COMP1521 25T2

Week 5 Lecture 2

Floating Point, Operating Systems and File Systems

Adapted from Angela Finlayson, Hammond Pearce, Andrew Taylor and John Shepherd's slides

Assignment 1 is due Friday 6pm

Week 4: test: due tomorrow 9pm (MIPS basics, control, arrays)

Flex week next week!

No lectures, tutorials or labs. Nothing due!

Lab 5 will be due in week 7.
Test 5 will be due in week 7.
Test 6 will be due in week 7

There is no lab 6

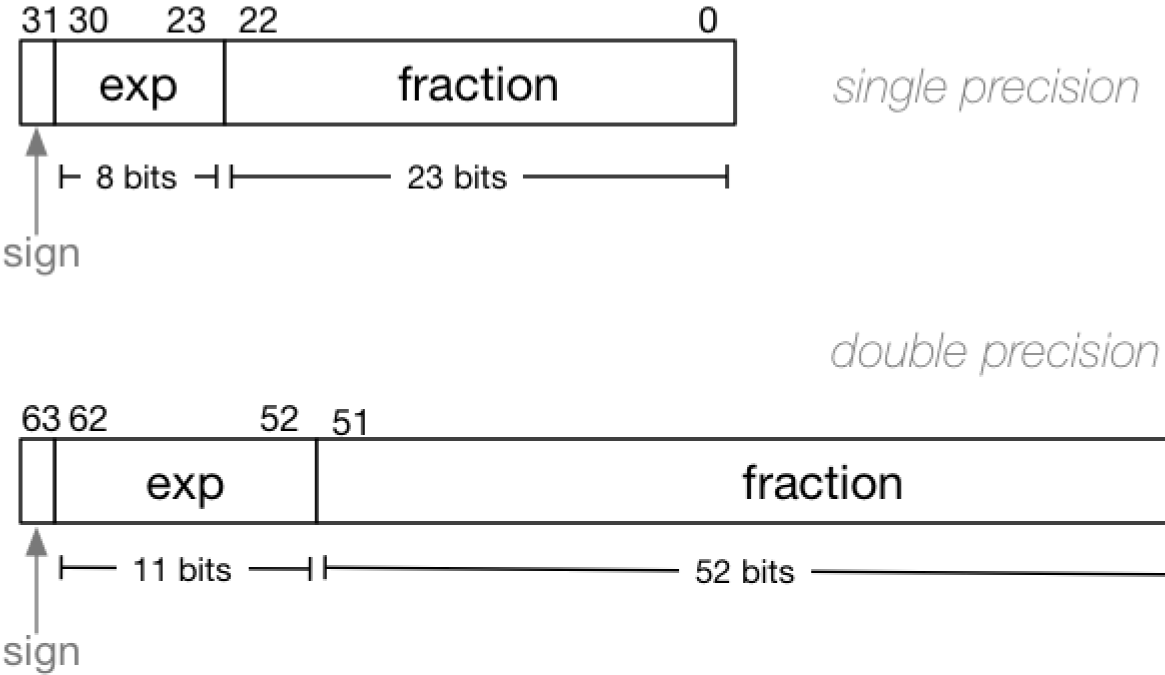
Help sessions will still be on 🥳

Today's Lecture

- Floating Point Recap

- Operating Systems
- File Systems
  - System Calls

IEEE 754 Standard



Note:
float in C is represented in this single precision format.
double in C is represented in this double precision format

Note: the fraction part is often called the mantissa

IEEE 754 Example

150.75 = 10010110.11

// normalise fraction, compute exponent

= 1.001011011×2^7

// determine sign bit,

// map fraction to 24 bits, (don’t store the leading 1)

// map exponent to 8 bits after adding on the bias of 127

= 01000011000101101100000000000000

where red is sign bit, green is exponent, blue is fraction

Note: B=127, e=2^7, so exponent = 127+7 = 134 = **10000110**

Check using explain_float_representation.c or Floating Point Calculator

Floating Point Recap Exercise

Keep in mind 10000000 = 2^7 = 128

Convert -42.5 to IEEE 754 float?

