Systems Programming

Intro, Getting Started in C

Instructors:

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Course Staff: Instructors

- Justin Hsia (he/him)
  - CSE Associate Teaching Professor
  - You can just call me “Justin”
  - ⚠️ Much baby duty/doody 💩 this quarter

- Amber Hu (they/them)
  - CSE Lecturer (part-time)
  - You can call me “Amber,” or for fun “Doctor Hu?”
  - Fun fact: I took CSE 333 the very first time Justin taught it
    - Guess what year that was/how old I am 😅

Course Staff: Teaching Assistants

- TAs:

  - Learn more about us on the course website!

- More than anything, we want you to feel…
  - ✓ Comfortable and welcome in this space
  - ✓ Able to learn and succeed in this course
  - ✓ Comfortable reaching out if you need help or want change

Introductions: Students

- ~200 students registered, split across two lectures

- Expected background
  - **Prereq:** CSE 351 – C, pointers, memory model, linker, system calls
  - **Indirect Prereq**: CSE 123 – Classes, Inheritance, Basic Data structures, and general good style practices
  - CSE 391 or Linux skills needed for CSE 351 assumed

- Get to know each other! Help each other out!
  - Working well with others is a valuable life skill
  - Take advantage of partner work, where permissible, to *learn*, not just get a grade
    - Good chance to learn collaboration tools and tricks

Lecture Outline (1/3)

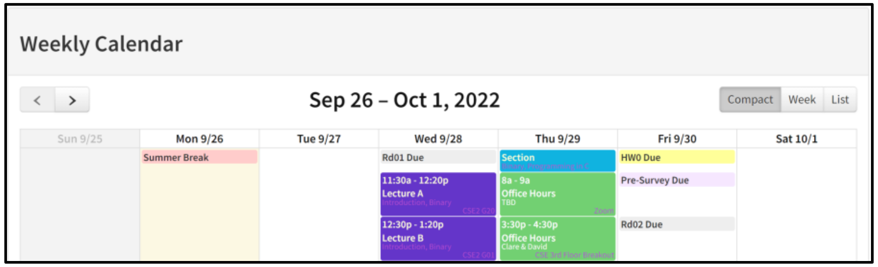
- **Course Policies**
  - https://courses.cs.washington.edu/courses/cse333/26wi/syllabus.html
  - Digest here, but you ***must*** read the full details online
- Course Introduction
- Getting Started in C
  - What do you need to write a C program from scratch?

Staff-Student Communication

- **Website:** http://cs.uw.edu/333
  - Schedule, policies, materials, assignments, etc.
- **Discussion:** https://edstem.org/us/courses/89933/
  - Announcements made here
  - Ask and answer questions – staff will monitor and contribute
- **Office Hours:** Google Sheet queue (UW login) for both in-person and virtual OHs
- **1-on-1 Meetings:** can request a limited number of appointments via Google Form (UW login)
- **Anonymous feedback**

Office Hours

- Check Weekly Calendar for scheduled office hours:
  - Zoom meeting links found in Zoom tab within Canvas

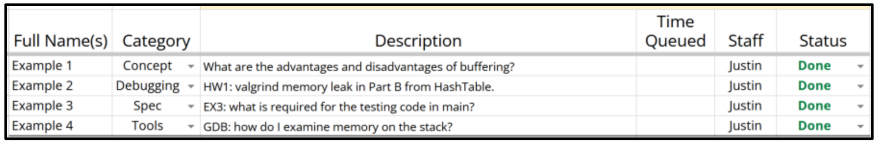


Weekly Calendar

< > Sep 26 – Oct 1, 2022 Compact Week List

Sun 9/25	Mon 9/26	Tue 9/27	Wed 9/28	Thu 9/29	Fri 9/30	Sat 10/1
	Summer Break		Rd01 Due	Section Binary, Programming in C	HW0 Due	
			11:30a - 12:20p Lecture A Introduction, Binary CSE2 G20	8a - 9a Office Hours TBD Zoom	Pre-Survey Due	
			12:30p - 1:20p Lecture B Introduction, Binary CSE2 G01	3:30p - 4:30p Office Hours Clare & David CSE 3rd Floor Breakout	Rd02 Due	

