, etc. and speak up if that's not working.

Today's Goals

- An introduction to C++
  - Some comparisons to C and shortcomings that C++ addresses
  - Give you a perspective on how to learn C++
  - Kick the tires and look at some code

- **Advice:** You ***must*** read related sections in the *C++ Primer*
  - It's hard to learn the "why is it done this way" from reference docs, and even harder to learn from random stuff on the web
  - Lectures and examples will introduce the main ideas, but aren't everything you'll ~~want~~ need to understand
  - 3 hours of web searching *might* save you 20 min. of reading in the *Primer* – but is that a good tradeoff?
  - And *free* access through UW libraries (O'Reilly books online)

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
    - Function 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 support for classes and 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
  - Generic linked list using `void*` payload
  - Pass function pointers to generalize different "methods" for data structures
    - 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 strings: `vector<string> 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, name is global and visible everywhere
  - We used naming conventions to help avoid collisions in the global namespace
    - *e.g.* `LLIteratorNext` vs. `HTIteratorNext`, etc.

C++

- Permits a module to define its own namespace!
  - The linked list module could define an "`LL`" namespace while the hash table 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 group and isolate names in collections of classes and other "global" things (somewhat like Java packages)
    - Entire C++ standard library is in a namespace `std` (more later…)

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 reinvent the wheel… poorly
    - 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 end up tinkering with them or tweak your code to use them

C++

- The C++ standard library is huge!
  - **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
  - *e.g.* if `a()` calls `b()`, which 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()`, which 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 that are not exception-safe, so still uses return codes, exit(), etc.
    - We won't use (and Google style guide doesn't use either)

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
    - C++'s destructors permit a pattern known as "Resource Allocation Is Initialization" (RAII) (terrible name but super useful idea)
      - Useful for releasing memory, locks, database transactions, and more

