Intro, C

CSE 333 Spring 2018

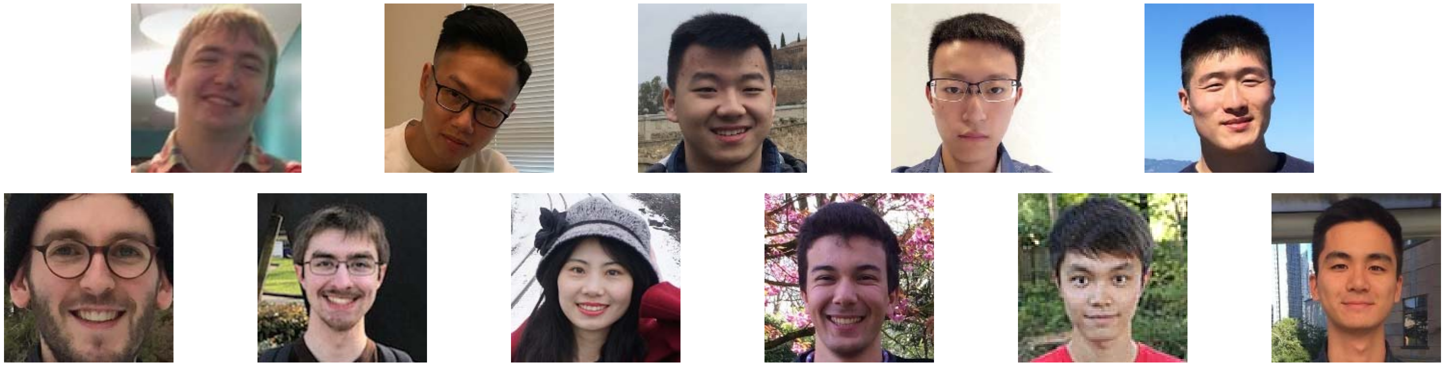
Instructor: Justin Hsia

Teaching Assistants:

Danny Allen	Dennis Shao	Eddie Huang
Kevin Bi	Jack Xu	Matthew Neldam
Michael Poulain	Renshu Gu	Robby Marver
Waylon Huang	Wei Lin	

Introductions: Course Staff

- Your Instructor: just call me Justin
  - From California (UC Berkeley and the Bay Area)
  - I like: teaching, the outdoors, board games, and ultimate
  - Excited to be teaching this course for the 1st time!
- TAs:



