Intro, C Refresher

CSE 333 Spring 2023

Instructor: Chris Thachuk

Teaching Assistants:

Byron Jin

Deeksha Vatwani

Humza Lala

Noa Ferman

Seulchan (Paul) Han

Tim Mandzyuk

CJ Reith

Edward Zhang

Lahari Nidadavolu

Saket Gollapudi

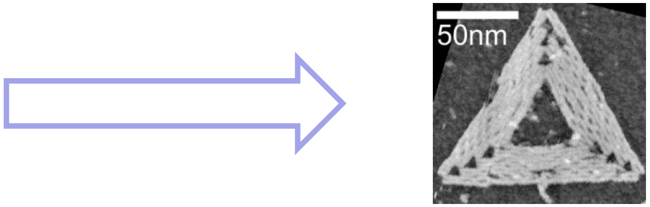
Timmy Yang

Wui Wu

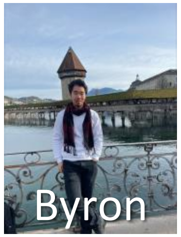
Introductions: Instructor

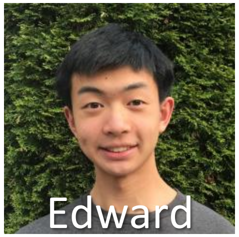
- Chris (he/him)
  - From Canada (with lots of moving around)
    - Windsor (CA) → Toronto (CA) → Vancouver (CA) → Mexico City (MX) → Vancouver (CA) → Oxford (UK) → Pasadena (USA) → Seattle (USA)
  - I like: research, teaching, training, hiking, sci-fi
  - As a high school student (many years ago) I won a contest and was gifted a copy of "Visual Studio C++" and have been programming in C/C++ ever since
  - I research *systems programming* of molecules such as DNA!

```c
int main(int argc, char** argv) {
  make_triangle_from_DNA();
  return EXIT_SUCCESS;
}
```



Introductions: Teaching Assistants





- Available in section, office hours, and discussion board

- 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

- ~170 students registered
  - There are no overload forms or waiting lists for CSE courses
    - Majors must add using the UW system as space becomes available
    - Non-majors should work with undergraduate advisors (in the Gates Center) to handle enrollment details

- Expected background
  - **Prereq:** CSE 351 – C, pointers, memory model, linker, system calls
  - **Indirect Prereq**: CSE 143 – Classes, Inheritance, Basic Data structures, and general good style practices
  - CSE 391 or Linux skills needed for CSE 351 assumed

Introductions: Students

- 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

- **Course Policies**
  - https://courses.cs.washington.edu/courses/cse333/23sp/syllabus.html
  - Digest here, but you ***must*** read the full details online
- Course Introduction
- C Reintroduction

Communication

- **Website:** http://cs.uw.edu/333
  - Schedule, policies, materials, assignments, etc.
- **Discussion:** https://edstem.org/us/courses/38123/discussion/
  - Announcements made here
  - Ask and answer questions – staff will monitor and contribute
- **Office Hours:** spread throughout the week
  - Can fill out Google Form to schedule individual 1-on-1 appointments
- **Anonymous feedback**

Course Components

- Lectures (28+2)
  - Introduce the concepts; take notes!!!
- Sections (10)
  - Applied concepts, important tools and skills for assignments, clarification of lectures, exam review and preparation
- Programming Exercises (12-15)
  - One due roughly every 2-4 days
  - We are checking for: correctness, memory issues, code style/quality
- Programming Projects (0+4)
  - Warm-up, then 4 “homework” that build on each other
- Take-home Exams (2)
  - **Midterm**
  - **Final**

Grading

- **Exercises:** 30% total
  - Submitted via GradeScope (under your UW email)
  - Graded on correctness and style by autograders and TAs

- **Projects:** 43% total
  - Submitted via GitLab; must tag commit that you want graded
  - Binaries provided if you didn’t get previous part working
  - Graded on test suite, manual tests, and style

