CS 33

Files Part 3

The File Abstraction

- A file is a simple array of bytes
- A file is made larger by writing beyond its current end
- Files are named by paths in a naming tree
- System calls on files are synchronous
- Files are permanent

Naming

- (almost) everything has a path name
  - files
  - directories
  - devices (known as *special files*)
    - keyboards
    - displays
    - disks
    - etc.

I/O System Calls

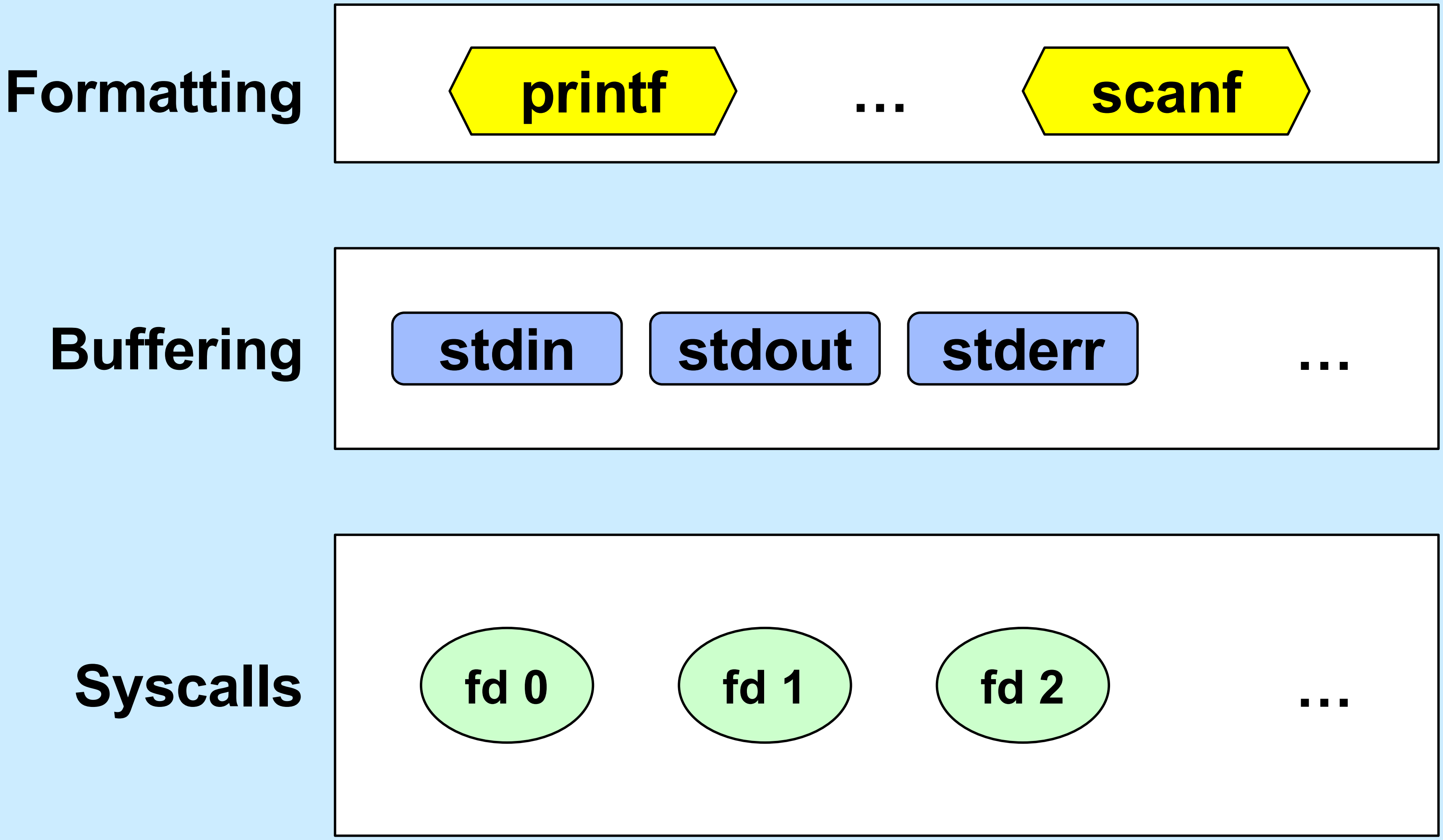
- **int** file_descriptor = open(pathname, mode [, permissions])
- **int** close(file_descriptor)
- **ssize_t** count = read(file_descriptor, buffer_address, buffer_size)
- **ssize_t** count = write(file_descriptor, buffer_address, buffer_size)
- **off_t** position = lseek(file_descriptor, offset, whence)

