File Access in C

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Unix Paradigm

- Everything is a file!
  - Except processes

- Directory contents could include:
  - Hard links
  - Symbolic links
  - Named pipes
  - Device character special file
  - Device block special file
  - Named socket

What is a File in UNIX?

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- System Programmer View:
  - A stream of bytes
    - Could be accessed as an array
    - Newlines/carriage returns & tabs are all just bytes, too!
  - Persistent

- How do we access files for reading and writing?

Opening a File

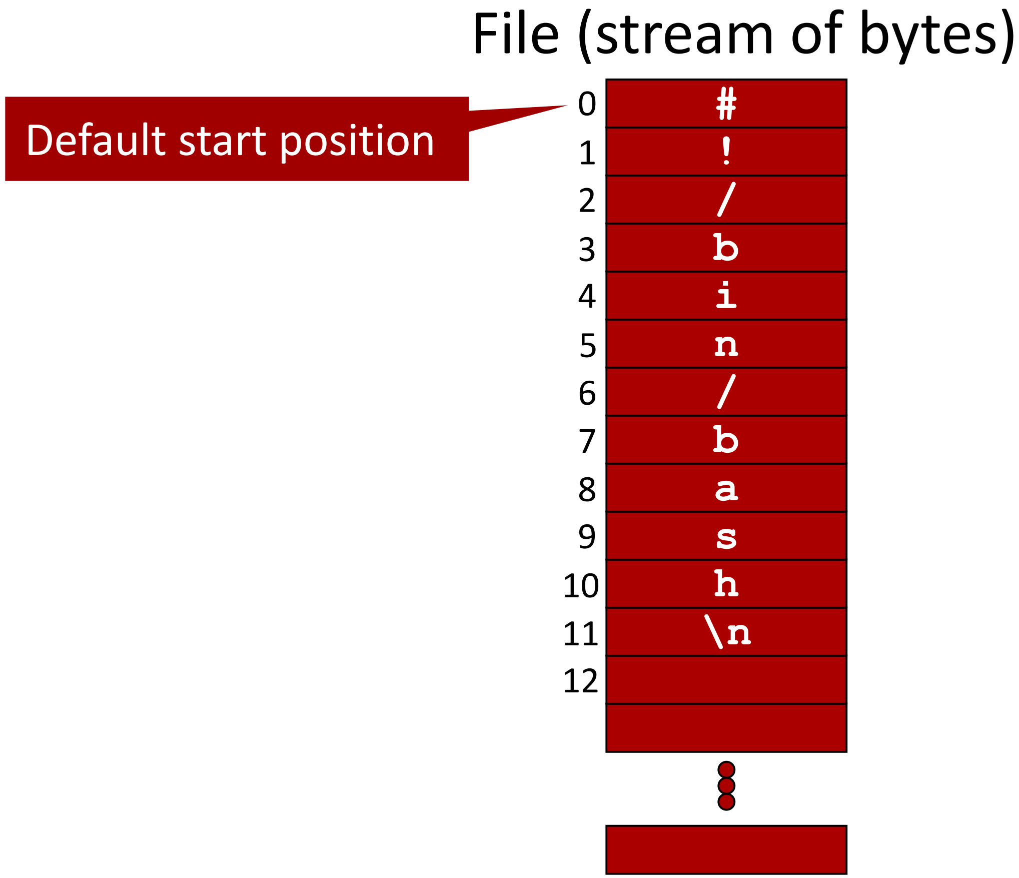
Reminder: We’re talking about C programming now, not shell scripts

- Files can be open for:
  - read only :: O_RDONLY
  - write only :: O_WRONLY
  - read and write :: O_RDWR

- When you open a file for writing…
  - Should you delete an existing file with the same name?
  - If not, where do you want to start writing
    - Beginning? End? Somewhere else?
  - If the file doesn’t exist, should you create it?
  - If you create it, what should the initial access permissions be?

The File Pointer

- Tracks where the next file operation occurs in an open file
- A separate file pointer is maintained for each open file
- All of the operations we’re talking about:
    - Directly impact which byte in a file is pointed to by the file pointer when the file is opened
    - Move the file pointer



File (stream of bytes)

Default start position

0	#
1	!
2	/
3	b
4	i
5	n
6	/
7	b
8	a
9	s
10	h
11	\n
12	

Open for Read

```
#include <fcntl.h>
#include <stdio.h>
#include <stdlib.h>

int main(void)
{
        char file[] = "cs344/grades.txt";
        int file_descriptor;

        file_descriptor = open(file, O_RDONLY);

        if (file_descriptor < 0)
        {
                fprintf(stderr, "Could not open %s\n", file);
                exit(1);
        }

        close(file_descriptor);
        return(0);
}
```

Using `open()` and `close()` allows us to represent file descriptors as **int**s.

The more modern `fopen()` and `fclose()` require a special file descriptor type.

