
WELCOME
TO
15-213
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System-Level I/O

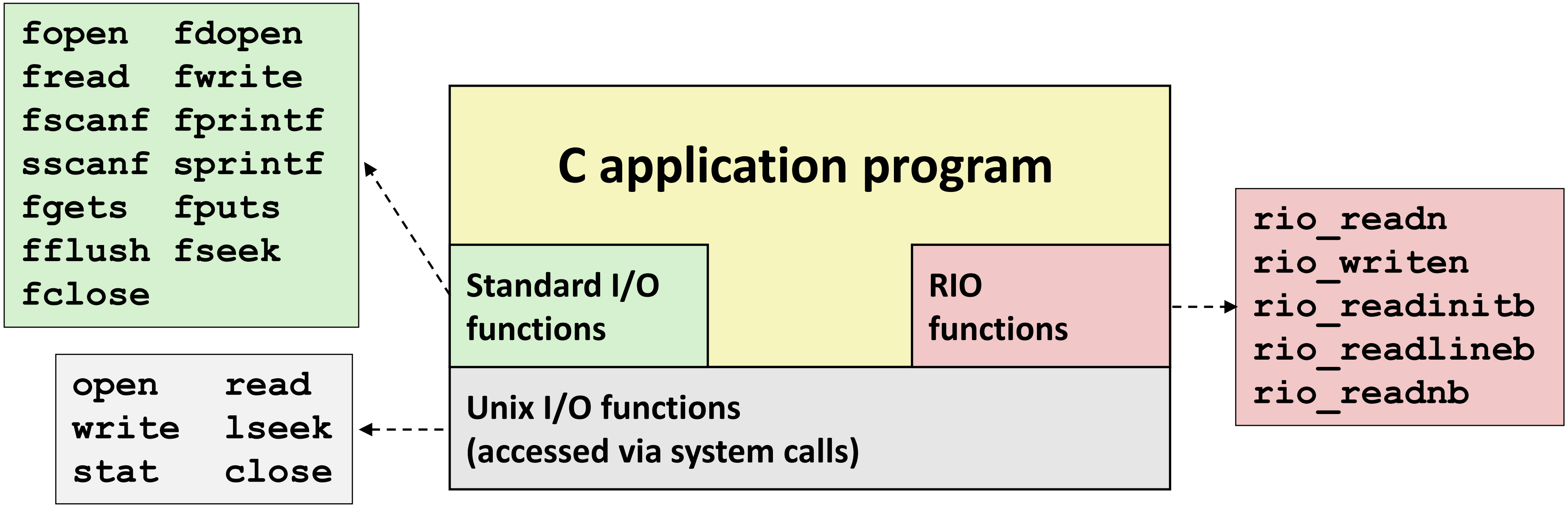
15-213/18-213/15-513/18-613:
Introduction to Computer Systems
21st Lecture, 13 April 2021

Today

- **Unix I/O** — CSAPP 10.1-10.4
- Metadata, sharing, and redirection — CSAPP 10.6-10.9
- Standard I/O — CSAPP 10.10
- RIO (robust I/O) package — CSAPP 10.5
- Closing remarks — CSAPP 10.11

Today: Unix I/O, C Standard I/O and RIO

- **Two sets: system-level and C level**
- **Robust I/O (RIO): 15-213 special wrappers**
  good coding practice: handles error checking, signals, and "short counts"

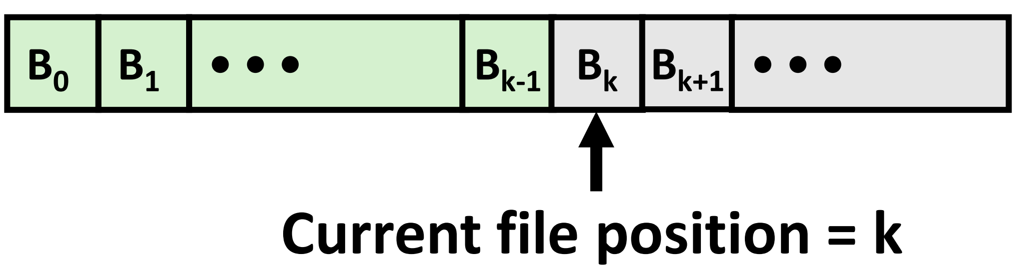


Unix I/O Overview

- A Linux ***file*** is a sequence of *m* bytes:
  - $B_0, B_1, \ldots., B_k, \ldots., B_{m-1}$
- Cool fact: All I/O devices are represented as files:
  - **`/dev/sda2`** (**`/usr`** disk partition)
  - **`/dev/tty2`** (terminal)
- Even the kernel is represented as a file:
  - **`/boot/vmlinuz-3.13.0-55-generic`** (kernel image)
  - **`/proc`** (kernel data structures)

Unix I/O Overview

- **Elegant mapping of files to devices allows kernel to export simple interface called *Unix I/O:***
  - Opening and closing files
    - **`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()`**



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*
  - *Character and block devices*

Regular Files

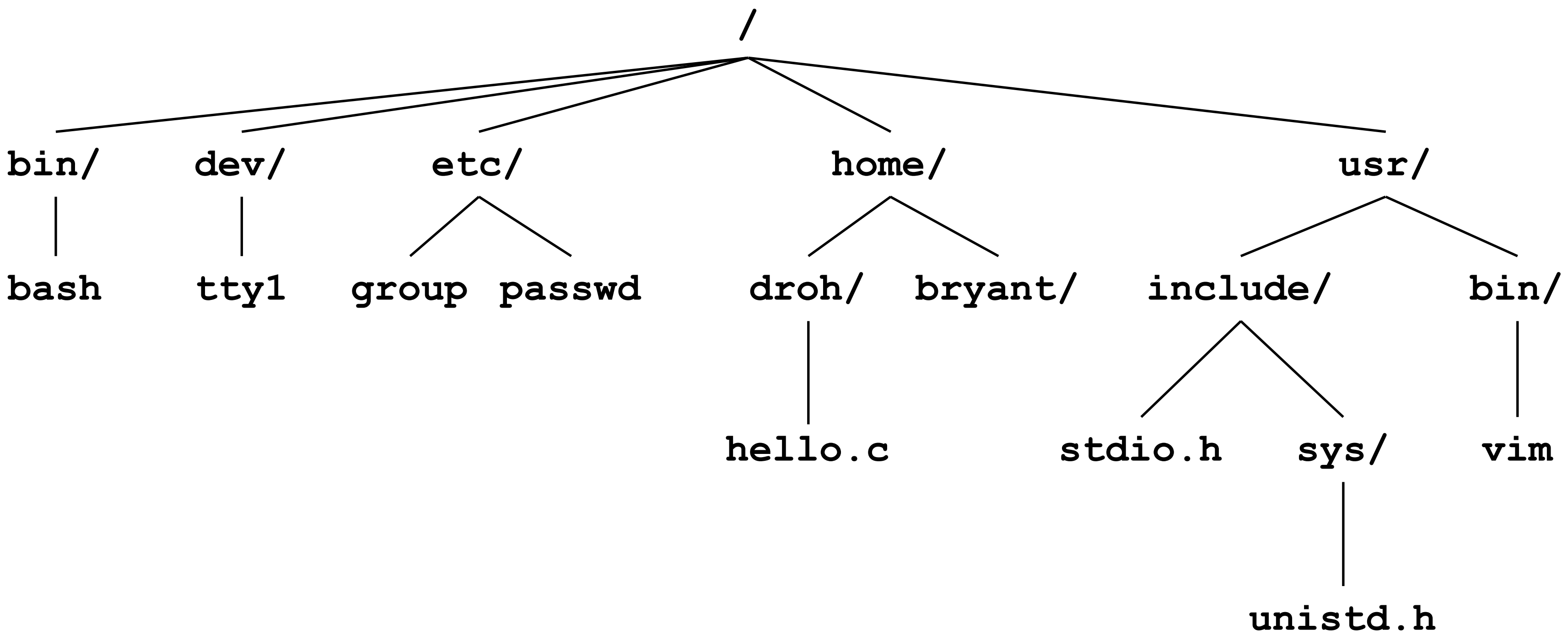
- **A regular file contains arbitrary data**
- **Applications often distinguish between *text files* and *binary files***
  - Text files are regular files with only ASCII or Unicode characters
  - Binary files are everything else
    - e.g., object files, JPEG images
  - Kernel doesn't know the difference!
- **Text file is sequence of *text lines***
  - Text line is sequence of chars terminated by *newline char* (**'`\n`'**)
    - Newline is **`0xa`**, same as ASCII line feed character (LF)
- **End of line (EOL) indicators in other systems**
  - Linux and Mac OS: **'`\n`'** (**`0xa`**)
    - line feed (LF)
  - Windows and Internet protocols: **'`\r\n`'** (**`0xd 0xa`**)
    - Carriage return (CR) followed by line feed (LF)

