I/O Management

Goals of this Lecture

- Help you to learn about:
  - The Unix **stream** concept
  - Standard C I/O functions
  - Unix system-level functions for I/O
  - How the standard C I/O functions use the Unix system-level functions
  - Additional abstractions provided by the standard C I/O functions

Streams are a beautiful Unix abstraction

Stream Abstraction

- Any source of input or destination for output
  - E.g., keyboard as input, and screen as output
  - E.g., files on disk or CD, network ports, printer port, …

Sequential Access to a Stream

- Each stream has an associated file position
  - Starting at beginning of file (if opened to read or write)
  - Or, starting at end of file (if opened to append)

- Read/write operations advance the file position
  - Allows sequencing through the file in sequential manner
- Support for random access to the stream
  - Functions to learn current position and seek to new one

Using Streams in C

- Accessed in C programs through file pointers
  - E.g., `FILE *fp1, *fp2;`
  - E.g., `fp1 = fopen("myfile.txt", "r");`
- Supported by Standard I/O Library (stdio)
- Three streams provided by stdio.h
  - Streams **stdin**, **stdout**, and **stderr**
    - Typically map to keyboard, screen, and screen
  - Can redirect to correspond to other streams
    - E.g., stdin can be the output of another program
    - E.g., stdout can be the input to another program

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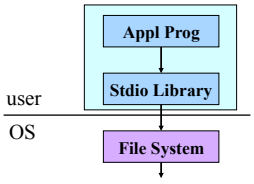
Standard I/O (stdio) Functions

- Portability
  - Generic I/O support for C programs
  - Invokes the OS-specific system calls for I/O
    - Specific implementations for various host Oses
- Abstractions for C programs
  - Streams
  - Line-by-line input
  - Formatted output
- Additional optimizations
  - Buffered I/O
  - Safe writing



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Example: Opening a File

- `FILE *fopen("myfile.txt", "r")`
  - Open the named file and return a stream
  - Includes a mode, such as "r" for read or "w" for write
- Creates a FILE data structure for the file
  - Mode, status, buffer, …
  - Assigns fields and returns a pointer
- Opens or creates the file, based on the mode
  - Write ('w'): create file with default permissions
  - Read ('r'): open the file as read-only
  - Append ('a'): open or create file, and seek to the end

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Example: Formatted I/O

- `int fprintf(fp1, "Number: %d\n", i)`
  - Convert and write output to stream in specified format
- `int fscanf(fp1, "FooBar: %d", &i)`
  - Read from stream in format and assign converted values
- Specialized versions
  - `printf(…)` is just `fprintf(stdout, …)`
  - `scanf(…)` is just `fscanf(stdin, …)`

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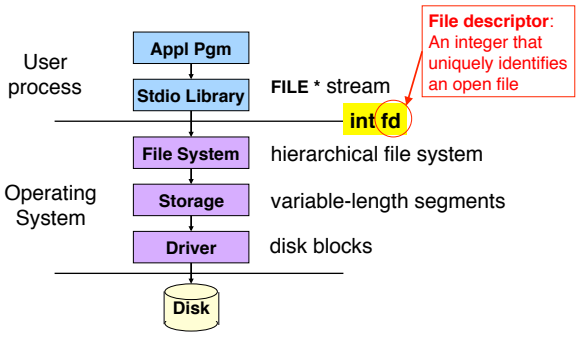
Streams in the Operating System



System-Level (OS) Functions for I/O

```
int creat(char *pathname, mode_t mode);
```
- Create a new file named **pathname**, and return a file descriptor

```
int open(char *pathname, int flags, mode_t mode);
```
- Open the file **pathname** and return a file descriptor

```
int close(int fd);
```
- Close **fd**

```
int read(int fd, void *buf, int count);
```
- Read up to **count** bytes from **fd** into the buffer at **buf**

```
int write(int fd, void *buf, int count);
```
- Writes up to **count** bytes into **fd** from the buffer at **buf**

```
int lseek(int fd, int offset, int whence);
```
- Assigns the file pointer of **fd** to a new value by applying an **offset**

Example: `open()`

- Converts a path name into a file descriptor
  - `int open(const char *pathname, int flags, mode_t mode);`
- Arguments
  - Pathname: name of the file
  - Flags: bit flags for `O_RDONLY`, `O_WRONLY`, `O_RDWR`
  - Mode: permissions to set if file must be created
- Returns
  - File descriptor (or a -1 if an error)
- Performs a variety of checks
  - E.g., whether the process is entitled to access the file
- Underlies `fopen()`

Example: `read()`

- Reads bytes from a file descriptor
  - `int read(int fd, void *buf, int count);`
- Arguments
  - File descriptor: integer descriptor returned by `open()`
  - Buffer: pointer to memory to store the bytes it reads
  - Count: maximum number of bytes to read
- Returns
  - Number of bytes read
    - Value of 0 if nothing more to read
    - Value of -1 if an error
- Performs a variety of checks
  - Whether file has been opened, whether reading is okay
- Underlies `getchar()`, `fgets()`, `scanf()`, etc.

How C Uses OS Functions (e.g.)

```
int getchar(void) {
   char c;
   if (read(0, &c, 1) == 1)
      return c;
   else return EOF;
}
```

- Read one character from `stdin`
  - File descriptor `0` is `stdin`
  - `&c` points to the buffer
  - `1` is the number of bytes to read
- Read returns the number of bytes read
  - In this case, `1` byte means success

Making `getchar()` More Efficient

- Poor performance reading one byte at a time
  - Read system call is accessing the device (e.g., a disk)
  - Reading one byte from disk is very time consuming
  - Better to read and write in *larger chunks*
- Buffered I/O
  - Read a large chunk from disk into a buffer
    - Dole out bytes to the user process as needed
    - Discard buffer contents when the stream is closed
  - Similarly, for writing, write individual bytes to a buffer
    - And write to disk when full, or when stream is closed
    - Known as "flushing" the buffer

Details of FILE in stdio.h (K&R 8.5)

```
#define OPEN_MAX 20  /* max files open at once */

typedef struct _iobuf {
   int  cnt;     /* num chars left in buffer */
   char *ptr;    /* ptr to next char in buffer */
   char *base;   /* beginning of buffer */
   int  flag;    /* open mode flags, etc. */
   char fd;      /* file descriptor */
} FILE;
extern FILE _iob[OPEN_MAX];

#define stdin  (&_iob[0])
#define stdout (&_iob[1])
#define stderr (&_iob[2])
```


A Funny Thing About Buffered I/O

- The standard library also buffers **output**; example:

```
int main(void) {
   printf("Step 1\n");
   sleep(10);
   printf("Step 2\n");
   return 0;
}
```

- Run "a.out > out.txt &" and then "tail -f out.txt"
  - To run `a.out` in the background, outputting to `out.txt`
  - And then to see the contents on `out.txt`
- Neither line appears till ten seconds have elapsed
  - Because the output is being buffered
  - Add `fflush(stdout)` to flush the output buffer
  - `fclose()` also flushes the buffer before closing

Summary

- System-level I/O functions provide simple abstractions
  - Stream as a source or destination of data
  - Functions for manipulating streams
- Standard I/O library builds on system-level functions
  - Calls system-level functions for low-level I/O
  - Adds buffering
- Powerful examples of abstraction
  - Application pgms interact with streams at a high level
  - Standard I/O library interact with streams at lower level
  - Only the OS deals with the device-specific details

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