Open for Write

```
#include <fcntl.h>
#include <stdio.h>
#include <stdlib.h>

int main(void)
{
        char file[] = "cs344/grades.txt";
        int file_descriptor;

        file_descriptor = open(file, O_WRONLY);

        if (file_descriptor < 0)
        {
                fprintf(stderr, "Could not open %s\n", file);
                perror("Error in main()");
                exit(1);
        }

        close(file_descriptor);
        return(0);
}
```

Truncating an Existing File

- When you open a file for writing, should you delete all contents of an existing file with the same name, or write over existing contents?
  - To delete it and start fresh: `O_TRUNC`

- Example:

```
file_descriptor = open(file, O_WRONLY | O_TRUNC);
```

  - Opens an existing file for writing only, then deletes all the data in it
  - Sets the file pointer to position 0

Appending to an Existing File

- Open the file in append mode with flag: `O_APPEND`

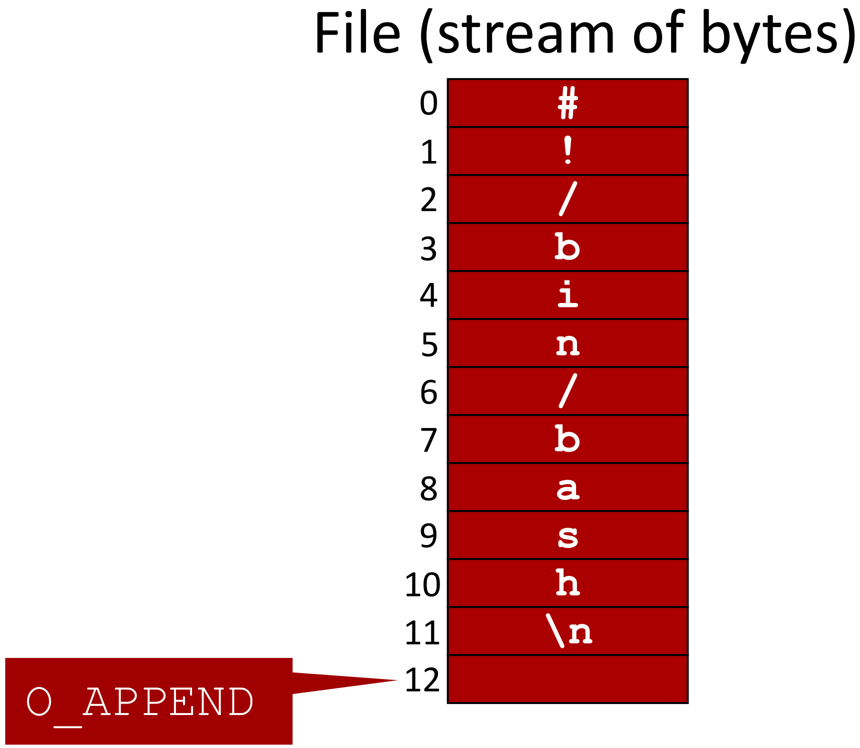
- Before *every* write, the file pointer will be automatically set to the end of the file

- Example

  ```
  file_descriptor = open(filepath, O_WRONLY | O_APPEND);
  ```

  - Opens an existing file for writing only in append mode

O_APPEND and the File Pointer



File (stream of bytes)

0	#
1	!
2	/
3	b
4	i
5	n
6	/
7	b
8	a
9	s
10	h
11	\n
12	

O_APPEND

Creating a New File

- To open (or create) a file that doesn't exist, use flag: `O_CREAT`
- Example: open a file for writing only, creating it if it doesn't exist:

```
file_descriptor = open(filepath, O_WRONLY | O_CREAT, 0600);
```

- The third parameter of `open()` *must* be used when the creation of a new file is requested (i.e. using `O_CREAT` or `O_TMPFILE`)

Even though the `open()` call will probably fail in bizarre ways if you don't include the third argument here, it still compiles! Thanks, C!

Creating a New File - Access Permissions

- Again, the third parameter of `open()` *must* be used when the creation of a new file is requested (i.e. using `O_CREAT` or `O_TMPFILE`)

- Third parameter contains octal number permissions bits:
  - Specify directly as with chmod: `0600`
  - Or you can bit-wise OR flags together: `S_IRUSR | S_IWUSR`

- Example:

User has read and write permission

```
file_descriptor = open(file, O_WRONLY | O_CREAT, 0600);
file_descriptor = open(file, O_WRONLY | O_CREAT, S_IRUSR | S_IWUSR);
```

User has read permission

User has write permission

lseek()

- Manipulates a file pointer in a file
- Used to control where you’re messing with da bitz