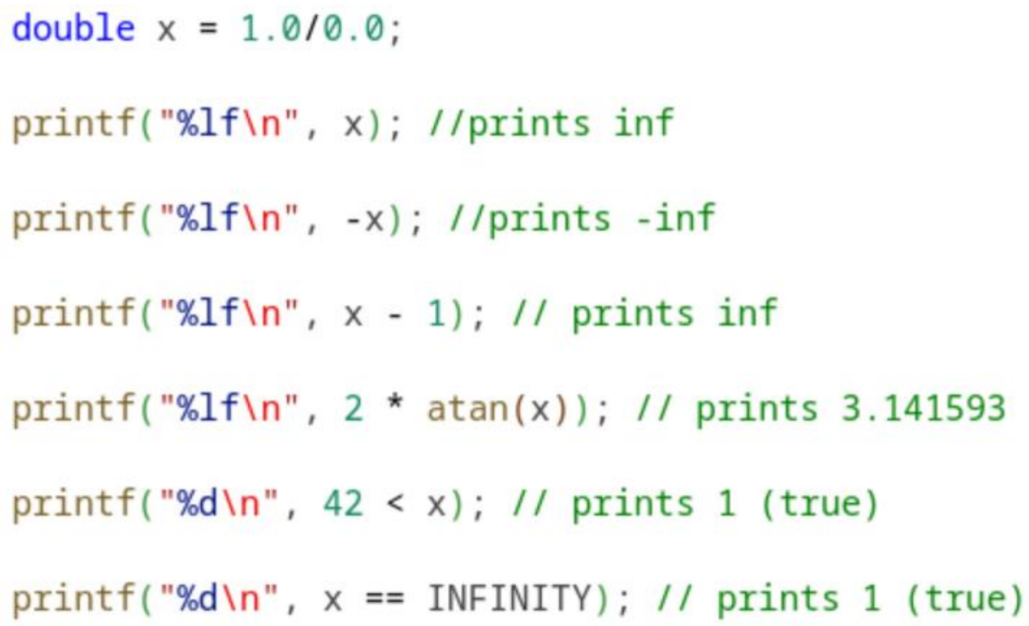
Convert to decimal from IEEE 754 float
00111110100000000000000000000000

IEEE 754 Standard: Special Cases

Value	Exponent	Fraction	Example
0 (+ve or -ve)	all 0’s	all 0’s	
inf (∞ and -∞)	all 1’s	all 0’s	1.0/0
nan	all 1’s	Not all 0’s	0.0/0

