System-Level I/O

CSE4100: Multicore Programming

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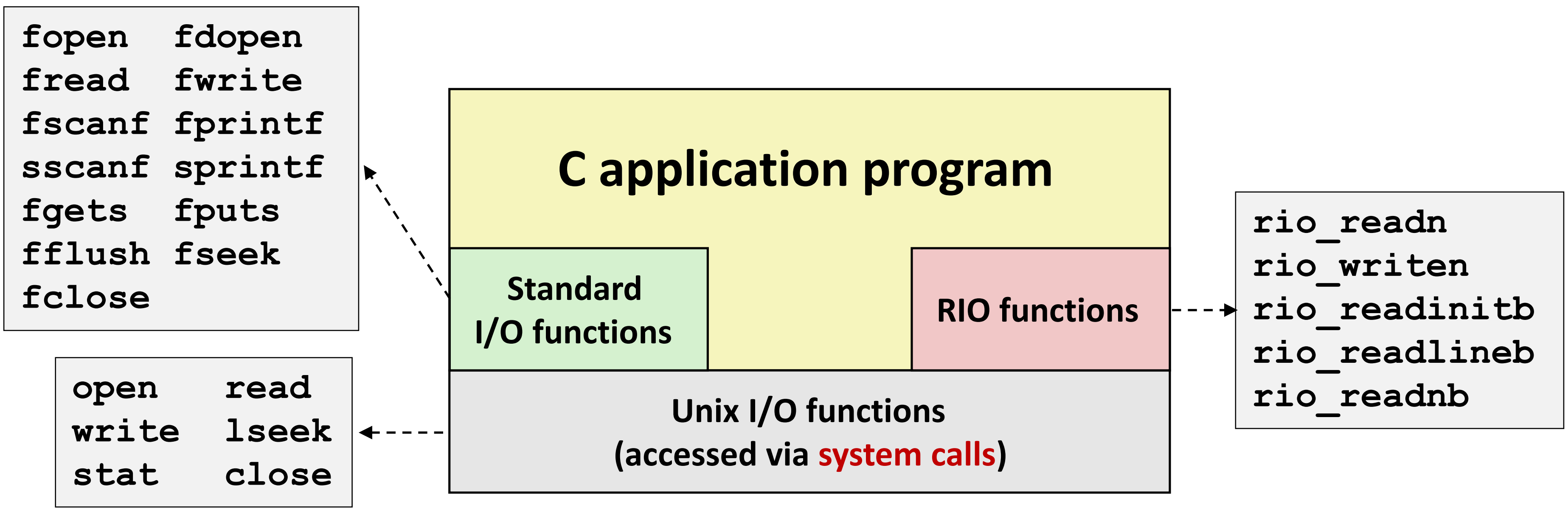
Scope of This Chapter

- Standard I/O and RIO are implemented using low-level Unix I/O



- What are these functions?
- Which ones should you use in your programs?

System Level: Below Standard Level

```c
#include <stdio.h>

int main(void) {
    FILE *fp = fopen("output.txt", "w");
    if (!fp) {
        perror("output.txt");
        return 1;
    }
    fputs("baby shark (do doo dooo)\n", fp);
    if (fclose(fp)) {
        perror("output.txt");
        return 1;
    }
    return 0;
}
```

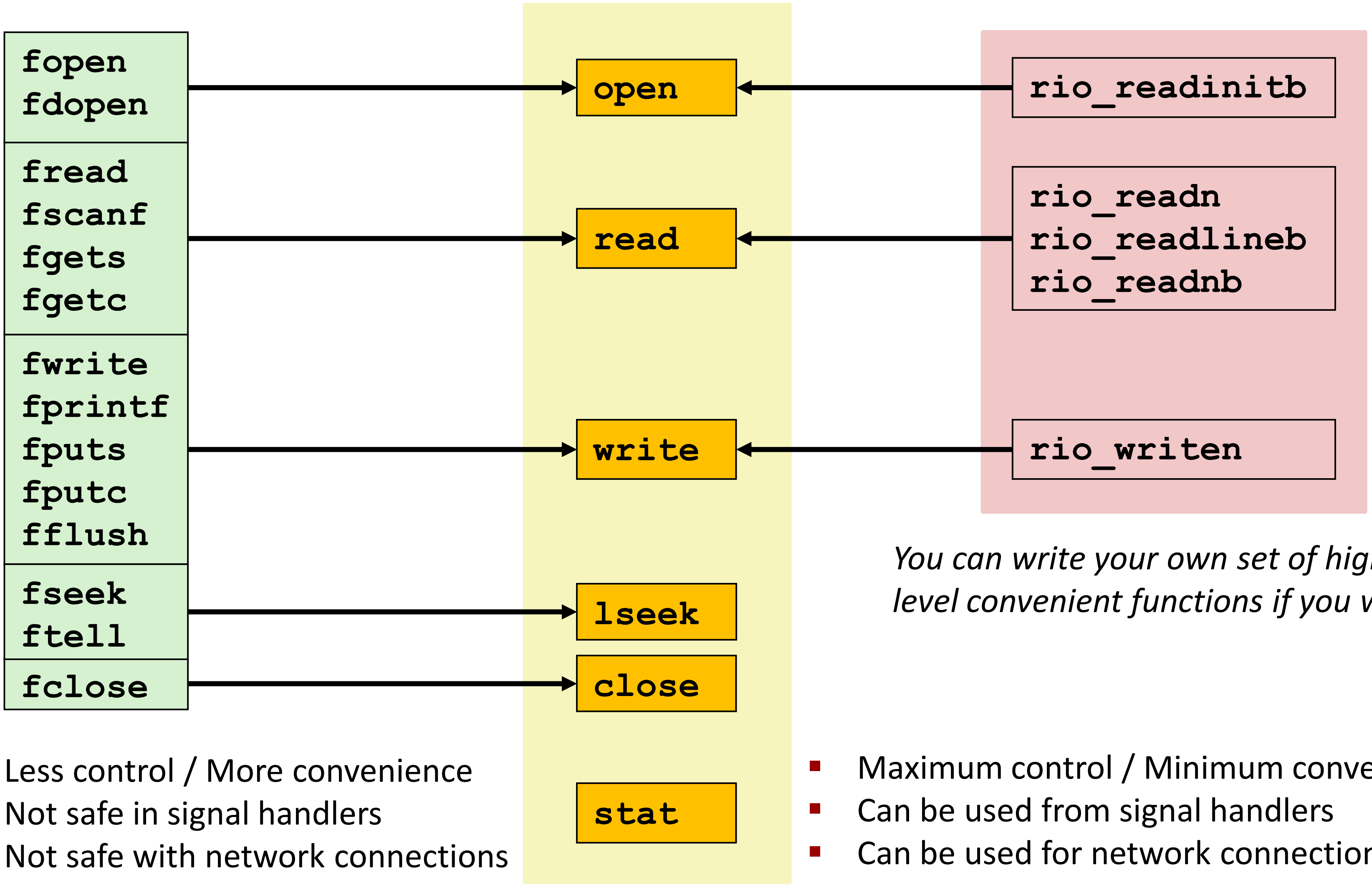
```c
FILE *fopen(const char *fname,
            const char *mode) {
    int fd = open(fname,
                  __mode2flags(mode),
                  DEFFILEPERMS);
    if (fd == -1) {
        return NULL;
    }
    return fdopen(fd, mode);
}
```

```c
int fputs(const char *s, FILE *fp) {
    size_t n = strlen(s);
    while (n > 0) {
        ssize_t written =
            write(fp->fd, s, n);
        if (written < 0) return EOF;
        n -= written;
        s += written;
    }
    return 0;
}
```

```c
int fclose(FILE *fp) {
    int rv = close(fp->fd);
    __ffree(fp);
    return rv;
}
```

```asm
.globl close
close:
    mov $3, %eax
    syscall
    cmp $-4096, %rax
    jae __syscall_error
    ret
```

Why Do We Have Two Sets?



You can write your own set of high-level convenient functions if you want!