- *All* office hours will use a Google Sheets queue:
  - Fill out first 3 columns to enter queue:



Full Name(s)	Category	Description	Time Queued	Staff	Status
Example 1	Concept	What are the advantages and disadvantages of buffering?		Justin	Done
Example 2	Debugging	HW1: valgrind memory leak in Part B from HashTable.		Justin	Done
Example 3	Spec	EX3: what is required for the testing code in main?		Justin	Done
Example 4	Tools	GDB: how do I examine memory on the stack?		Justin	Done

- We encourage you to chat with other students if the TAs are busy!
  - Keep it high level, no sharing code or answers
  - Trade debugging strategies, tips for using course tools

Course Components

- Lectures (27)
  - Introduce the concepts; take notes!!!
- Sections (10)
  - Applied concepts, important tools and skills for assignments, clarification of lectures, exam review and preparation
- Programming Exercises (17)
  - One due most lectures
  - We are checking for: correctness, memory issues, code style/quality
- Programming Project (4)
  - “Homework” that build on each other
- In-Person Exams (2)
  - **Midterm:** Monday, February 9 from 5:30–6:40 PM (unconfirmed)
  - **Final:** Wednesday, March 18 from 12:30–2:20 PM

Grading

- **Exercises:** 30% total
  - Graded on correctness and style by autograders and TAs
- **Projects:** 40% total
  - Binaries provided if you didn't get previous part working
  - Graded on test suite, manual tests, and style
- **Exams:** Midterm (14%) and Final (14%)
  - Pen and paper to check mastery of concepts
- **Effort, Participation, and Altruism:** 2%
  - Many ways to earn credit here, relatively lenient on this

Academic Integrity and Student Conduct

- We trust you implicitly and will follow up if that trust is violated
  - In short: don’t attempt to gain credit for something you didn’t do and don’t help others do so, either
- This does ***not*** mean suffer in silence – learn from the course staff and peers, talk, share ideas; *but* don’t share or copy work that is supposed to be yours
  - Partners allowed this quarter on projects!
- If you find yourself in a situation where you are tempted to perform academic misconduct, please reach out to the instructors to explain your situation instead
  - See the Extenuating Circumstances section of the syllabus

Lecture Outline (2/3)

- Course Policies
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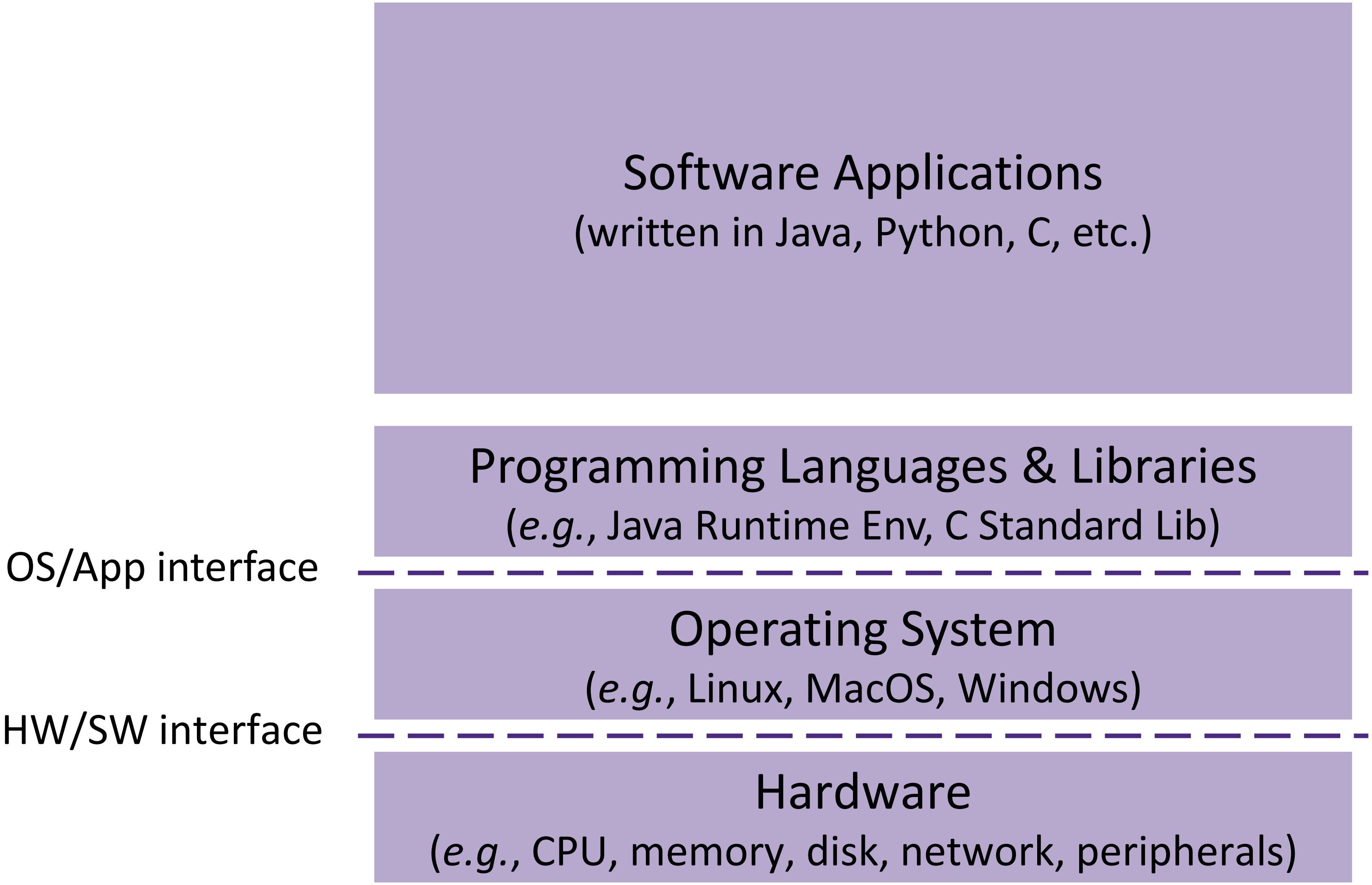
- **Course Introduction**
- Getting Started in C
  - What do you need to write a C program from scratch?