IEEE 754 infinity.c

Representation of +- infinity : propagates sensibly through calculations

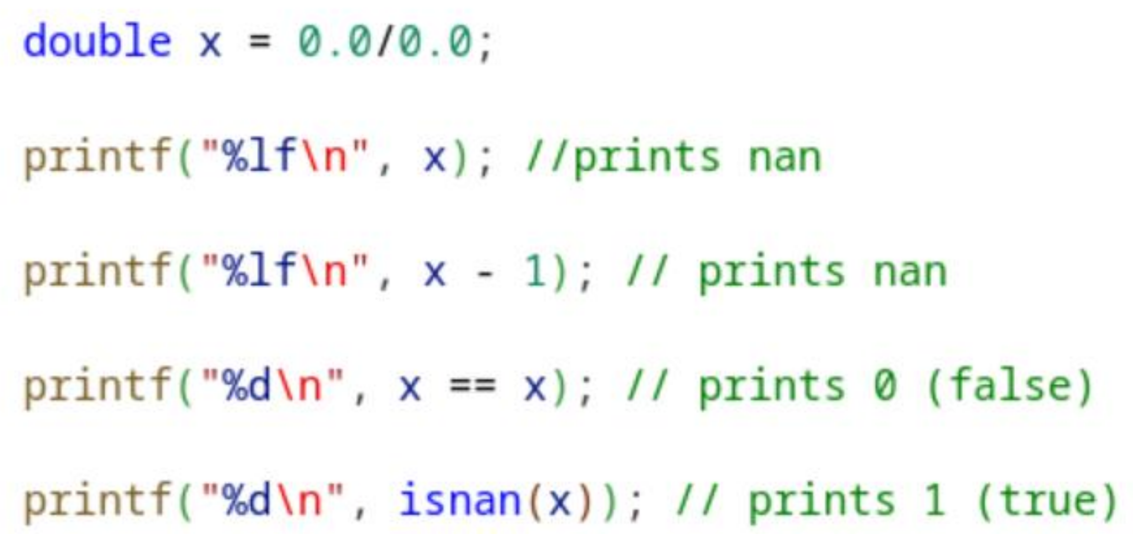


```
double x = 1.0/0.0;

printf("%lf\n", x); //prints inf

printf("%lf\n", -x); //prints -inf

printf("%lf\n", x - 1); // prints inf

printf("%lf\n", 2 * atan(x)); // prints 3.141593

printf("%d\n", 42 < x); // prints 1 (true)

printf("%d\n", x == INFINITY); // prints 1 (true)
```

IEEE 754 nan.c

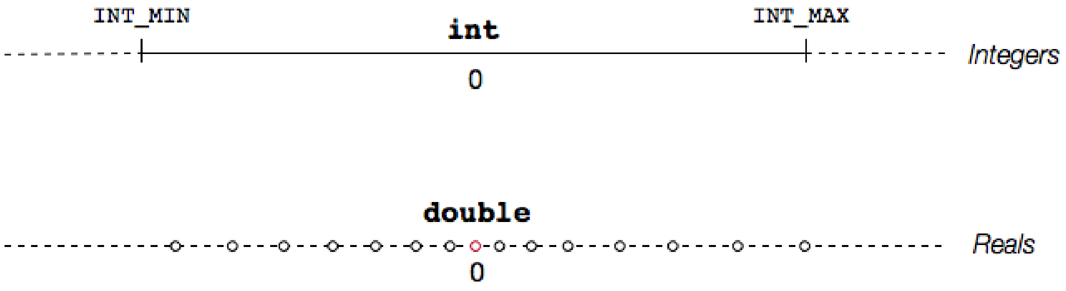
Representation for invalid results NaN (not a number)

- ensures errors propagates sensibly through calculations



```
double x = 0.0/0.0;

printf("%lf\n", x); //prints nan

printf("%lf\n", x - 1); // prints nan

printf("%d\n", x == x); // prints 0 (false)

printf("%d\n", isnan(x)); // prints 1 (true)
```

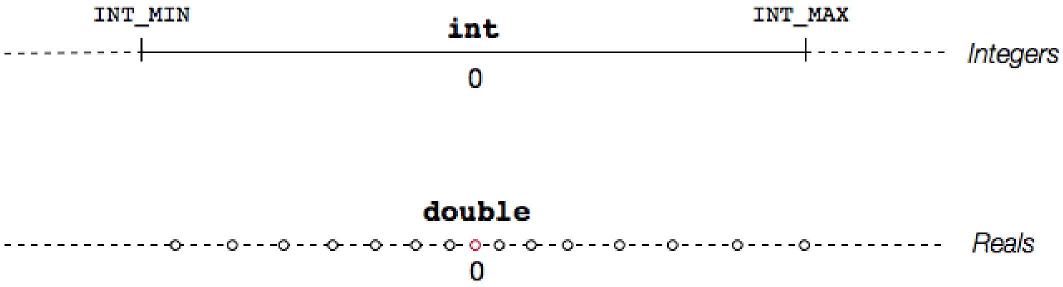
Distribution of Floating Point Numbers



integers ... subset (range) of the mathematical integers

- can represent all integer values in that subset
- each integer is 1 away from the next one and previous one
- all integers are represented accurately

Distribution of Floating Point Numbers



floating point ... subset of the mathematical real numbers

- floating point numbers not evenly distributed
  - numbers closer to 0 have higher precision which is good
  - representations get further apart as values get bigger
  - this works well for most calculations but can cause weird bugs

Distribution of Floating Point Numbers

A 64-bit **double** uses 52 bits for the fraction (mantissa).

