C++ Intro

CSE 333 Autumn 2025

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Administrivia

- Homework 2 due in next Thursday (10/23)
  - File system crawler, indexer, and search engine
  - Spec posted and starter files pushed out last Friday
  - Demo in section this week
- New exercise 8 out today – First C++ program: read a number and print its factors
  - Due Wed. morning 10 am

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)

Programming Terminology Review

- **Encapsulation and Abstraction:** Hiding implementation details (restricting access) and associating behaviors (methods) with data

- **Polymorphism:** The provision of a single interface to entities of different types

- **Generics:** Algorithms written in terms of types *to-be-specified-later*

Encapsulation and Abstraction (C)

- Used header file conventions and the `static` specifier to separate "private" functions, definitions, and constants from "public"

- Used forward-declared `struct`s and opaque pointers (*i.e.*, `void*`) to hide implementation-specific details

- Can't associate behaviors with encapsulated state
  - Functions that operate on a `LinkedList` not actually tied to the struct

Really difficult to mimic – implemented primarily via coding conventions

Encapsulation and Abstraction (C++)

- Support for classes and objects!
  - Public, private, and protected access specifiers
  - **Methods** and **instance variables** ("`this`")
  - (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

Generics (C)

- Generic linked list and hash table by using `void*` payload
- Function pointers to generalize different behavior for data structures
  - Comparisons, deallocation, pickling up state, etc.

Emulated generic data structures primarily by disabling type system

Generics (C++)

- Templates facilitate generic data types
  - *Parametric polymorphism:* same idea as Java generics, but different in details, particularly implementation
    - A vector of `int`s: `vector<int> x;`
    - A vector of `float`s: `vector<float> x;`
    - A vector of (vectors of `float`s): `vector<vector<float>> x;`

- Specialized casts to increase type safety

Namespaces (C)

- Names are global and visible everywhere
  - Can use `static` to prevent a name from being visible outside a source file (as close as C gets to "private")

- Naming conventions help avoid collisions in the global namespace
  - *e.g.*, `LinkedList_Allocate`, `HTIterator_Next`, etc.

Avoid collisions primarily via coding conventions

Namespaces (C++)

- Explicit namespaces!
  - 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` and the other would be globally named `HT::Iterator`

- Classes also allow duplicate names without collisions
  - Classes can also define their own pseudo-namespace, very similar to Java static inner classes

Standard Library (C)

- C does not provide any standard data structures
  - We had to implement our own linked list and hash table
- Hopefully, you can use somebody else's libraries
  - But C's lack of abstraction, encapsulation, and generics means you'll probably end up tweak them or tweak your code to use them

YOU implement the data structures that you need

Standard Library (C++)

- **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
- **Generic algorithms:** sort, filter, remove duplicates, etc.

Error Handling (C)

- Error handling is a pain
- Define error codes and return them
  - Either directly return or via a "global" like `errno`
  - No type checking: does `1` mean `EXIT_FAILURE` or `true`?

- Customers and implementors 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

Error handling is a pain – mixture of coding conventions and discipline

Error Handling (C++)

- Supports exceptions!
  - `try` / `throw` / `catch`
  - If used with discipline, can simplify error processing
  - 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()`

- We will largely avoid in 333
  - You still benefit from having more interpretable errors!
  - 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 still have to manage memory allocation & deallocation and track
    - 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 constructors and destructors permit a pattern known as "Resource Allocation Is Initialization" (RAII)
      - Useful for releasing memory, locks, database transactions, etc.