- Less control / More convenience
- Not safe in signal handlers
- Not safe with network connections

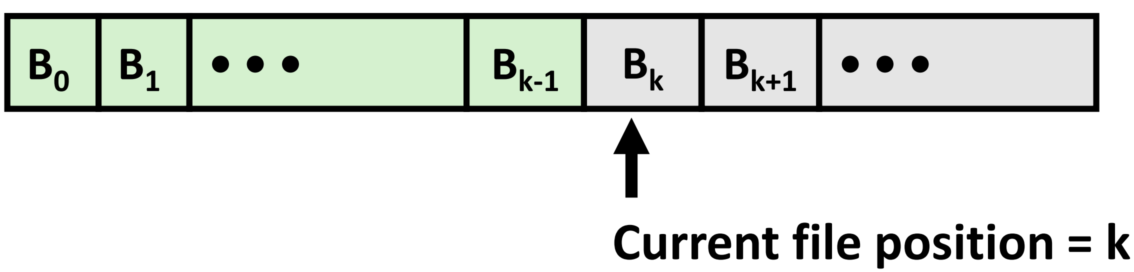
- Maximum control / Minimum convenience
- Can be used from signal handlers
- Can be used for network connections

Unix I/O Overview

- A ***file*** **is a sequence of bytes:**
  - $B_0, B_1, \ldots., B_k, \ldots., B_{m-1}$
- **Cool fact: All I/O devices are represented as files**
  - `/dev/sda2` (disk partition)
  - `/dev/tty2` (terminal)
  - `/dev/null` (discard all writes / read empty file)
- **Cool fact: Kernel data structures are exposed as files**
  - `cat /proc/$$/status` (`$$` means *pid* of the shell)
  - `ls -l /proc/$$/fd/`
  - `ls –RC /sys/devices | less`

Unix I/O Overview

- **Kernel offers a set of basic operations for all files**
  - Opening and closing files
    - **`open()`** and **`close()`**
  - Reading and writing a file
    - **`read()`** and **`write()`**
  - Look up information about a file (size, type, last modification time, …)
    - **`stat()`**, **`lstat()`**, **`fstat()`**
  - Changing the current file position (seek)
    - indicates next offset into file to read or write
    - **`lseek()`**



File Types

- **Each file has a *type* indicating its role in the system**
  - *Regular file:* Contains arbitrary data
  - *Directory:* Index for a related group of files
  - *Socket:* For communicating with a process on another machine

- **Other file types beyond our scope**
  - *Named pipes (FIFOs)*
  - *Symbolic links* (using *ln –s* command)
  - *Character and block devices*

```
$ ls -l /dev/hda[1-3]
brw-rw----   1 root  disk  3, 1 Jul  5  2000 /dev/hda1
brw-rw----   1 root  disk  3, 2 Jul  5  2000 /dev/hda2
brw-rw----   1 root  disk  3, 3 Jul  5  2000 /dev/hda3

crw-rw----   1 root  dial 4, 64 Feb 18 23:34 /dev/ttyS0
crw-r-----   1 root  dial 4, 65 Nov 17 10:26 /dev/ttyS1
crw-rw----   1 root  dial 4, 66 Jul  5  2000 /dev/ttyS2
crw-rw----   1 root  dial 4, 67 Jul  5  2000 /dev/ttyS3
```

```
prompt> ls -al
drwxr-x--- 2  parksy parksy 29   May 3 19:10 ./
drwxr-x--- 27 parksy parksy 4096 May 3 15:14 ../           /* directory */
-rw-r----- 1  parksy parksy 6    May 3 19:10 file          /* regular file */
lrwxrwxrwx 1  parksy parksy 4    May 3 19:10 file2 -> file /* symbolic link */
```

Regular Files

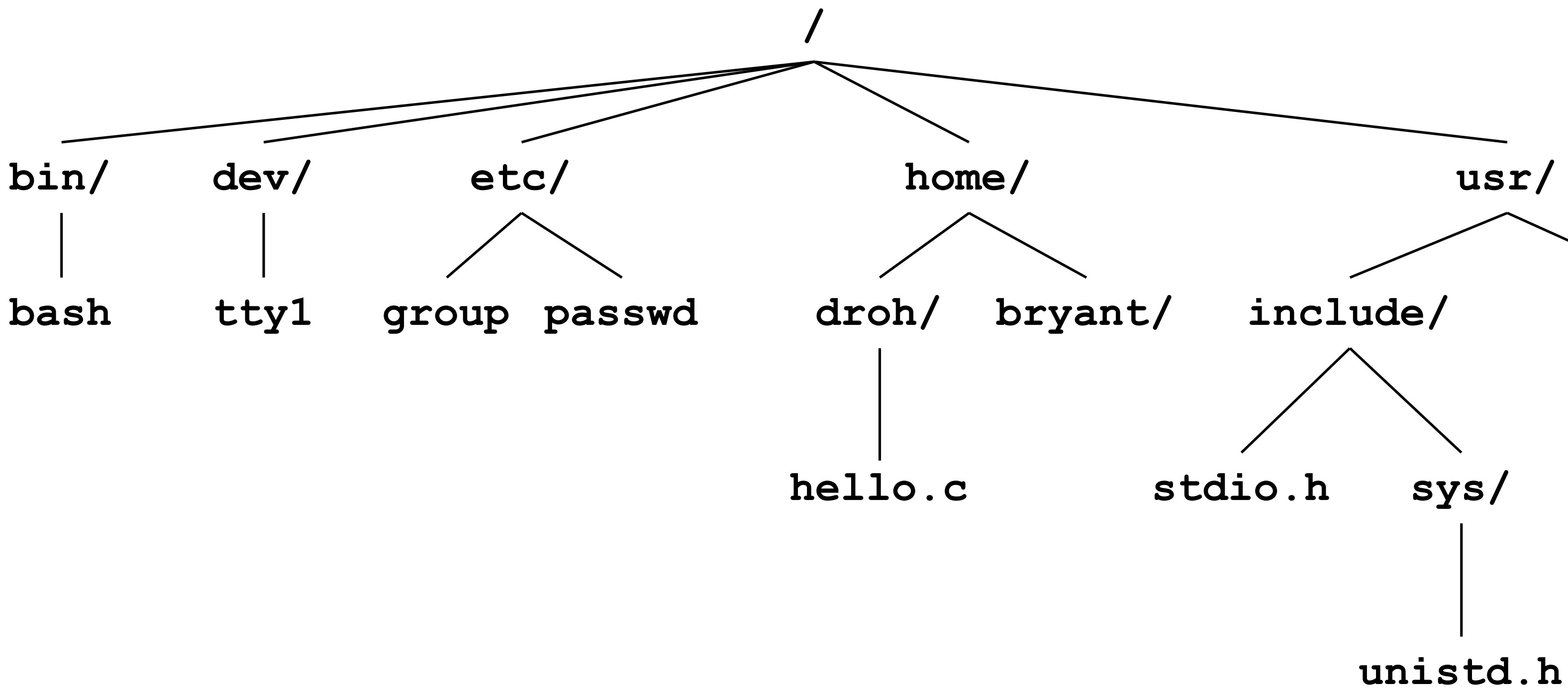
- **A regular file contains arbitrary data**
- **Applications often distinguish between *text* and *binary files***
  - Text files contain human-readable text
  - Binary files are everything else (object files, JPEG images, …)
  - Kernel doesn't care! It's all just bytes!
- **Text file is sequence of *text lines***
  - Text line is sequence of characters terminated by *end of line indicator*
  - Characters are defined by a *text encoding* (ASCII, UTF-8/16/32, EUC-KR …)
- **End of line (EOL) indicators:**
  - All "Unix": Single byte **`0x0A`**
    - line feed (LF)
  - DOS, Windows: Two bytes **`0x0D 0x0A`**
    - Carriage return (CR) followed by line feed (LF)
    - Also used by many Internet protocols

Directories

- **Directory consists of an array of *entries* (also called *links*)**
  - Each entry maps a *filename* to a file
  - Each entry also contains the attributes of a file (e.g., time, owner, etc.)
- **Each directory contains at least two entries**
  - `.` (dot) maps to the directory itself
  - `..` (dot dot) maps to *the parent directory* in the *directory hierarchy* (next slide)
- **Commands for manipulating directories**
  - **`mkdir`**: create empty directory
  - **`ls`**: view directory contents
  - **`rmdir`**: delete empty directory

Directory Hierarchy

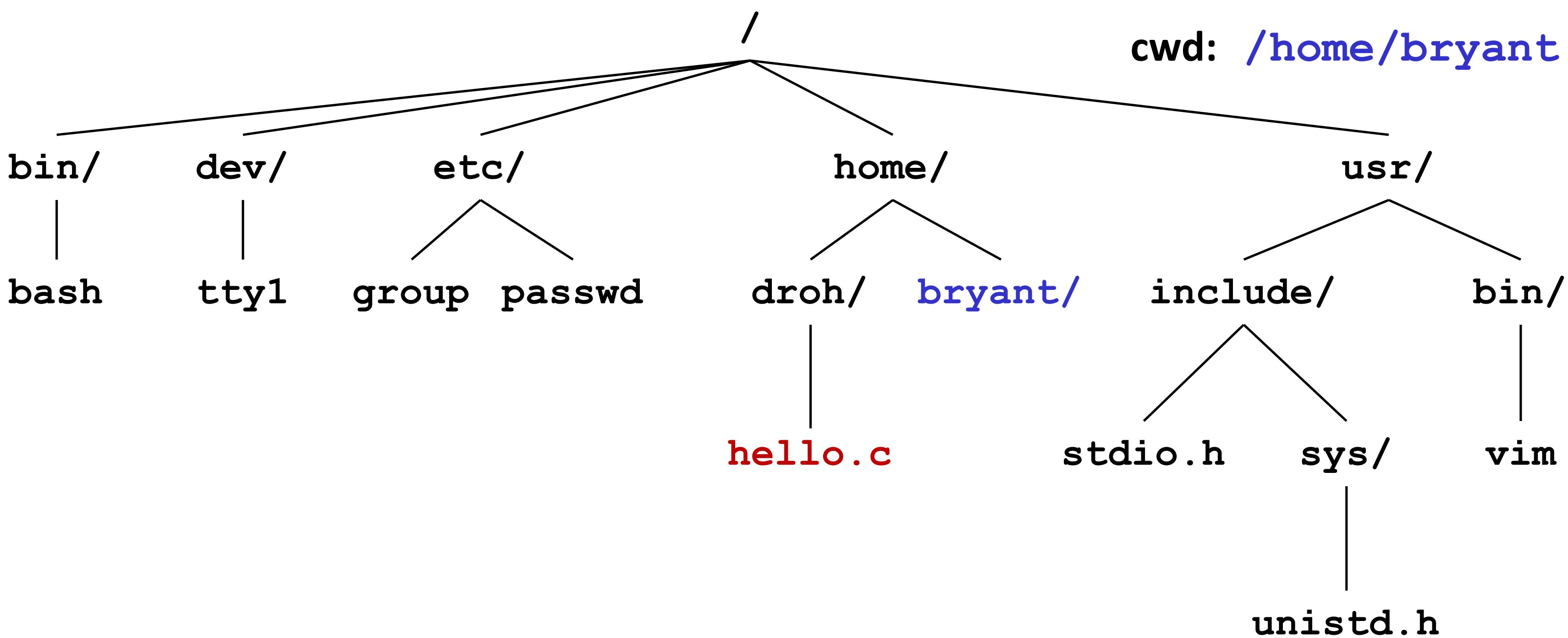
- **All files are organized as a hierarchy anchored by root directory named / (slash)**



