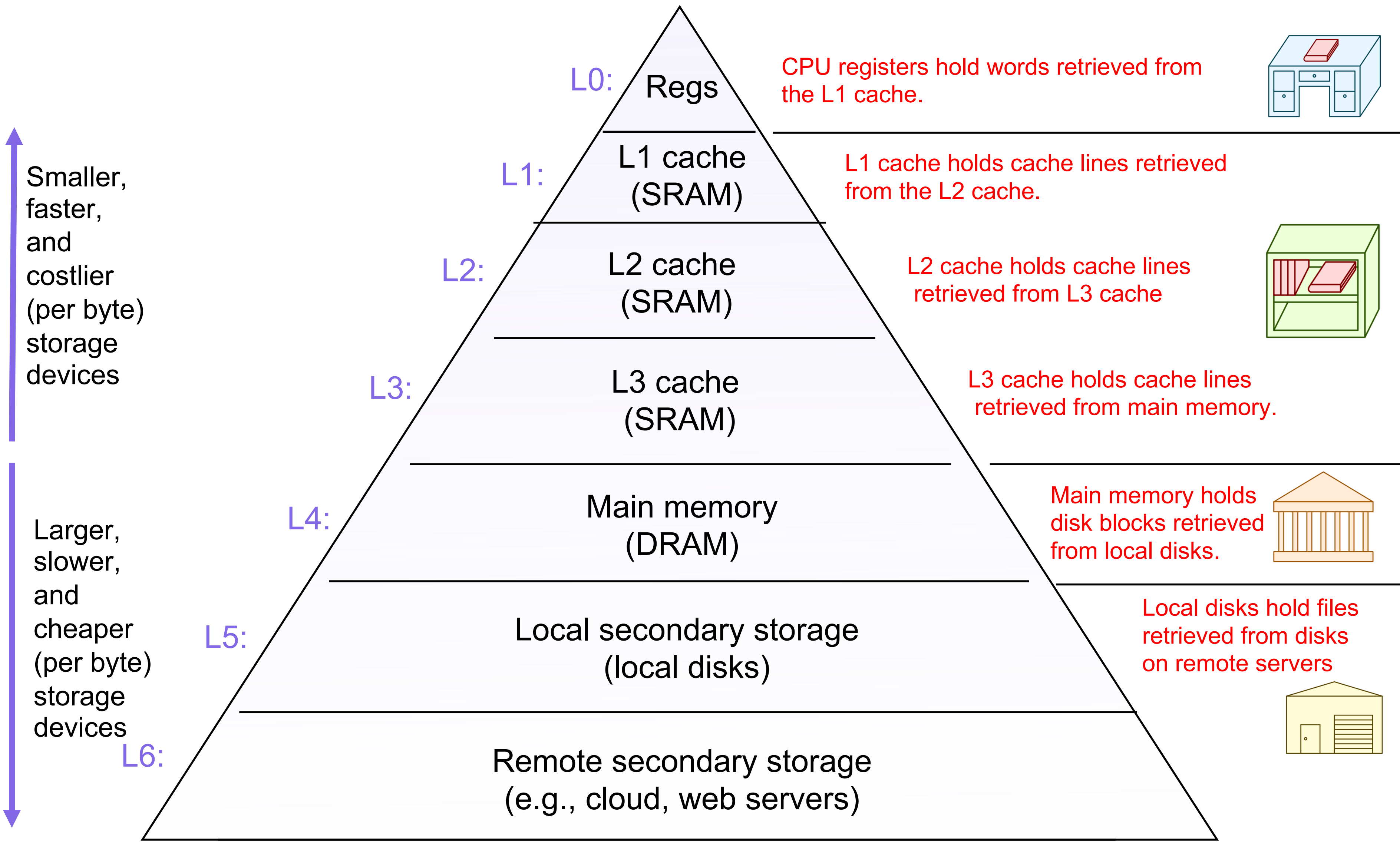
Lecture 23: System I/O

CS 105

Memory Hierarchy

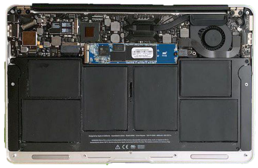


Storage Devices

- Magnetic Disks
  - Storage that rarely becomes corrupted
  - Large capacity at low cost
  - Block-level random access
  - Slow performance for random access
  - Better performance for streaming access
- Solid State Disks (Flash Memory)
  - Storage that rarely becomes corrupted
  - Capacity at moderate cost (50x magnetic disk)
  - Block-level random access
  - Good performance for random reads
  - Not-as-good performance for random writes

1950s
IBM 350
5 MB

2021
WD Red
10 TB



2021
MacBook
512GB

File Systems 101

- Long-term information storage goals
  - should be able to store large amounts of information
  - information must survive processes, power failures, etc.
  - processes must be able to find information
  - needs to support concurrent accesses by multiple processes