Directories

- **Directory consists of an array of *links***
  - Each link maps a *filename* to a file
- **Each directory contains at least two entries**
  - `.` (dot) is a link to itself
  - `..` (dot dot) is a link 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

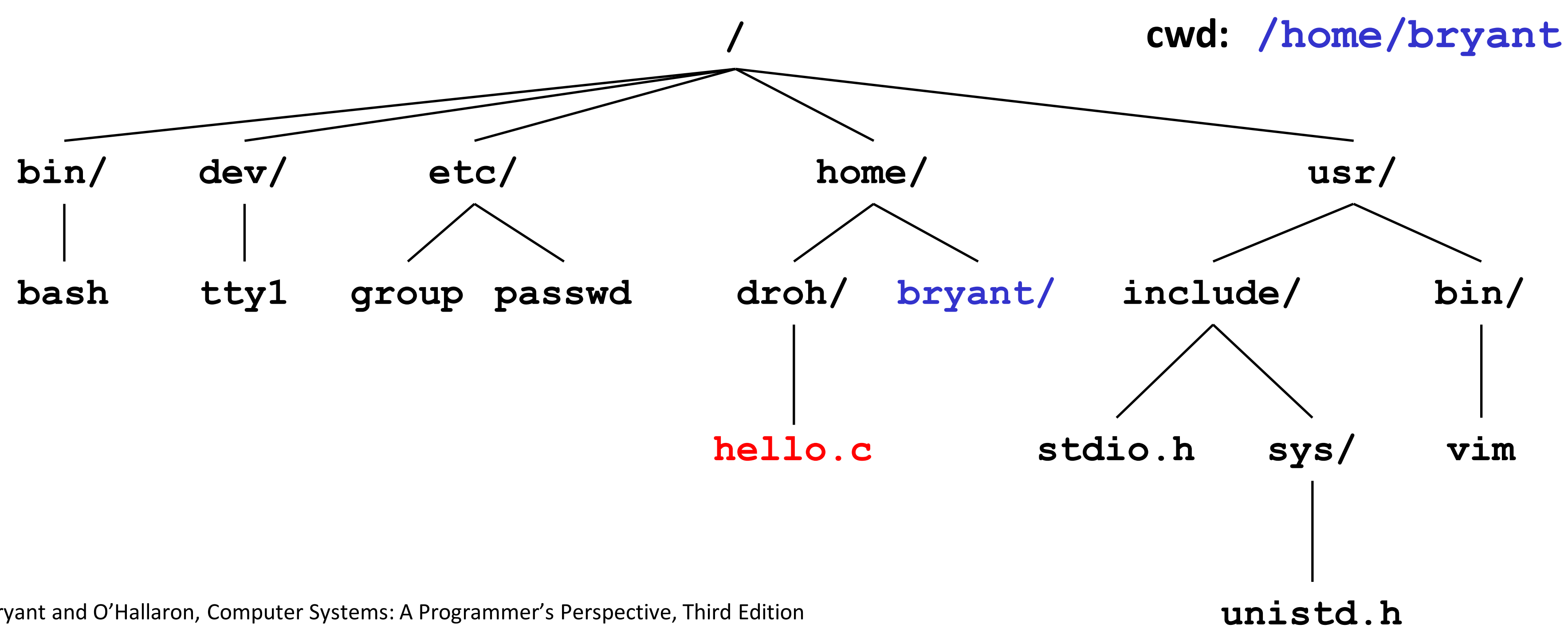
- All files are organized as a hierarchy anchored by root directory named / (slash)



- 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 (cwd)
    - `../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***
  - Lowest numbered file descriptor not currently open for the process
  - `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)

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 (more on this later)
- 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**

```
#include <unistd.h>
char buf[512];
int fd;             /* file descriptor */
ssize_t 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 */
ssize_t 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!

Simple Unix I/O example

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

```
#include "csapp.h"

int main(int argc, char *argv[])
{
    char c;
    int infd = STDIN_FILENO;
    if (argc == 2) {
        infd = Open(argv[1], O_RDONLY, 0);
    }
    while(Read(infd, &c, 1) != 0)
        Write(STDOUT_FILENO, &c, 1);
    exit(0);
}
```

showfile1_nobuf.c

- **Demo:**

```
linux> strace ./showfile1_nobuf names.txt
```

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

- **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.**

Home-grown buffered I/O code

- Copying file to stdout, BUFSIZE bytes at a time

```
#include "csapp.h"
#define BUFSIZE 64


int main(int argc, char *argv[])
{
    char buf[BUFSIZE];
    int infd = STDIN_FILENO;
    if (argc == 2) {
        infd = Open(argv[1], O_RDONLY, 0);
    }
    while((nread = Read(infd, buf, BUFSIZE)) != 0)
        Write(STDOUT_FILENO, buf, nread);
    exit(0);
}
```

showfile2_buf.c

- Demo:

```
linux> strace ./showfile2_buf names.txt
```

Today

- Unix I/O
- **Metadata, sharing, and redirection**
- Standard I/O
- RIO (robust I/O) package
- Closing remarks

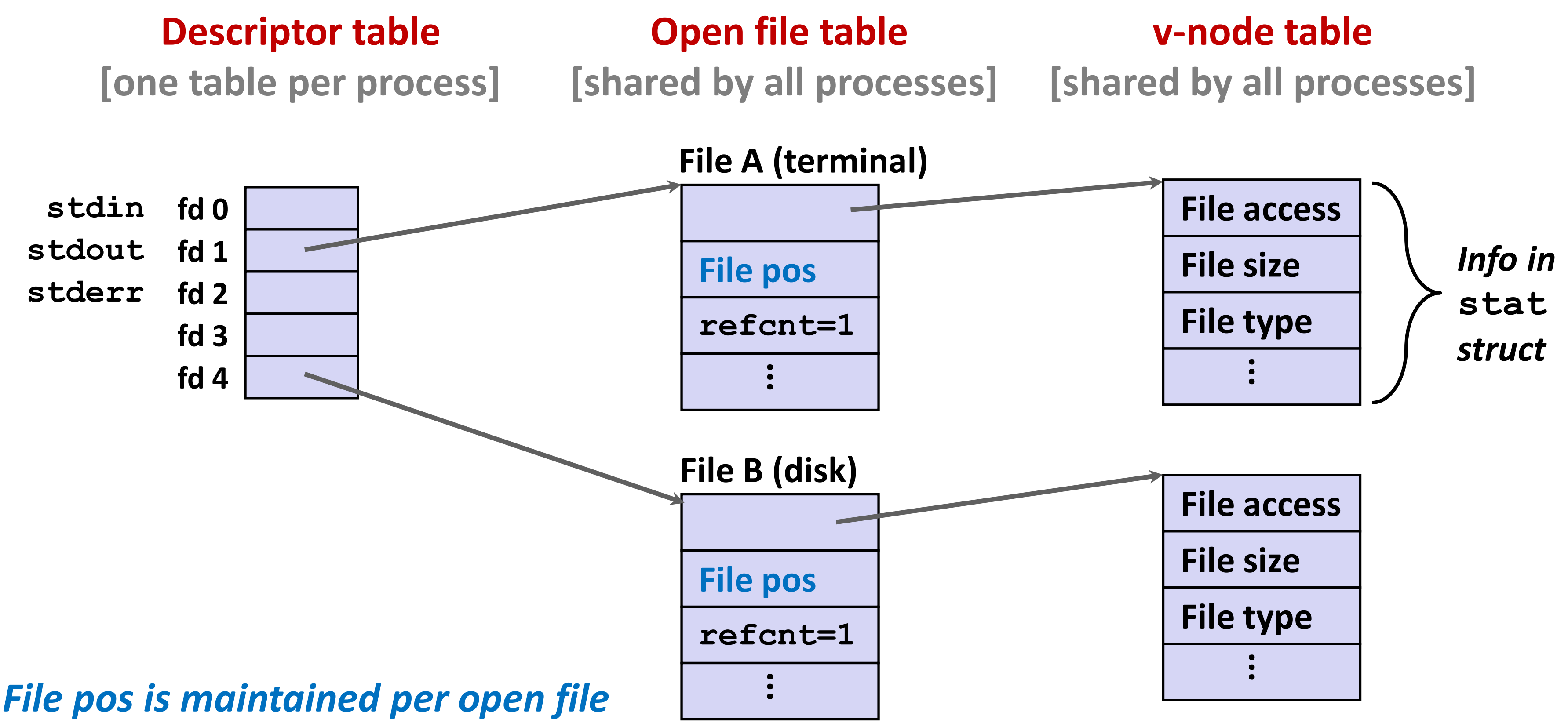
File Metadata

- *Metadata* is data about data, in this case file data
- Per-file metadata 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 */
};
```

How the Unix Kernel Represents Open Files

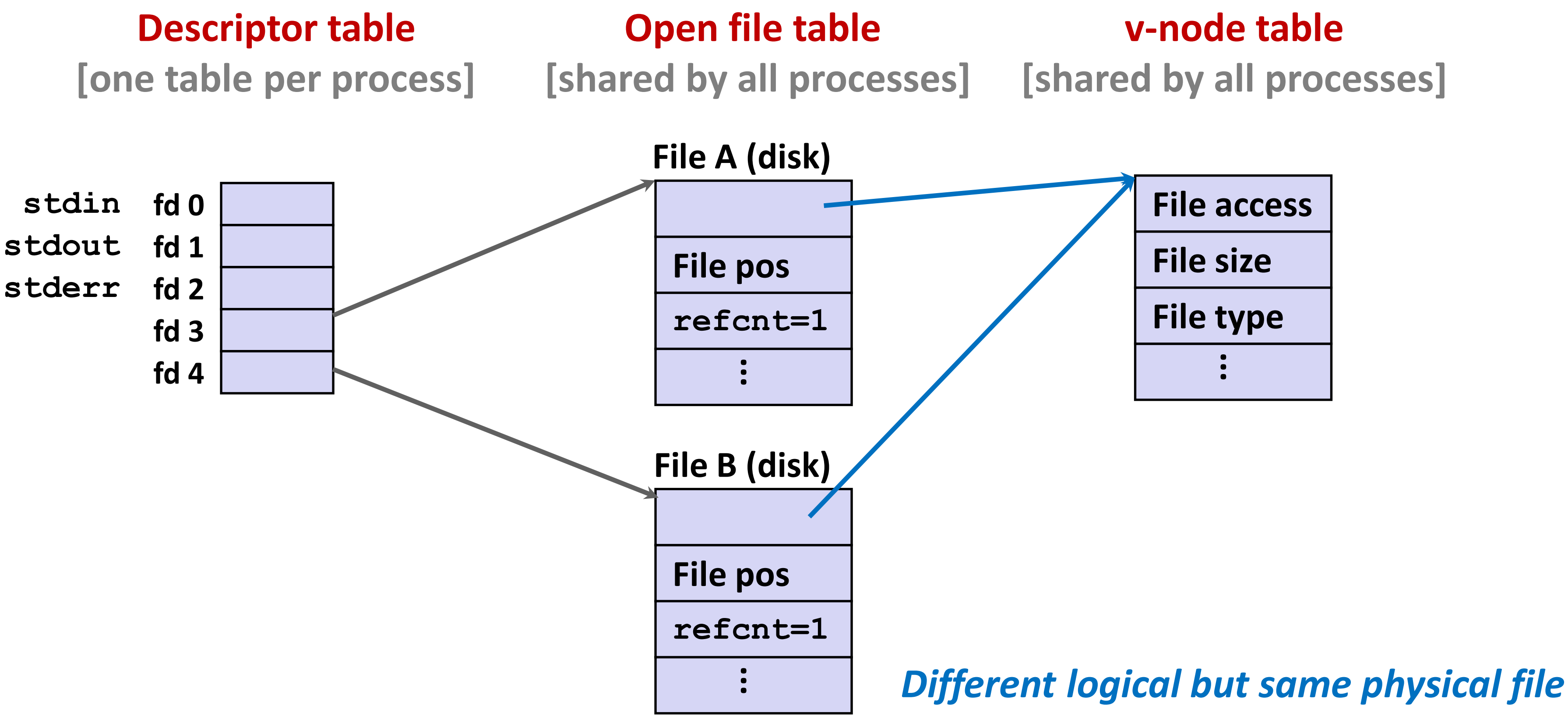
- **Two descriptors referencing two distinct open files. Descriptor 1 (stdout) points to terminal, and descriptor 4 points to open disk file**