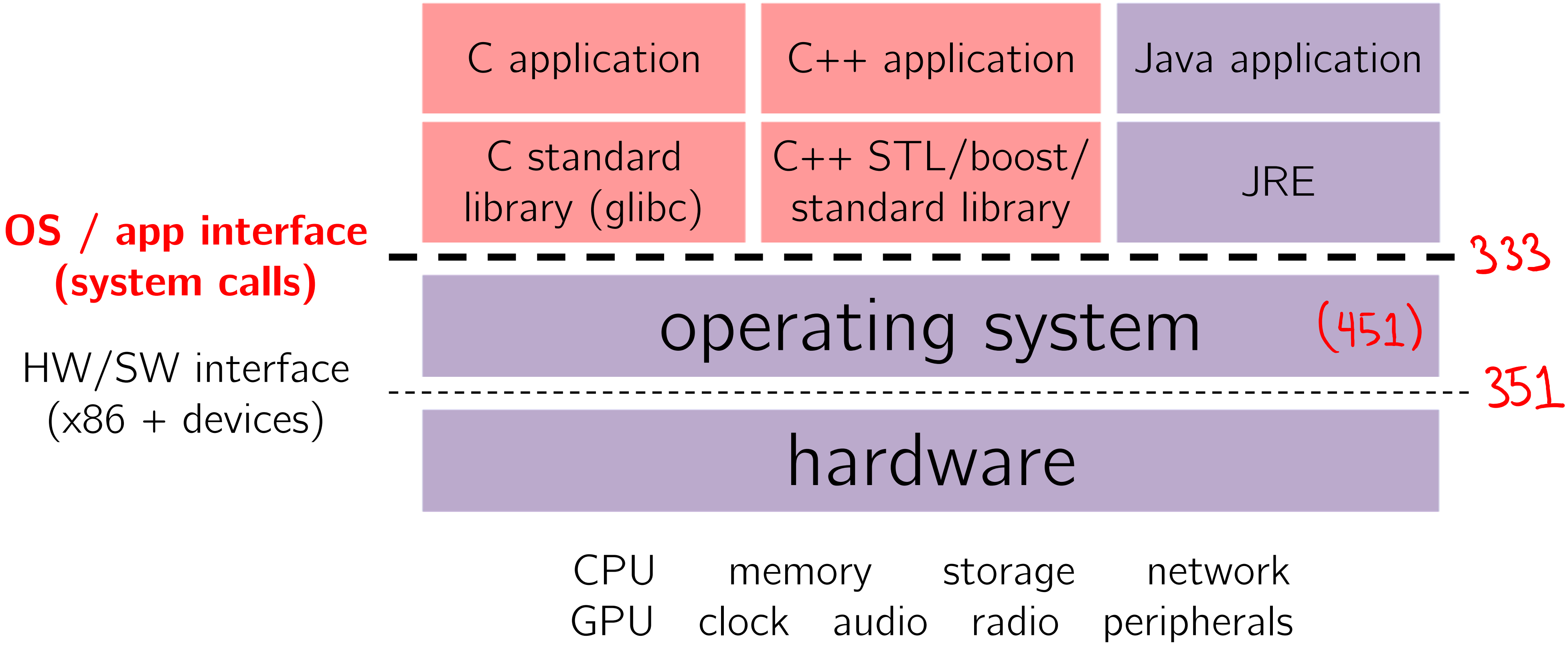
  - Available in section, office hours, and on Piazza
  - An invaluable source of information and help
- Get to know us
  - We are here to help you succeed!

Introductions: Students

- ~175 students registered, split across two lectures
  - Largest offering of this class EVER!!!
  - There are no longer overload forms for CSE courses
    - Majors must add using the UW system as space becomes available
    - Non-majors must have submitted petition form (closed now)

- Expected background
  - **Prereq:** CSE351 – C, pointers, memory model, linker, system calls

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)

333

operating system (451)

HW/SW interface (x86 + devices)

351

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 understanding of the "layer below"

Discipline?!?

- 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

Lecture Outline

- Course Introduction
- **Course Policies**
  - https://courses.cs.washington.edu/courses/cse333/18sp/syllabus/
- C Intro

Communication

- Website: http://cs.uw.edu/333
  - Schedule, policies, materials, assignments, etc.

- Discussion: http://piazza.com/washington/spring2018/cse333
  - Announcements made here
  - Ask and answer questions – staff will monitor and contribute

- Office Hours: spread throughout the week
  - Can also e-mail to make individual appointments

- Anonymous feedback:
  - Comments about anything related to the course where you would feel better not attaching your name

Course Components

- Lectures (28)
  - Introduce the concepts; take notes!!!
- Sections (10)
  - Applied concepts, important tools and skills for assignments, clarification of lectures, exam review and preparation
- Programming Exercises (~20)
  - Roughly one per lecture, due the morning of the next lecture
  - Coarse-grained grading (0, 1, 2, or 3)
- Programming Projects (4.5)
  - Warm-up, then 4 "homework" that build on each other
- Exams (2)
  - **Midterm:** Friday, May 4, time TBD (joint)
  - **Final:** Wednesday, June 6, 12:30-2:20 pm (joint)

Grading

- **Exercises:** 20% total
  - Submitted via Canvas
  - Graded on correctness and style by TAs
- **Projects:** 40% total
  - Submitted via GitLab; must tag commit that you want graded
  - Binaries provided if you didn't get previous part working
- **Exams:** Midterm (15%) and Final (20%)
  - Some old exams on course website
- **EPA:** Effort, Participation, and Altruism (5%)

- More details on course website

Deadlines and Student Conduct

- Late policies
  - Exercises: no late submissions accepted
  - Projects: 4 late day "tokens" for quarter, max 2 per project
  - Need to get things done on time – difficult to catch up!