- Between 2^n and 2^{n+1} there are 2^{52} doubles evenly spaced
  - e.g. in the interval 2^{-42} and 2^{-43} there are 2^{52} doubles
  - and in the interval between 1 and 2 there are 2^{52} doubles
  - and in the interval between 2^{42} and 2^{43} there are 2^{52} doubles

- near 0.001 - doubles are about 0.0000000000000000002 apart
- near 1000 - doubles are about 0.0000000000002 apart
- near 1000000000000000 - doubles are about 0.25 apart
- **above 2^{53} - doubles are more than 1 apart**

Operating Systems and File Systems

Operating Systems

- This course is a great way to see different areas in computing to
  - See what electives you might be interested in!!
  - See what area you might want to work in!!
- **Question 1**: What is YOUR favourite operating system?
  - Write in the chat
- **Question 2**: What do operating systems do?
  - Write in the chat

A World without Operating Systems

- Manually Boot Your Computer
    - No OS means no automatic booting into a familiar environment.
- Write your own file system
    - No folders, no directories, your hard drive is just raw data
- Run Programs… If You Can
    - Multi-tasking?? Good luck.
- Security?
    - Your dodgy game can steal your passwords you typed into your online banking… if you could connect to the internet… because…
- Why won’t my mouse, printer, usb port, internet connection work??
    - No OS = No drivers. Every program must **talk directly to the hardware**

A World without Operating Systems

- You would need to learn to do this for every specific computer unless it happened to have the same exact configuration of hardware
  - You would not be too keen to use a different device
  - Or get an upgrade would you??

- You would need to write different code for all different configurations of hardware!

A world with Operating Systems

We want to **generalise** computers and provide functionality so:

- Users can easily use different machines with different configurations of hardware
- We can write code that can target lots of computers regardless of their hardware
  - **Abstraction:** We can write higher level code where we don’t have to understand the exact hardware specs, or voltages etc.
  - **Portable code:** We can write code that runs on other machines!

Operating Systems

- Operating system (OS) sits between the user and the hardware
- The OS effectively provides a virtual machine to each user.
  - much easier for user to write code and use machine
  - difficult (bug-prone) code implemented by operating system
  - coordinates access to resources e.g. file systems, multiple processes
  - The virtual machine interface can stay the same across different hardware making it easier for user to write portable code

Operating Systems: Privileged Mode

- Needs hardware to provide a **privileged** mode
  - OS kernel runs in this mode
  - Code can access all hardware, memory and CPU instructions
- Needs hardware to provide a **non-privileged** mode, in which:
  - Code can not access hardware directly
  - Code can only access the memory it was allocated
  - User code (e.g. your code) runs in this mode

Operating Systems: System Calls

- System calls allow user level code to request hardware operations
- System calls transfer execution to OS kernel code in **privileged mode**
    - includes arguments specifying details of request being made
    - OS carefully checks operation is valid & permitted
    - OS carries out operation
    - transfers execution back to user code in **non-privileged** mode

System Calls

- Different operating system have different system calls
  - Linux system calls are very different to Windows system calls
  - Linux provides 400+ system calls. Type man syscalls to find out more

- Examples of operations that might be provided by system call
  - read or write bytes to a file
  - create a process (run a program) or terminate a process
  - send information over the network