File pos is maintained per open file

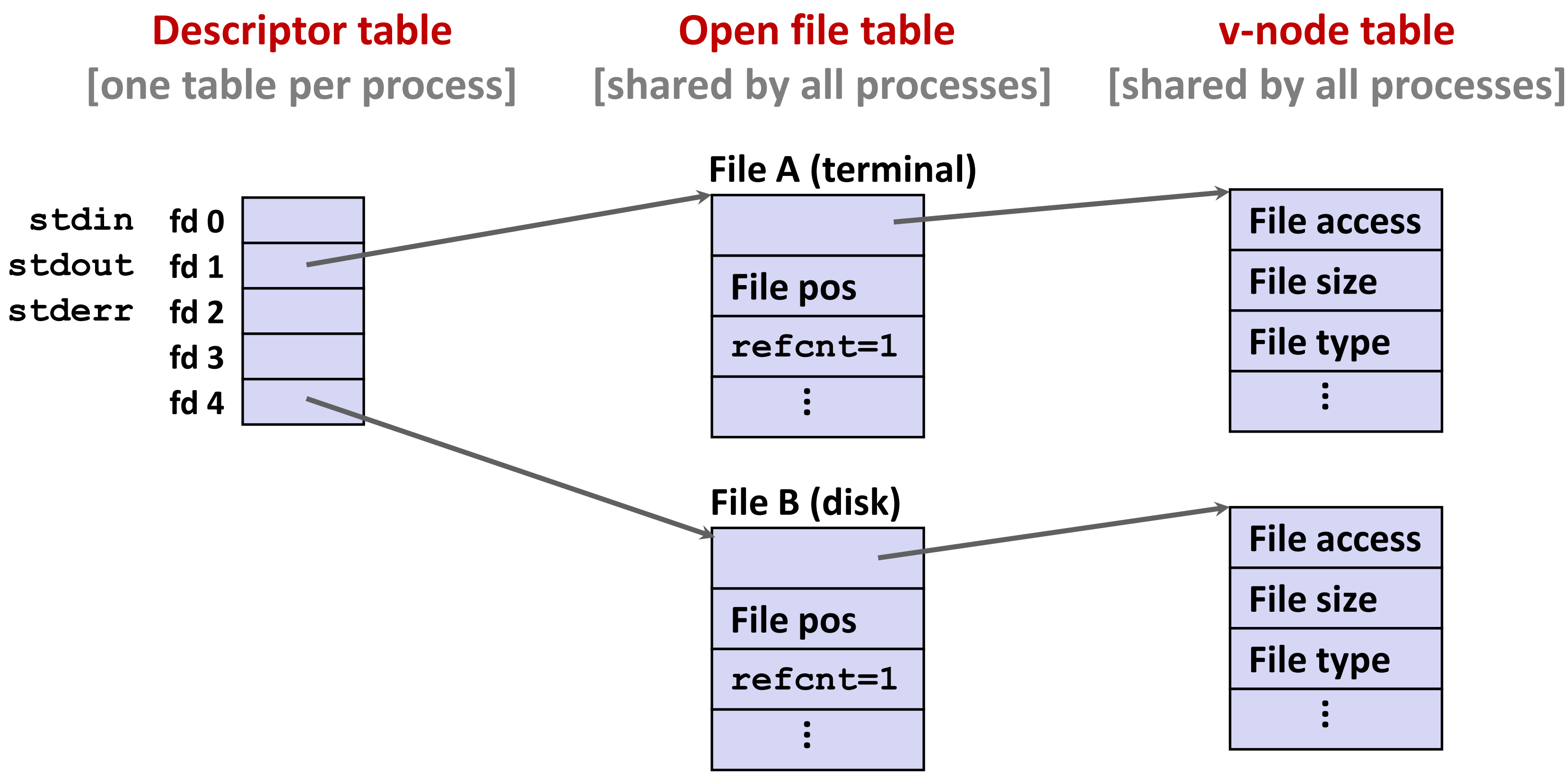
File Sharing

- **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



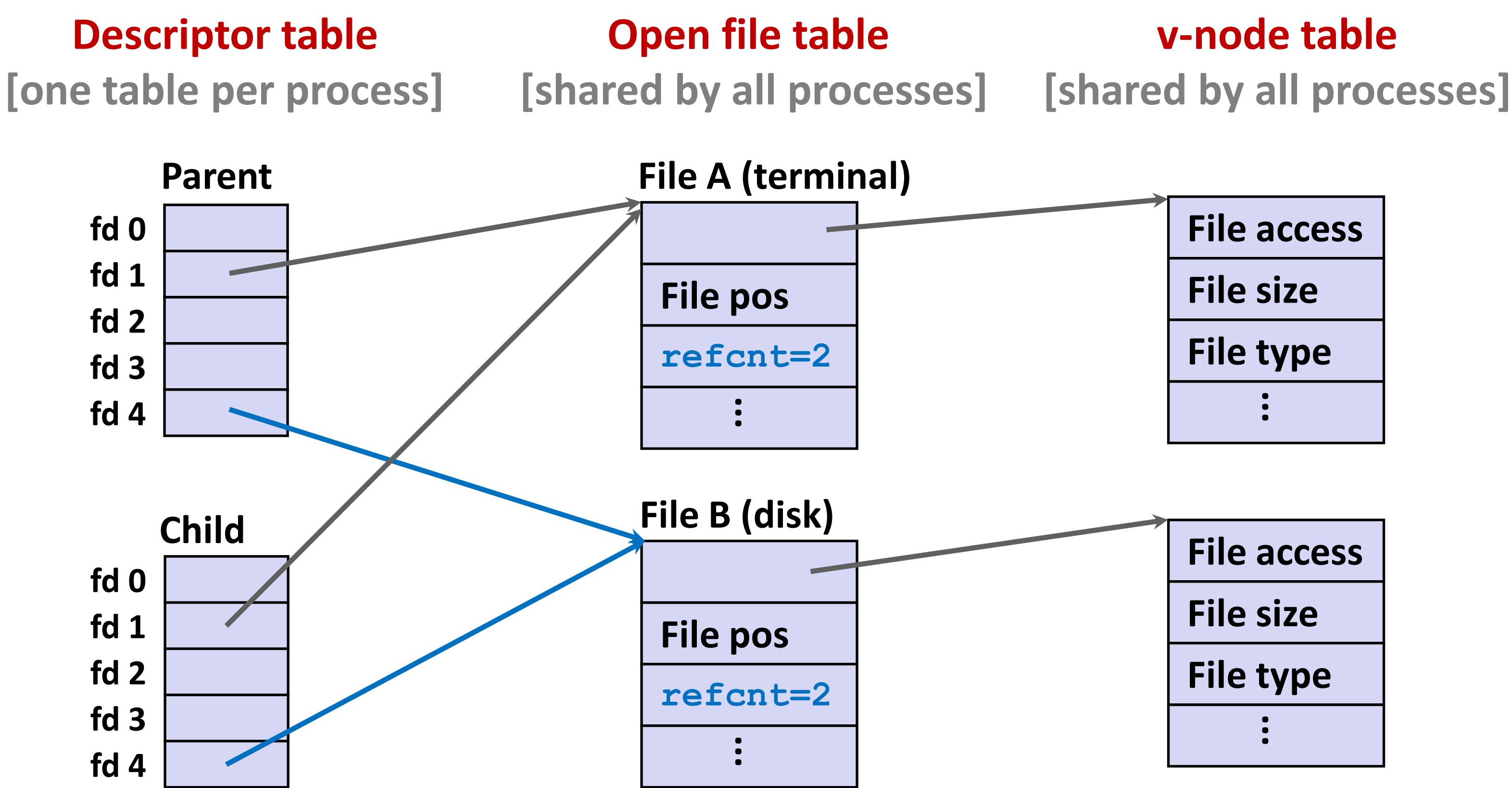
How Processes Share Files: `fork`

- 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



File is shared between processes