- Examples:
  - Move to byte #16

    ```
    newpos = lseek(file_descriptor, 16, SEEK_SET);
    ```

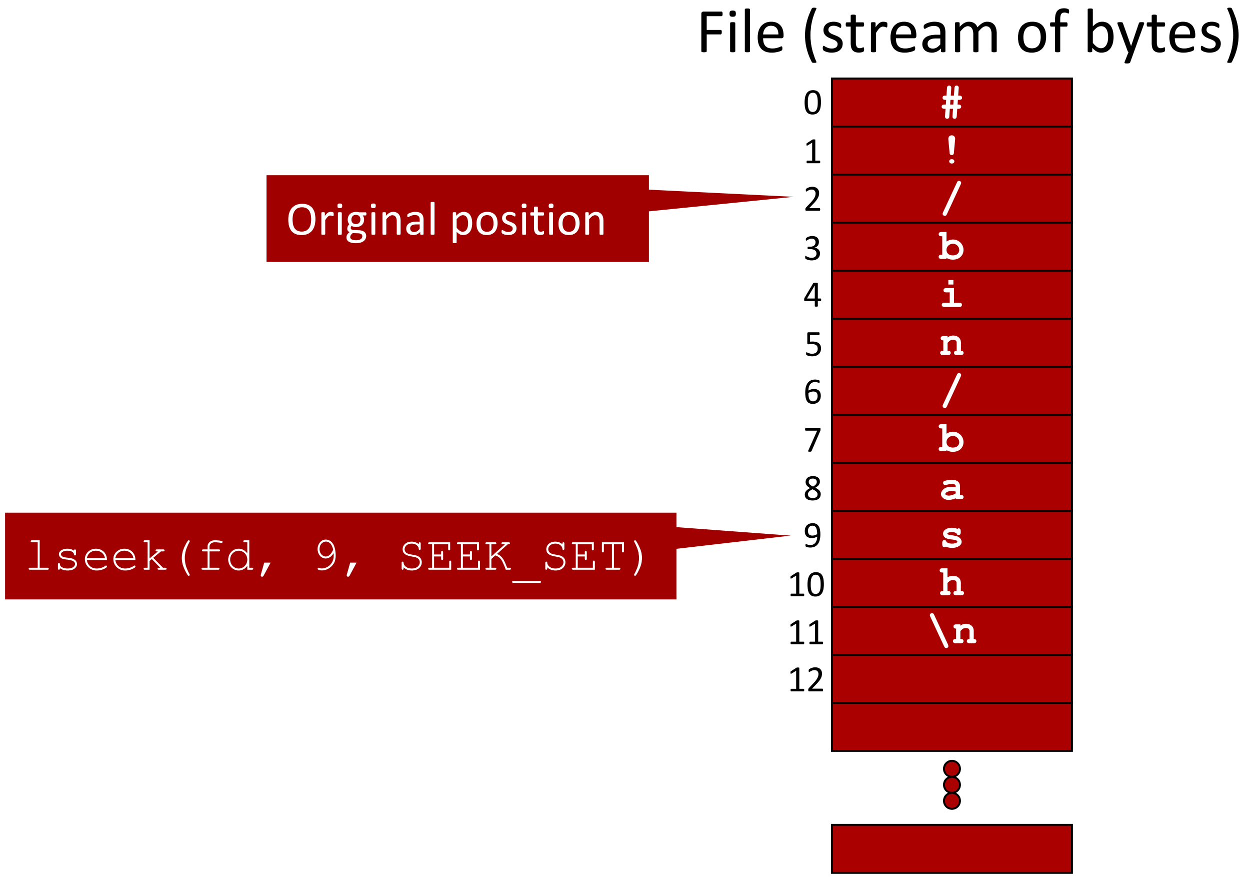
  - Move forward 4 bytes

    ```
    newpos = lseek(file_descriptor, 4, SEEK_CUR);
    ```

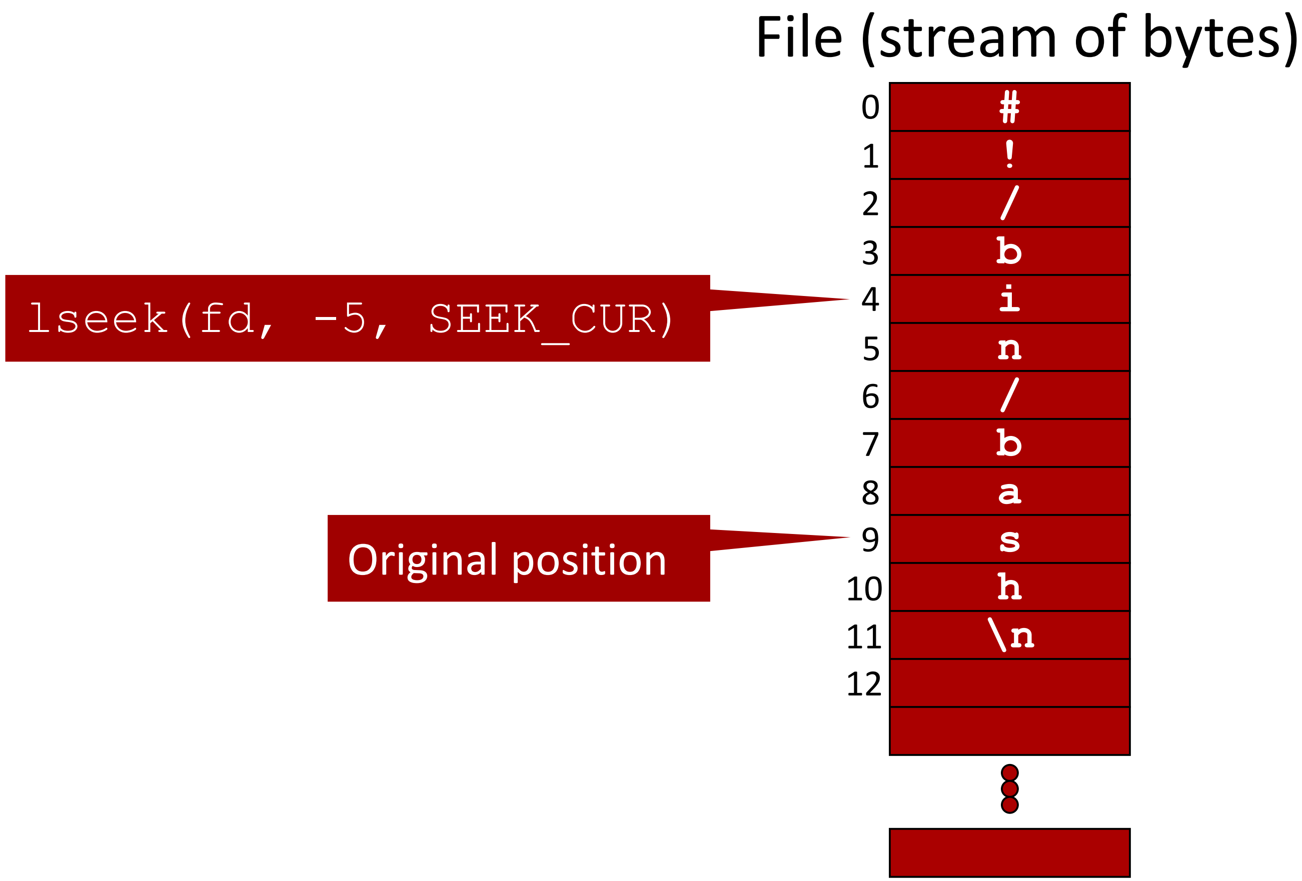