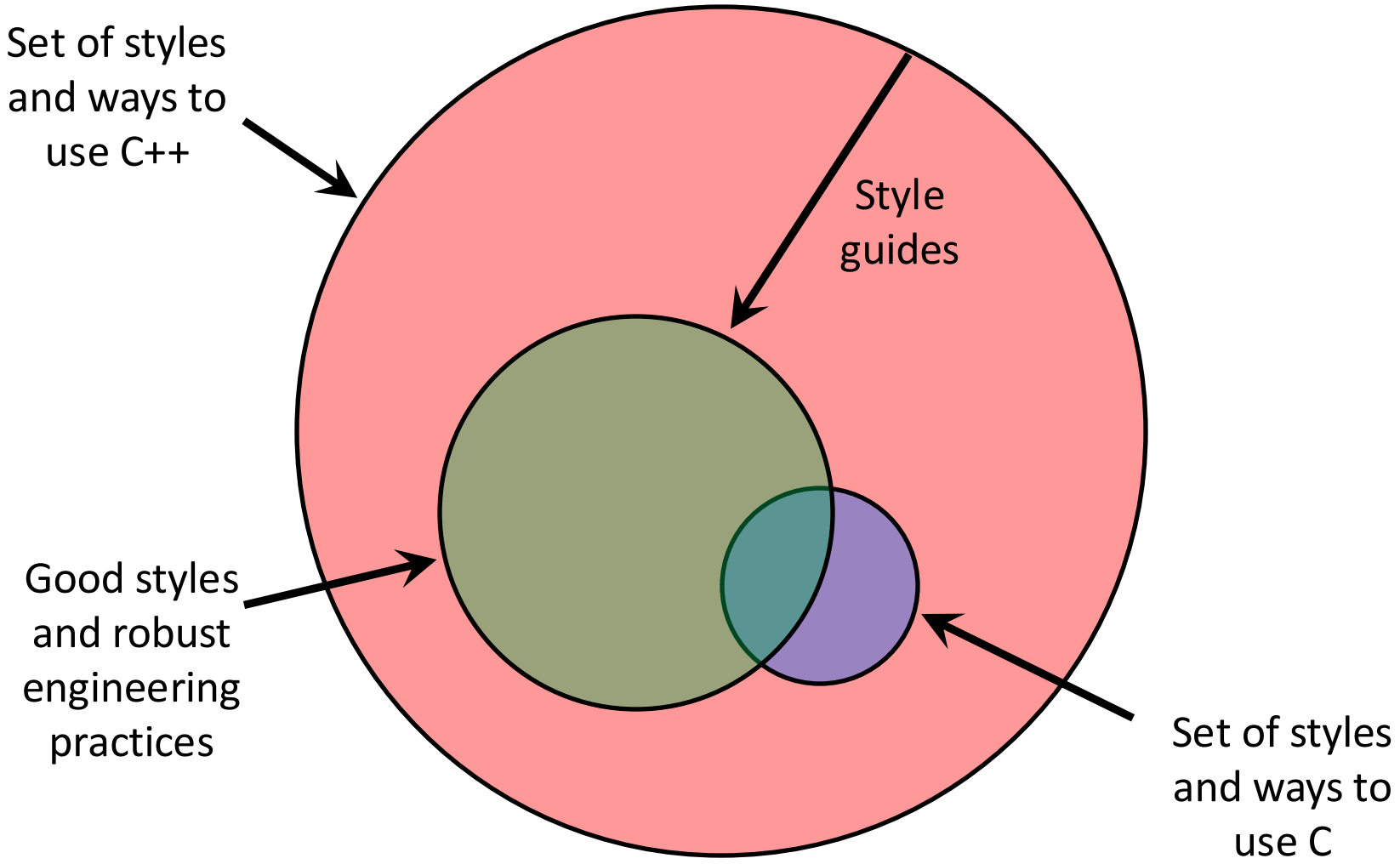
Some Tasks Still Hurt in C++

- 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

```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 helloworld helloworld.c
```

  - Based on what you know now, what is one thing that goes on in the execution of this "simple" program?
    - Be detailed!

Hello World in C++

helloworld.cc

```
#include <iostream>    // for cout, endl
#include <cstdlib>     // for EXIT_SUCCESS

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
```

  - What are some differences you notice in the C++ program compared to C?
  - Let's walk through the program step-by-step to highlight some differences

Hello World in C++

helloworld.cc

```
#include <iostream>   // for cout, endl
#include <cstdlib>    // for EXIT_SUCCESS

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

- `iostream` is part of the ***C++*** standard library
  - You don't add "`.h`" when including C++ standard library headers
    - But you *do* for local headers (*e.g.* `#include "ll.h"`)
  - `iostream` declares stream *object* instances in the "`std`" namespace
    - Callback: C++ supports classes and objects
    - *e.g.* `std::cin`, `std::cout`, `std::cerr`

Hello World in C++

helloworld.cc

```
#include <iostream>   // for cout, endl
#include <cstdlib>    // for EXIT_SUCCESS

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>    // for cout, endl
#include <cstdlib>     // for EXIT_SUCCESS

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>   // for cout, endl
#include <cstdlib>    // for EXIT_SUCCESS

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!