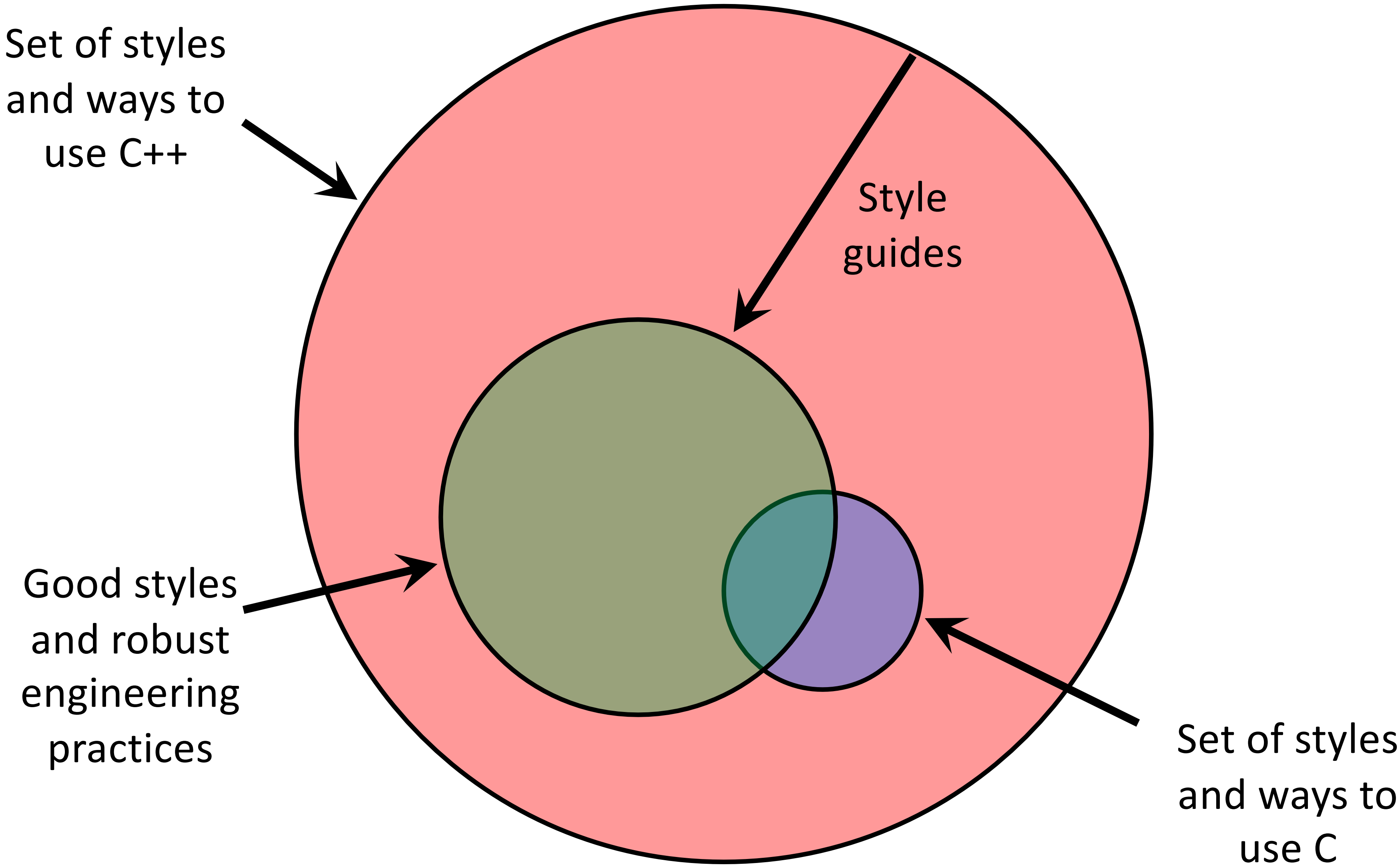
Some Tasks Still Hurt in C++

- 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 memory
    - Have dangling pointers
    - Conjure up a pointer to an arbitrary 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
  - True call-by-reference instead of always call-by-value
- Advanced Objects
  - Multiple inheritance, virtual base classes, dynamic dispatch

How to Think About C++



Or…

In the hands of a disciplined programmer, C++ is a powerful tool

But if you're not so disciplined about how you use C++…

Hello World in C

helloworld.c

```
#include <stdio.h>    // for printf()
#include <stdlib.h>   // for EXIT_SUCCESS

int main(int argc, char** argv) {
  printf("Hello, World!\n");
  return EXIT_SUCCESS;
}
```

- You never had a chance to write this!
  - Compile with `gcc`:

```
gcc -Wall -g -std=c17 -o hello helloworld.c
```