Mipsy System Calls

- **mipsy** provides a virtual machine which can execute MIPS programs
- **mipsy** also provides a tiny operating system
- **mipsy** system calls
- **syscall** instruction
    - Small number of very specific system calls
    - Designed for students writing small programs with no library functions
    - MIPS programs running on real hardware and real OS also use **syscall**

Linux System Calls

- Linux system calls also have a number
  - e.g system call **1** is **write** bytes to a file
- Linux provides 400+ system calls

```
$ cat /usr/include/x86_64-linux-gnu/asm/unistd_64.h
...
#define __NR_read 0
#define __NR_write 1
#define __NR_open 2
#define __NR_close 3
...
#define __NR_set_mempolicy_home_node 450
```

Reminder: Linux Manual

The linux manual (**`man`**) is divided into sections.

Important sections for this course include:

1. Executable programs eg. ls, cp
2. System calls
   - we will be looking at many of these in the coming weeks
3. Library calls eg. strcpy, scanf

And other sections that you can find out about by using the command **`man man`**
Advice: **`man`** will be available in the exam. Get used to using it!

System Calls to Manipulate Files

Important file related system calls

Id	Name	Function
0	read	read some bytes from a **file descriptor**
1	write	write some bytes to a **file descriptor**
2	open	open a file system object, returning a **file descriptor**
3	close	close a **file descriptor**
4	stat	get file system metadata for a pathname
8	lseek	move **file descriptor** to a specified offset within a file

System Calls in Linux

syscall function

- Not usually used in practice
- Syscalls vary between operating system -- code is less portable
- Hard to understand

Libc syscall wrapper:

- More meaningful names: open(...), read(...), write(...)
- Does syscall for you and helps with error checking
- More portable than **syscall** but still not portable
  - Some work on POSIX compliant systems (e.g. Linux and MacOS)

System Calls in Linux

stdio.h provides higher-level library functions:

- fopen(...), fgets(...), fputc(...)
- Calls syscall wrapper for you
- Portable
- You have been using these to indirectly do your system calls the whole time!
- Sometimes we need lower-level non-portable functions
  - e.g. Database software needs precise control over I/O

Unix Files

- On Unix-like systems a **file** is sequence/stream of zero or more bytes
    - File metadata doesn't record that it is e.g. ASCII, MP4, JPG, …
    - File extensions are just hints

Demo: Different File formats on Linux

Files and File Systems

- Files typically live on a mechanical or solid state hard drive
  - To interact with their data - they need to be read into RAM
  - We need to use system calls to do this!
    - A system call to open the file
    - System calls to read or write bytes from/to the file
    - A system call to close the file when we finish
- File Systems provide a mapping from the file name to where the files are stored on the drive.

File Descriptors

- **file descriptors** are small integers
  - Uniquely identify a stream/file that is open within a process
  - Are indexes into a per process OS file descriptor table

- OS stores info for each file descriptor such as:
  - File offset: current position in the file
  - File status: read-only, write-only etc
  - Information to locate the actual bytes related to the file/stream