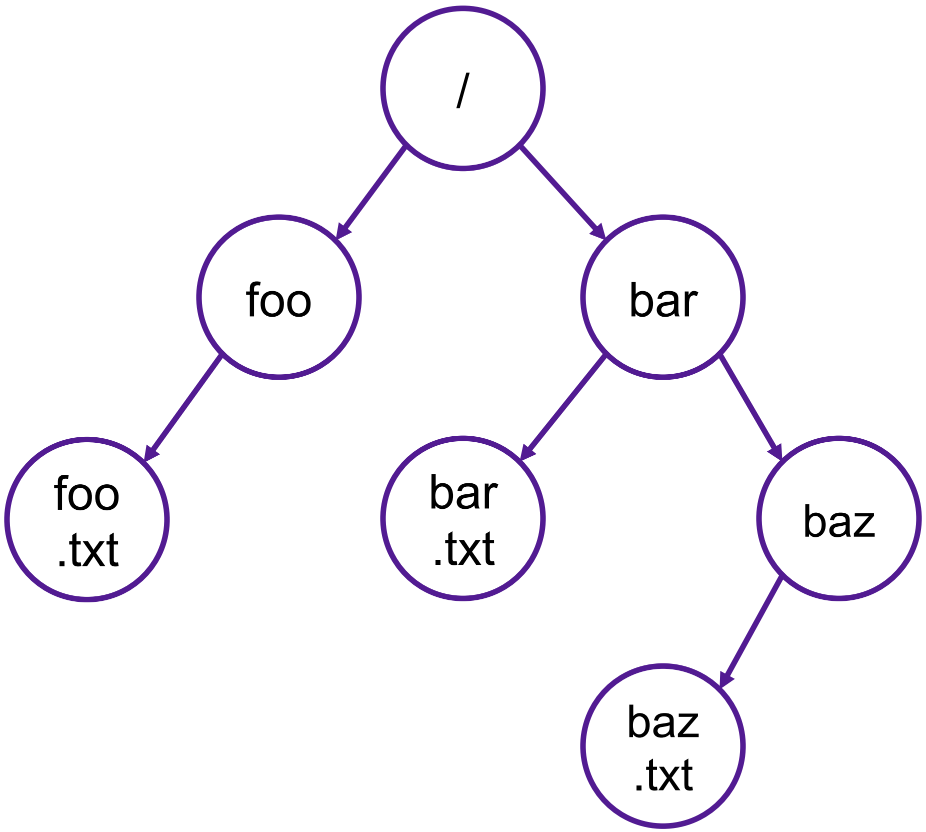
- Solution: the File System Abstraction
  - interface that provides operations involving
    - files
    - directories (a special kind of file)

The File System Abstraction

- interface that provides operations on data stored long-term on disk
- a **file** is a named sequence of stored bytes
  - name is defined on creation
  - processes use name to subsequently access that file
- a file is comprised of two parts:
  - **data**: information a user or application puts in a file
    - an array of untyped bytes
  - **metadata**: information added and managed by the OS
    - e.g., size, owner, security info, modification time
- two types of files
  - **normal files**: data is an arbitrary sequence of bytes
  - **directories**: a special type of file that provides mappings from human-readable names to low-level names (i.e., file numbers)

Path Names

- Each path from root is a name for a leaf
  - /foo/foo.txt
  - /bar/baz/baz.txt
- Each UNIX directory contains 2 special entries
  - "." = this directory
  - ".." = parent directory
- **Absolute paths:** path of file from the root directory
- **Relative paths:** path from current working directory



Exercise 0: Path Names

I’ve created a file named `example1.txt` in the directory `data`, which is located in the root directory.

1. Specify an absolute path to the file example1.txt
2. Specify a relative path to the file example1.txt from your home directory

Create a file named `example2.txt` in your home directory.

3. Specify an absolute path to the file example2.txt
4. Specify a relative path to the file example2.txt from your home directory

Hint: you can always get back to your home directory with `cd ~`

Hint: the name of your home directory is your username

Exercise 0: Path Names

I've created a file named `example1.txt` in the directory `data`, which is located in the root directory.

1. Specify an absolute path to the file example1.txt
2. Specify a relative path to the file example1.txt from your home directory
   `/data/example1.txt` **`../../../data/example1.txt`**

Create a file named `example2.txt` in your home directory.