- Academic Integrity
  - I will 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 – can still learn from the course staff and peers

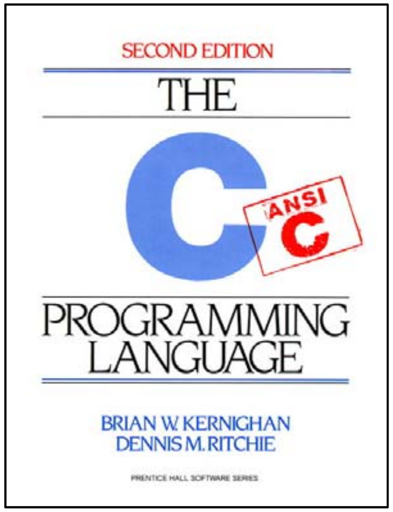
Hooked on Gadgets

- Gadgets reduce focus and learning
    - Bursts of info (*e.g.* emails, IMs, etc.) are *addictive*
    - Heavy multitaskers have more trouble focusing and shutting out irrelevant information
        - http://www.npr.org/2016/04/17/474525392/attention-students-put-your-laptops-away
    - Seriously, you will learn more if you use **paper** instead!!!
- Non-disruptive use okay
    - NO audio allowed (mute phones & computers)
    - Stick to side and back seats
    - Stop/move if asked by fellow student

Lecture Outline

- Course Introduction
- Course Policies
  - https://courses.cs.washington.edu/courses/cse333/18sp/syllabus/
- **C Intro**
  - **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)

- 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"