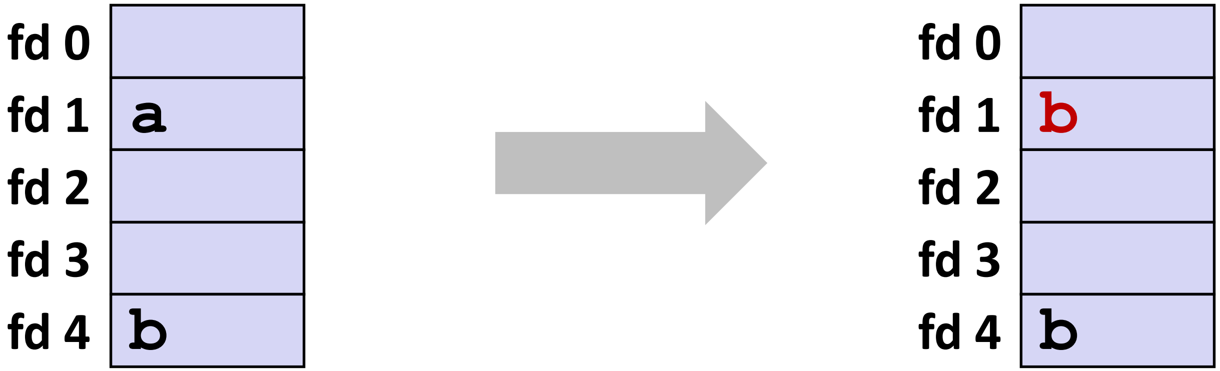
I/O Redirection

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

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

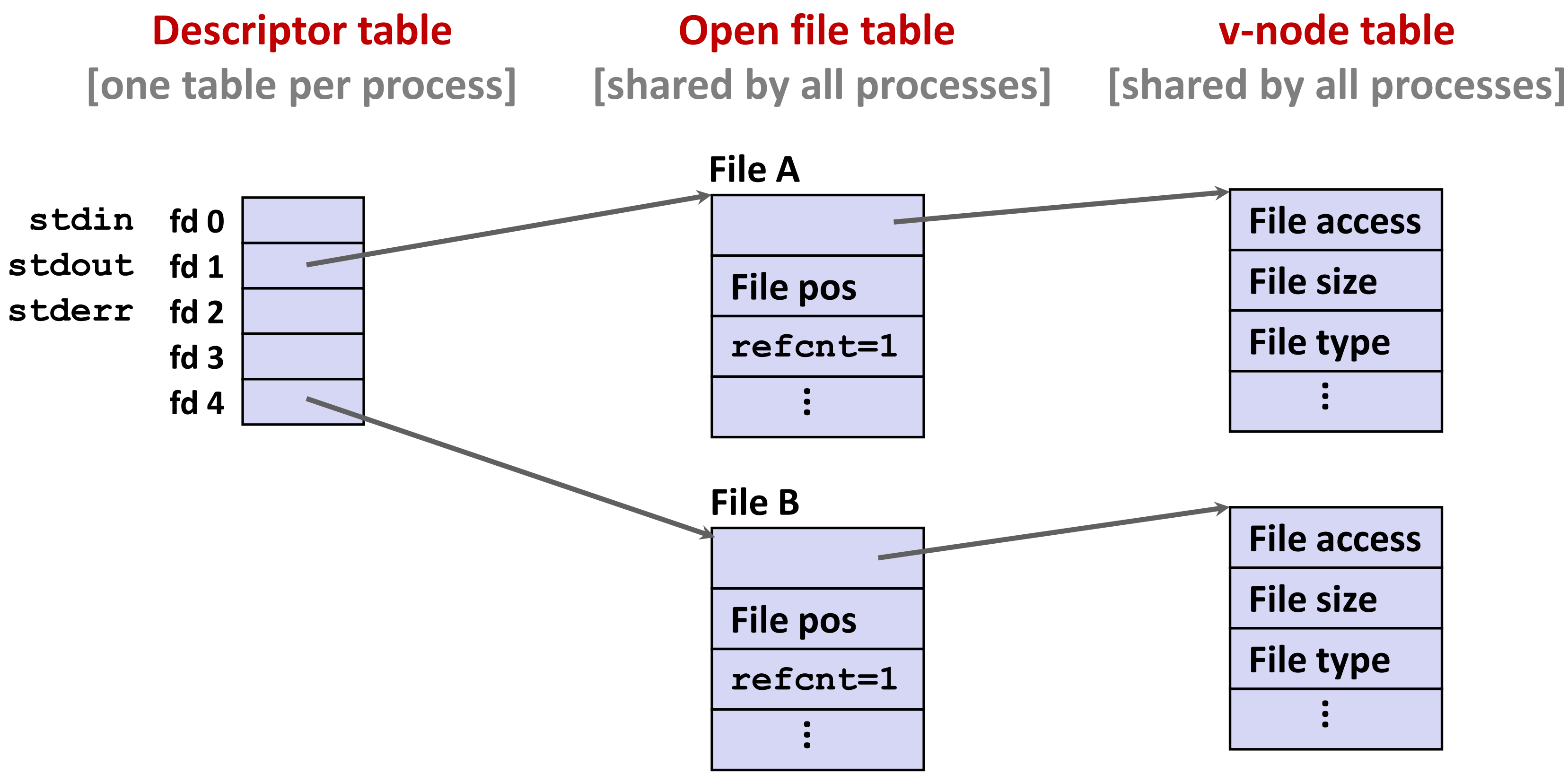
- **Answer: By calling the `dup2(oldfd, newfd)` function**
  - Copies (per-process) descriptor table entry **`oldfd`** to entry **`newfd`**