- **Exams:** Midterm (12%) and Final (12%)
  - Take-home; short answer questions based on assignments

- **Effort, Participation, Altruism:** 3%
  - Many ways to earn credit here, relatively lenient on this

Deadlines and Student Conduct

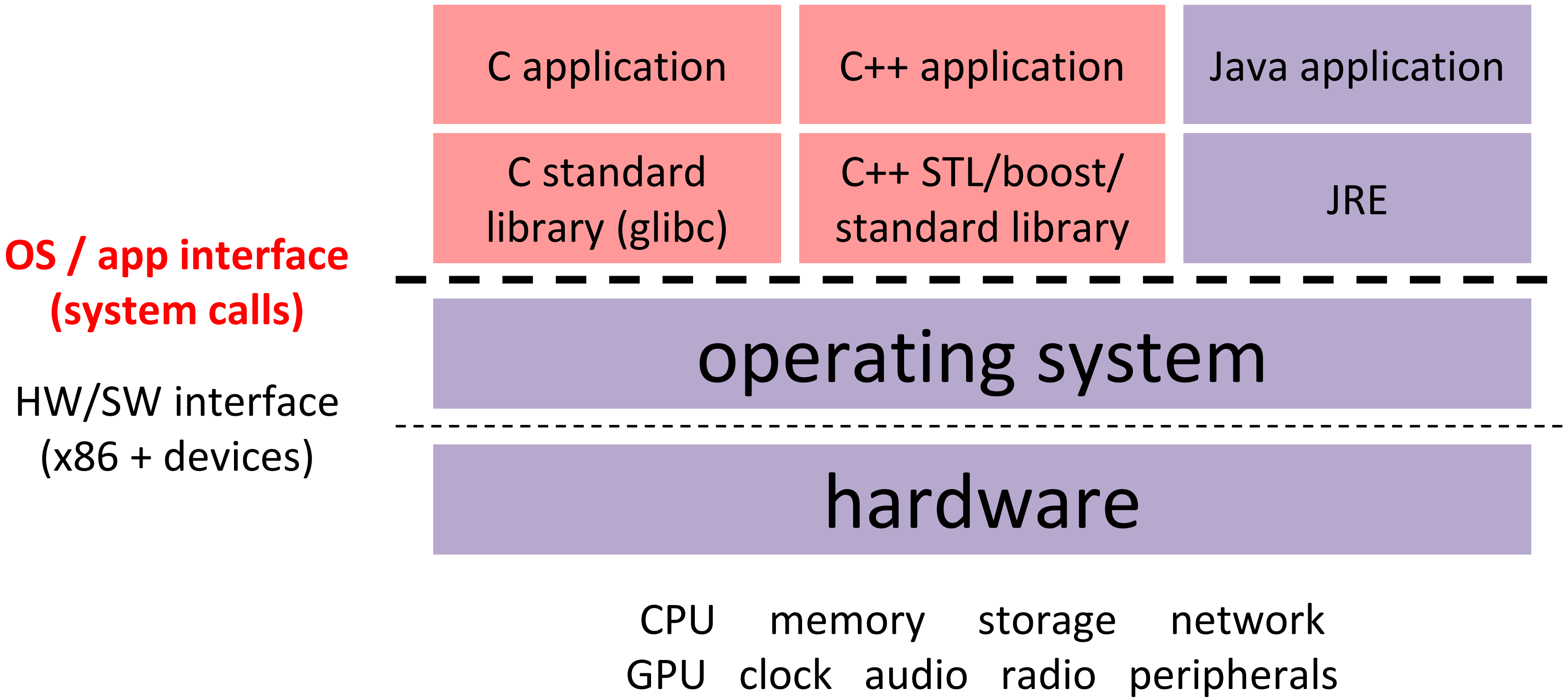
- Academic Integrity (**read** the full policy on the web)
  - I trust you implicitly and will follow up if that trust is violated
  - In short: don't attempt to gain credit for something you didn't do and don't help others do so either
  - This does ***not*** mean suffer in silence – learn from the course staff and peers, talk, share ideas; *but* don't share or copy work that is supposed to be yours