3. Specify an absolute path to the file example2.txt
4. Specify a relative path to the file example2.txt from your home directory
   `/home/CAMPUS/ebac2018/example1.txt` **`./example1.txt`**

Hint: you can always get back to your home directory with `cd ~`

Hint: the name of your home directory is your username

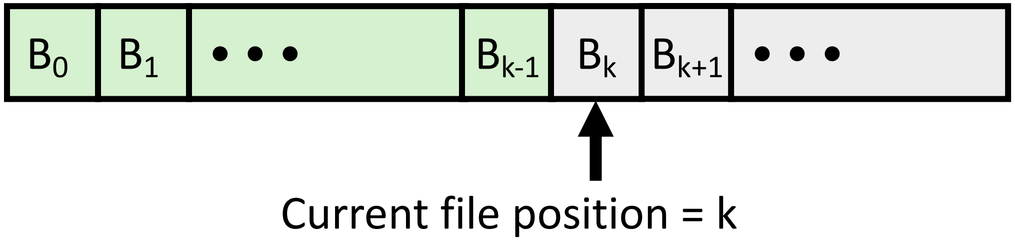
Basic File System Operations

- Create a file
- Delete a file
- Write to a file
- Read from a file
- Seek to somewhere in a file

How should we implement this?

Unix I/O Interface

- Elegant mapping of files to devices allows kernel to export simple interface:
  - Opening a file
    - **`open()`** and **`close()`**
  - Reading and writing a file
    - **`read()`** and **`write()`**
  - Changing the current **file position** (seek)
    - indicates next offset into file to read or write
    - **`lseek()`**



The File System Stack

Application

Language Libraries (e.g.,fopen, fread, fwrite, fclose,…)

POSIX API (open, read, write, close, …)

File System

Generic Block Interface (block read/write)

Generic Block Layer

Specific Block Interface (protocol-specific read/write)

Device Driver

user level

kernel mode

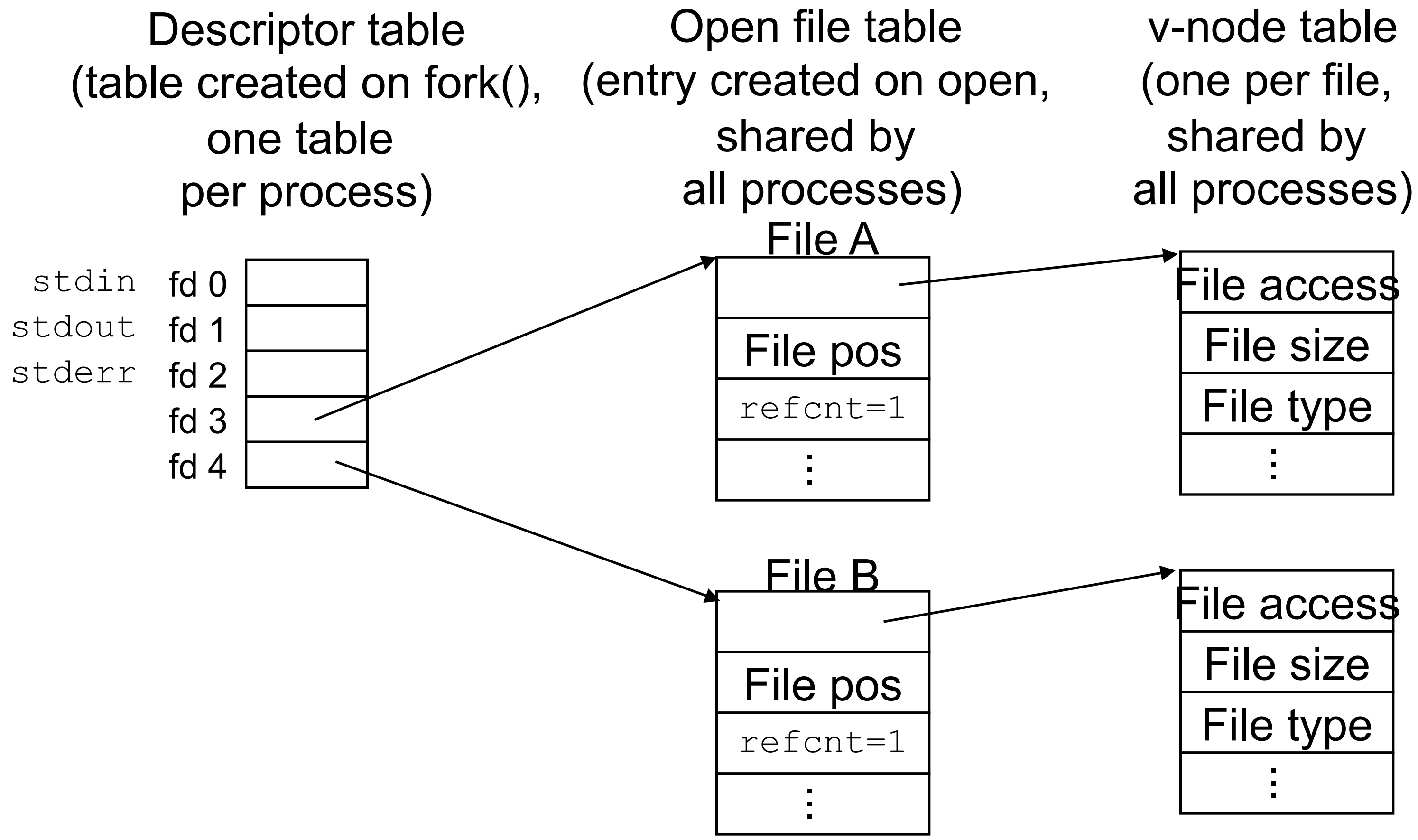
Opening Files

- Opening a file informs the kernel that you are getting ready to access that file

```
int fd;   /* file descriptor */

if ((fd = open("/etc/hosts", O_RDONLY)) < 0) {
   perror("open");
   exit(1);
}
```