  - Move to 8 bytes from the end

    ```
    newpos = lseek(file_descriptor, -8, SEEK_END);
    ```

`lseek()` :: `SEEK_SET` :: Setting Position



lseek() :: SEEK_CUR :: Moving backwards



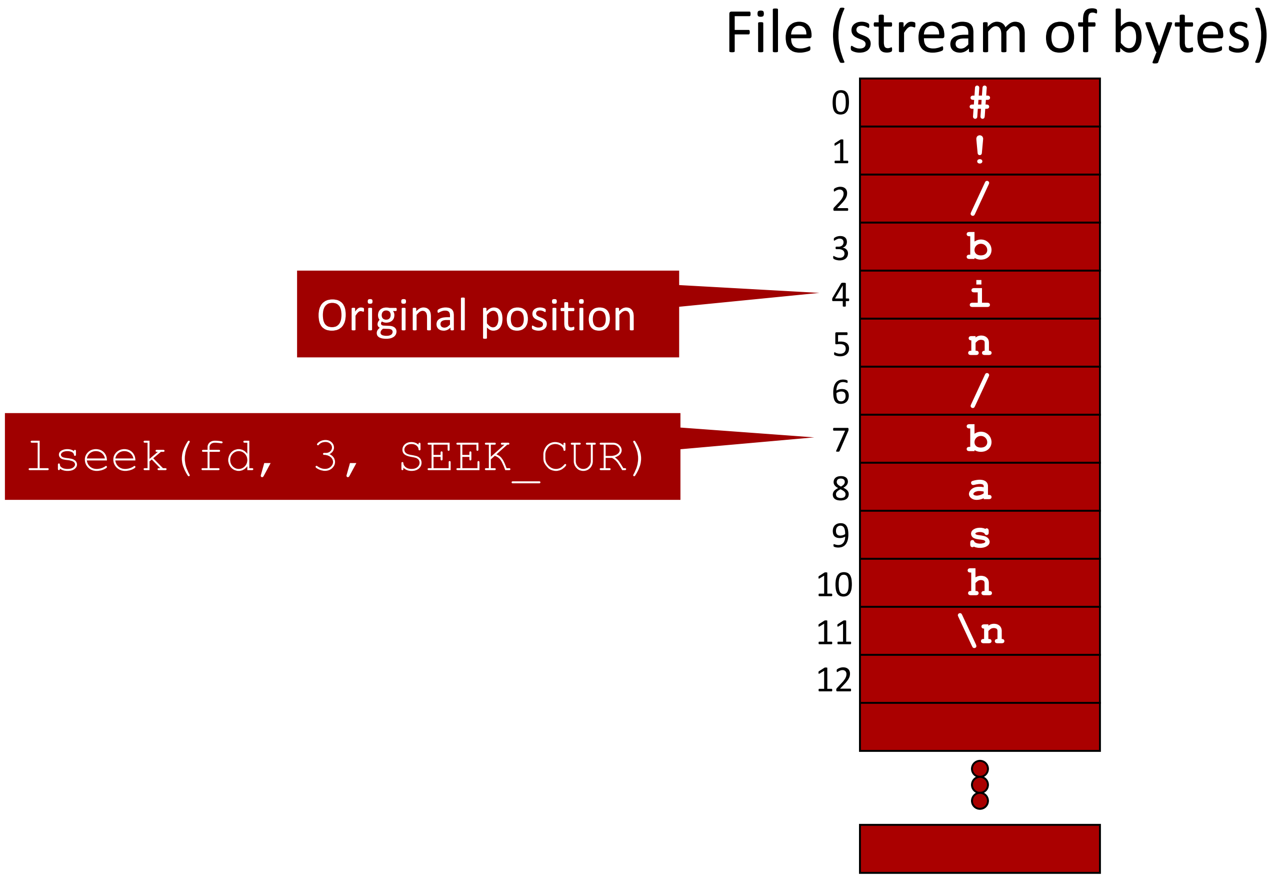
File (stream of bytes)

