Poll Everywhere

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Which concept did you find the most difficult in the context of Homework 1?

A. Pointers
B. Output parameters
C. Dynamic memory allocation
D. Structs
E. GDB
F. Style considerations
G. Prefer not to say

Systems Programming
C++ Intro

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Relevant Course Information

- Exercise 8 released today, due Wednesday @ 11 AM
  - First exercise in C++; Parallels to Exercise 0
  - Don't use the `--clint` flag with the linter!

- Homework 2 released last Friday, due next Thursday (2/5)
  - Fill out partner sign-up form by Thursday, 1/29 @ 11:59 PM
  - Building a file search engine: (A) File Parser, (B) File Crawler & Indexer, and (C) Query Processor
    - More details about data structures in Section this week
    - Requires `libhw1.a` to be in `hw1/` directory
  - **START EARLY** – longer than Homework 1

Homework 2 Demo

- **`make`** produces two executables:
  - `test_suite` runs unit tests on different parts of the project
  - `searchshell` is the file search engine (need to finish all parts)
    - Need to provide name of directory to crawl & index (we've given you `test_tree/` for this)
  - Can test expected behavior of `searchshell` using `solution_binaries/searchshell`

- Queries are words separated by spaces
  - Returns ranked list of documents by naïve word count – documents must contain *all* words, but rank is just sum of individual word counts
  - Used Ctrl-D to exit "gracefully," Ctrl-C will not clean up resources

Today's Goals

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

- **Advice:** 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
  - Can access for free using SSO login with your UW email address on O'Reilly's website: https://learning.oreilly.com/library/view/c-primer-fifth/9780133053043/

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 behind the scenes 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++ Unpacked (1/8)

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`

stdin stdout stderr

Hello World in C++ Unpacked (2/8)

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++

C: #include <stdlib>

- `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>`

math.h <cmath>

  - We include it here for `EXIT_SUCCESS`, as usual

Hello World in C++ Unpacked (3/8)

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` ← FILE*
  - `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++ Unpacked (4/8)

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++ Unpacked (5/8)

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 (LHS) of the << operator
  - Without the syntactic sugar/abstraction:

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

Hello World in C++ Unpacked (6/8)

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

char*

- `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++ Unpacked (7/8)

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;
}
```

this single line is equivalent to:

```
std::cout << "Hello, World!";
std::cout << endl;
```

- 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++ Unpacked (8/8)

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: String

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: Namespace (1/2)

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::` (linter will complain)
  - ✅ `using std::cout;` imports *only* `std::cout` (used as `cout`)

Let's Refine It a Bit: Namespace (2/2)

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: Scope

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

more details on these later

Let's Refine It a Bit: Operator Overloading

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

string char* ← in this example

```
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!"));`

operators are just member functions

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;
}
```

Hi!___5_5
10_d
16_13

- 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 & clear errors
  - Useful for Exercise 8

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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;
}
```

160+12 = 10(16)+12 = 0xac

(not counting these)

"my face!"

cout << str → std::string (1)
cout << 15U → unsigned int (2)
cout << n → int (3)
cout << "e!" → char* (4)

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