Lower Computing Layers (1/2)



Software Applications
(written in Java, Python, C, etc.)

Programming Languages & Libraries
(*e.g.*, Java Runtime Env, C Standard Lib)

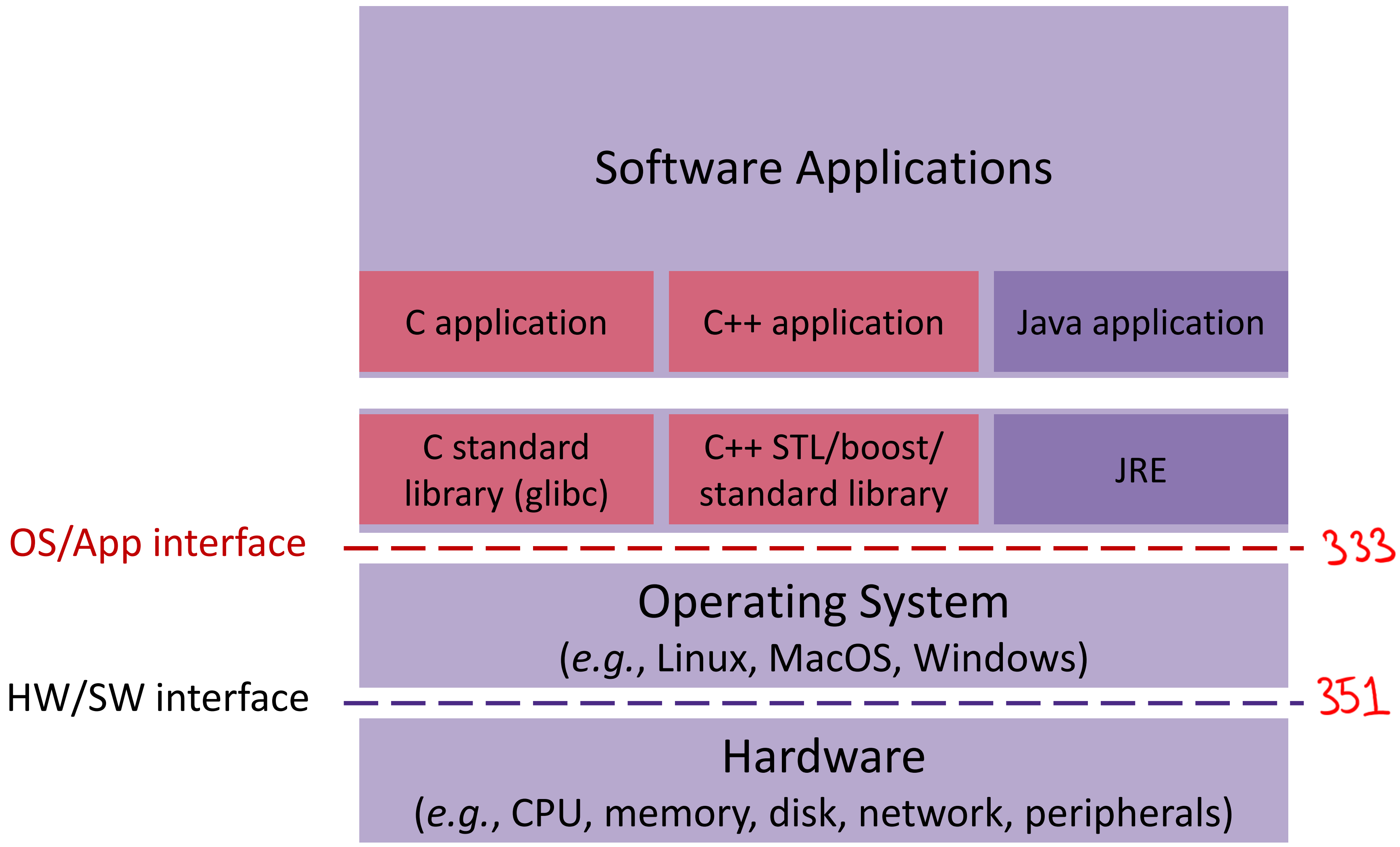
OS/App interface

Operating System
(*e.g.*, Linux, MacOS, Windows)

HW/SW interface

Hardware
(*e.g.*, CPU, memory, disk, network, peripherals)

Lower Computing Layers (2/2)


Software Applications
C application
C++ application
Java application
C standard library (glibc)
C++ STL/boost/ standard library
JRE
OS/App interface
333
Operating System (e.g., Linux, MacOS, Windows)
HW/SW interface
351
Hardware (e.g., CPU, memory, disk, network, peripherals)

Systems Programming

- **The programming skills, engineering discipline, and knowledge you need to build a system**
  - **Programming:** C / C++
  - **Discipline:** testing, debugging, performance analysis
  - **Knowledge:** long list of interesting topics
    - Concurrency, OS interfaces and semantics, techniques for consistent data management, distributed systems algorithms, …
    - Most important: a deep(er) understanding of the "layer below"

Discipline?!?

STYLE TIP

- Cultivate good habits, encourage clean code
  - Coding style conventions
  - Unit testing, code coverage testing, regression testing
  - Reading/writing documentation (code comments, design docs)
  - Code reviews

- Will take you a lifetime to learn, but oh-so-important, especially for systems code
  - Avoid write-once, read-never code
  - ★ Treat assignment submissions in this class as production code
    - Comments must be updated, no commented-out code, no extra (debugging) output

Style Grading in 333

- A **style guide** is a “set of standards for the writing, formatting, and design of documents” – in this case, code
- No style guide is perfect
  - Inherently limiting to coding as a form of expression/art
  - Rules should be motivated (*e.g.*, consistency, performance, safety, readability), even if not everyone agrees
- In 333, we will use a subset of the Google C++ Style Guide
  - Want you to experience adhering to a style guide
  - Hope you view these more as *design decisions* to be considered rather than rules to follow to get a grade
  - We acknowledge that judgments of language implicitly encode certain values and not others

Lecture Outline (3/3)

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  - Summary here, but you ***must*** read the full details online
- Course Introduction
- **Getting Started in C**
  - **What do you need to write a C program from scratch?**

C Data Structures Review

- C does not support objects!
- **Arrays** are contiguous chunks of memory
  - No implicit initialization; declaration just gives you "mystery data"
  - Don't know their own length, so no bounds checking
- **C-strings** are null-terminated arrays of characters
  - Example: `char x[] = "hi\n";`

x	'h'	'i'	'\n'	'\0'