- If you find yourself in a situation where you are tempted to perform academic misconduct, please reach out to Chris to explain your situation instead
  - See the Extenuating Circumstances section of the syllabus

Lecture Outline

- Course Policies
  - https://courses.cs.washington.edu/courses/cse333/23sp/syllabus/
  - Summary here, but you ***must*** read the full details online
- **Course Introduction**
- C Reintroduction

Course Map: 100,000 foot view



C application
C++ application
Java application
C standard library (glibc)
C++ STL/boost/ standard library
JRE
OS / app interface (system calls)
operating system
HW/SW interface (x86 + devices)
hardware
CPU memory storage network
GPU clock audio radio 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
  - 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

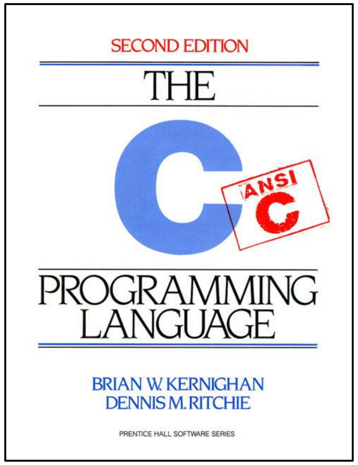
Style Grading in 333

- 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

- Course Policies
  - https://courses.cs.washington.edu/courses/cse333/23sp/syllabus/
  - Summary here, but you ***must*** read the full details online
- Course Introduction
- **C Reintroduction**
  - **Workflow, Variables, Functions**