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



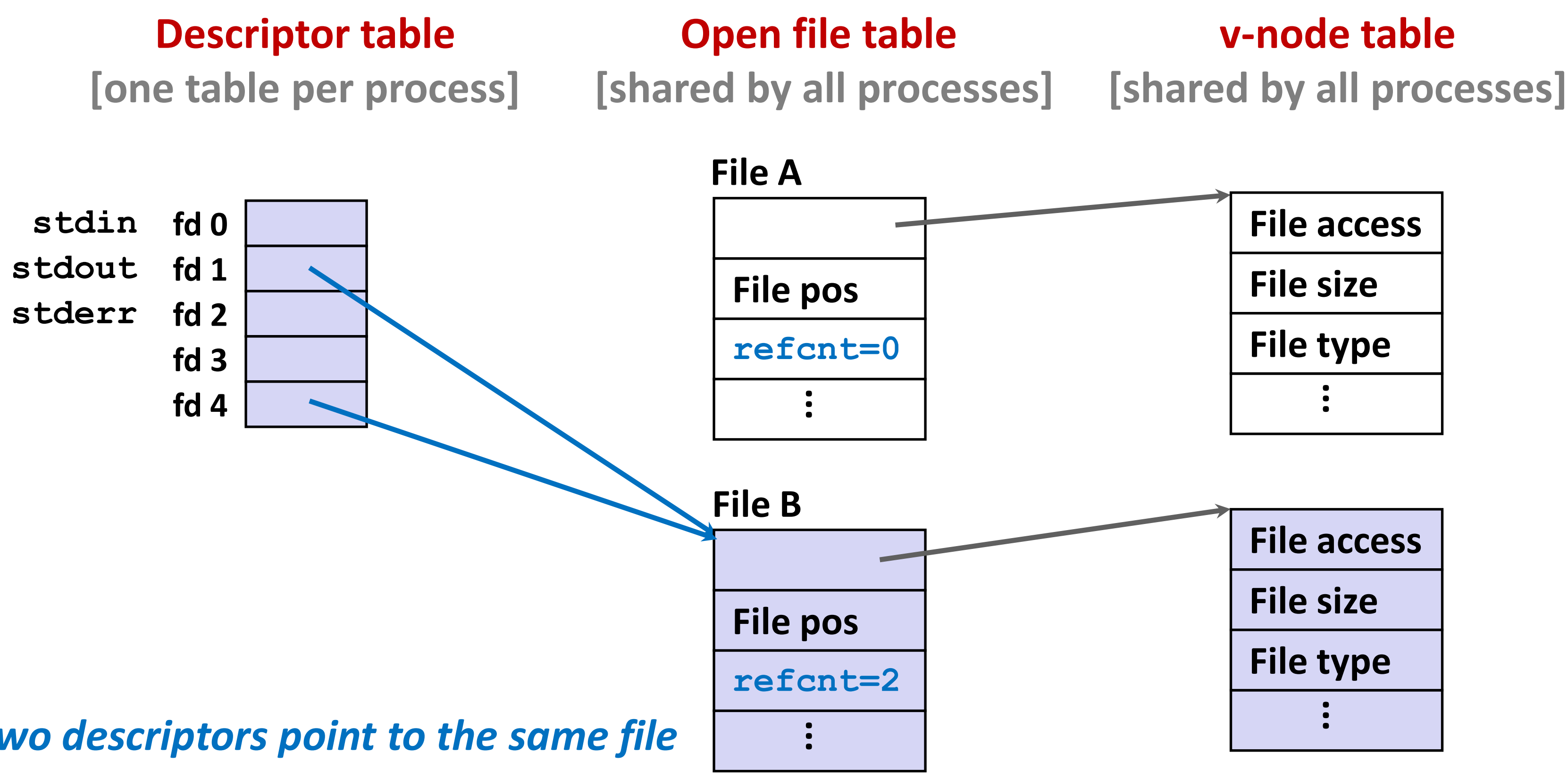
I/O Redirection Example

- **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



Two descriptors point to the same file

Warm-Up: I/O and Redirection Example

```
#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`"?**

Warm-Up: I/O and Redirection Example

```
#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"?

Master Class: 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"?**

Master Class: 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”?

Quiz Time!

Check out:

https://canvas.cmu.edu/courses/17808

Today

- Unix I/O
- Metadata, sharing, and redirection
- **Standard I/O**
- RIO (robust I/O) package
- Closing remarks

Standard I/O Functions

- **The C standard library (`libc.so`) contains a collection of higher-level *standard I/O* functions**
  - Documented in Appendix B of K&R

- **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");
}
```

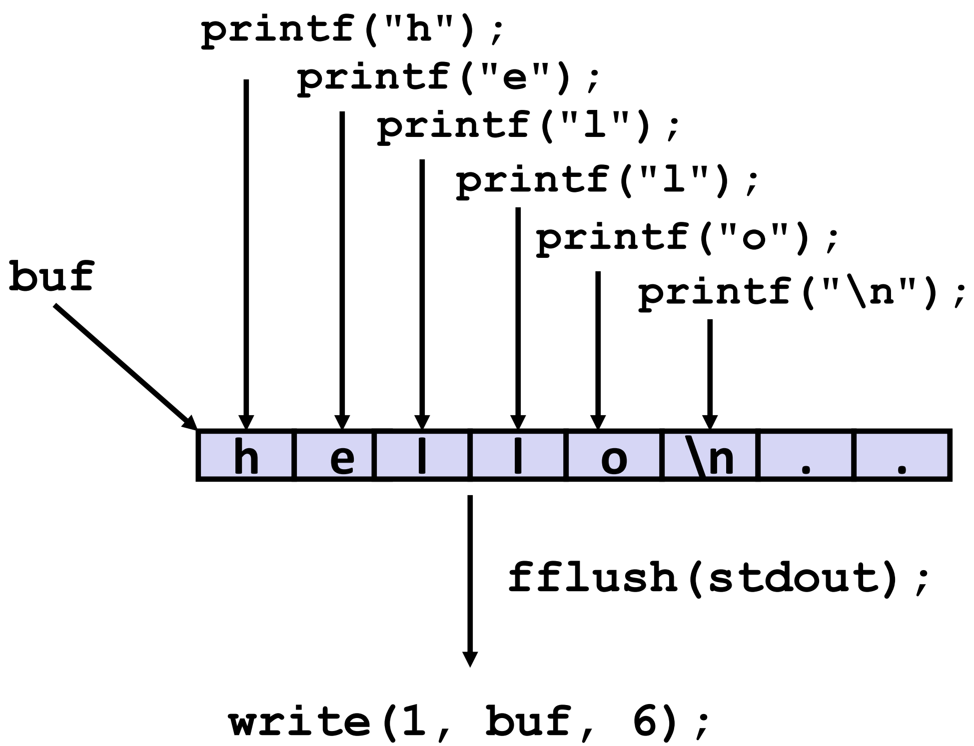
Buffered I/O: Motivation

- **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

Buffer

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)                           = ?
```