  - `string.h` has helpful library/utility functions
    - Documentation: http://www.cplusplus.com/reference/cstring/
- **Structs** are collections of fields (variables)
  - The most object-like, but no methods

Generic C Program Layout

STYLE TIP

```
#include <system_files>
#include "local_files"

#define macro_name macro_expr

/* declare functions */
/* declare external variables & structs */

int main(int argc, char* argv[]) {
  /* the innards */
}

/* define other functions */
```

C Syntax: `main` (1/2)

- To get command-line arguments in `main`, use:

```
int main(int argc, char* argv[])
```

same as char** argv

instead of: int main()

- What does this mean?
  - needed because C doesn't track array lengths!
  - `argc` contains the number of strings on the command line (the executable name counts as one, plus one for each argument)
  - `argv` is an array containing *pointers* to the arguments as strings (more on pointers later) v for "vector"

string or number?

- Example:

```
$ ./foo hello 87
```

  - `argc = 3`
  - `argv[0]="./foo", argv[1]="hello", argv[2]="87"`

C Syntax: `main` (2/2)

- To get command-line arguments in `main`, use:

```c
int main(int argc, char* argv[])
```

- Advantages:
  - Easy to implement – keyboard presses are passed as characters
  - Flexible – can handle any number of arguments

- Disadvantages:
  - Input checking needed by programmer – prevent user misuse
    - Common C idiom is to print back usage messages
  - Data conversion might be needed – if argument is not intended to be used as characters
    - See Exercise 0!

Poll Everywhere

pollev.com/cse333a

How much memory would you expect to be allocated for `argv` & all of its pointed-to arrays?

```
$ cp -r dir1 dir2
```

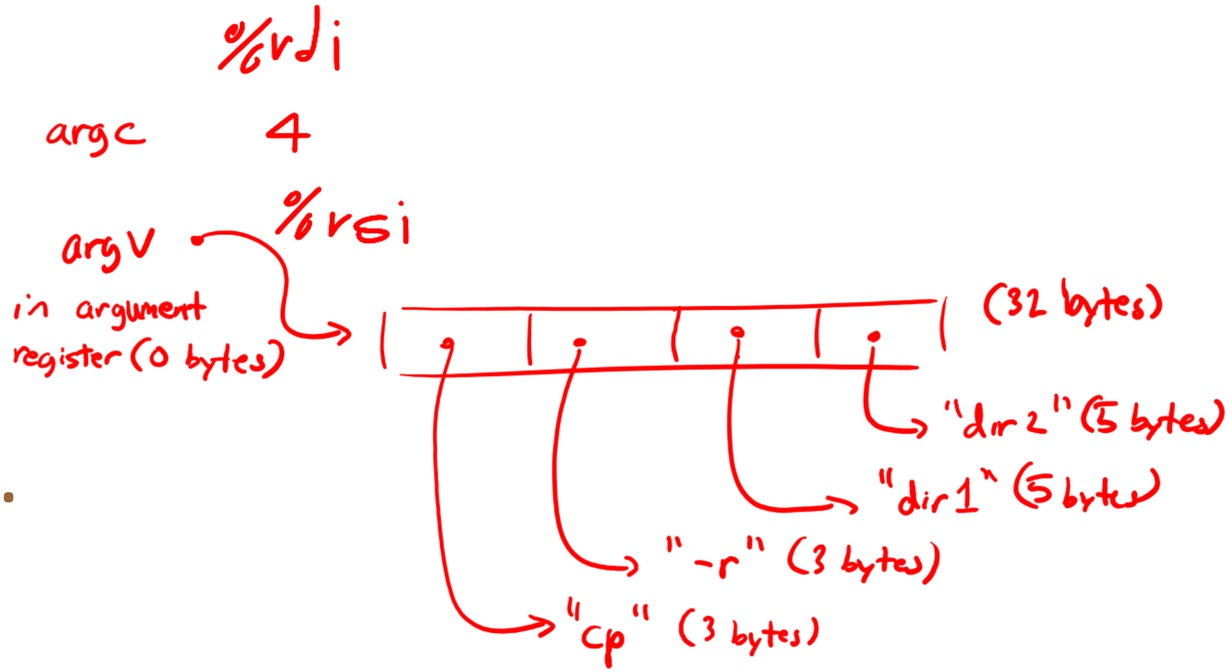
A. 44 bytes

[✓ B. 48 bytes]