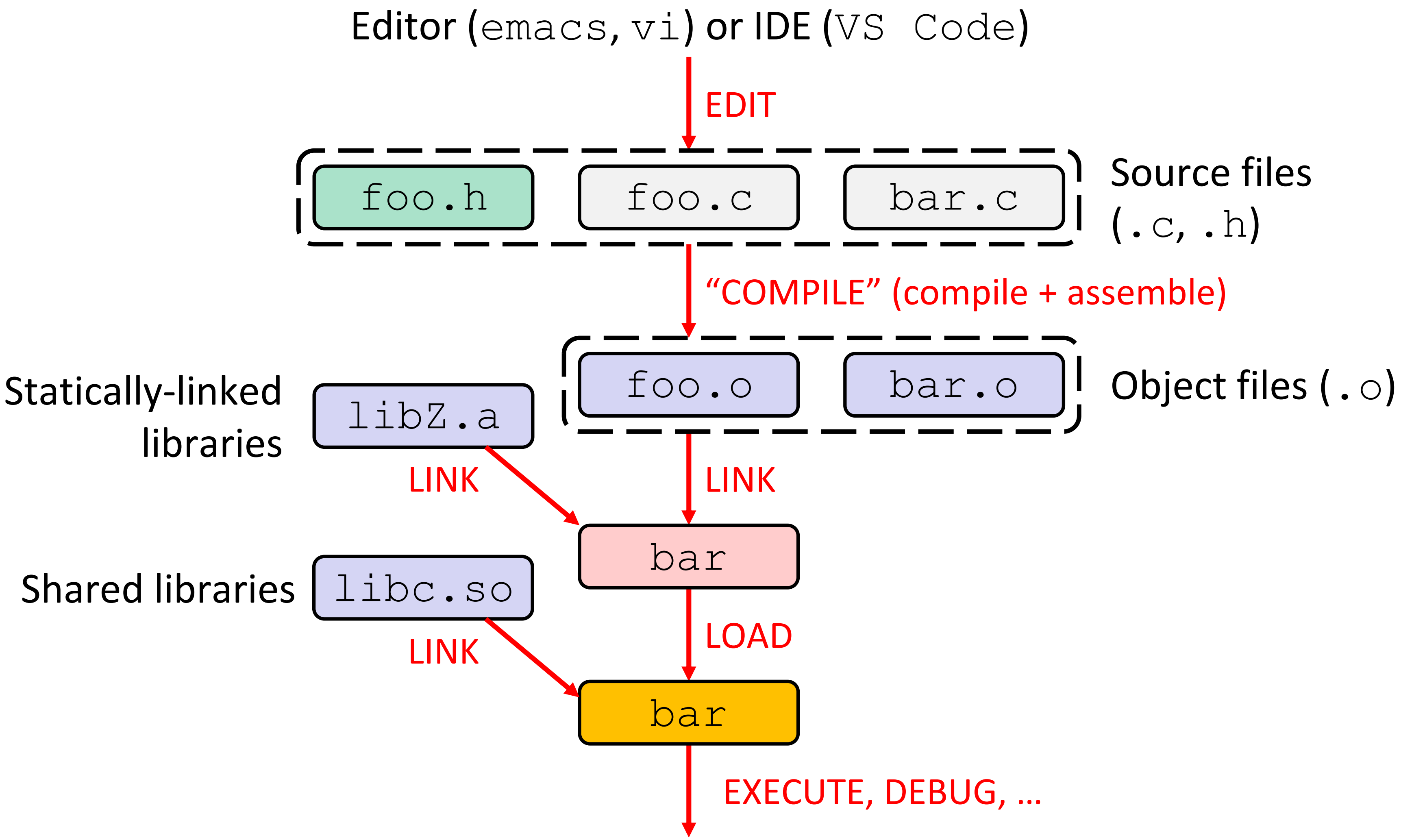
C



- Created in 1972 by Dennis Ritchie
  - Designed for creating system software
  - Portable across machine architectures
  - Most recently updated in 1999 (C99) and 2011 (C11)
    - There's also C17, which is a bug-fix version of C11.

- Characteristics
  - "Low-level" language that allows us to exploit underlying features of the architecture – but easy to fail spectacularly (!)
  - Procedural (not object-oriented)
  - "Weakly-typed" or "type-unsafe"
  - Small, basic library compared to Java, C++, most others….

C Workflow



Editor (emacs, vi) or IDE (VS Code)

EDIT

foo.h foo.c bar.c

Source files (.c, .h)

"COMPILE" (compile + assemble)

foo.o bar.o

Object files (.o)