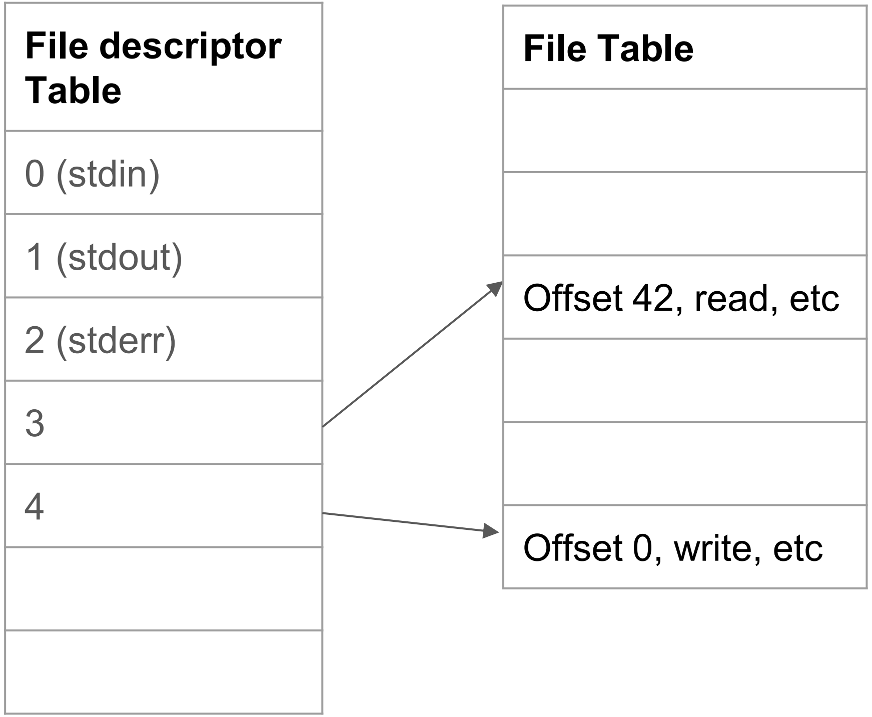
File Descriptors

Every process starts with the 3 standard streams, 0, 1, 2.

When a file is opened a new file descriptor is added to the table.

When a file is closed the file descriptor is removed

When a file is read to or written from, the offset is updated



File descriptor Table
0 (stdin)
1 (stdout)
2 (stderr)
3
4

File Table
Offset 42, read, etc
Offset 0, write, etc

What on earth is stderr?

- There are 3 standard streams in linux
    - stdin (0), stdout (1), stderr (2)
- They are treated like they are files in linux
    - They are a sequence of bytes like a file is
- By default
    - stdin : connected to keyboard
    - stdout: connected to terminal
    - stderr: connected to terminal

What on earth is stderr?

- The user can use redirection to send stdout and stderr to different places to separate the output from the error messages
  - ./prog > output   #redirects stdout to a file
  - ./prog 2> error_msgs   #redirects stderr to a file

System call to print a message to stdout

`syscall` : make a system call without writing assembler code

- Not usually used by programmers
- Use to experiment and learn

```c
char bytes[13] = "Hello, Zac!\n";

// argument 1 to syscall is the system call number, 1 is write
// remaining arguments are specific to each system call

// write system call takes 3 arguments:
//   1) file descriptor, 1 == stdout
//   2) memory address of first byte to write
//   3) number of bytes to write

syscall(1, 1, bytes, 12); // prints Hello, Zac! on stdout
```

Unix C Library Wrappers for System Calls

- Unix-like systems have C library wrapper functions corresponding to most system calls
  - e.g. **open**, **read**, **write**, **close**
  - Not portable
  - Typically return **-1** on error and set the error code **errno**
  - Better to use library functions (eg stdio.h functions) where possible.

errno

- C library has an interesting way of returning error information
  - functions typically return **-1** to indicate error
  - and set **errno** to integer value indicating reason for error
  - you can think of **errno** as a global integer variable

- These integer values are **#define**-d in **errno.h**
  - see man errno for more information
  - **perror()** looks at **errno** and prints message with reason
  - **strerror()** converts **errno** to string describing reason for error

- To see all error codes type **errno -l** on command line

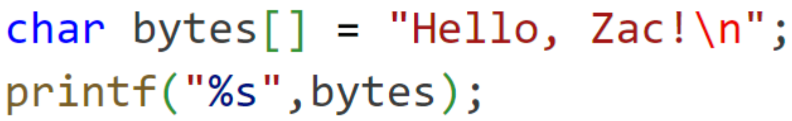
Libc wrapper to print message to stdout

```
char bytes[13] = "Hello, Zac!\n";

// write takes 3 arguments:
//   1) file descriptor, 1 == stdout
//   2) memory address of first byte to write
//   3) number of bytes to write
write(1, bytes, 12); // prints Hello, Zac! on stdout
```

stdio.h - C Standard Library I/O Functions

- **stdio.h** provides a portable higher-level API to manipulate files.
  - part of standard C library
  - available in every C implementation that can do I/O
  - functions are portable, convenient & efficient
  - on Unix-like systems they will call open()/read()/write() ... with buffering
- Use **stdio.h** functions for file operations unless you have a good reason not to
  - e.g .program with special I/O requirements like a database implementation

stdio library to print message to stdout



```c
char bytes[] = "Hello, Zac!\n";
printf("%s",bytes);
```

