Low-Level I/O – the POSIX Layer

CSE 333 Spring 2025

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Administrivia

- HW1 due tomorrow night
  - Any last-minute surprises? Questions?
- No exercise due Friday morning!
- Sections tomorrow: POSIX I/O and reading directories
- Next exercise: find text files in directory and print contents
  - Based on section stuff and is a warmup for hw2
  - Out tomorrow after sections; due Monday morning
- Friday: HW2 out; demo in class, starter code pushed to repos by Friday or Saturday

Exercises, hw, and code quality

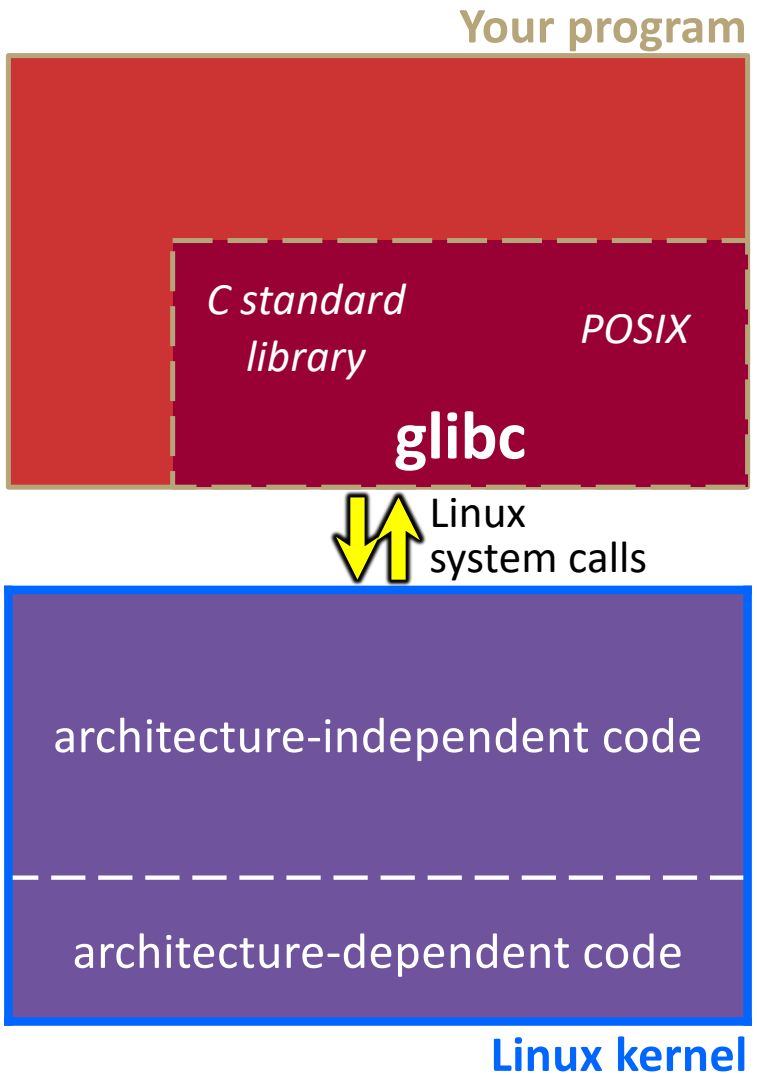
- In the initial set of exercises, we've been focusing on trying to provide helpful feedback as we get better at writing high-quality code, without necessarily affecting final scores. But there are a few things that should be fixed by now yet are persisting, and will be more of a problem if they continue. A couple of particular ones:
  - Use cpplint.py to check code and fix things it catches (except for known exceptions to the rules, like matching library functions that use long ints)
  - Match the Google Style guide for conventions like variable naming, using 2 spaces (only) for indenting, etc.
  - All functions must be declared in a file before any function definitions – either in a #included header for "public" things, or at the top of the file for local "private" things, and there need to be appropriate comments specifying how the function works
  - Run valgrind to check for memory bugs
- Overall, keep up the good work – we're seeing lots of improvement and great code that continues to get better

Lecture Outline

- **POSIX Lower-Level I/O**

Remember This Picture?

- Your program can access many layers of APIs:
  - C standard library
    - Some are just ordinary functions (<string.h>, for example)
    - Some also call OS-level (POSIX) functions (<stdio.h>, for example)
  - POSIX compatibility API
    - C-language interface to OS system calls (fork(), read(), etc.)
  - Underlying OS system calls
    - Assembly language ☺



C Standard Library File I/O

- So far you've used the C standard library to access files
  - Use a provided `FILE*` *stream* abstraction
  - **`fopen`**`()`, **`fread`**`()`, **`fwrite`**`()`, **`fclose`**`()`, **`fseek`**`()`

- These are convenient and portable
  - They are buffered
  - They are implemented using lower-level OS calls

Lower-Level File Access

- Most UNIX-en support a common set of lower-level file access APIs: POSIX – Portable Operating System Interface
  - `open()`, `read()`, `write()`, `close()`, `lseek()`
    - Similar in spirit to their `f*()` counterparts from C std lib
    - Lower-level and unbuffered compared to their counterparts
    - Also less convenient
  - We will have to use these to read file system directories and for network I/O, so we might as well learn them now

open()/close()

- To open a file:
  - Pass in the filename and access mode
    - Similar to **fopen**()
  - Get back a "file descriptor"
    - Similar to FILE* from **fopen**(), but is just an int
    - Defaults: **0** is stdin, **1** is stdout, **2** is stderr

```
#include <fcntl.h>     // for open()
#include <unistd.h>    // for close()
  ...
  int fd = open("foo.txt", O_RDONLY);
  if (fd == -1) {
    perror("open failed");
    exit(EXIT_FAILURE);
  }
  ...
  close(fd);
```

Reading from a File

- `ssize_t read(int fd, void* buf, size_t count);`

  - Returns the number of bytes read
    - Might be fewer bytes than you requested (**!!!**)
    - Returns `0` if you're already at the end-of-file
    - Returns `-1` on error

  - **`read`** has some surprising error modes…

Read error modes

- `ssize_t read(int fd, void* buf, size_t count);`

  - On error, `read` returns -1 and sets the global **`errno`** variable

  - You need to check **`errno`** to see what kind of error happened
    - `EBADF:` bad file descriptor
    - `EFAULT:` output buffer is not a valid address
    - `EINTR:` read was interrupted, please try again (ARGH!!!! 😤😠)
    - And many others…

One way to `read()` n bytes

```
int fd = open(filename, O_RDONLY);
char* buf = ...;  // buffer of appropriate size
int bytes_left = n;
int result;

while (bytes_left > 0) {
  result = read(fd, buf + (n - bytes_left), bytes_left);
  if (result == -1) {
    if (errno != EINTR) {
      // a real error happened, so return an error result
    }
    // EINTR happened, so do nothing and try again
    continue;
  } else if (result == 0) {
    // EOF reached, so stop reading
    break;
  }
  bytes_left -= result;
}

close(fd);
```

readN.c

Other Low-Level Functions

- Read man pages to learn about:
  - **`write`**`()` – write data
  - **`fsync`**`()` – flush data to the underlying device
  - **`opendir`**`()`, **`readdir`**`()`, **`closedir`**`()` – deal with directory listings
    - Make sure you read the section 3 version (*e.g.* `man 3 opendir`)

- A useful shortcut sheet (from CMU):
  http://www.cs.cmu.edu/~guna/15-123S11/Lectures/Lecture24.pdf

- More in sections this week…. (as in, *tomorrow!*)