Generic C Program Layout

```
#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`

Advantages: ① easy – keyboard chars passed as chars
② flexible – any number

Disadvantages: ① input checking – prevent user misuse (usage messages)
② data conversion – if not intended to be chars

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

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

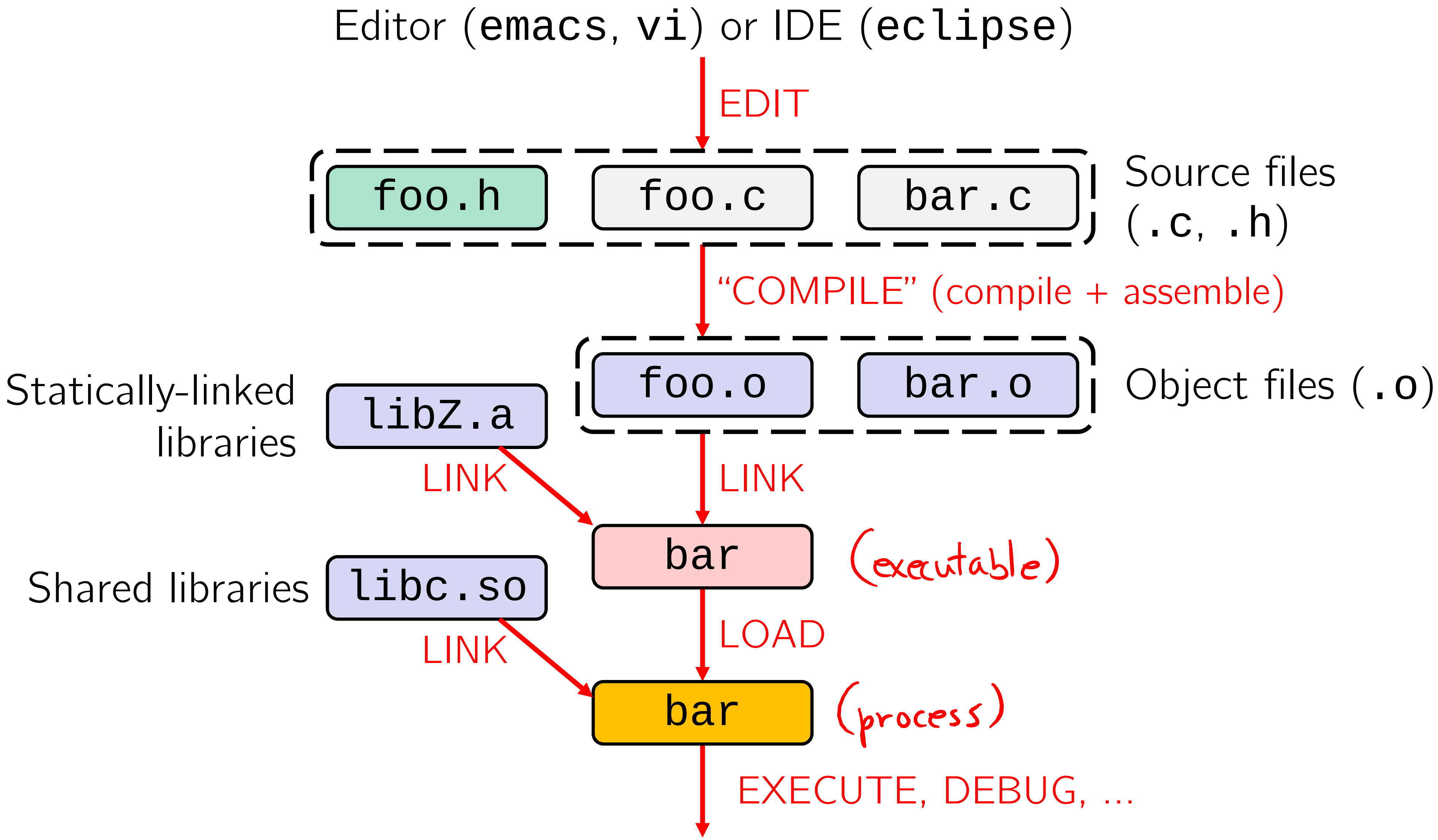
same as char** argv

instead of: int main()

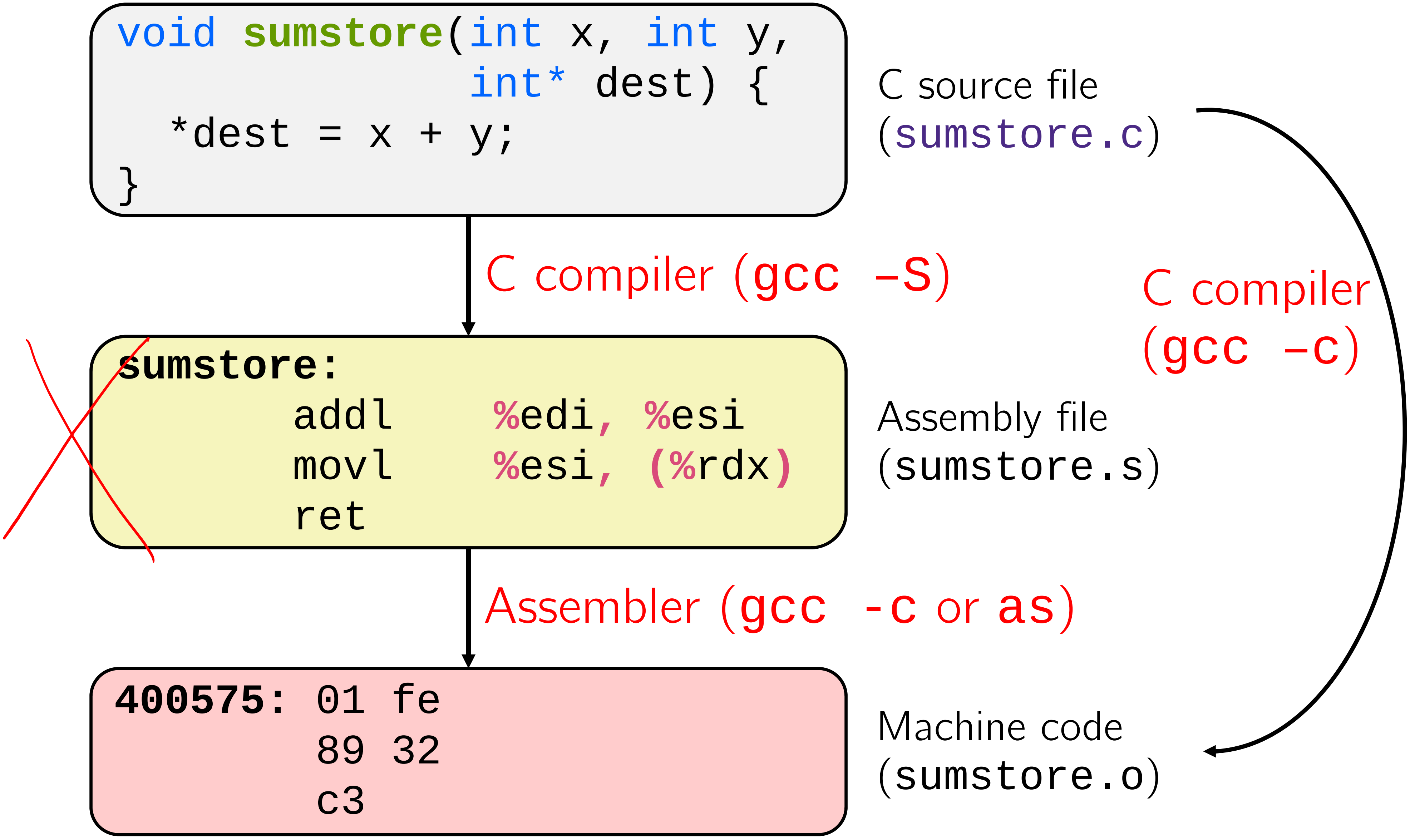
- What does this mean?
  - `argc` contains the number of strings on the command line (the executable name counts as one, plus one for each argument). needed because C doesn't track array lengths!
  - `argv` is an array containing *pointers* to the arguments as strings (more on pointers later)

- Example: `$ foo hello 87` string or number?
  - `argc = 3`
  - `argv[0]="foo"`, `argv[1]="hello"`, `argv[2]="87"`

C Workflow


Editor (emacs, vi) or IDE (eclipse)
EDIT
foo.h
foo.c
bar.c
Source files (.c, .h)
"COMPILE" (compile + assemble)
Statically-linked libraries
libZ.a
foo.o
bar.o
Object files (.o)
LINK
LINK
bar
(executable)
Shared libraries
libc.so
LINK
LOAD
bar
(process)
EXECUTE, DEBUG, …

C to Machine Code