0	#
1	!
2	/
3	b
4	i
5	n
6	/
7	b
8	a
9	s
10	h
11	\n
12	

`lseek(fd, -5, SEEK_CUR)`

Original position

lseek() :: SEEK_CUR :: Moving Forwards



File (stream of bytes)

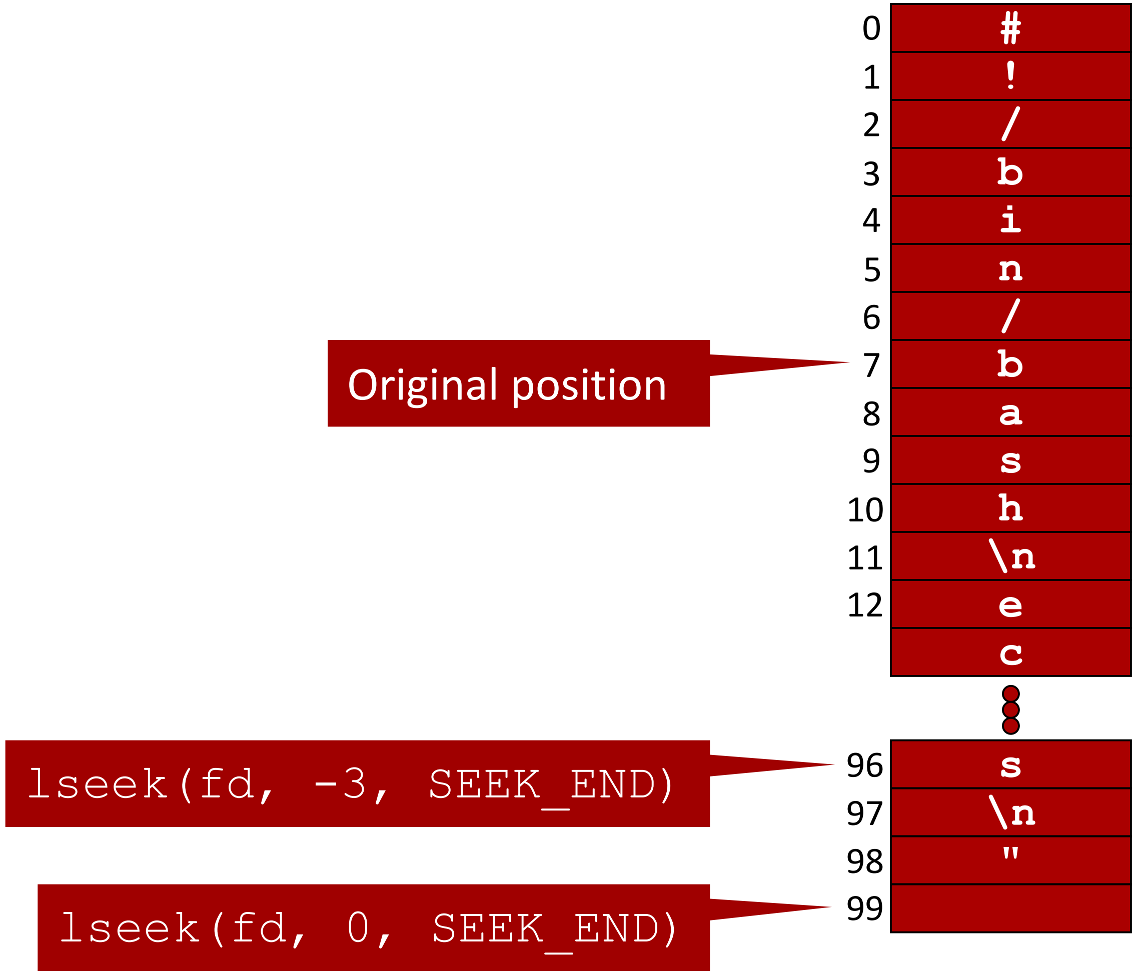
0	#
1	!
2	/
3	b
4	i
5	n
6	/
7	b
8	a
9	s
10	h
11	\n
12	

Original position

`lseek(fd, 3, SEEK_CUR)`

lseek() :: SEEK_END :: Moving Relative to the End

File (stream of bytes)