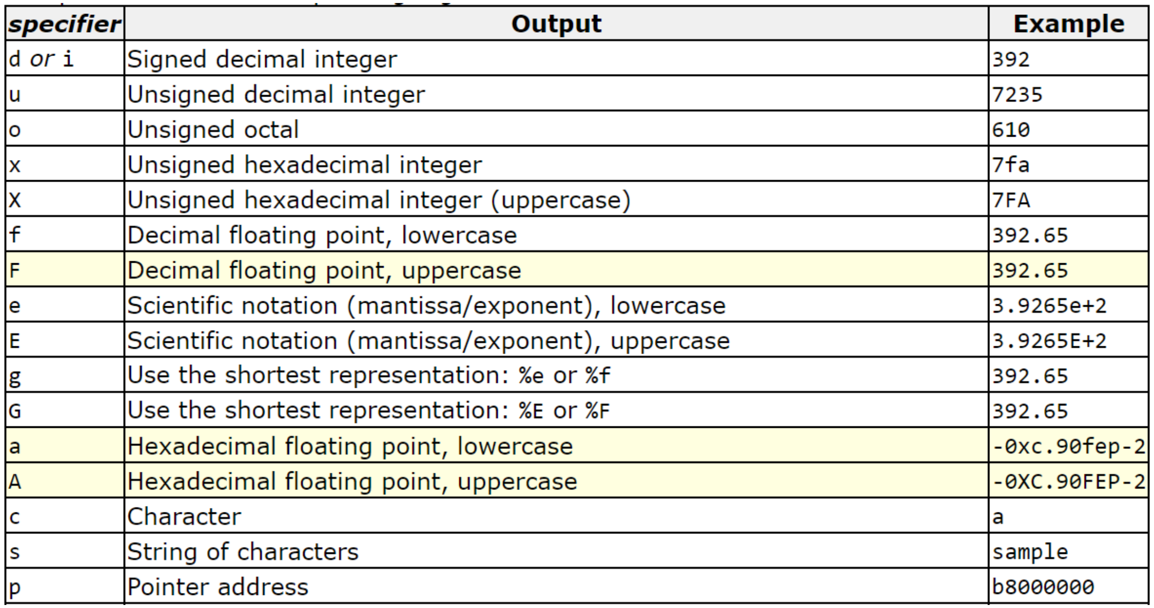
C. 52 bytes

D. 56 bytes

E. We're lost…



Printing in C

-
  ```c
  int printf(const char* format, ...);
  ```
  - Can check documentation to learn about (1) parameters, (2) the return value, and (3) *error handling*
    - https://www.cplusplus.com/reference/cstdio/printf/
  - Very important to use correct format specifier for the value you want to print, otherwise implicit casting will occur
    - 

specifier	**Output**	**Example**
d *or* i	Signed decimal integer	392
u	Unsigned decimal integer	7235
o	Unsigned octal	610
x	Unsigned hexadecimal integer	7fa
X	Unsigned hexadecimal integer (uppercase)	7FA
f	Decimal floating point, lowercase	392.65
F	Decimal floating point, uppercase	392.65
e	Scientific notation (mantissa/exponent), lowercase	3.9265e+2
E	Scientific notation (mantissa/exponent), uppercase	3.9265E+2
g	Use the shortest representation: %e or %f	392.65
G	Use the shortest representation: %E or %F	392.65
a	Hexadecimal floating point, lowercase	-0xc.90fep-2
A	Hexadecimal floating point, uppercase	-0XC.90FEP-2
c	Character	a
s	String of characters	sample
p	Pointer address	b8000000