Standard I/O Example

- **Copying file to stdout, line-by-line with stdio**

```
#include "csapp.h"
#define MLINE 1024

int main(int argc, char *argv[])
{
    char buf[MLINE];
    FILE *infile = stdin;
    if (argc == 2) {
        infile = fopen(argv[1], "r");
        if (!infile) exit(1);
    }
    while(fgets(buf, MLINE, infile) != NULL)
        fprintf(stdout, buf);
    exit(0);
}
```

showfile3_stdio.c

- **Demo:**

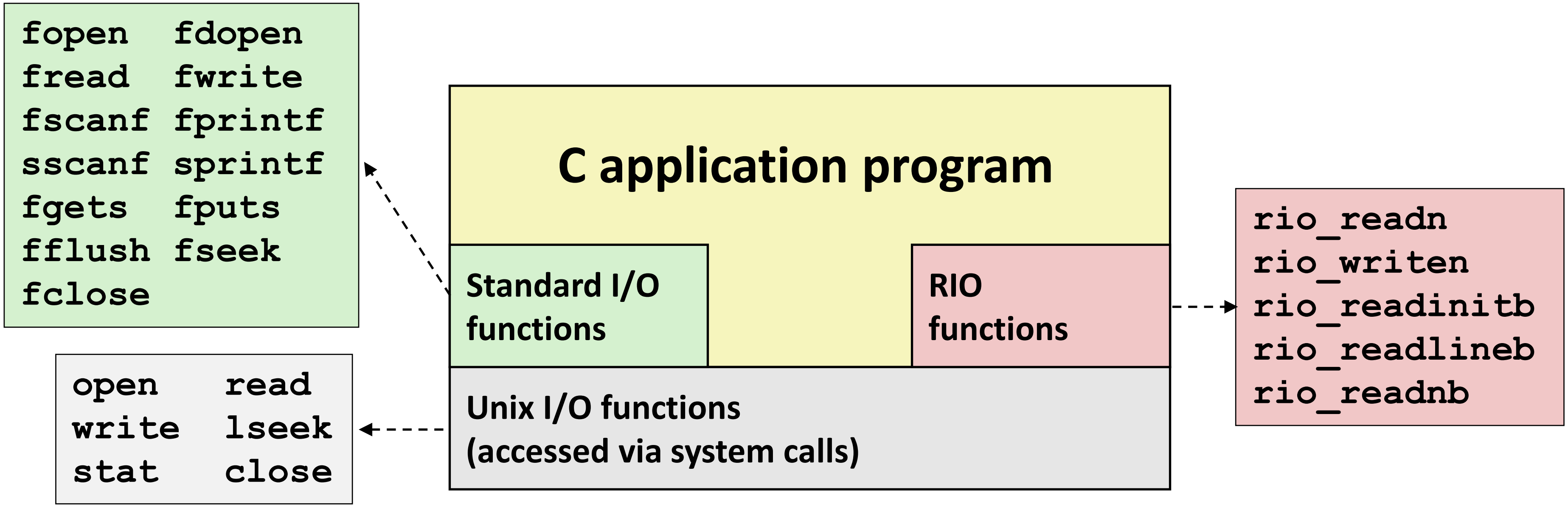
```
linux> strace ./showfile3_stdio names.txt
```

Today

- Unix I/O
- Metadata, sharing, and redirection
- Standard I/O
- **RIO (robust I/O) package**
- Closing remarks

Today: Unix I/O, C Standard I/O and RIO

- Two *incompatible* libraries building on Unix I/O
- Robust I/O (RIO): 15-213 special wrappers
  good coding practice: handles error checking, signals, and "short counts"



Unix I/O Recap

```
/* Read at most max_count bytes from file into buffer.
   Return number bytes read, or error value */
ssize_t read(int fd, void *buffer, size_t max_count);
```

```
/* Write at most max_count bytes from buffer to file.
   Return number bytes written, or error value */
ssize_t write(int fd, void *buffer, size_t max_count);
```

- **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
- **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.**

The RIO Package (15-213/CS:APP 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
- Download from http://csapp.cs.cmu.edu/3e/code.html
  → `src/csapp.c` and `include/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)

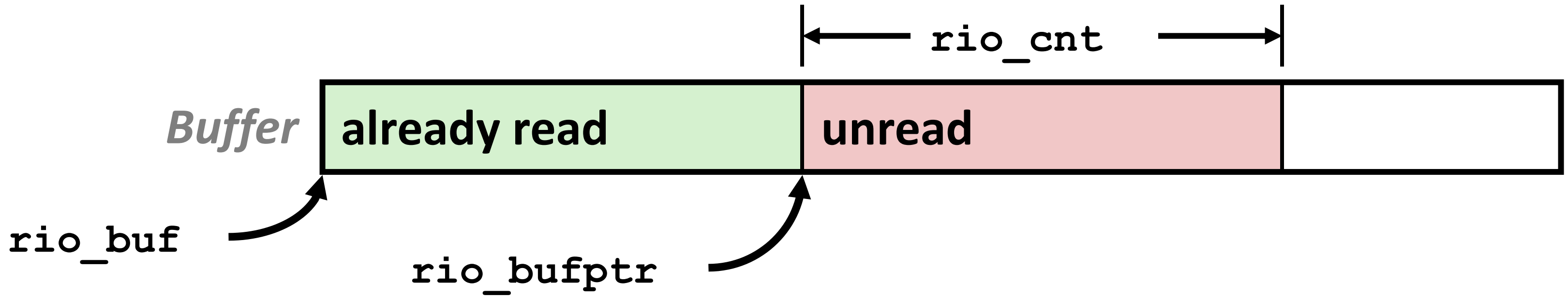
```
#include "csapp.h"

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

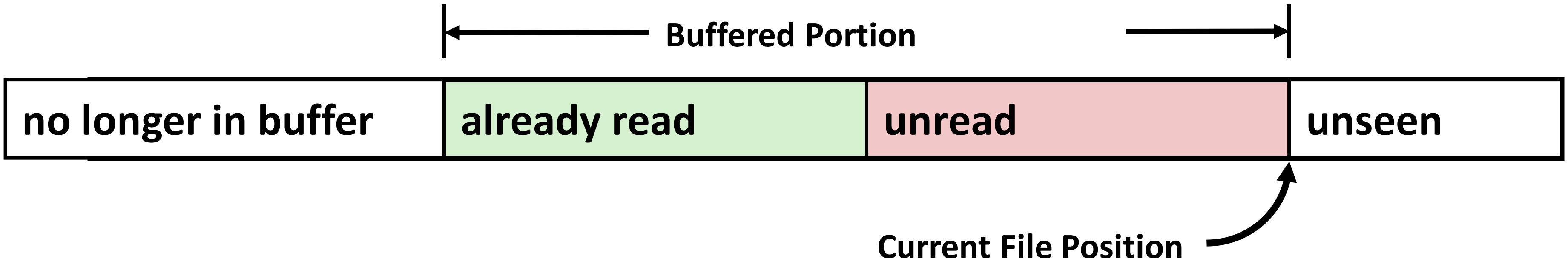
- `rio_readnb` reads up to `n` ***bytes*** from file `fd`
- Stopping conditions
  - `n` bytes read
  - EOF encountered
- Calls to `rio_readlineb` and `rio_readnb` can be interleaved arbitrarily on the same descriptor
  - **Warning:** Don't interleave with calls to `rio_readn`

Buffered I/O: Implementation

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

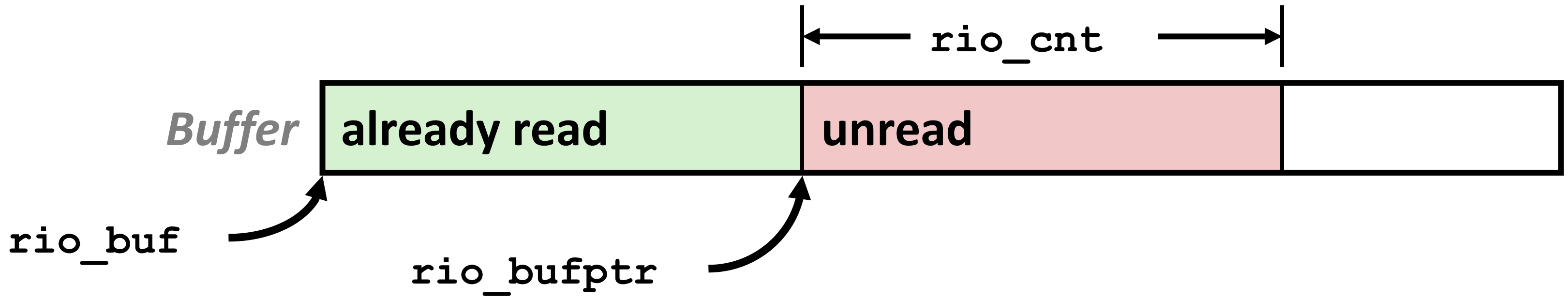


- Layered on Unix file:



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;
```