0	#
1	!
2	/
3	b
4	i
5	n
6	/
7	b
8	a
9	s
10	h
11	\n
12	e
	c
96	s
97	\n
98	"
99	

Original position

`lseek(fd, -3, SEEK_END)`

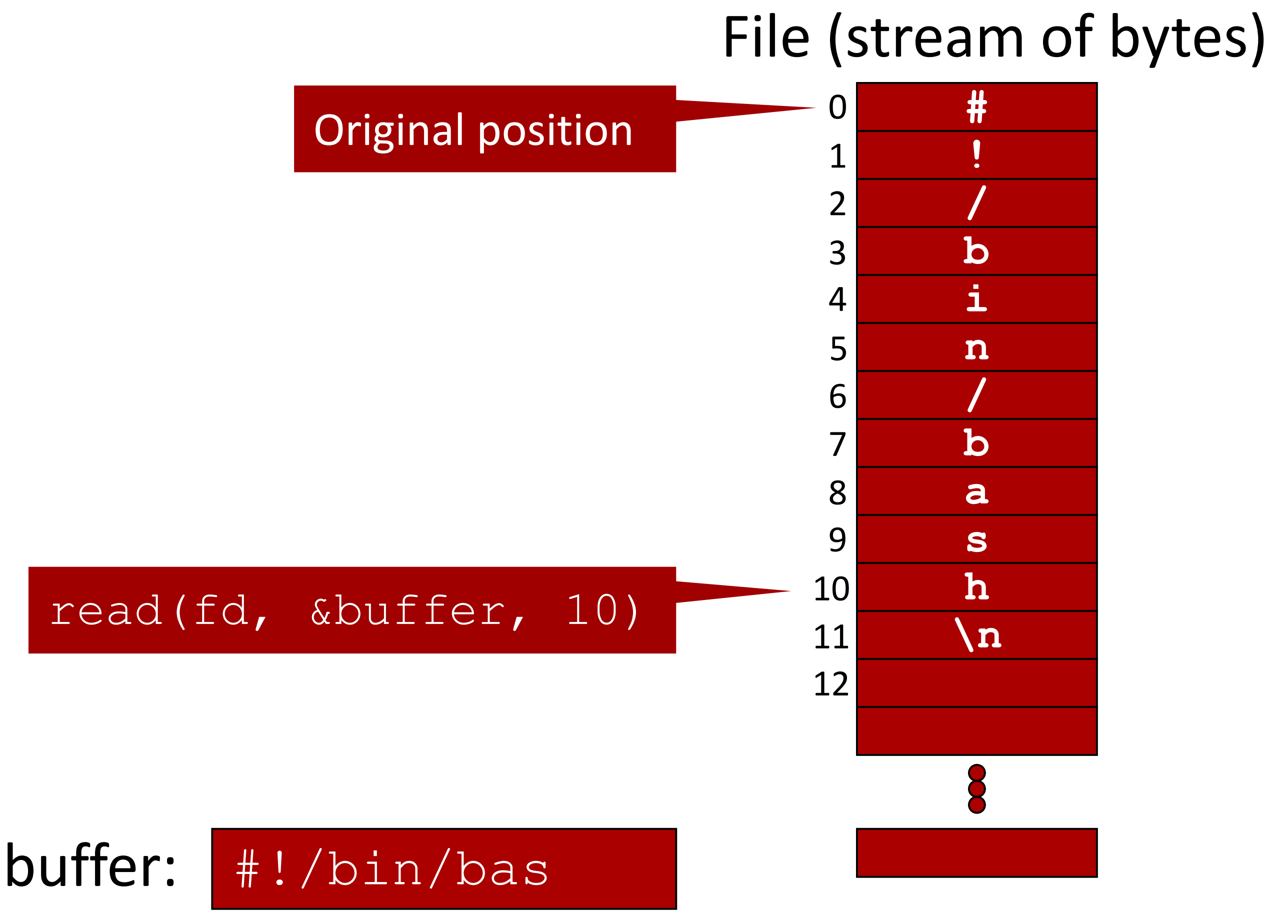
`lseek(fd, 0, SEEK_END)`

Read/Write and the File Pointer

- If you’ve opened a file for reading and/or writing, be aware that *both* of these operations will change the file pointer location!

- The pointer will be incremented by exactly the number of bytes read or written

read() and the File Pointer



File (stream of bytes)