- Returns a small identifying integer **file descriptor**
  - `fd == -1` indicates that an error occurred
- Each process created by a Linux shell begins life with three open files associated with a terminal:
  - 0: standard input (stdin)
  - 1: standard output (stdout)
  - 2: standard error (stderr)

Kernel Data Structures



Closing Files

- Closing a file informs the kernel that you are finished accessing that file

```
int fd;      /* file descriptor */
int retval; /* return value */

if ((retval = close(fd)) < 0) {
   perror("close");
   exit(1);
}
```

- Closing an already closed file is a recipe for disaster in threaded programs
- Moral: Always check return codes, even for seemingly benign functions such as `close()`

Reading Files

- Reading a file copies bytes from the current file position to memory, and then updates file position

```
char buf[512];
int fd;        /* file descriptor */
int nbytes;    /* number of bytes read */

/* Open file fd ...  */
/* Then read up to 512 bytes from file fd */
if ((nbytes = read(fd, buf, sizeof(buf))) < 0) {
   perror("read");
   exit(1);
}
```

- Returns number of bytes read from file `fd` into `buf`
  - Return type **`ssize_t`** is signed integer
  - **`nbytes < 0`** indicates that an error occurred
  - Short counts (**`nbytes < sizeof(buf)`**) are possible and are not errors!

Writing Files

- Writing a file copies bytes from memory to the current file position, and then updates current file position

```
char buf[512];
int fd;         /* file descriptor */
int nbytes;     /* number of bytes read */

/* Open the file fd ... */
/* Then write up to 512 bytes from buf to file fd */
if ((nbytes = write(fd, buf, sizeof(buf)) < 0) {
   perror("write");
   exit(1);
}
```

- Returns number of bytes written from `buf` to file `fd`
  - **`nbytes < 0`** indicates that an error occurred
  - As with reads, short counts are possible and are not errors!

On Short Counts

- Short counts can occur in these situations:
  - Encountering (end-of-file) EOF on reads
  - Reading text lines from a terminal
- Short counts never occur in these situations:
  - Reading from disk files (except for EOF)
  - Writing to disk files
- Best practice is to always allow for short counts.

Buffered Reads/Writes

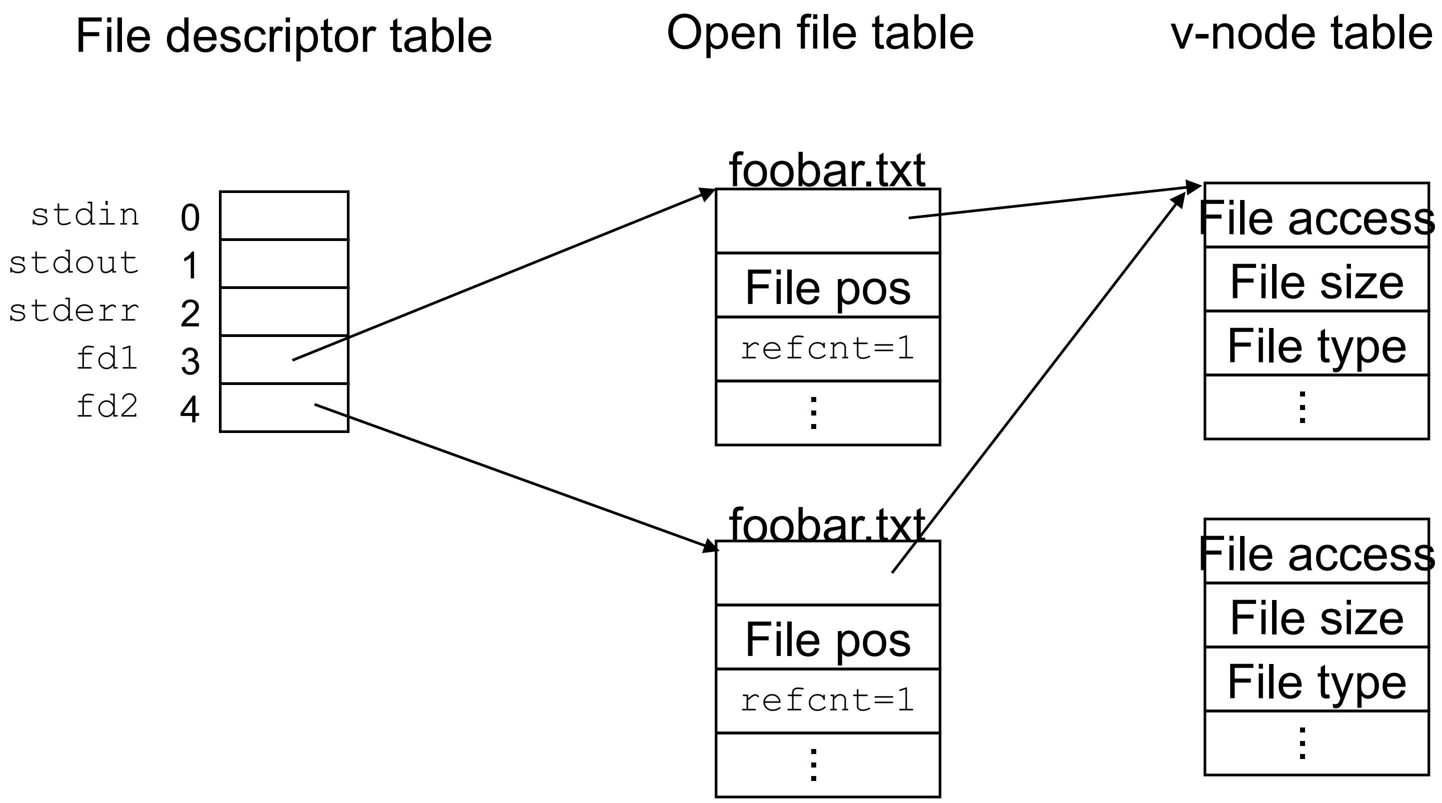
- stream data is stored in a kernel buffer and returned to the application on request
- enables same system call interface to handle both streaming reads (e.g., keyboard) and block reads (e.g., disk)