Hello World in C++

helloworld.cc

```
#include <iostream>   // for cout, endl
#include <cstdlib>    // for EXIT_SUCCESS

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
  - Without the syntactic sugar (without abstraction)

```
std::cout.operator<<(char* c_str);
```

Hello World in C++

helloworld.cc

```
#include <iostream>    // for cout, endl
#include <cstdlib>     // for EXIT_SUCCESS

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>    // for cout, endl
#include <cstdlib>     // for EXIT_SUCCESS

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`
  - Synonymous to `std::cout.operator<<("Hello, World!");`

Hello World in C++

helloworld.cc

```
#include <iostream>    // for cout, endl
#include <cstdlib>     // for EXIT_SUCCESS

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

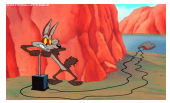
- Next, another member function on `std::cout` is invoked to handle `<<` with RHS `std::endl`
  - `std::endl` is a pointer to a "manipulator" function
    - This manipulator function writes newline (`'\n'`) to the `ostream` it is invoked on and then flushes the `ostream`'s buffer
    - This *enforces* that something is printed to the console at this point

Wow…

helloworld.cc

```
#include <iostream>    // for cout, endl
#include <cstdlib>     // for EXIT_SUCCESS

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>    // for cout, endl
#include <cstdlib>     // for EXIT_SUCCESS
#include <string>      // for 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++17) – 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>   // for cout, endl
#include <cstdlib>    // for EXIT_SUCCESS
#include <string>     // for 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>    // for cout, endl
#include <cstdlib>     // for EXIT_SUCCESS
#include <string>      // for string

using std::string;
using std::cout;
using std::endl;

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

- Benefits of importing namespaces
  - We can now refer to `std::string` as `string`, `std::cout` as `cout`, and `std::endl` as `endl`

Let's Refine It a Bit

helloworld2.cc

```
#include <iostream>    // for cout, endl
#include <cstdlib>     // for EXIT_SUCCESS
#include <string>      // for 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>    // for cout, endl
#include <cstdlib>     // for EXIT_SUCCESS
#include <string>      // for 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>    // for cout, endl
#include <cstdlib>     // for EXIT_SUCCESS
#include <string>      // for 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

```
hello.operator+(", World!");
```

String Assignment

concat.cc

```
#include <iostream>    // for cout, endl
#include <cstdlib>     // for EXIT_SUCCESS
#include <string>      // for 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

```
hello.operator=(string);
```

String Manipulation

concat.cc

```
#include <iostream>    // for cout, endl
#include <cstdlib>     // for EXIT_SUCCESS
#include <string>      // for 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>    // for cout, endl
#include <cstdlib>     // for EXIT_SUCCESS
#include <iomanip>     // for dec, hex, setw

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>    // for cout, endl
#include <cstdlib>     // for EXIT_SUCCESS
#include <iomanip>     // for dec, hex, setw

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>   // for cout, endl
#include <cstdlib>    // for EXIT_SUCCESS
#include <iomanip>    // for dec, hex, setw

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 *integers* 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>      // for printf
#include <cstdlib>     // for EXIT_SUCCESS

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
    - E.g. Use `std::cerr` instead of `fprintf(stderr, …)`
  - Can mix C and C++ idioms if needed to work with existing code, but avoid mixing if you can
    - **Use C++(17)**

Reading

echonum.cc

```
#include <iostream>   // for cout, endl
#include <cstdlib>    // for EXIT_SUCCESS

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

Poll Everywhere

pollev.com/cse333

How many *different* versions of << are called?

- Ignore the stream manipulators for now
- Also, what is output?

A. 1
B. 2
C. 3
D. 4
E. We're lost…

msg.cc

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

using namespace std;

int main(int argc, char** argv) {
  int n = 172;
  string str("m");
  str += "y";
  cout << str << hex << setw(2)
       << 15U << n << "e!" << endl;
  return EXIT_SUCCESS;
}
```

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