Final C Details, Intro to File I/O

CSE 333 Autumn 2025

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Administrivia

- Today: C wrapup, File I/O with C standard library

- New exercise 6 posted today, due Wednesday morning
  - Will use concepts from today's lecture on File I/O

- Graded hw0 out later today, hw2 out soon

- And you should be well along on hw1 by now…
  - Slides with hw1 hints will be sent via Ed this afternoon

Lecture Outline

- **Preprocessor tricks**
- Additional C topics
- File I/O with the C standard library
- C Stream Buffering

Other Preprocessor Tricks

- A way to deal with "magic numbers" (constants)

```
int globalbuffer[1000];

void circalc(float rad,
             float* circumf,
             float* area) {
  *circumf = rad * 2.0 * 3.1415;
  *area = rad * rad * 3.1415;
}
```

Bad code
(littered with magic constants)

```
#define BUFSIZE 1000
#define PI 3.14159265359

int globalbuffer[BUFSIZE];

void circalc(float rad,
             float* circumf,
             float* area) {
  *circumf = rad * 2.0 * PI;
  *area = rad * rad * PI;
}
```

Better code

Macros

- You can pass arguments to macros

```
#define ODD(x) ((x) % 2 != 0)

void foo() {
  if ( ODD(5) )
    printf("5 is odd!\n");
}
```

cpp →

```

void foo() {
  if ( ((5) % 2 != 0) )
    printf("5 is odd!\n");
}
```

- Beware of operator precedence issues!
  - Use parentheses

```
#define ODD(x) ((x) % 2 != 0)
#define WEIRD(x) x % 2 != 0

ODD(5 + 1);

WEIRD(5 + 1);
```

cpp →

```

((5 + 1) % 2 != 0);

5 + 1 % 2 != 0;
```

Conditional Compilation

- You can change what gets compiled
  - In this example, `#define TRACE` before `#ifdef` to include debug `printf`s in compiled code

```
#ifdef TRACE
#define ENTER(f) printf("Entering %s\n", f);
#define EXIT(f)  printf("Exiting  %s\n", f);
#else
#define ENTER(f)
#define EXIT(f)
#endif

// print n
void pr(int n) {
  ENTER("pr");
  printf("\n = %d\n", n);
  EXIT("pr");
}
```

ifdef.c

Defining Symbols

- Besides `#defines` in the code, preprocessor values can be given as part of the `gcc` command:

```
bash$ gcc -Wall -g -DTRACE -o ifdef ifdef.c
```

- assert can be controlled the same way – defining `NDEBUG` causes assert to expand to “empty”
  - It’s a macro – see `assert.h`

```
bash$ gcc -Wall -g -DNDEBUG -o faster useassert.c
```

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Additional C Topics

- Teach yourself!
  - **man pages** are your friend!
  - String library functions in the C standard library
    - `#include <string.h>`
      - strlen(), strcpy(), strdup(), strcat(), strcmp(), strchr(), strstr(), …
    - `#include <stdlib.h>` or `#include <stdio.h>`
      - atoi(), atof(), sprint(), sscanf()
  - How to declare, define, and use a function that accepts a variable-number of arguments (`varargs`)
  - `union`s and what they are good for
  - `enum`s and what they are good for
  - Pre- and post-increment/decrement
  - Harder: the meaning of the "`volatile`" storage class

Lecture Outline

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File I/O

- We'll start by using C's standard library
  - These functions are part of `glibc` on Linux
  - They are implemented using Linux system calls (POSIX)

- C's `stdio` defines the notion of a stream
  - A sequence of characters that flows **to** and **from** a device
    - Can be either *text* or *binary*; Linux does not distinguish
  - Is *buffered* by default; `libc` reads ahead of your program
  - Three streams provided by default: `stdin`, `stdout`, `stderr`
    - keyboard → console
    - console (buffered)
    - console (unbuffered)
    - You can open additional streams to read and write to files
  - C streams are manipulated with a `FILE*` pointer, which is defined in `stdio.h`

C Stream Functions (1 of 2)

- Some stream functions (complete list in `stdio.h`):

  NULL if error!