Exercise 1: Reading and Writing

- Assume the file `foobar.txt` consists of the six ASCII characters `foobar`. What gets printed when the following program is run?

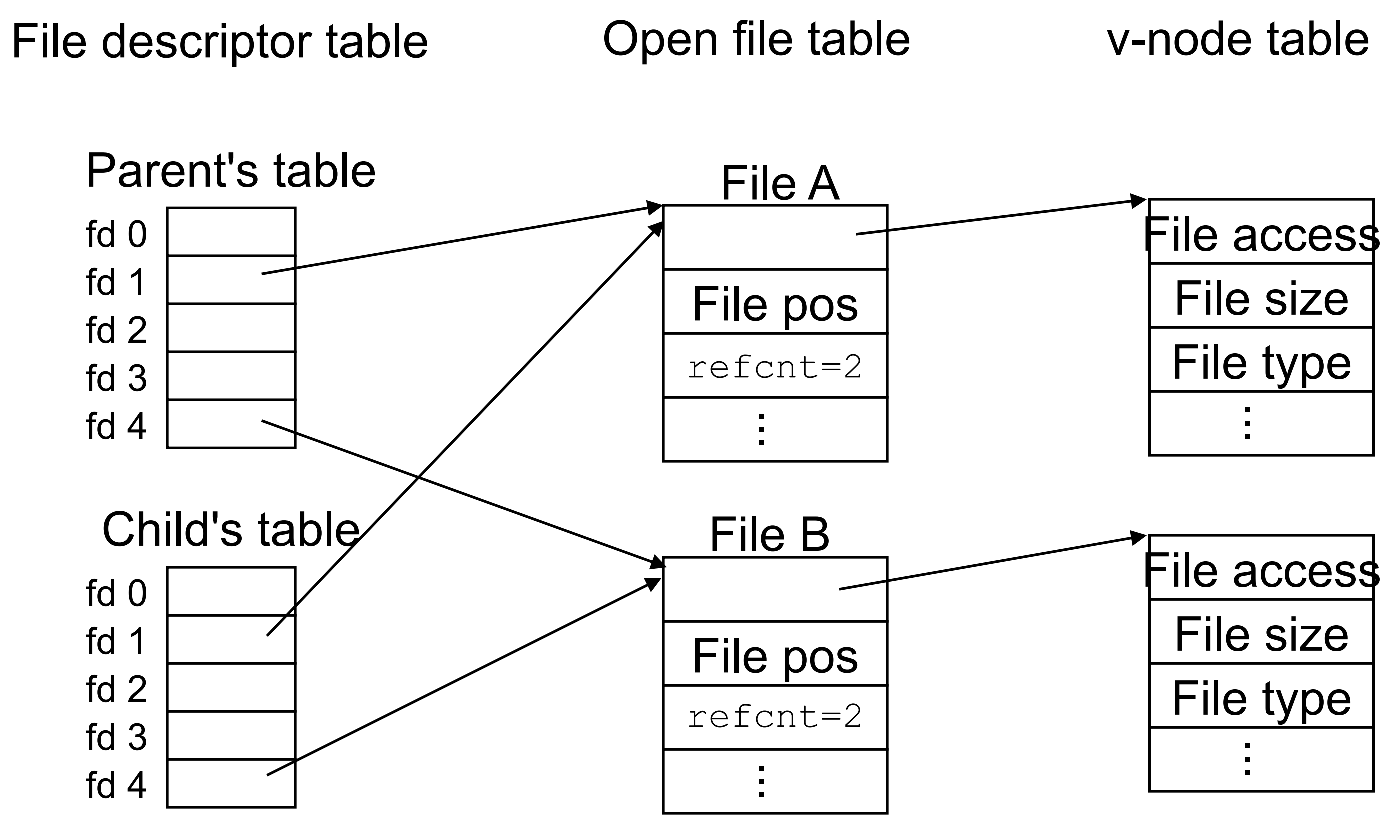
```
int main(int argc, char ** argv){
    int fd1, fd2;
    char c;

    fd1 = open("foobar.txt", O_RDONLY);
    fd2 = open("foobar.txt", O_RDONLY);

    read(fd1, &c, 1);
    read(fd2, &c, 1);

    printf("c = %c\n", c);

    return 0;
}
```