Statically-linked libraries

libZ.a

LINK

LINK

bar

Shared libraries

libc.so

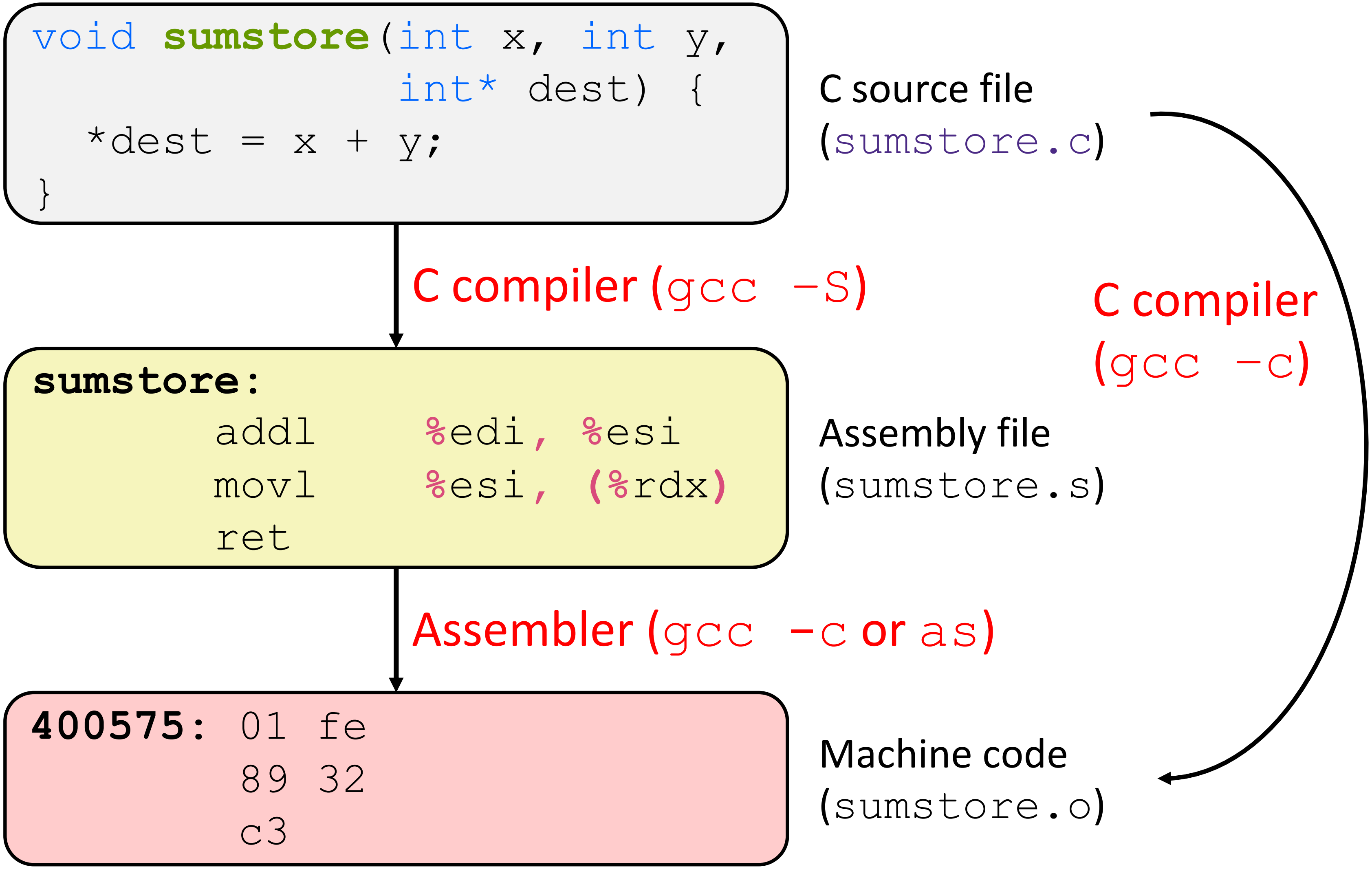
LINK

LOAD

bar

EXECUTE, DEBUG, …

C to Machine Code



```
void sumstore(int x, int y,
              int* dest) {
  *dest = x + y;
}
```

C source file (sumstore.c)

C compiler (gcc -S)

```
sumstore:
        addl    %edi, %esi
        movl    %esi, (%rdx)
        ret
```

Assembly file (sumstore.s)

Assembler (gcc -c or as)

```
400575: 01 fe
        89 32
        c3
```

Machine code (sumstore.o)

C compiler (gcc -c)

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`

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

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

- What does this mean?
  - `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)

- Example:

```
$ foo hello 87
```

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

When Things Go South…

STYLE TIP

- Errors and Exceptions
  - C does not have exception handling (no `try`/`catch`)
  - Errors are returned as integer error codes from functions
    - Standard codes found in `stdlib.h`:
      `EXIT_SUCCESS` (usually 0) and `EXIT_FAILURE` (non-zero)
    - Return value from **`main`** is a status code
  - Because of this, error handling is ugly and inelegant

- Crashes
  - If you do something bad, you hope to get a "segmentation fault" (believe it or not, this is the "good" option)

Java vs. C (351 refresher)