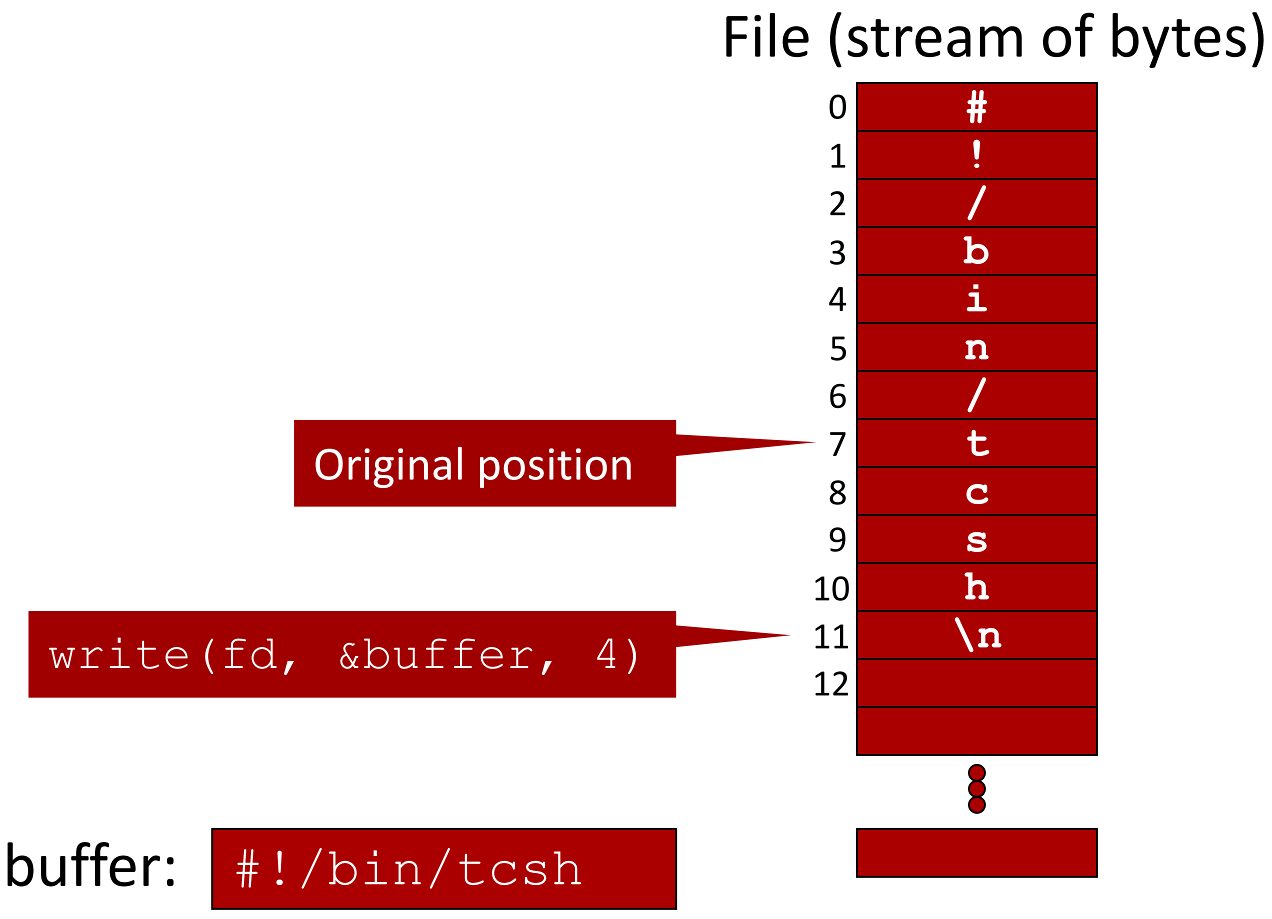
0	#
1	!
2	/
3	b
4	i
5	n
6	/
7	b
8	a
9	s
10	h
11	\n
12	

Original position

`read(fd, &buffer, 10)`

buffer: `#!/bin/bas`

`write()` and the File Pointer



Complete Read/Write Example

```c
#include <stdio.h>
#include <stdlib.h>
#include <fcntl.h>
#include <string.h>

int main(void)
{
        int file_descriptor;
        char *newFilePath = "./newFile.txt";
        char *giveEm = "THE BUSINESS\n";
        ssize_t nread, nwritten;
        char readBuffer[32];

        file_descriptor = open(newFilePath, O_RDWR | O_CREAT | O_TRUNC, S_IRUSR | S_IWUSR);

        if (file_descriptor == -1)
        {
                printf("Hull breach - open() failed on \"%s\"\n", newFilePath);
                perror("In main()");
                exit(1);
        }

        nwritten = write(file_descriptor, giveEm, strlen(giveEm) * sizeof(char));

        memset(readBuffer, '\0', sizeof(readBuffer)); // Clear out the array before using it
        lseek(file_descriptor, 0, SEEK_SET); // Reset the file pointer to the beginning of the file
        nread = read(file_descriptor, readBuffer, sizeof(readBuffer));

        printf("File contents:\n%s", readBuffer);
        exit(0);
}
```

Mode bits

Permissions

These two steps are really important to avoid nasty bugs

The Standard IO Library in C

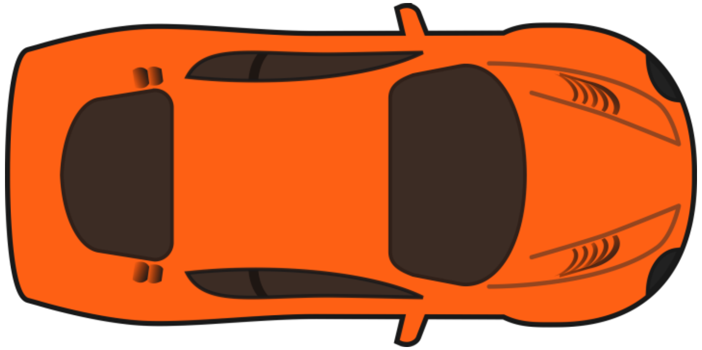
- `fopen`, `fclose`, `printf`, `fprintf`, `sprintf`, `scanf`, `fscanf`, `getc`, `putc`, `gets`, `fgets`, `fseek`, etc.
- Automatically buffers input and output intelligently
- Easy to work in line mode
  - i.e., read one line at a time
  - write one line at a time
- Powerful string and number formatting
- To use them:

  `#include <stdio.h>`

Why Teach and Use `read()` & `write()`?