Exercise 1: Reading and Writing



Processes and Files

- A child process inherits all file descriptors from its parent

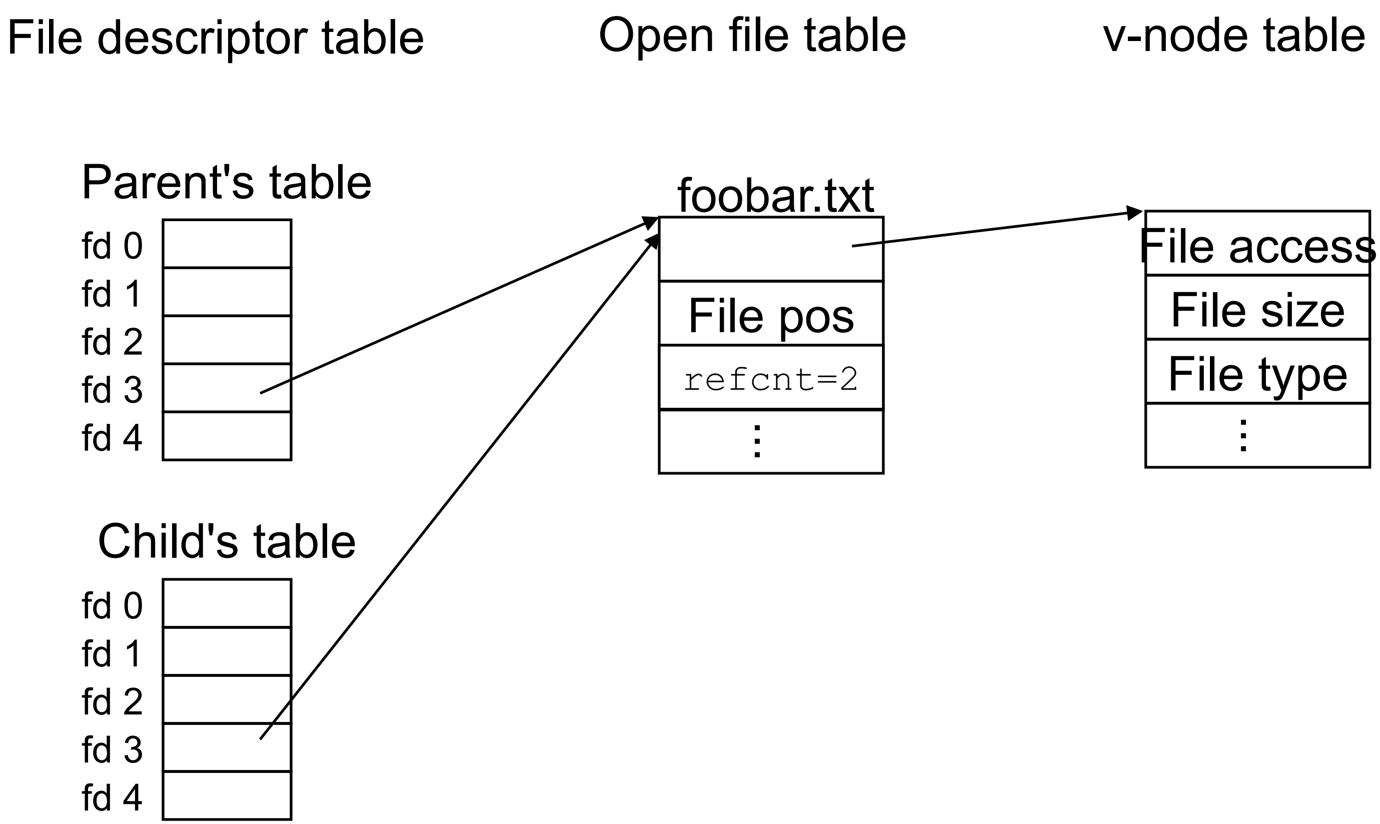


Exercise 2: Processes and Files

- Suppose the file `foobar.txt` consists of the six ASCII characters `foobar`. What is printed when the following program is run?

```
int main(int argc, char ** argv){
    int fd1;
    char c;

    fd1 = open("foobar.txt", O_RDONLY);
    if(fork() == 0){
        read(fd, &c, 1);
        return 0;
    } else {
        wait();
        read(fd, &c, 1);
        printf("c = %c\n", c);
        return 0;
    }
}
```