Standard I/O Example

- **Copying file to stdout, line-by-line with rio**

```c
#include "csapp.h"
#define MLINE 1024

int main(int argc, char *argv[])
{
    rio_t rio;
    char buf[MLINE];
    int infd = STDIN_FILENO;
    ssize_t nread = 0;
    if (argc == 2) {
        infd = Open(argv[1], O_RDONLY, 0);
    }
    Rio_readinitb(&rio, infd);
    while((nread = Rio_readlineb(&rio, buf, MLINE)) != 0)
        Rio_writen(STDOUT_FILENO, buf, nread);
    exit(0);
}
```

showfile4_stdio.c

- **Demo:**

```
linux> strace ./showfile4_rio names.txt
```

Today

- Unix I/O
- Metadata, sharing, and redirection
- Standard I/O
- RIO (robust I/O) package
- **Closing remarks**

Standard I/O Example

- **Copying file to stdout, loading entire file with mmap**

```
#include "csapp.h"


int main(int argc, char **argv)
{
    struct stat stat;
    if (argc != 2) exit(1);
    int infd = Open(argv[1], O_RDONLY, 0);
    Fstat(infd, &stat);
    size_t size = stat.st_size;
    char *bufp = Mmap(NULL, size, PROT_READ,
                      MAP_PRIVATE, infd, 0);
    Write(1, bufp, size);
    exit(0);
}
```

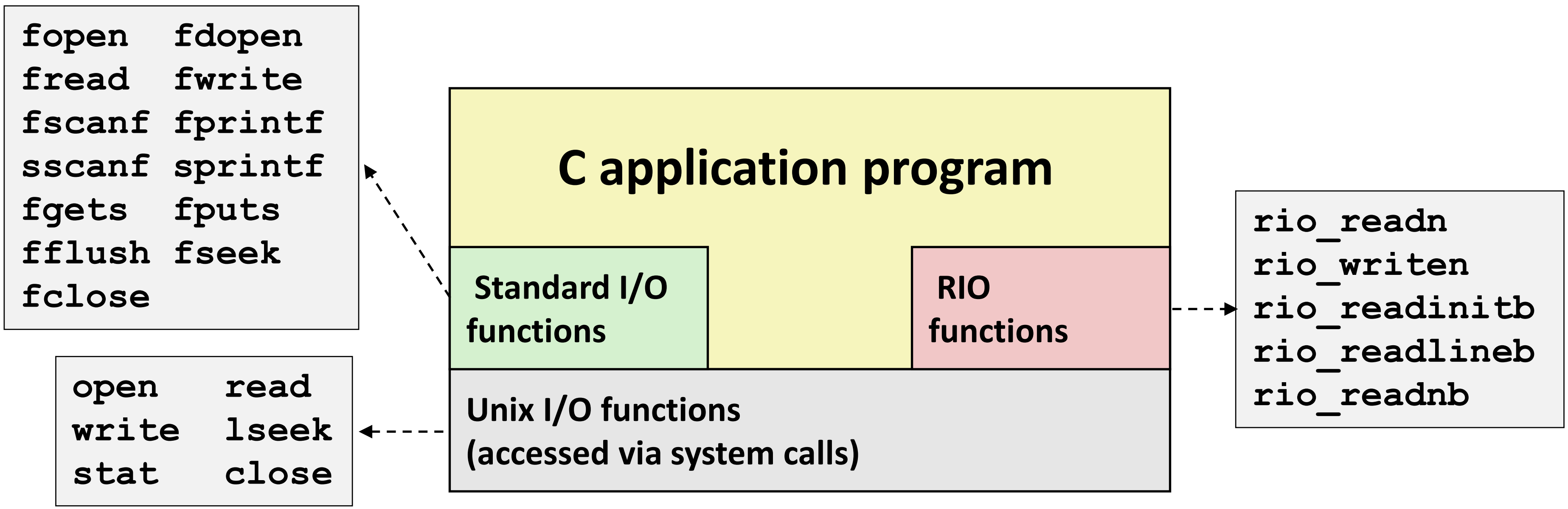
showfile5_mmap.c

- **Demo:**

```
linux> strace ./showfile5_mmap names.txt
```

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

- **Binary File**
  - Sequence of arbitrary bytes
  - Including byte value 0x00
- **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

Extra Slides

Fun with File Descriptors (3)

```
#include "csapp.h"
int main(int argc, char *argv[])
{
    int fd1, fd2, fd3;
    char *fname = argv[1];
    fd1 = Open(fname, O_CREAT|O_TRUNC|O_RDWR, S_IRUSR|S_IWUSR);
    Write(fd1, "pqrs", 4);
    fd3 = Open(fname, O_APPEND|O_WRONLY, 0);
    Write(fd3, "jklmn", 5);
    fd2 = dup(fd1);  /* Allocates descriptor */
    Write(fd2, "wxyz", 4);
    Write(fd3, "ef", 2);
    return 0;
}                                                ffiles3.c
```

- What would be the contents of the resulting file?

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);
}
```

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

For Further Information

- **The Unix bible:**
  - W. Richard Stevens & Stephen A. Rago, ***Advanced Programming in the Unix Environment***, 3rd Edition, Addison Wesley, 2013
    - Updated from Stevens's 1993 classic text

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