  - You should be able to describe in detail everything in this code

Hello World in C++

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++17 -o helloworld helloworld.cc
```

  - Let's walk through the program step-by-step to highlight some differences

Hello World in C++

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 write "`.h`" when you include C++ standard library headers
    - But you *do* for local headers (*e.g.* `#include "ll.h"`)
  - `iostream` declares stream *object* instances in the "`std`" namespace
    - *e.g.* `std::cin`, `std::cout`, `std::cerr`

Hello World in C++

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`
  - Nearly all C standard library functions are available to you
    - For C header `foo.h`, you should `#include <cfoo>`
  - We include it here for `EXIT_SUCCESS`, as usual

Hello World in C++

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/ostream/ostream/
  - Used to format and write output to the console
  - The entire standard library is in the namespace `std`

Hello World in C++

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
  - These include the familiar ones from C: `char`, `short`, `int`, `long`, `float`, `double`, etc.
  - C++ also defines `bool` as a primitive type (woo-hoo!)
    - Use it!
    - (but bool and int values silently convert types for compatiblity)

Hello World in C++

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
  - Defined in C as well: usually it bit-shifts integers (in C/C++)
  - C++ allows classes and functions to overload operators!
    - Here, the `ostream` class overloads "<<"
    - *i.e.* it defines different member functions (methods) that are invoked when an `ostream` is the left-hand side of the << operator

Hello World in C++

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 functions differ in the type of the right-hand side (RHS) of <<
  - *e.g.* if you do `std::cout << "foo";` then C++ invokes `cout`'s function to handle << with RHS `char*`

Hello World in C++

helloworld.cc

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

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

- The `ostream` class' member functions that handle `<<` return a reference to themselves
  - When `std::cout << "Hello, World!";` is evaluated:
    - A member function 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 in C++

helloworld.cc

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

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

- Next, another member function on `std::cout` is invoked to handle << with RHS `std::endl`
  - `std::endl` is a pointer to a "manipulator" function
    - This manipulator function writes newline (`'\n'`) to the `ostream` it is invoked on and then flushes the `ostream`'s buffer
    - This *enforces* that something is printed to 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 everything together (templates, operator overloading, method overloading, generics, multiple inheritance), it can get *really* hard to know what's actually happening!

Let's Refine 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
    - Seems to be automatically included in `iostream` on CSE Linux environment (C++11) – but include it explicitly anyway if you use it
  - http://www.cplusplus.com/reference/string/

Let’s Refine 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 a namespace (or part of) into the current region
  - `using namespace std;` imports all names from `std::`
  - `using std::cout;` imports *only* `std::cout` (used as `cout`)

Let’s Refine 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;
}
```

- Benefits of `using namespace std;`
  - We can now refer to `std::string` as `string`, `std::cout` as `cout`, and `std::endl` as `endl`
    - Google style guide says never use `using namespace`, only `using` for individual items; but for 333 `using namespace std;` is ok

Let's Refine 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;
}
```

- Here we are instantiating a `std::string` object *on the stack* (an ordinary local variable)
  - Passing the C string `"Hello, World!"` to its constructor method
  - `hello` is deallocated (and its destructor invoked) when `main` returns

Let’s Refine 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 also overloads the << operator
  - Defines a function (*not* an object method) that is invoked when the LHS is `ostream` and the RHS is `std::string`
    - http://www.cplusplus.com/reference/string/string/operator<</

String Concatenation

concat.cc

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

using namespace std;

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

- The string class overloads the "+" operator
  - Creates and returns a new string that is the concatenation of the LHS and RHS

String Assignment

concat.cc

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

using namespace std;

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

- The string class overloads the "=" operator
  - Copies the RHS and replaces the string's contents with it

String Manipulation

concat.cc

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

using namespace std;

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

- This statement is complex!
  - First "+" creates a string that is the concatenation of `hello`'s current contents and `", World!"`
  - Then "=" creates a copy of the concatenation to store in `hello`
  - Without the syntactic sugar:
    - `hello.operator=(hello.operator+(", World!"));`

Stream Manipulators

manip.cc

```
#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
    - http://www.cplusplus.com/reference/iomanip/
    - http://www.cplusplus.com/reference/ios/

Stream Manipulators

manip.cc

```
#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 (*i.e.* it is not persistent)

Stream Manipulators

manip.cc

```
#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`, `dec`, and `oct` set the numerical base for *integer* output to the stream
  - Stays in effect until you set the stream to another base (*i.e.* it is persistent)

C and C++

helloworld3.cc

```
#include <cstdio>
#include <cstdlib>

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

- C is (roughly) a subset of C++
  - You can still use `printf` – but bad style in ordinary C++ code
  - Can mix C and C++ idioms if needed to work with existing code, but avoid mixing if you can
    - Use C++(11)

Reading

echonum.cc

```
#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"
    - Can be used in conditionals – `(std::cin>>num)` is `true` if successful
  - Has a `getline()` method and methods to detect and clear errors

Extra Exercise #1

- Write a C++ program that uses stream to:
  - Prompt the user to type 5 floats
  - Prints them out in opposite order with 4 digits of precision