- **Kernel maintains *current working directory (cwd)* for each process**
  - Modified using the `cd` command

Pathnames

- **Locations of files in the hierarchy denoted by *pathnames***
  - *Absolute pathname* starts with '/' and denotes path from root
    - `/home/droh/hello.c`
  - *Relative pathname* denotes path from current working directory
    - `../home/droh/hello.c`



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 begins life with three open files
  - 0: standard input (stdin)
  - 1: standard output (stdout)
  - 2: standard error (stderr)

<unistd.h>

```
/* Standard file descriptors. */
#define STDIN_FILENO 0 /* Standard input. */
#define STDOUT_FILENO 1 /* Standard output. */
#define STDERR_FILENO 2 /* Standard error output. */
```

Lots of Ways To Call Open

Open an existing file:

`open(path, flags)`

`flags` must include exactly one of:

O_RDONLY	Only want to read from file
O_WRONLY	Only want to write to file
O_RDWR	Want to do both

Flags may also include (use | to combine)

O_APPEND	All writes go to the very end
O_TRUNC	Delete existing contents if any
O_CLOEXEC	Close this file if execve() is called

Open or create a file:

`open(path, flags, mode)`

`flags` must include

O_CREAT	Create the file if it doesn't exist

and exactly one of:

O_WRONLY	Only want to write to file
O_RDWR	Want to write and read

and maybe also some of:

O_EXCL	Fail if file does exist
O_APPEND	All writes go to the very end
O_TRUNC	Delete existing contents if any
O_CLOEXEC	Close this file if execve() is called

(and many more… consult the open() man page)

The Third Argument to `Open`

- **Open takes either two or three arguments**
  - Third argument must be present when O_CREAT appears in second argument; ignored otherwise
- **Third argument gives *access permissions* for newly created files**
  - Use DEFFILEMODE (from `sys/stat.h`) unless you have a specific reason to want something else
    - #define DEFFILEMODE (S_IRUSR | S_IWUSR | S_IRGRP | S_IWGRP | S_IROTH | S_IWOTH) /* 0666 */
  - Modified by *umask(mask)* setting (see `man umask`)
    - Permission bits of the file are set to mode (3rd argument) & ~mask

```
#define DEF_UMASK ( S_IWGRP | S_IWOTH )
umask(DEF_MASK);
fd = Open("foo.txt", O_CREAT | O_TRUNC | O_WRONLY, DEFFILEMODE);
```

  - More explanation:
    - https://linuxfoundation.org/blog/classic-sysadmin-understanding-linux-file-permissions/
    - https://linuxcommand.org/lc3_lts0090.php
    - https://devconnected.com/linux-file-permissions-complete-guide/

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);
}
```

- **Take care not to close any file more than once**
  - Same as not calling free() twice on the same pointer
- **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
  - Reading and writing network sockets, pipes, etc.

- **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**

Simple Unix I/O example

- **Copying stdin to stdout, one byte at a time**

```
#include "csapp.h"

int main(void)
{
    char c;

    while(Read(STDIN_FILENO, &c, 1) != 0)
        Write(STDOUT_FILENO, &c, 1);
    exit(0);
}
```

- **Always check return cods from system call -> use wrapper**
- **This is not a good code !**
  - Invoking system call (boundary crossing between user and kernel) takes much time !

Standard I/O Functions

- **The C standard library (`libc.so`) contains a collection of higher-level *standard I/O* functions**

- **Examples of standard I/O functions:**
  - Opening and closing files (**`fopen`** and **`fclose`**)
  - Reading and writing bytes (**`fread`** and **`fwrite`**)
  - Reading and writing text lines (**`fgets`** and **`fputs`**)
  - Formatted reading and writing (**`fscanf`** and **`fprintf`**)

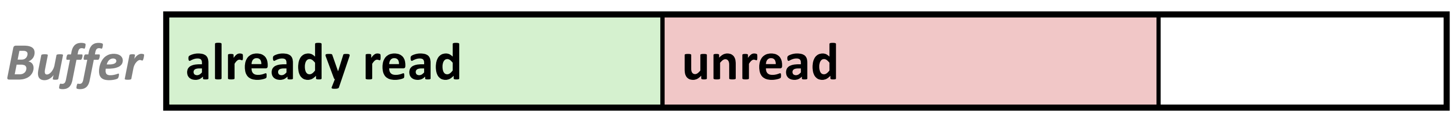
Standard I/O Streams

- **Standard I/O models open files as *streams***
  - Abstraction for a file descriptor and a buffer in memory
- **C programs begin life with three open streams (defined in `stdio.h`)**
  - `stdin` (standard input)
  - `stdout` (standard output)
  - `stderr` (standard error)

```
#include <stdio.h>
extern FILE *stdin;  /* standard input  (descriptor 0) */
extern FILE *stdout; /* standard output (descriptor 1) */
extern FILE *stderr; /* standard error  (descriptor 2) */

int main() {
    fprintf(stdout, "Hello, world\n");
}
```

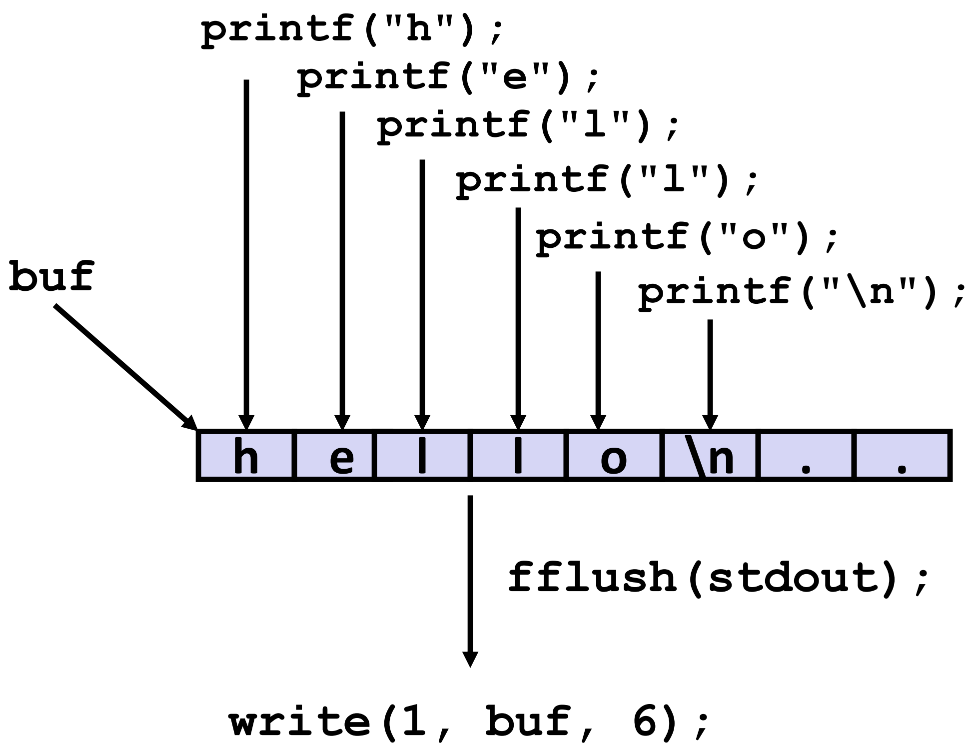
Buffered I/O: Motivation

- **Applications often read/write one character at a time**
  - `getc, putc, ungetc`
  - `gets, fgets`
    - Read line of text one character at a time, stopping at newline
- **Implementing as Unix I/O calls expensive**
  - **`read`** and **`write`** require Unix kernel calls
    - > 10,000 clock cycles
- **Solution: Buffered read**
  - Use Unix **`read`** to grab block of bytes
  - User input functions take one byte at a time from buffer
    - Refill buffer when empty



Buffering in Standard I/O

- Standard I/O functions use buffered I/O



- Buffer flushed to output fd on “\n”, call to `fflush` or `exit`, or return from `main`.

Standard I/O Buffering in Action

- You can see this buffering in action for yourself, using the always fascinating Linux `strace` program:

```
#include <stdio.h>

int main()
{
    printf("h");
    printf("e");
    printf("l");
    printf("l");
    printf("o");
    printf("\n");
    fflush(stdout);
    exit(0);
}
```

```
linux> strace ./hello
execve("./hello", ["hello"], [/* ... */]).
...
write(1, "hello\n", 6)                   = 6
...
exit_group(0)                            = ?
```

The RIO Package

- **RIO is a set of wrappers that provide efficient and robust I/O in apps, such as network programs that are subject to short counts**
- **RIO provides two different kinds of functions**
  - Unbuffered input and output of binary data
    - **`rio_readn`** and **`rio_writen`**
  - Buffered input of text lines and binary data
    - **`rio_readlineb`** and **`rio_readnb`**
    - Buffered RIO routines are thread-safe and can be interleaved arbitrarily on the same descriptor
- **Refer to**

  → **`csapp.c`** and **`csapp.h`**

Unbuffered RIO Input and Output

- **Same interface as Unix `read` and `write`**
- **Especially useful for transferring data on network sockets**

```
#include "csapp.h"

ssize_t rio_readn(int fd, void *usrbuf, size_t n);
ssize_t rio_writen(int fd, void *usrbuf, size_t n);
```

Return: num. bytes transferred if OK, 0 on EOF (`rio_readn` only), -1 on error

- **`rio_readn`** returns short count only if it encounters EOF
  - Only use it when you know how many bytes to read
- **`rio_writen`** never returns a short count
- Calls to **`rio_readn`** and **`rio_writen`** can be interleaved arbitrarily on the same descriptor

Implementation of `rio_readn`

```
/* rio_readn - Robustly read n bytes (unbuffered) */
ssize_t rio_readn(int fd, void *usrbuf, size_t n)
{
    size_t nleft = n;
    ssize_t nread;
    char *bufp = usrbuf;

    while (nleft > 0) {
        if ((nread = read(fd, bufp, nleft)) < 0) {
            if (errno == EINTR) /* Interrupted by sig handler return */
                nread = 0;      /* and call read() again */
            else
                return -1;      /* errno set by read() */
        }
        else if (nread == 0)
            break;              /* EOF */
        nleft -= nread;
        bufp += nread;
    }
    return (n - nleft);         /* Return >= 0 */
}
```

csapp.c

Buffered RIO Input Functions

- **Efficiently read text lines and binary data from a file partially cached in an internal memory buffer**

```
#include "csapp.h"

void rio_readinitb(rio_t *rp, int fd);

ssize_t rio_readlineb(rio_t *rp, void *usrbuf, size_t maxlen);
ssize_t rio_readnb(rio_t *rp, void *usrbuf, size_t n);
```

Return: num. bytes read if OK, 0 on EOF, -1 on error

- `rio_readlineb` reads a text line of up to `maxlen` bytes from file `fd` and stores the line in `usrbuf`
  - Especially useful for reading text lines from network sockets
- Stopping conditions
  - `maxlen` bytes read
  - EOF encountered
  - Newline (‘`\n`’) encountered

Buffered RIO Input Functions (cont)

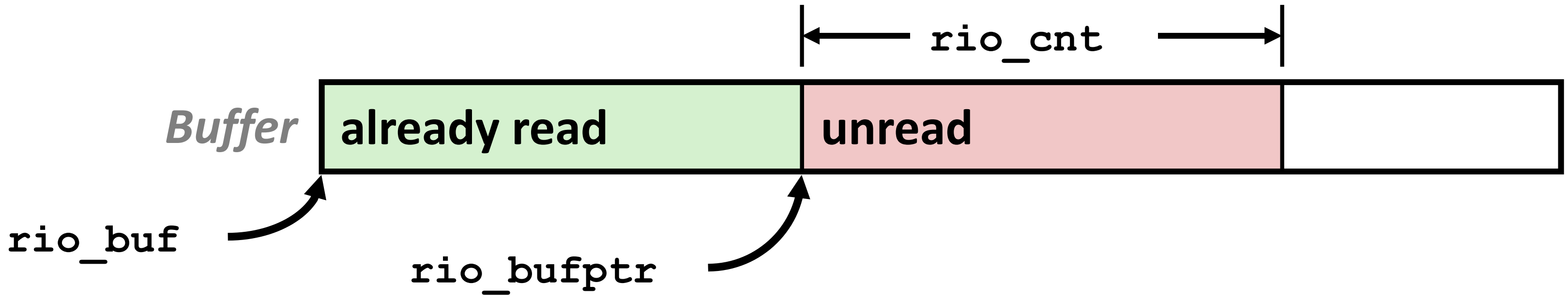
```
#include "csapp.h"

void rio_readinitb(rio_t *rp, int fd);

ssize_t rio_readlineb(rio_t *rp, void *usrbuf, size_t maxlen);
ssize_t rio_readnb(rio_t *rp, void *usrbuf, size_t n);
```

Return: num. bytes read if OK, 0 on EOF, -1 on error

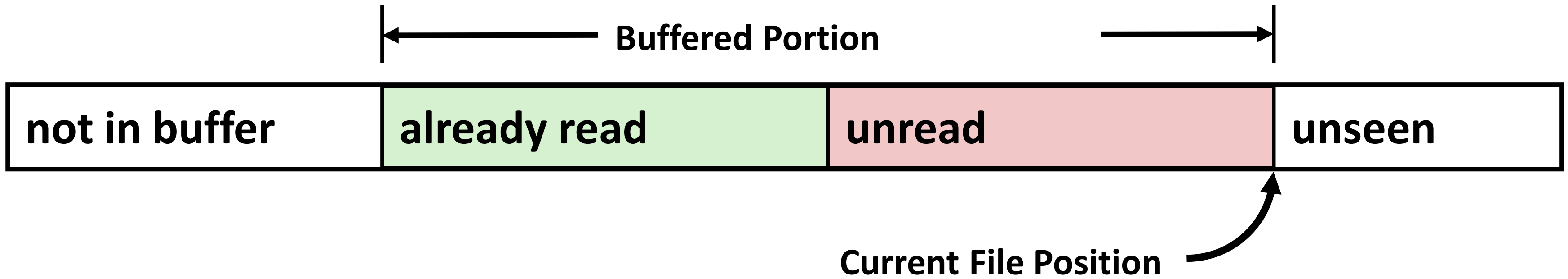
- **`rio_readnb`** reads up to **`n`** bytes from file **`fd`**
- Stopping conditions
  - **`maxlen`** bytes read
  - EOF encountered
- Calls to **`rio_readlineb`** and **`rio_readnb`** can be interleaved arbitrarily on the same descriptor
  - Warning: Don’t interleave with calls to **`rio_readn`**

Buffered I/O: Implementation

- For reading from a file
- File has associated buffer to hold bytes that have been read from the file but not yet read by user code

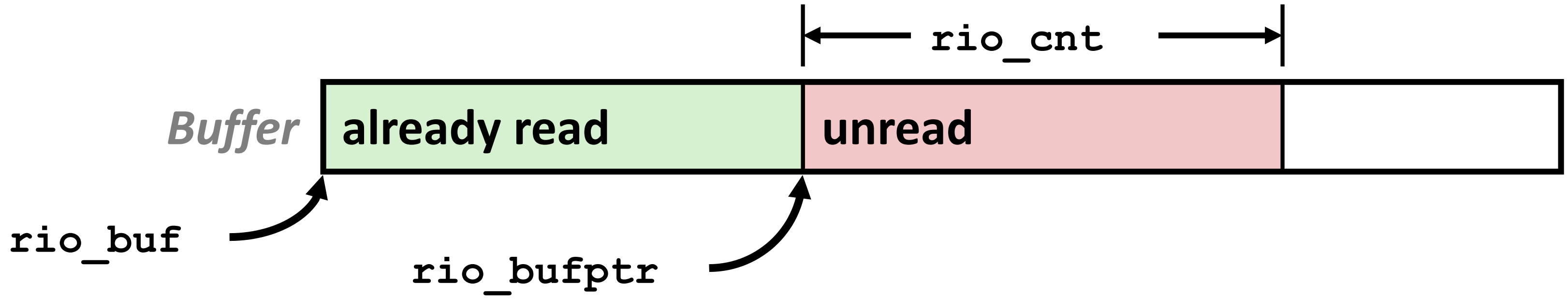


- Layered on Unix file:



Buffered I/O: Declaration

- All information contained in `struct`




```
typedef struct {
    int rio_fd;                /* descriptor for this internal buf */
    int rio_cnt;               /* unread bytes in internal buf */
    char *rio_bufptr;          /* next unread byte in internal buf */
    char rio_buf[RIO_BUFSIZE]; /* internal buffer */
} rio_t;
```

RIO Example

- **Copying the lines of a text file from standard input to standard output**

```
#include "csapp.h"

int main(int argc, char **argv)
{
    int n;
    rio_t rio;
    char buf[MAXLINE];