```c
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`)

When Things Go South…

- 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

- 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')

(these are not exhaustive)

Language Feature	S/D	Differences in C
Control structures	S	
Primitive datatypes	S/D	yes pointers, no String, yes unsigned different data widths (e.g. char)
Operators	S	Java has >>> C has ->
Casting	D	C has no casting restrictions
Arrays	D	C has no length or bounds checking
Memory management	D	no garbage collection explicit requests: malloc / free

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

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

```
#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
  ...
}
```

fine for generic C code

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

needed for "system" code – please use on your exercises!

```
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

Function Definitions

- Generic format:

```
returnType fname(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 += 1;
  }

  return sum;
}
```

Function Ordering

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

C compiler goes line-by-line:

sum_badorder.c

```
#include <stdio.h>

int main(int argc, char** argv) {
  printf("sumTo(5) is: %d\n", sumTo(5));
  return 0;
}

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

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

???

← defined here

fix

Solution 1: Reverse Ordering

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

sum_betterorder.c

```
#include <stdio.h>

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

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

int main(int argc, char** argv) {
  printf("sumTo(5) is: %d\n", sumTo(5));
  return 0;
}
```

← defined first ☑

seen later

Solution 2: Function Declaration

- Teaches the compiler arguments and return types; function definitions can then be in a logical order

sum_declared.c

```
#include <stdio.h>

int sumTo(int);  // func prototype

int main(int argc, char** argv) {
  printf("sumTo(5) is: %d\n", sumTo(5));
  return 0;
}

// sum of integers from 1 to max
int sumTo(int max) {
  int i, sum = 0;
  for (i = 1; i <= max; i++) {
    sum += 1;
  }
  return sum;
}
```

parameter names optional

declared here

has seen already

defined here

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;
}
```

← defined here

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);
  printf("%d + %d = %d\n",x,y,z);
  return 0;
}
```

optional: ~~x~~, ~~y~~, ~~dest~~

← declared here

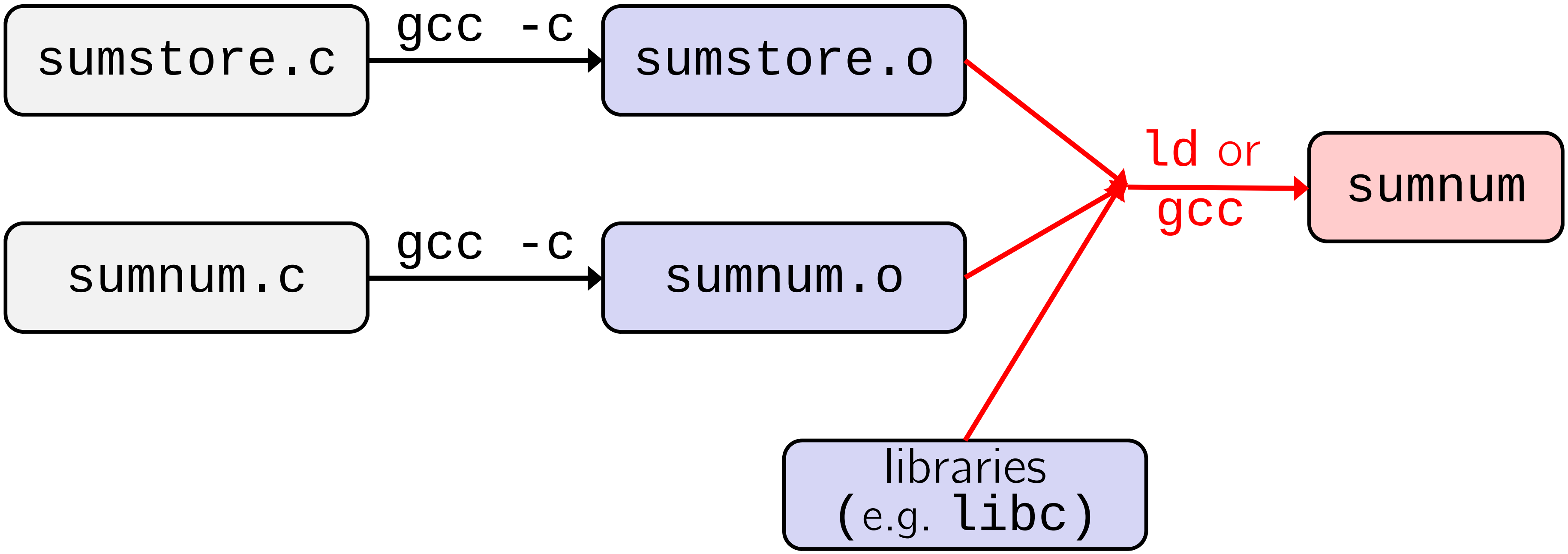
← used here

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



Peer Instruction Question

- Which of the following statements is FALSE?
  - Vote at http://PollEv.com/justinh

A. With the standard `main()` syntax, It is always safe to use `argv[0]`. ← will be the name of the executable

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

C. Using function declarations is beneficial to both single- and multi-file C programs.
single : flexible ordering of functions
multi : use definitions in other files

D. When compiling multi-file programs, not all linking is done by the Linker. Loader does some linking (shared libraries)

E. We're lost…

To-do List

- Make sure you're registered on Canvas, Piazza, and Poll Everywhere
- Explore the website *thoroughly*: http://cs.uw.edu/333
- Computer setup: CSE lab, attu, or CSE Linux VM
- Exercise 0 is due Wednesday before class (11 am)
    - Find exercise spec on website, submit via Canvas
    - Sample solution will be posted Wednesday at 12 pm