  - `FILE* fopen(filename, mode);`
    - Opens a stream to the specified file in specified file access mode
  - `int fclose(stream);`
    - Closes the specified stream (and file)
  - `int fprintf(stream, format, ...);`
    - Writes a formatted C string
      - `printf(...);` is equivalent to `fprintf(stdout, ...);`
  - `int fscanf(stream, format, ...);`
    - Reads data and stores data matching the format string

C Stream Functions (2 of 2)

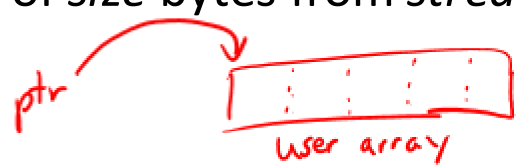
- Some stream functions (complete list in `stdio.h`):
  - `FILE* fopen(filename, mode);`
    - Opens a stream to the specified file in specified file access mode
  - `int fclose(stream);`
    - Closes the specified stream (and file)

tries to move
size * count bytes total

  - `size_t fwrite(ptr, size, count, stream);`

# of elements actually moved (unsigned)

    - Writes an array of *count* elements of *size* bytes from *ptr* to *stream*
  - `size_t fread(ptr, size, count, stream);`
    - Reads an array of *count* elements of *size* bytes from *stream* to *ptr*



C Stream Error Checking/Handling

- Some error functions (complete list in `stdio.h`):
  - `int ferror(stream);`
    - Checks if the error indicator associated with the specified stream is set
  - `int clearerr(stream);`
    - Resets error and EOF indicators for the specified stream
  - `void perror(message);`
    - Prints `message` followed by an error message related to `errno` to `stderr`

global var

error message

① fprintf(stderr, ...); // single, known cause

② perror("my error msg"); // multiple possible causes

C Streams Example

cp_example.c

```
#include <stdio.h>
#include <stdlib.h>
#include <errno.h>
#define READBUFSIZE 128

int main(int argc, char** argv) {
  FILE* fin;
  FILE* fout;          ← stream variables
  char readbuf[READBUFSIZE]; ← arbitrarily-sized buffer
  size_t readlen;
                          prints to console, even if you pipe program output
  if (argc != 3) {
    fprintf(stderr, "usage: ./cp_example infile outfile\n");
    return EXIT_FAILURE;       // defined in stdlib.h
  }

  // Open the input file    file must exist when reading
  fin = fopen(argv[1], "rb");  // "rb" -> read, binary mode
  if (fin == NULL) {
    perror("fopen for read failed"); ← prints extra info on source of error
    return EXIT_FAILURE;
  }
  ...   // next slide's code
```

C Streams Example

cp_example.c

```
int main(int argc, char** argv) {

  ...   // previous slide's code

  // Open the output file
  fout = fopen(argv[2], "wb");  // "wb" -> write, binary mode
  if (fout == NULL) {
    perror("fopen for write failed");
    fclose(fin);
    return EXIT_FAILURE;
  }

  // Read from the file, write to fout
  while ((readlen = fread(readbuf, 1, READBUFSIZE, fin)) > 0) {
    // Test to see if we encountered an error while reading
    if (ferror(fin)) {
      perror("fread failed");
      fclose(fin);
      fclose(fout);
      return EXIT_FAILURE;
    }
    ...   // next slide's code
}
```

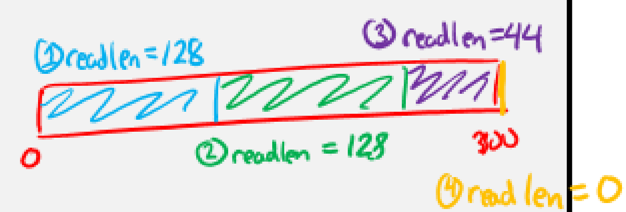
when writing, file created if it doesn't exist

make sure to clean up for every exit path!

# of bytes actually read

(check if error on input stream)

for file of size 300 bytes, fread called 4 times:



C Streams Example

cp_example.c

```
int main(int argc, char** argv) {

  ...   // two slides ago's code

  ...   // previous slide's code

    if (fwrite(readbuf, 1, readlen, fout) < readlen) {
      perror("fwrite failed");
      fclose(fin);
      fclose(fout);
      return EXIT_FAILURE;
    }
  } // end of while loop

  fclose(fin);
  fclose(fout);

  return EXIT_SUCCESS;
}
```

return value from fread

something wrong if didn't write all requested bytes

close streams when done with them!