    Rio_readinitb(&rio, STDIN_FILENO);
    while((n = Rio_readlineb(&rio, buf, MAXLINE)) != 0)
        Rio_writen(STDOUT_FILENO, buf, n);
    exit(0);
}
```

cpfile.c

File Metadata

- *Metadata* is data about data, in this case, file data
- Per-file metadata is maintained by kernel
  - accessed by users with the **stat** and **fstat** functions

```
/* Metadata returned by the stat and fstat functions */
struct stat {
    dev_t           st_dev;      /* Device */
    ino_t           st_ino;      /* inode */
    mode_t          st_mode;     /* Protection and file type */
    nlink_t         st_nlink;    /* Number of hard links */
    uid_t           st_uid;      /* User ID of owner */
    gid_t           st_gid;      /* Group ID of owner */
    dev_t           st_rdev;     /* Device type (if inode device) */
    off_t           st_size;     /* Total size, in bytes */
    unsigned long st_blksize;  /* Blocksize for filesystem I/O */
    unsigned long st_blocks;   /* Number of blocks allocated */
    time_t          st_atime;    /* Time of last access */
    time_t          st_mtime;    /* Time of last modification */
    time_t          st_ctime;    /* Time of last change */
};
```

Example of Accessing File Metadata

```
linux> ./statcheck statcheck.c
type: regular, read: yes
linux> chmod 000 statcheck.c
linux> ./statcheck statcheck.c
type: regular, read: no
linux> ./statcheck ..
type: directory, read: yes
```

```
int main (int argc, char **argv)
{
    struct stat stat;
    char *type, *readok;

    Stat(argv[1], &stat);
    if (S_ISREG(stat.st_mode))     /* Determine file type */
        type = "regular";
    else if (S_ISDIR(stat.st_mode))
        type = "directory";
    else
        type = "other";
    if ((stat.st_mode & S_IRUSR)) /* Check read access */
        readok = "yes";
    else
        readok = "no";

    printf("type: %s, read: %s\n", type, readok);
    exit(0);
}
```

statcheck.c

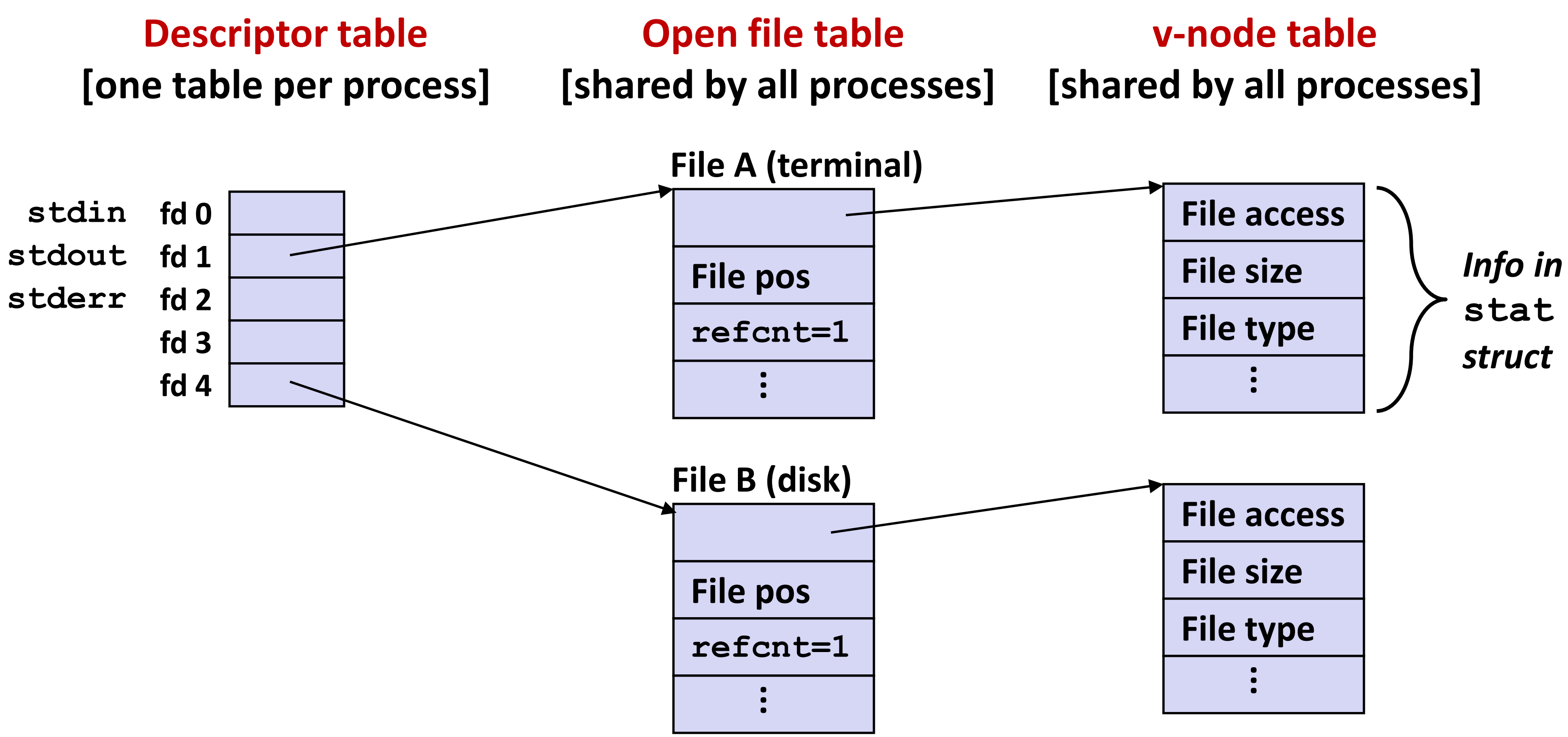
Accessing Directories

- **Only recommended operation on a directory: read its entries**
  - `dirent` structure contains information about a directory entry
  - DIR structure contains information about directory while stepping through its entries