`printf` will do the write system call for us!

Many examples in the code sections of the course website:
https://cgi.cse.unsw.edu.au/~cs1521/25T2/topic/files/code/

Libc wrapper to open a file

```
int open(char *pathname, int flags);
```

- open file at **`pathname`**, according to **`flags`**
- **`flags`** is a bit-mask defined in **`<fcntl.h>`**

```
int open(char *pathname, int flags, mode_t mode);
```

- Use this version when potentially creating a new file
- **`mode`** is an octal number representing access permissions (on POSIX compliant systems)

If successful, they return file descriptor (small non-negative int)

If unsuccessful, they return **`-1`** and set **`errno`** to value indicating reason

Libc wrapper to open a file

Flag	Use
`O_RDONLY`	open for reading
`O_WRONLY`	open for writing
`O_APPEND`	append on each write
`O_RDWR`	open object for reading and writing
`O_CREAT`	create file if doesn't exist
`O_TRUNC`	truncate to size 0

Flags can be combined e.g. `(O_WRONLY|O_CREAT)`

Libc wrapper to close a file

```
int close(int fd);
```

- Release open file descriptor **`fd`**
- If successful, return **`0`**
- If unsuccessful, return **`-1`** and set errno
  - Could be unsuccessful if **`fd`** was already closed

- Limited number of file open at any time, so use **`close()`**

Libc library wrapper for read system call

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

- Read (up to) **`count`** bytes from **`fd`** into **`buf`**
    - **`buf`** should point to array of at least **`count`** bytes
    - read cannot check **`buf`** points to enough space
- If successful, number of bytes actually read is returned
- If no more bytes to read, **`0`** returned
- If error, **-1** is returned and **errno** set
- File descriptor **current position** in file is updated

Libc library wrapper for read system call

```
ssize_t write(int fd, const void *buf, size_t count);
```

- Attempt to write **`count`** bytes from **`buf`** into stream identified by **`fd`**
- If successful, number of bytes actually written is returned
- If unsuccessful**, -1** returned and **errno is set**
- File descriptor **current position** in file is updated

stdio.h - fopen()

```
FILE *fopen(const char *pathname, const char *mode);
```

- **mode** is string of 1 or more characters including:
    - r open file for reading.
    - w open file for writing
      truncated to 0 zero length if it exists
      created if does not exist
    - a   open file for writing
      writes append to it if it exists
      created if does not exist

FILE *

fopen returns a **FILE** pointer

- FILE is an opaque struct - OS dependent. We can not access fields.
- FILE stores file descriptor.
- FILE may also for efficiency -- store buffered data

stdio.h fclose()

```
int fclose(FILE *stream);
```

- "Flushes" (writes) unwritten buffered data to the stream
- Closes the file
- Number of streams open at any time is limited (to maybe 1024)

stdio.h reading and writing

```
int fgetc(FILE *stream) ;                   // read a byte
int fputc(int c, FILE *stream);             // write a byte

// read/write array of bytes (fgetc/fputc + loop often better)
size_t fread(void *ptr, size_t size, size_t nmemb,
             FILE *stream);

size_t fwrite(const void *ptr, size_t size, size_t nmemb,
              FILE *stream);
```

stdio.h reading and writing text only

```
char *fputs(char *s, FILE *stream);                // write a string
char *fgets(char *s, int size, FILE *stream);  // read a line

//formatted input/output
int fscanf(FILE *stream, const char *format, ...);
int fprintf(FILE *stream, const char *format, ...);
```