Lecture Outline

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- **C Stream Buffering**

Buffering

- By default, `stdio` uses buffering for streams:
  - Data written by **`fwrite`**`()` is copied into a buffer allocated by `stdio` inside your process' address space
  - At some point, the buffer will be "drained" into the destination:
    - When you explicitly call **`fflush`**`()` on the stream
    - When the buffer size is exceeded (often 1024 or 4096 bytes)
    - For `stdout` to console, when a newline is written (*"line buffered"*) or when some other function tries to read from the console
    - When you call **`fclose`**`()` on the stream
    - When your process exits gracefully (**`exit`**`()` or `return` from **`main`**`()`)

Buffering Example

```
int main(int argc, char** argv) {
  FILE* fout = fopen("test.txt", "wb");


  // write "hi" one char at a time
  if (fwrite("h", sizeof(char), 1, fout) < 1) {
    perror("fwrite failed");
    fclose(fout);
    return EXIT_FAILURE;
  }

  if (fwrite("i", sizeof(char), 1, fout) < 1) {
    perror("fwrite failed");
    fclose(fout);
    return EXIT_FAILURE;
  }

  fclose(fout);
  return EXIT_SUCCESS;
}
```

buffered_hi.c

C stdio buffer

'h'	'i'	...

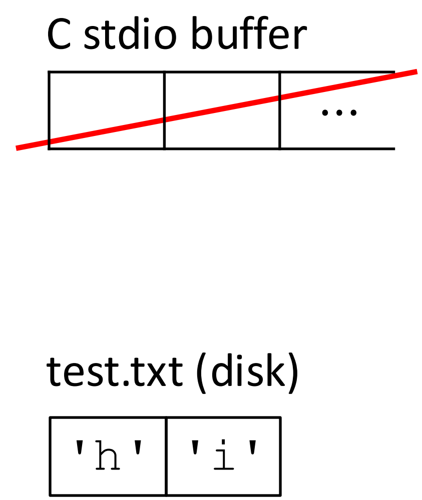
test.txt (disk)

'h'	'i'

No Buffering Example

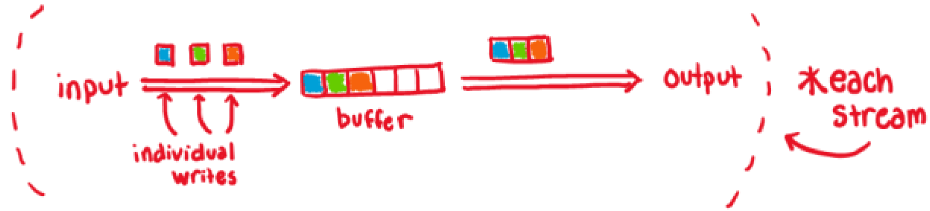
```c
int main(int argc, char** argv) {
  FILE* fout = fopen("test.txt", "wb");
  setbuf(fout, NULL); // turn off buffering

  // write "hi" one char at a time
  if (fwrite("h", sizeof(char), 1, fout) < 1) {
    perror("fwrite failed");
    fclose(fout);
    return EXIT_FAILURE;
  }

  if (fwrite("i", sizeof(char), 1, fout) < 1) {
    perror("fwrite failed");
    fclose(fout);
    return EXIT_FAILURE;
  }

  fclose(fout);
  return EXIT_SUCCESS;
}
```

unbuffered_hi.c



Why Buffer?

- Performance – avoid disk accesses
  - Group many small writes into a single larger write



  - Disk Latency = 😱😱😱 (Jeff Dean from LADIS '09)

orders of magnitude still accurate!

Numbers Everyone Should Know

L1 cache reference	0.5 ns
Branch mispredict	5 ns
L2 cache reference	7 ns
Mutex lock/unlock	25 ns
Main memory reference	100 ns
Compress 1K bytes with Zippy	3,000 ns
Send 2K bytes over 1 Gbps network	20,000 ns
Read 1 MB sequentially from memory	250,000 ns
Round trip within same datacenter	500,000 ns
Disk seek	10,000,000 ns
Read 1 MB sequentially from disk	20,000,000 ns
Send packet CA->Netherlands->CA	150,000,000 ns

- Convenience – nicer API
  - We'll compare C's `fread()` with POSIX's `read()`

Why NOT Buffer?

- Reliability – the buffer needs to be flushed
  - Loss of computer power = loss of data
  - "Completion" of a write (*i.e.*, return from `fwrite()`) does not mean the data has actually been written
    - What if you signal another process to read the file you just wrote to?

- Performance – buffering takes time
  - Copying data into the `stdio` buffer consumes CPU cycles and memory bandwidth
  - Can potentially slow down high-performance applications, like a web server or database (*"zero-copy"*)

many small writes large writes

- When is buffering faster? Slower?

We Need To Go Deeper…

Preview for next lecture!

- So far we've seen 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

Extra Exercise #1

- Write a program that:
  - Prompts the user to input a string (use `fgets()`)
    - Assume the string is a sequence of whitespace-separated integers (*e.g.* `"5555 1234 4 5543"`)
  - Converts the string into an array of integers
  - Converts an array of integers into an array of strings
    - Where each element of the string array is the binary representation of the associated integer
  - Prints out the array of strings