- Maximum performance
  - IF you know exactly what you are doing
  - No additional hidden overhead from stdio, which is much slower!
  - No hidden system calls behind stdio functions which may be non-reentrant

- Control exactly what is written/read and at what times



Some stdio Functions

• `fclose`	Close a stream
• `feof`	Check if End Of File has been reached
• `fgetc`	Get next character from a stream
• `fgetpos`	Get position in a stream
• `fopen`	Open a file
• `fprintf`	Print formatted data to a stream
• `fputc`	Write character to a stream
• `fread`	Read block of data from a stream
• `fseek`	Reposition stream's position indicator (stdio version of `lseek`)
• `getc`	Get the next character
• `getchar`	Get the next character from stdin

Some More stdio Functions

• `gets`	Get a string from stdin
• `printf`	Print formatted data to stdout
• `putc`	Write character to a stream
• `putw`	Write an integer to a stream
• `remove`	Delete a file
• `rename`	Rename a file or directory
• `rewind`	Reposition file pointer to the beginning of a stream
• `scanf`	Read formatted data from stdin
• `sprintf`	Format data to a string
• `sscanf`	Read formatted data from a string
• `ungetc`	Push a character back into stream

Files or Streams?

- **stdin**, **stdout**, and **stderr** are actually *file streams*, not file system files
- File streams wrap around, and provide buffering to, the underlying file descriptor among other features
- The stdio library streams are of type `FILE*` which are connected with the `fopen()` call to a `FILE*` variable:

```
FILE* myFile = fopen("datafile103", "r");
```

- Streams are closed when a process terminates, but file descriptors with open files are passed on to child processes, for example:
    - The shell bash executes *`ls > abc`*; `ls` can access the file abc opened by bash
    - A process spawns a new child process with `fork()`, all open files are shared

Getting Input From the User: userinput.c

```c
#include <stdio.h>
#include <string.h>
#include <stdlib.h>

void main()
{
        int numCharsEntered = -5; // How many chars we entered
        int currChar = -5; // Tracks where we are when we print out every char
        size_t bufferSize = 0; // Holds how large the allocated buffer is
        char* lineEntered = NULL; // Points to a buffer allocated by getline() that holds our entered string + \n + \0

        while(1)
        {
                // Get input from the user
                printf("Enter in a line of text (CTRL-C to exit):");
                numCharsEntered = getline(&lineEntered, &bufferSize, stdin); // Get a line from the user
                printf("Allocated %zu bytes for the %d chars you entered.\n", bufferSize, numCharsEntered);
                printf("Here is the raw entered line: \"%s\"\n", lineEntered);

                // Print out the actual contents of the string that was entered
                printf("Here are the contents of the entire buffer:\n");
                printf("  # CHAR INT\n");
                for (currChar = 0; currChar < bufferSize; currChar++) // Display every character in both dec and ASCII
                        printf("%3d `%c\' %3d\n", currChar, lineEntered[currChar], lineEntered[currChar]);
                free(lineEntered); // Free the memory allocated by getline() or else memory leak
        }
}
```

When `bufferSize = 0` and `lineEntered = NULL`, `getline()` allocates a buffer for you with `malloc()`

Could also be a regular file opened as a stream with `fopen()`

`getline()` is my preferred tool to get user input

Results - Getting Input From the User: userinput.c

```
$ gcc -o userinput userinput.c
$ userinput
Enter in a line of text (CTRL-C to exit):abc o0OlI1
Allocated 120 bytes for the 11 chars you entered.
Here is the raw entered line: "abc o0OlI1
"
Here are the contents of the entire buffer:
  # CHAR INT
  0 `a'  97
  1 `b'  98
  2 `c'  99
  3 ` '  32
  4 `o' 111
  5 `0'  48
  6 `O'  79
  7 `l' 108
  8 `I'  73
  9 `1'  49
 10 `
'   10
 11 `'    0
 12 `'    0
            ...(cut)...
118 `'    0
119 `'    0
Enter in a line of text (CTRL-C to exit):^C
```

Newline; if you don't want this, just add:

```
lineEntered[numCharsEntered - 1] = '\0';
```

after calling `getline()`

Null terminator

Obtaining File Information

- `stat()` and `fstat()`

- Retrieve all sorts of information about a file
  - Which device it is stored on
  - Ownership/permissions of that file
  - Number of hard links pointing to it
  - Size of the file
  - Timestamps of last modification and access
  - Ideal block size for I/O to this file