These functions can not be used for binary data as they may contain zero bytes

- can use to read text (ASCII/Unicode)
- can **not** use to read a *jpg* for example

stdio.h convenience functions

To read/write to stdin/stdout

```
int getchar(void);                  // fgetc(stdin)
int putchar(int c);                 // fputc(c, stdout)
int puts(char *s);                  // fputs(s, stdout)
int scanf(char *format, ...);       // fscanf(stdin, format, ...)
int printf(char *format, ...);      // fprintf(stdout, format, ...)
```

These should never be used: security vulnerability, buffer overflow

```
char *gets(char *s);                // Ok in general.
scanf("%s", array);                 // Don’t use with %s
```

stdio.h - IO to strings

`stdio.h` provides useful functions which operate on strings

```
// like scanf, but input comes from char array str
int sscanf(const char *str, const char *format, ...);
```

```
// like printf, but output goes to char array str
// handy for creating strings passed to other functions
// size contains size of str
// Do not use similar function sprintf as it is a security vulnerability
int snprintf(char *str, size_t size, const char *format, ...);
```

Exercise

Implement linux **cp** command

1. byte at a time stdio.h
2. using fgets and fprintf/fputs - what is the problem with this approach?

We also have implementations using syscall and libc

Which is the best approach?

Demo: fgetc return type bug

- To make a buggy version:
  - Use char instead of int for fgetc (this creates bugs with getchar too)

- Reminder: getchar and fgetc return int
  - Legal values they can return -1..255. (257 possible values)
  - This can’t fit in signed char or unsigned char!

- signed char (or char on our system) can store -1 and detect EOF,
  - but valid byte value 0xFF gets mistaken for EOF

- unsigned char can’t store -1 and can’t detect EOF

Demo: cp using fgets and fprintf

- Using fgets and fprintf to copy a file
- Seems to work fine when copying text files BUT
  - Breaks for binary files with 0x00 bytes
  - They are interpreted as end of string ‘\0’ character

Reminder: only use fgets, fprintf, fscanf, or fputs for text

What did we learn today?

- Recap of floating-point representation
- System calls!
    - Specifically: open/read/write/close
    - Portable libc equivalents: fopen/fread/fwrite/fclose
    - stdio convenience functions: Too many to list here!
        - Mainly getc/putc/getchar/putchar/scanf/printf/sscanf/snprintf

Coming up after flex week

Working with stdio.h library and files

And much more about file systems!

Reach Out

Content Related Questions:

Forum

Admin related Questions email:

cs1521@cse.unsw.edu.au

Student Support | I Need Help With...

My Feelings and Mental Health Managing Low Mood, Unusual Feelings & Depression	**Mental Health Connect**	student.unsw.edu.au/**counselling** Telehealth
	Mind HUB	student.unsw.edu.au/**mind-hub** Online Self-Help Resources
	In Australia Call Afterhours UNSW Mental Health Support Line	1300 787 026 5pm-9am
	Outside Australia Afterhours 24-hour Medibank Hotline	+61 (2) 8905 0307
Uni and Life Pressures Stress, Financial, Visas, Accommodation & More	**Student Support Indigenous Student Support**	— student.unsw.edu.au/**advisors**
Reporting Sexual Assault/Harassment	**Equity Diversity and Inclusion (EDI)**	— edi.unsw.edu.au/**sexual-misconduct**
Educational Adjustments To Manage my Studies and Disability / Health Condition	**Equitable Learning Service (ELS)**	— student.unsw.edu.au/**els**
Academic and Study Skills	**Academic Language Skills**	— student.unsw.edu.au/**skills**
Special Consideration Because Life Impacts our Studies and Exams	Special Consideration	— student.unsw.edu.au/**special-consideration**