```
#include <sys/types.h>
#include <dirent.h>

{
  DIR *directory;
  struct dirent *de;
  ...
  if (!(directory = opendir(dir_name)))
      error("Failed to open directory");
  ...
  while (0 != (de = readdir(directory))) {
      printf("Found file: %s\n", de->d_name);
  }
  ...
  closedir(directory);
}
```

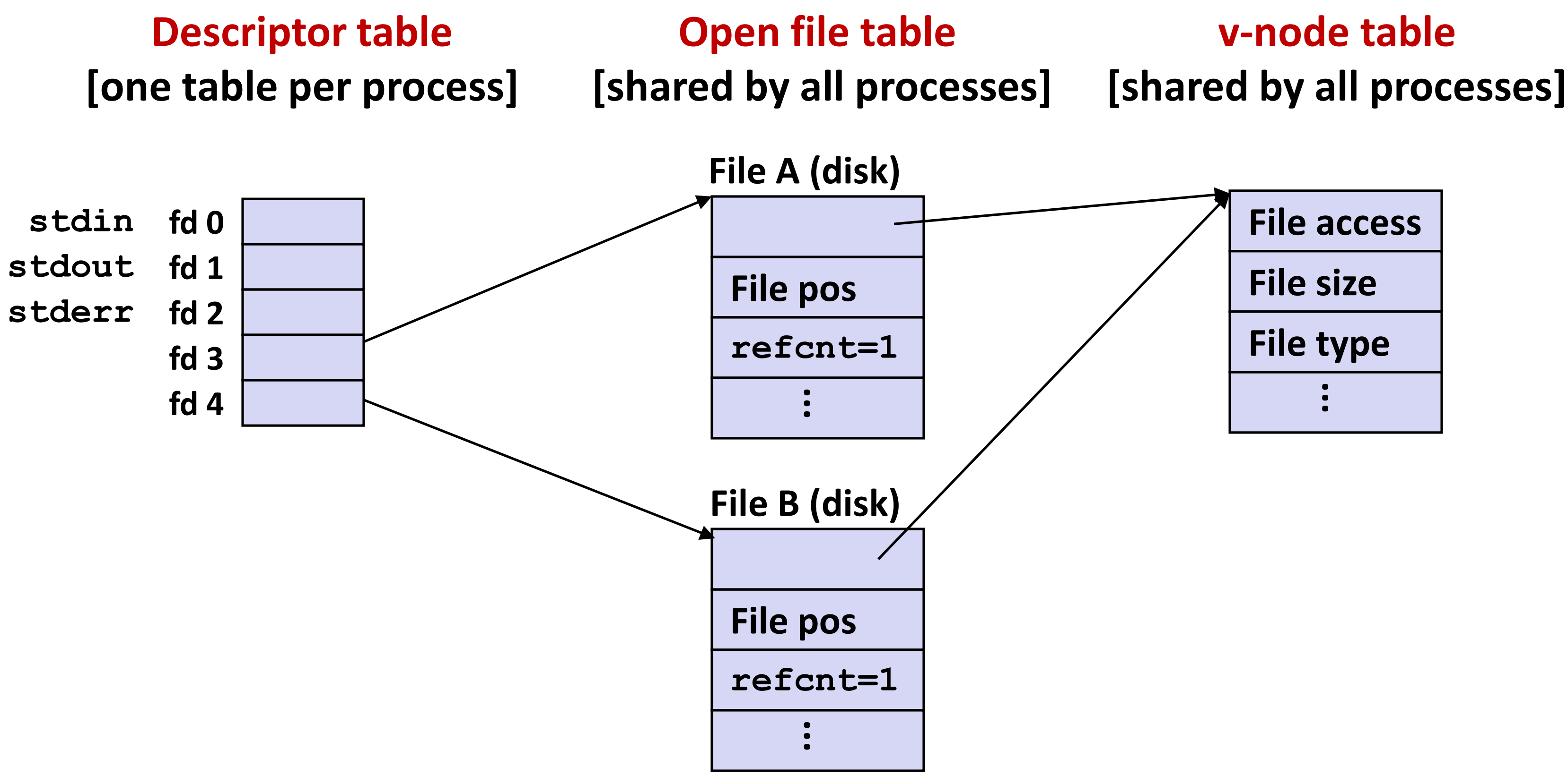
How the Unix Kernel Represents Open Files

- Two descriptors referencing two distinct open files. Descriptor 1 (stdout) points to terminal, and descriptor 4 points to open disk file



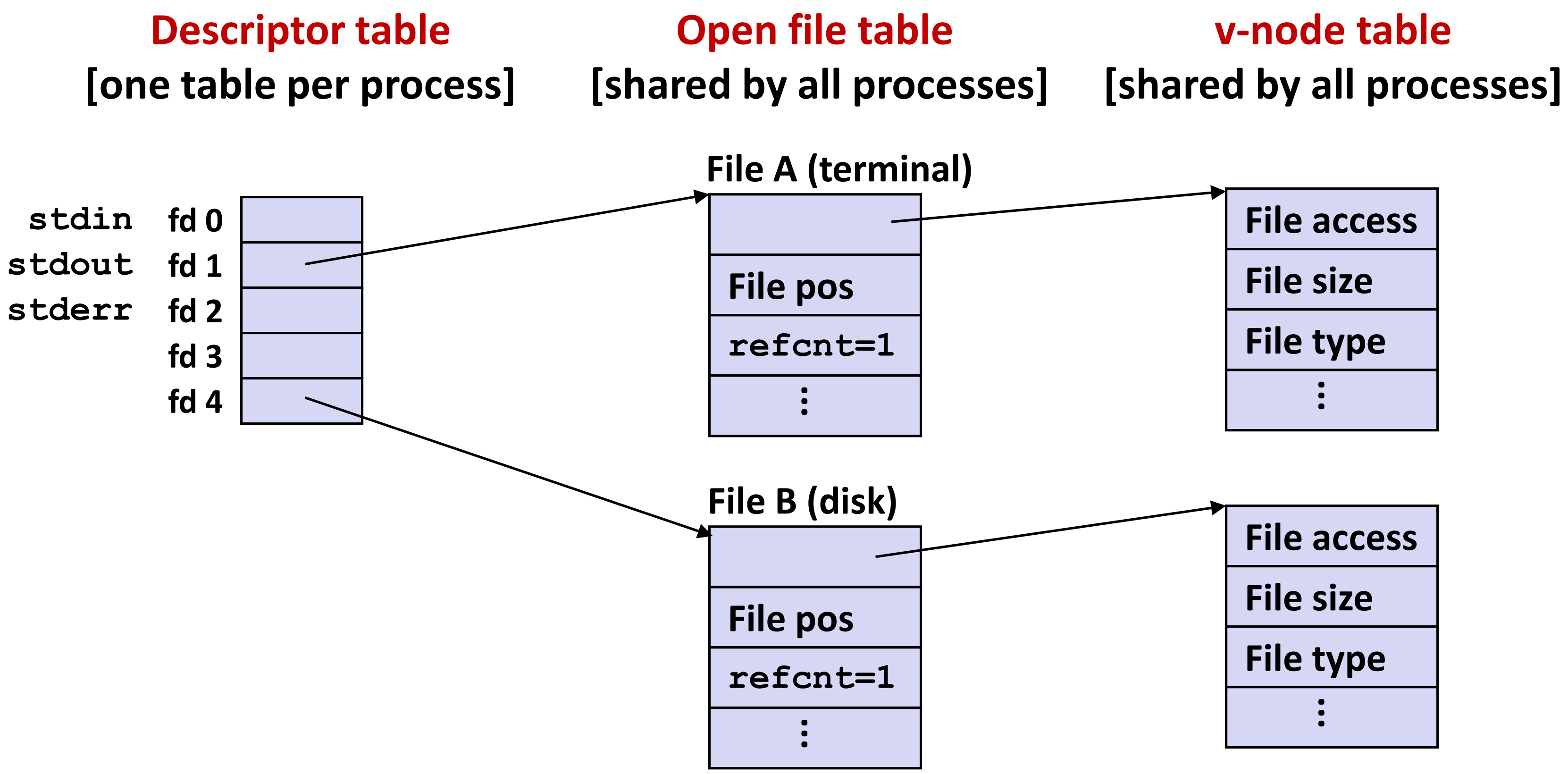
File Sharing

- **Two distinct descriptors sharing the same disk file through two distinct open file table entries**
  - E.g., Calling `open` twice with the same `filename` argument



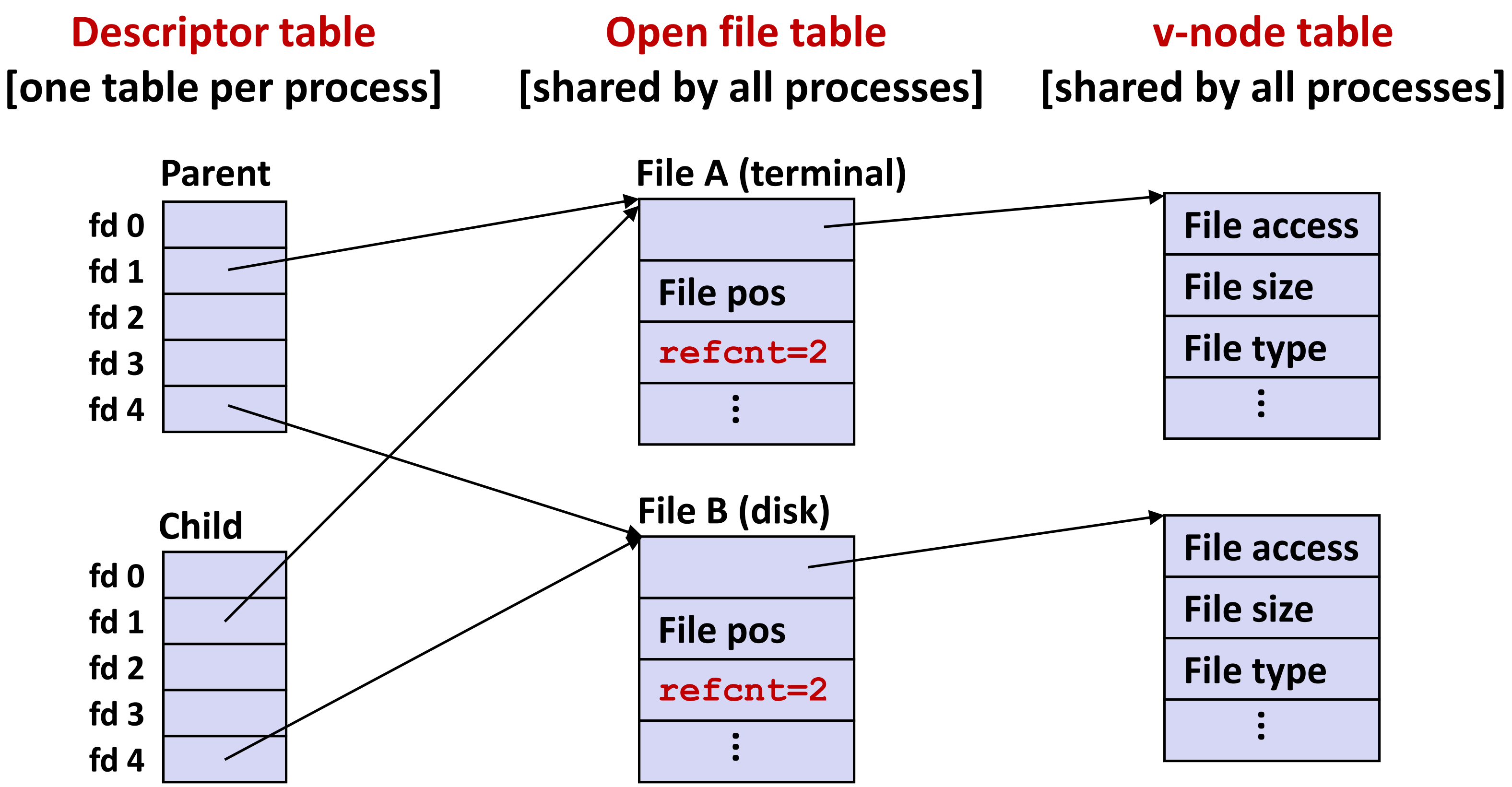
How Processes Share Files: `fork`

- **A child process inherits its parent's open files**
  - Note: situation unchanged by **`exec`** functions (use **`fcntl`** to change)
- ***Before*** **`fork`** **call:**



How Processes Share Files: `fork`

- A child process inherits its parent's open files
- *After* `fork`:
  - Child's table same as parent's, and +1 to each refcnt



I/O Redirection

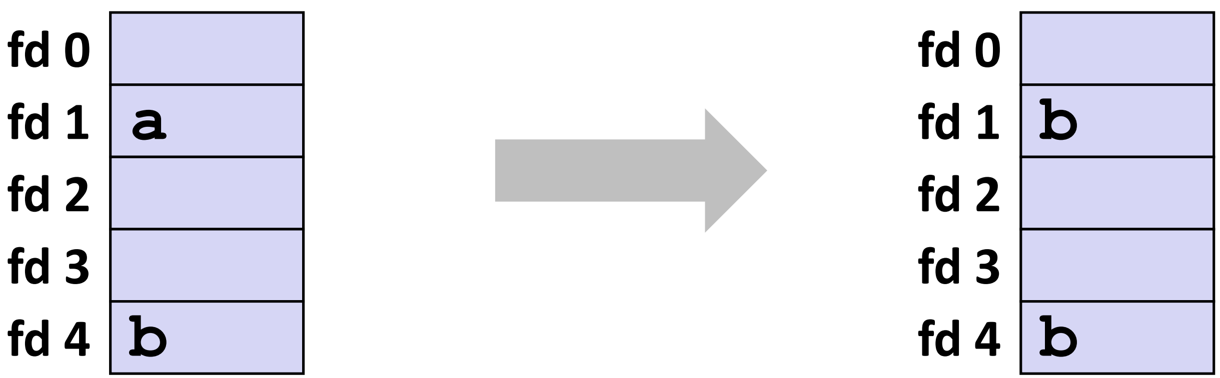
- **Question: How does a shell implement I/O redirection?**