Exercise 2: Processes and Files



I/O Redirection

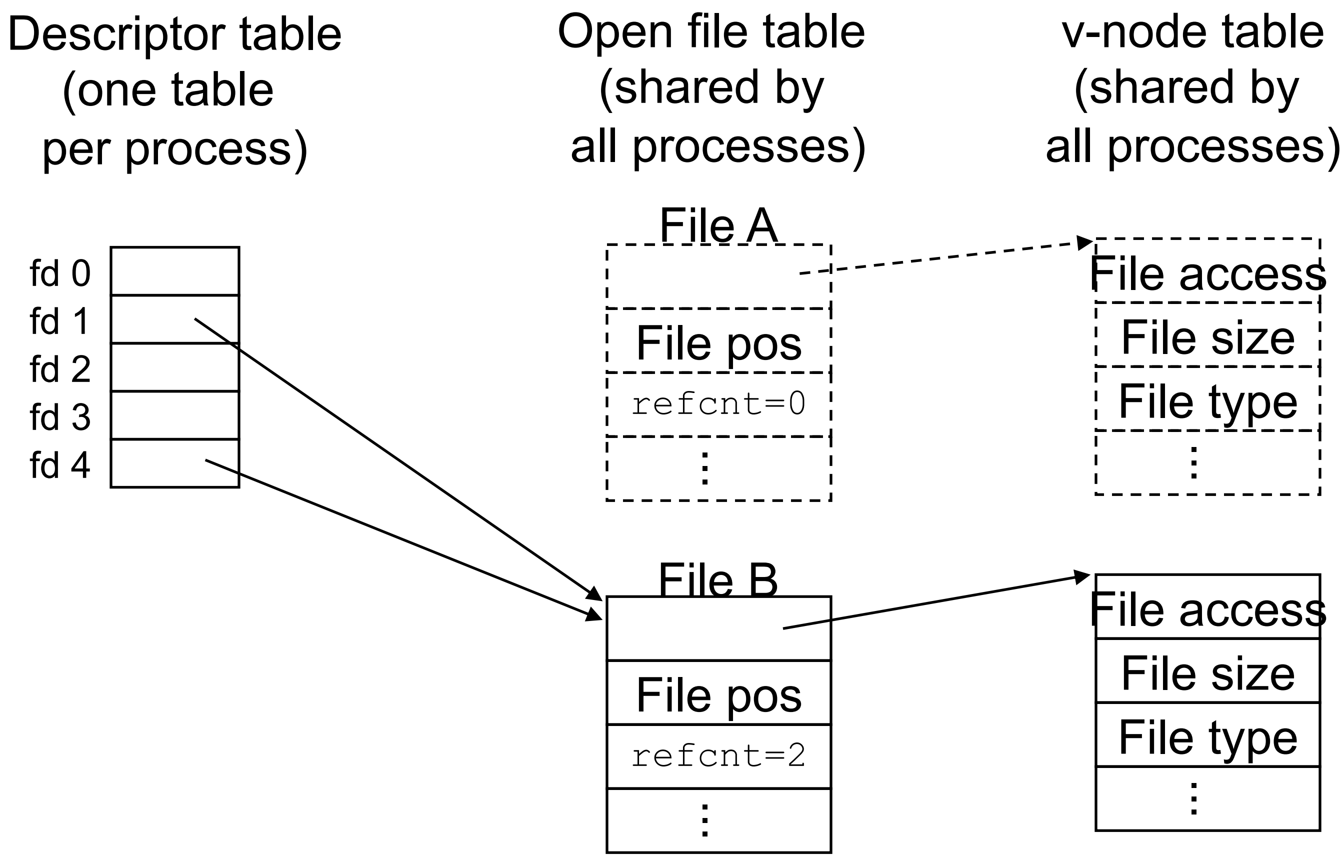
- Examples of I/O redirection
  - a program can send output to a file: ./ringbuf 4 > testout.txt
  - a program can read input from a file: ./ringbuf 4 < testin.txt
  - output of one program can be input to another: cpp file.c | cparse | cgen | as > file.o

- I/O redirection uses a function called dup2

```
int dup2(int oldfd, int newfd);
```