Standard File Descriptors

```
int main( ) {
  char buf[BUFSIZE];
  int n;
  const char *note = "Write failed\n";

  while ((n = read(0, buf, sizeof(buf))) > 0)
    if (write(1, buf, n) != n) {
          write(2, note, strlen(note));
          exit(1);
    }
  return(0);
}
```

Standard I/O Library



Formatting

printf … scanf

Buffering

stdin stdout stderr …

Syscalls

fd 0 fd 1 fd 2 …

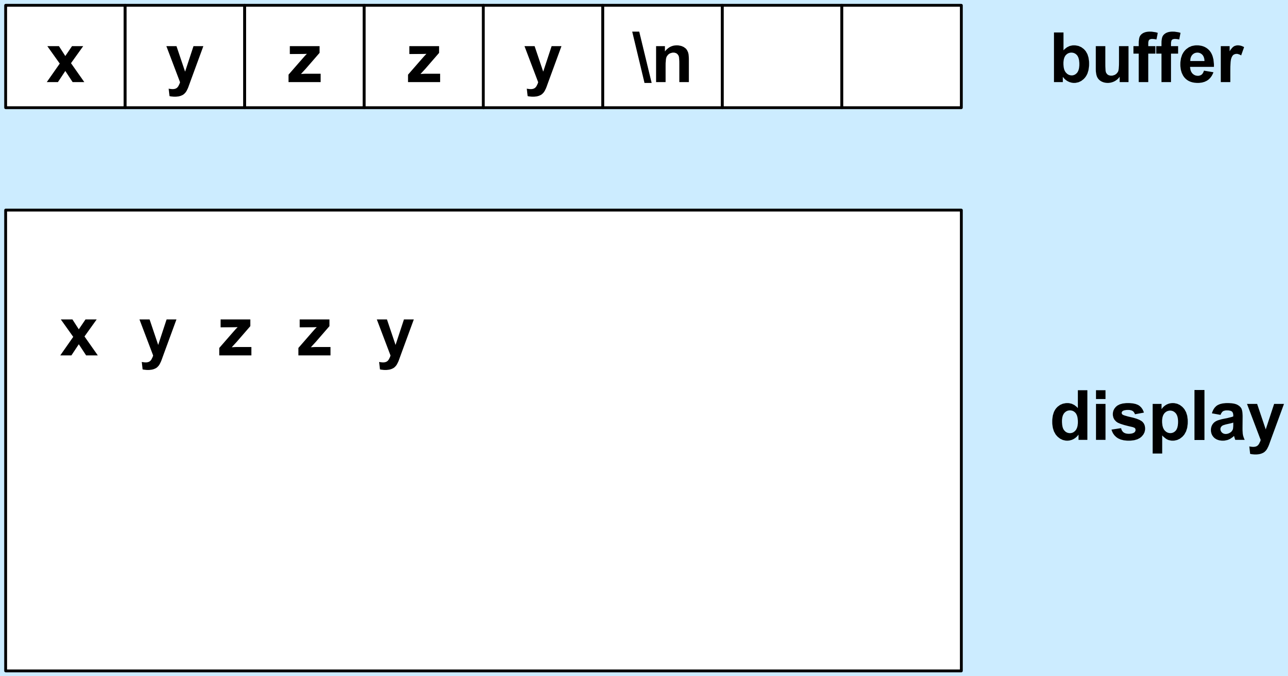
Standard I/O

```
FILE *stdin;        // declared in stdio.h
FILE *stdout;       // declared in stdio.h
FILE *stderr;       // declared in stdio.h

scanf("%d", &in);   // read via f.d. 0
printf("%d\n", in); // write via f.d. 1
fprintf(stderr, "there was an error\n");
     // write via f.d. 2
```

Buffered Output

```
printf("xy");
printf("zz");
printf("y\n");
```



x	y	z	z	y	\n		

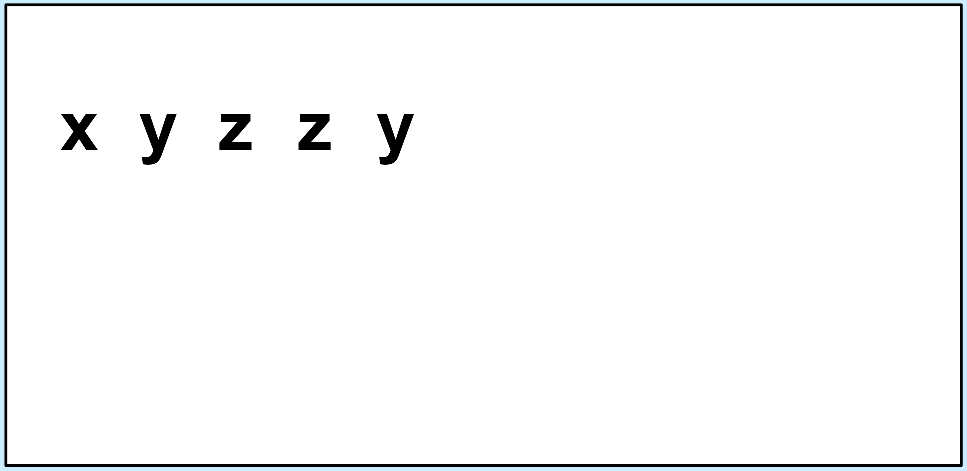
buffer

x y z z y

display

Unbuffered Output

```
fprintf(stderr, "xy");
fprintf(stderr, "zz");
fprintf(stderr, "y\n");
```