```
linux> ls > foo.txt
```

- **Answer: By calling the `dup2(oldfd, newfd)` function**
  - Copies (per-process) descriptor table entry **`oldfd`** to entry **`newfd`**

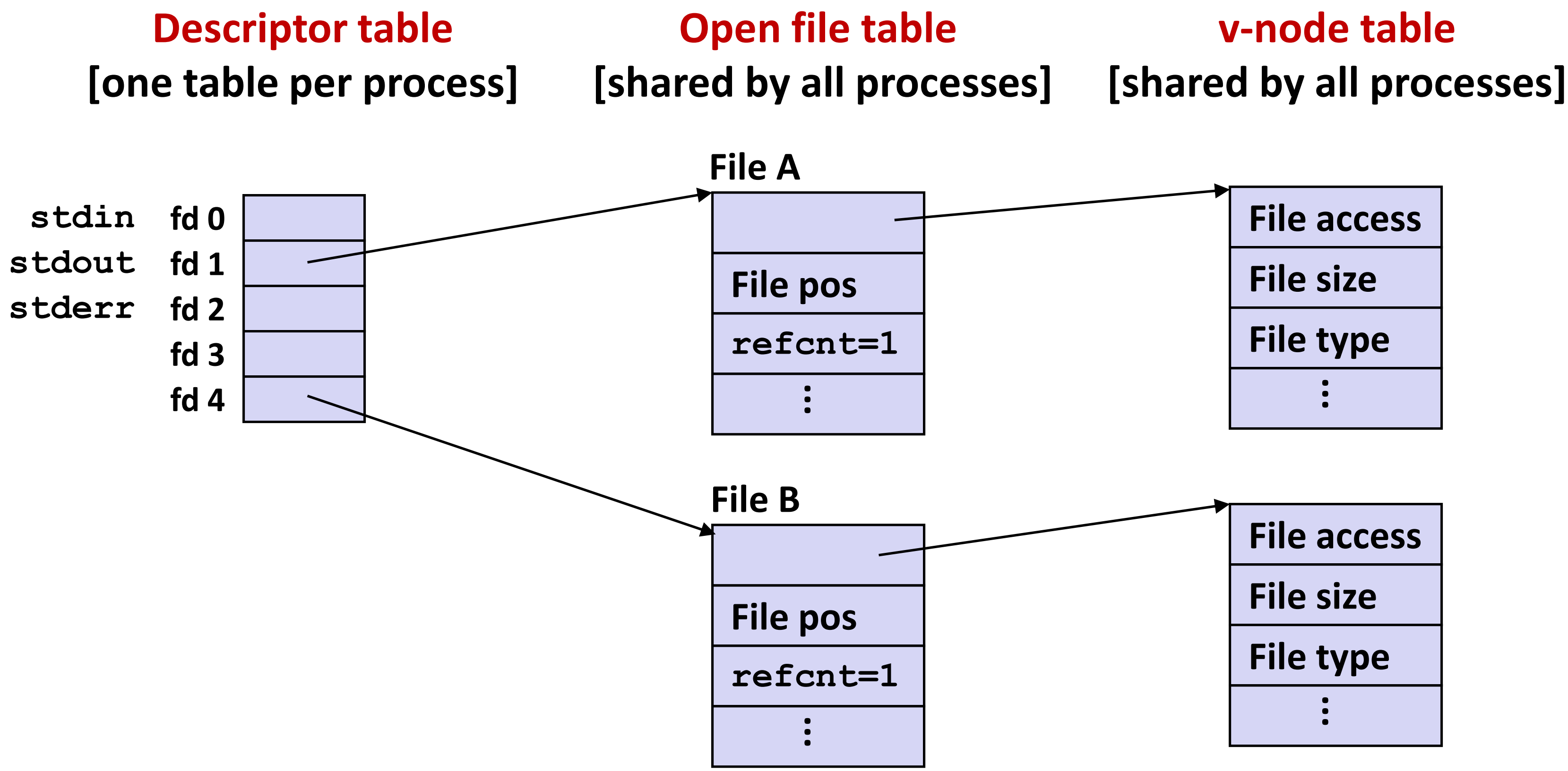
Descriptor table *before* `dup2(4,1)`

Descriptor table *after* `dup2(4,1)`



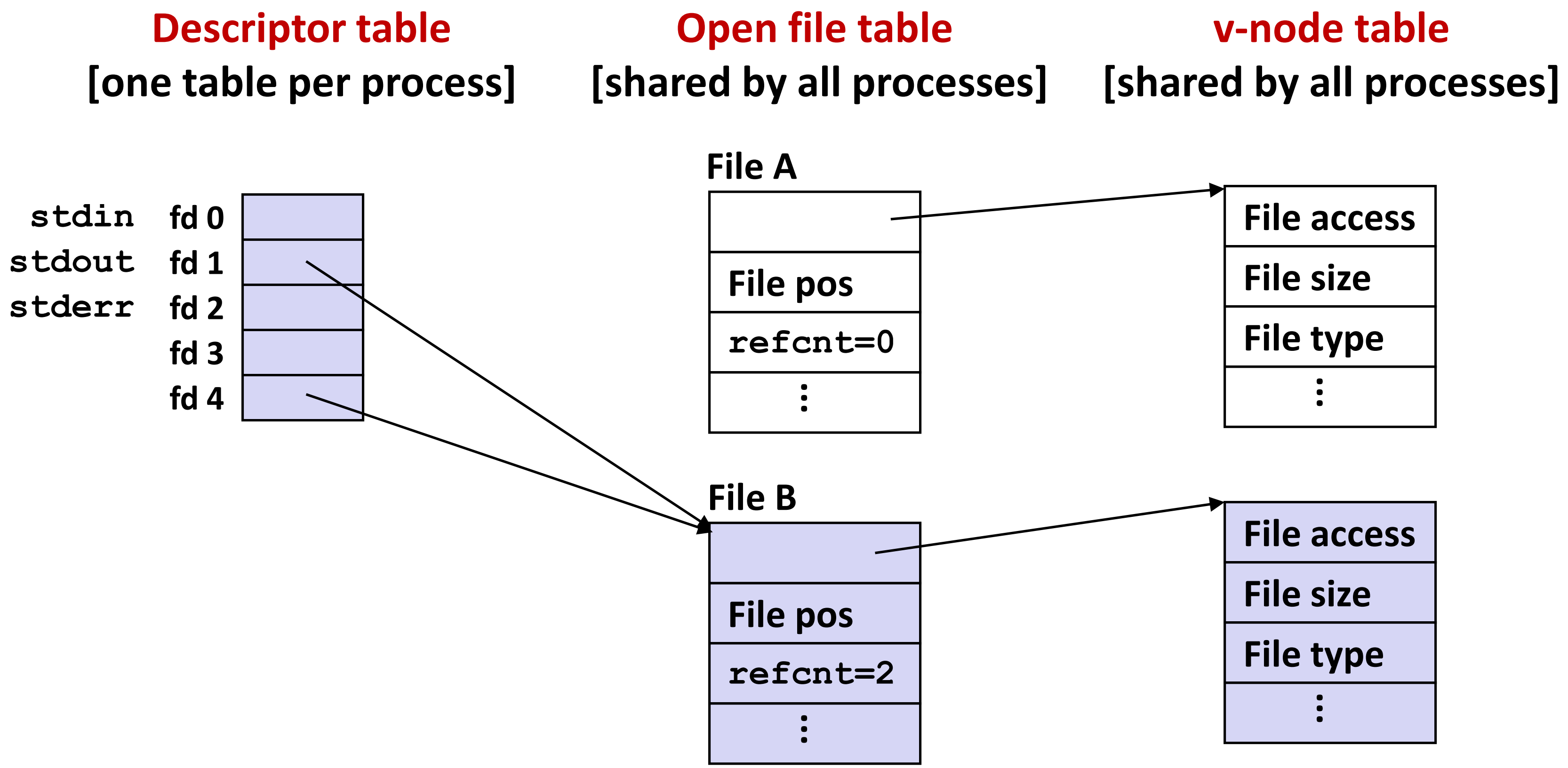
I/O Redirection Example

- **Step #1: open file to which stdout should be redirected**
  - Happens in child executing shell code, before **`exec`**



I/O Redirection Example (cont.)

- **Step #2: call `dup2(4,1)`**
  - cause fd=1 (stdout) to refer to disk file pointed at by fd=4



Example: I/O and Redirection