- returns file descriptor if OK, -1 on error

I/O Redirection

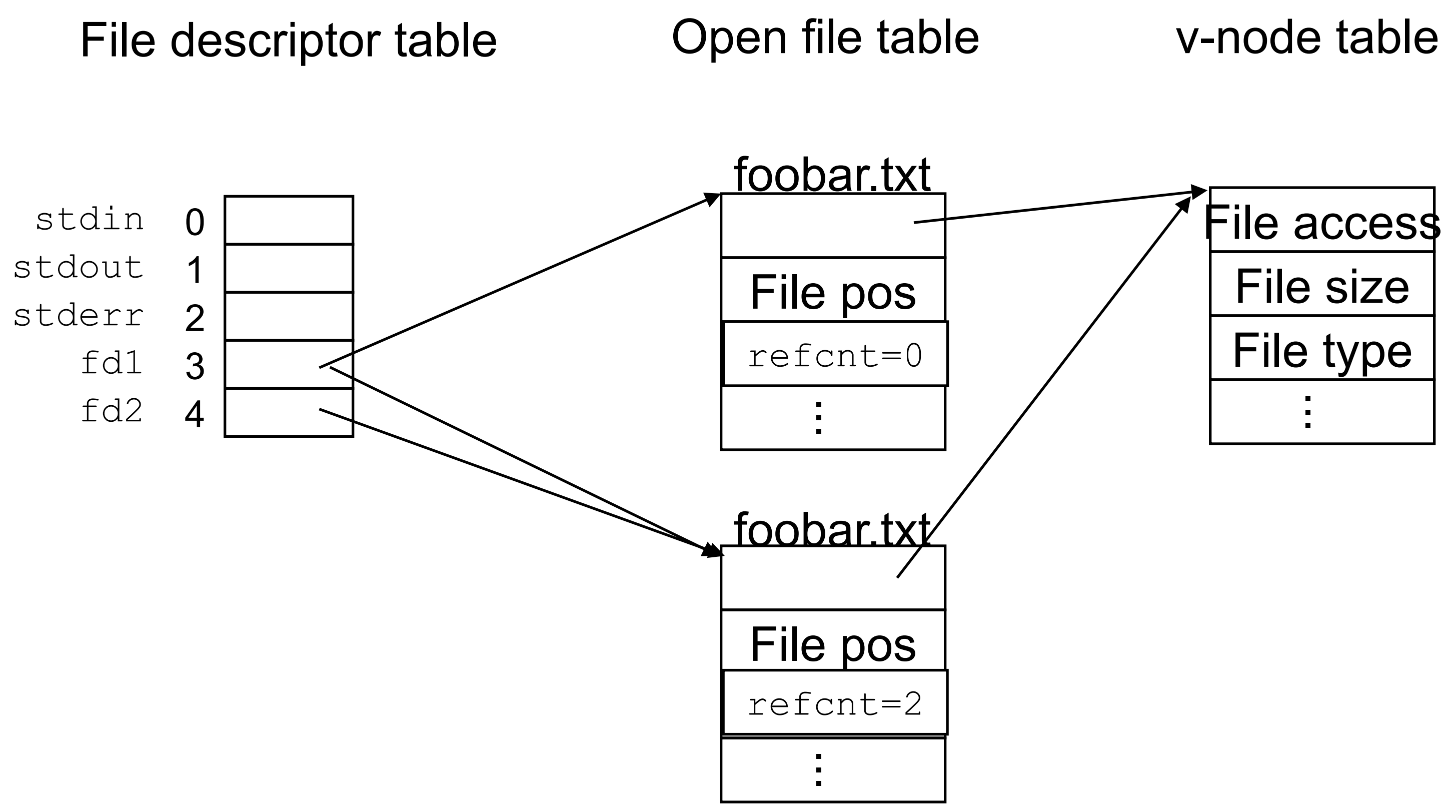


Exercise 3: I/O Redirection

- Suppose the file `foobar.txt` consists of the six ASCII characters `foobar`. What is printed when the following program is run?

```
int main(){
    int fd1, fd2;
    char c;

    fd1 = open("foobar.txt",O_RDONLY);
    fd2 = open("foobar.txt",O_RDONLY);

    read(fd2, &c, 1);
    dup2(fd2, fd1);
    read(fd1, &c, 1);

    printf("c = %c\n", c);

    return 0;
}
```

Exercise 3: I/O Redirect



System I/O as a Uniform Interface

- Operating systems use the System I/O commands as an interface for all I/O devices

- The commands to read and write to an open file descriptor are the same no matter what type of "file" it is

- Types of files include
  - file
  - keyboard
  - screen
  - pipe
  - device
  - network

Exercise 4: Feedback

1. Rate how well you think this recorded lecture worked
    1. Better than an in-person class
    2. About as well as an in-person class
    3. Less well than an in-person class, but you still learned something
    4. Total waste of time, you didn't learn anything

2. How much time did you spend on this video lecture?

3. Do you have any particular questions you'd like me to address in this week's problem session?

4. Do you have any other comments or feedback?