- Are Java and C mostly similar (S) or significantly different (D) in the following categories?
  - List any differences you can recall (even if you put 'S')

Language Feature	S/D	Differences in C
Control structures	S	`if-else if-else, switch, while, for` are all the same.
Primitive datatypes	S/D	S: same/similar names D: char (ASCII, 1 byte), machine-dependent sizes, no built-in boolean type, not initialized. Modifiers.
Operators	S	Almost all match. One notable difference is no >>> for logical shift.
Casting	D	Java has type-safe casting, while C does not.
Arrays	D	Not objects; don't know own length.
Memory management	D	Explicit memory management (malloc/free). No automatic garbage collection.

Primitive Types in C

- Integer types
  - `char`, `int`
- Floating point
  - `float`, `double`
- Modifiers
  - `short` [int]
  - `long` [int, double]
  - `signed` [char, int]
  - `unsigned` [char, int]

C Data Type	32-bit	64-bit	`printf`
`char`	1	1	`%c`
`short int`	2	2	`%hd`
`unsigned short int`	2	2	`%hu`
`int`	4	4	`%d` / `%i`
`unsigned int`	4	4	`%u`
`long int`	4	8	`%ld`
`long long int`	8	8	`%lld`
`float`	4	4	`%f`
`double`	8	8	`%lf`
`long double`	12	16	`%Lf`
`pointer`	4	8	`%p`

Typical sizes – see `sizeofs.c`

C99 Extended Integer Types

STYLE TIP

- Solves the conundrum of “how big is an `long int`?”

```c
#include <stdint.h>

void foo(void) {
  int8_t  a;  // exactly 8 bits, signed
  int16_t b;  // exactly 16 bits, signed
  int32_t c;  // exactly 32 bits, signed
  int64_t d;  // exactly 64 bits, signed
  uint8_t w;  // exactly 8 bits, unsigned
  ...
}
```

```c
void sumstore(int x, int y, int* dest) {
```

↓

```c
void sumstore(int32_t x, int32_t y, int32_t* dest) {
```

Basic Data Structures

- C does not support objects!!!

- **Arrays** are contiguous chunks of memory
  - Arrays have no methods and do not know their own length
  - Can easily run off ends of arrays in C – security bugs!!!

- **Strings** are null-terminated char arrays
  - Strings have no methods, but `string.h` has helpful utilities

```
char* x = "hello\n";
```

x	h	e	l	l	o	\n	\0

- **Structs** are the most object-like feature, but are just collections of fields – no "methods" or functions

Function Definitions

- Generic format:

```
returnType fname(type param1, …, type paramN) {
   // statements
}
```

```
// sum of integers from 1 to max
int32_t sumTo(int32_t max) {
  int32_t 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!

sum_badorder.c

```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
int32_t sumTo(int32_t max) {
  int32_t i, sum = 0;

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

Solution 1: Reverse Ordering

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

sum_betterorder.c

```c
// sum of integers from 1 to max
int32_t sumTo(int32_t max) {
  int32_t i, sum = 0;

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

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

sum_declared.c

```c
// sum of integers from 1 to max
int32_t sumTo(int32_t);   // func prototype

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

int32_t sumTo(int32_t max) {
  int32_t 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
  - Needs to appear in **all files** that use that thing
    - Should appear before first use

Multi-file C Programs

C source file 1 (sumstore.c)

```
void sumstore(int x, int y, int* dest) {
  *dest = x + y;
}
```

C source file 2 (sumnum.c)

```
#include <stdio.h>

void sumstore(int x, int y, int* dest);

int main(int argc, char** argv) {
  int z, x = 351, y = 333;
  sumstore(x, y, &z); <- used
  printf("%d + %d = %d\n", x, y, z);
  return 0;
}
```