```
#include "csapp.h"
int main(int argc, char *argv[])
{
    int fd1, fd2, fd3;
    char c1, c2, c3;
    char *fname = argv[1];
    fd1 = open(fname, O_RDONLY, 0);
    fd2 = open(fname, O_RDONLY, 0);
    fd3 = open(fname, O_RDONLY, 0);
    dup2(fd2, fd3);
    read(fd1, &c1, 1);
    read(fd2, &c2, 1);
    read(fd3, &c3, 1);
    printf("c1 = %c, c2 = %c, c3 = %c\n", c1, c2, c3);
    return 0;
}                                              ffiles1.c
```

- **What would this program print for file containing "`abcde`"?**

Example: I/O and Redirection

```
#include "csapp.h"
int main(int argc, char *argv[])
{
    int fd1, fd2, fd3;
    char c1, c2, c3;
    char *fname = argv[1];
    fd1 = open(fname, O_RDONLY, 0);
    fd2 = open(fname, O_RDONLY, 0);
    fd3 = open(fname, O_RDONLY, 0);
    dup2(fd2, fd3);
    read(fd1, &c1, 1);
    read(fd2, &c2, 1);
    read(fd3, &c3, 1);
    printf("c1 = %c, c2 = %c, c3 = %c\n", c1, c2, c3);
    return 0;
}
```

ffiles1.c

```
c1 = a, c2 = a, c3 = b
```

```
dup2(oldfd, newfd)
```

- What would this program print for file containing “abcde”?

Example: Process Control and I/O

```
#include "csapp.h"
int main(int argc, char *argv[])
{
    int fd1;
    int s = getpid() & 0x1;
    char c1, c2;
    char *fname = argv[1];
    fd1 = open(fname, O_RDONLY, 0);
    read(fd1, &c1, 1);
    if (fork()) { /* Parent */
        sleep(s);
        read(fd1, &c2, 1);
        printf("Parent: c1 = %c, c2 = %c\n", c1, c2);
    } else { /* Child */
        sleep(1-s);
        read(fd1, &c2, 1);
        printf("Child: c1 = %c, c2 = %c\n", c1, c2);
    }
    return 0;
}                                    ffiles2.c
```

- **What would this program print for file containing "abcde"?**

Example: Process Control and I/O

```
#include "csapp.h"
int main(int argc, char *argv[])
{
    int fd1;
    int s = getpid() & 0x1;
    char c1, c2;
    char *fname = argv[1];
    fd1 = open(fname, O_RDONLY, 0);
    read(fd1, &c1, 1);
    if (fork()) { /* Parent */
        sleep(s);
        read(fd1, &c2, 1);
        printf("Parent: c1 = %c, c2 = %c\n", c1, c2);
    } else { /* Child */
        sleep(1-s);
        read(fd1, &c2, 1);
        printf("Child: c1 = %c, c2 = %c\n", c1, c2);
    }
    return 0;
}
```

ffiles2.c

```
Child: c1 = a, c2 = b
Parent: c1 = a, c2 = c
```

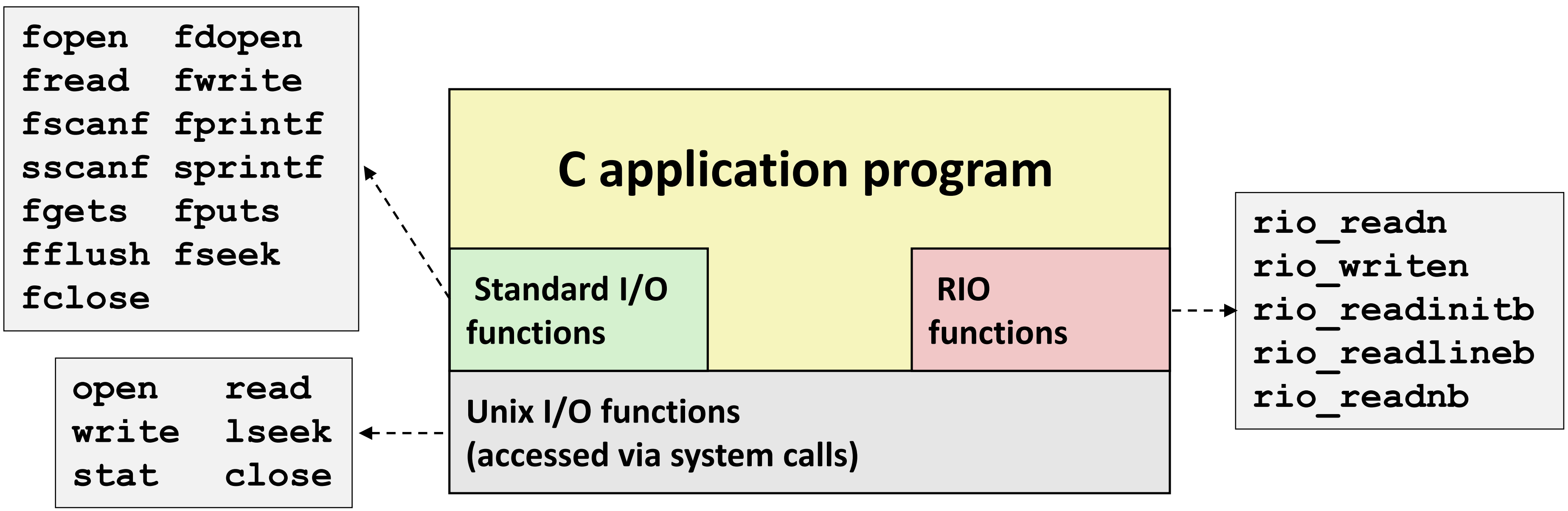
```
Parent: c1 = a, c2 = b
Child: c1 = a, c2 = c
```

Bonus: Which way does it go?

- What would this program print for file containing “abcde”?

Unix I/O vs. Standard I/O vs. RIO

- Standard I/O and RIO are implemented using low-level Unix I/O



- Which ones should you use in your programs?

Pros and Cons of Unix I/O

- **Pros**
  - Unix I/O is the most general and lowest overhead form of I/O
    - All other I/O packages are implemented using Unix I/O functions
  - Unix I/O provides functions for accessing file metadata
  - Unix I/O functions are async-signal-safe and can be used safely in signal handlers
- **Cons**
  - Dealing with short counts is tricky and error prone
  - Efficient reading of text lines requires some form of buffering, also tricky and error prone
  - Both of these issues are addressed by the standard I/O and RIO packages

Pros and Cons of Standard I/O

- **Pros:**
  - Buffering increases efficiency by decreasing the number of **`read`** and **`write`** system calls
  - Short counts are handled automatically
- **Cons:**
  - Provides no function for accessing file metadata
  - Standard I/O functions are not *async-signal-safe*, and not appropriate for signal handlers
  - Standard I/O is not appropriate for input and output on network sockets
    - There are poorly documented restrictions on streams that interact badly with restrictions on sockets (CS:APP3e, Sec 10.11)

Choosing I/O Functions

- **General rule: use the highest-level I/O functions you can**
  - Many C programmers are able to do all of their work using the standard I/O functions
  - But, be sure to understand the functions you use!

- **When to use standard I/O**
  - When working with **disk or terminal files**
- **When to use raw Unix I/O**
  - Inside **signal handlers**, because Unix I/O is *async-signal-safe*
  - In rare cases when you need absolute highest performance
- **When to use RIO**
  - When you are reading and writing **network sockets**
  - Avoid using standard I/O on sockets

Aside: Working with Binary Files

- **Functions you should never use on binary files**
  - Text-oriented I/O such as **`fgets, scanf, rio_readlineb`**
    - Interpret EOL characters
    - Use functions like **`rio_readn`** or **`rio_readnb`** instead
  - String functions
    - **`strlen, strcpy, strcat`**
    - Interprets byte value 0 (end of string) as special

For Further Information

- **The Unix bible:**
  - W. Richard Stevens & Stephen A. Rago, ***Advanced Programming in the Unix Environment***, 2nd Edition, Addison Wesley, 2005
    - Updated from Stevens's 1993 classic text

- **The Linux bible:**
  - Michael Kerrisk, ***The Linux Programming Interface***, No Starch Press, 2010
    - Encyclopedic and authoritative