Error Handling

STYLE TIP

- Errors and Exceptions
  - C does not have exception handling (no `try/catch`)
  - Errors are returned as **integer error codes** from functions
    - Because of this, error handling is ugly and inelegant
    - For readability, `CONSTANT_NAMES` are defined to abstract away the actual integer values – need to look up in documentation
  - Global variable **`errno`** holds value of last system error
- Status codes and signals ← our autograders check for these!
  - Processes exit (*e.g.*, `return` from **`main`**) with status code
    - Standard codes found in `stdlib.h`: `EXIT_SUCCESS` (usually 0) and `EXIT_FAILURE` (non-zero)
  - "Crashes" trigger signals from OS (*e.g.*, `SIGSEGV` for segfault)

Function Definitions

- Generic format:

```
ReturnType FuncName(type param1, …, type paramN) {
   // statements
}
```

```
// sum of integers from 1 to max
int sumTo(int max) {
  int i, sum = 0;

  for (i = 1; i <= max; i++) {
    sum += i;
  }

  return sum;
}
```

Function Ordering

- You *shouldn't* call a function that hasn't been declared yet

Note: code examples from slides are posted on the course website for you to experiment with!

C compiler goes line-by-line:

sum_badorder.c

```
int main(int argc, char** argv) {
  printf("sumTo(5) is: %d\n", sumTo(5));
  return EXIT_SUCCESS;
}

// sum of integers from 1 to max
int sumTo(int max) {
  int i, sum = 0;

  for (i = 1; i <= max; i++) {
    sum += i;
  }
  return sum;
}
```

???

← defined here

fix

Solution 1: Reverse Ordering

- Simple solution; however, imposes ordering restriction on writing functions (who-calls-what?)

sum_betterorder.c

```
// sum of integers from 1 to max
int sumTo(int max) {  ← defined first ☑
  int i, sum = 0;

  for (i = 1; i <= max; i++) {
    sum += i;
  }
  return sum;
}
                                                  seen later
int main(int argc, char** argv) {  ↙
  printf("sumTo(5) is: %d\n", sumTo(5));
  return EXIT_SUCCESS;
}
```

Solution 2: Function Declaration

STYLE TIP

- Teaches the compiler the arguments and return types; function definitions can then be in a logical order
  - Function comment usually by the *prototype*

sum_declared.c

declared here

parameter names optional, but strongly recommended

has seen already

defined here

```c
// sum of integers from 1 to max
int sumTo(int max);  // func prototype

int main(int argc, char** argv) {
  printf("sumTo(5) is: %d\n", sumTo(5));
  return EXIT_SUCCESS;
}

int sumTo(int max) {
  int i, sum = 0;
  for (i = 1; i <= max; i++) {
    sum += i;
  }
  return sum;
}
```

Function Declaration vs. Definition

- C/C++ make a careful distinction between these two

- Definition: The thing itself
  - *e.g.*, code for function, variable definition that creates storage
  - Must be **exactly one** definition of each thing (no duplicates)

- Declaration: Description of a thing
  - *e.g.*, function prototype, external variable declaration
    - Often in header files and incorporated via `#include`
    - Should also `#include` declaration in the file with the actual definition to check for consistency

      more on this in Lecture 5
  - Needs to appear in **all files** that use that thing
    - Should appear before first use

333 Workflow Aids/Upgrades

- See **Linux → Text Editors** on website for how to configure vim or VS Code for use in this class
  - From vi/vim, can compile and execute code without ever leaving the editor using "`:! <cmd>`"
  - For VS Code, can connect to attu remotely and take advantage of the IDE features
  - From either text editor, you will want to get comfortable navigating and editing multiple files *simultaneously*
- We will learn the basics of Makefiles to simplify the compilation steps into the command `make`
- *Required* as of 26wi: Husky OnNet VPN for off-campus `attu` access

To-do List

- Make sure you're registered on Canvas, Ed Discussion, Gradescope, and Poll Everywhere
  - All user IDs should be your uw.edu email address
- Explore the website *thoroughly*: http://cs.uw.edu/333
- Computer setup: CSE lab or SSH into attu
  - Husky OnNet VPN when you're off campus (required as of 26wi)
- Exercise 0 is due at 11 AM on Wednesday
  - Find exercise spec on website, submit via Gradescope
  - Sample solution will be posted Wednesday afternoon
  - **Hint:** look at documentation for `stdlib.h`, `string.h`, and `inttypes.h`
- Check for exercise Gitlab repo tomorrow, then follow our guide
- Pre-Quarter Survey (Canvas) due Friday @ 11:59 PM