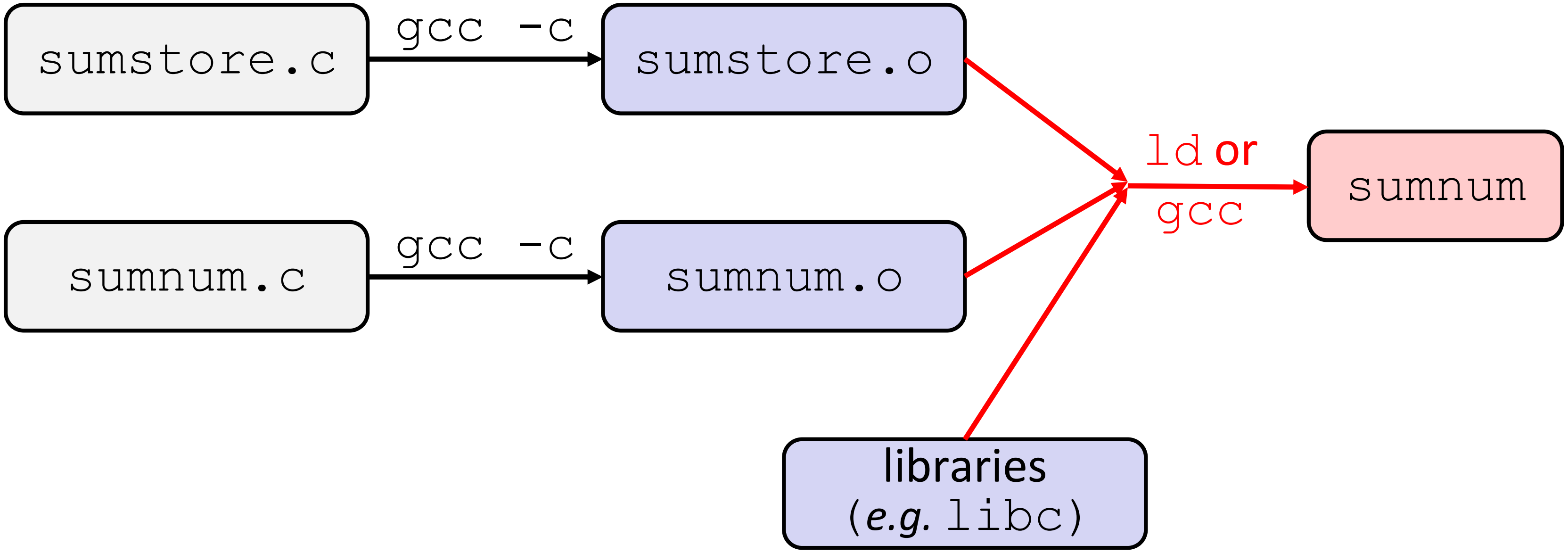
Note: not good style. More on multiple files in later lecture

Compile together:

```
$ gcc -o sumnum sumnum.c sumstore.c
```

Compiling Multi-file Programs

- The **linker** combines multiple object files plus statically-linked libraries to produce an executable
  - Includes many standard libraries (*e.g.* `libc`, `crt1`)
    - A *library* is just a pre-assembled collection of `.o` files



Polling Question

- Which of the following statements is FALSE?
  -

Discuss on Ed!

A. With the standard `main()` syntax, It is always safe to use `argv[0]`.

B. We can't use `uint64_t` on a 32-bit machine because there isn't a C integer primitive of that length.

C. Using function declarations is beneficial to both single- and multi-file C programs.

D. When compiling multi-file programs, not all linking is done by the Linker.

E. We're lost…

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, attu, or CSE Linux VM
- Exercise 1 is due 10 am on Friday
  - Find exercise spec on website, submit via Gradescope
    - Course "CSE 333" under "Spring 2023", Assignment "Exercise 1", then drag-n-drop file(s)!
  - Sample solution will be posted Friday afternoon
  - **Hint:** look at documentation for `stdlib.h`, `string.h`, and `inttypes.h`
- Homework 0 is out later today