x y z z y

display

I/O System Calls

- **int** file_descriptor = open(pathname, mode [, permissions])
- **int** close(file_descriptor)
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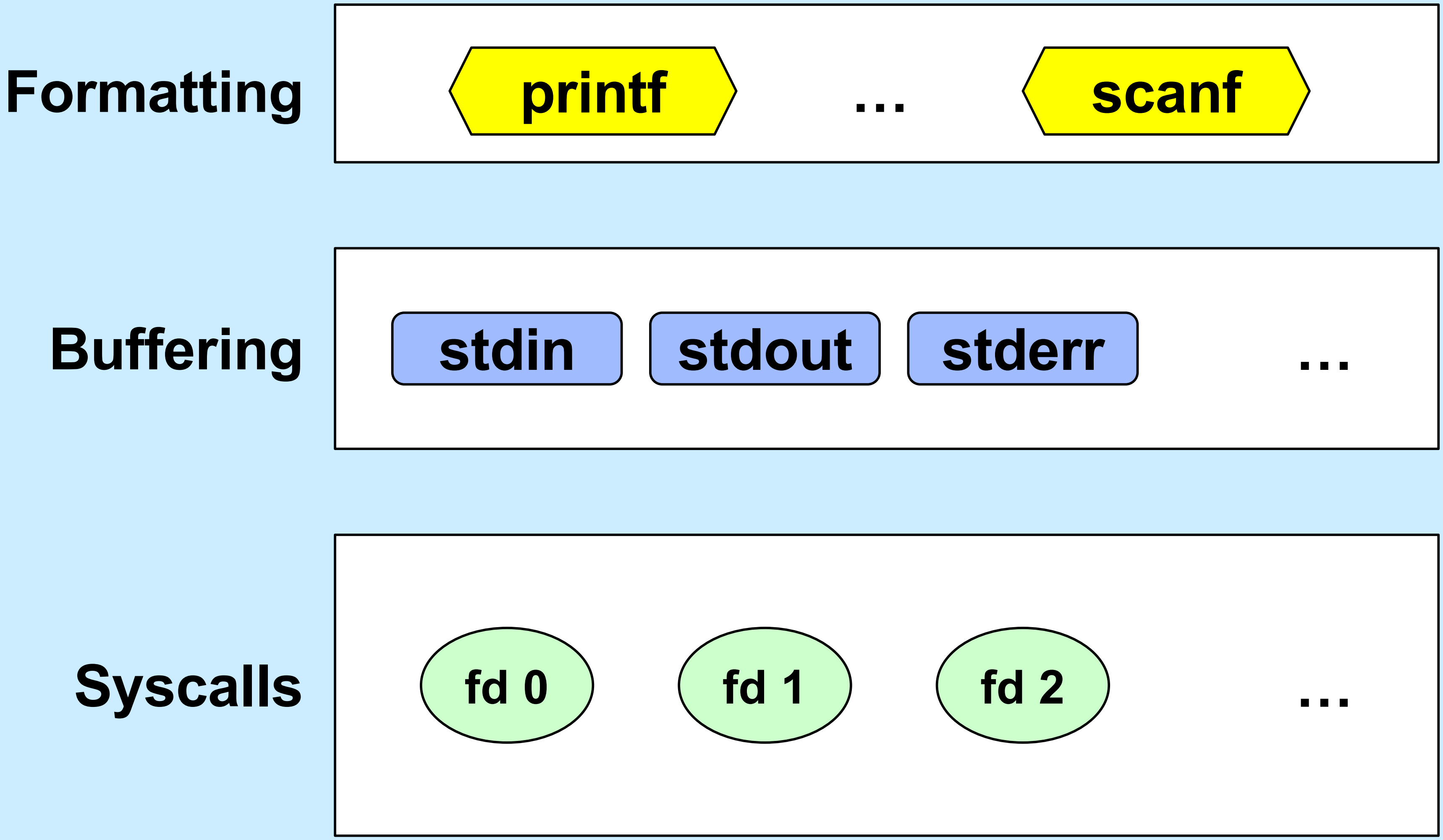
- **off_t** position = lseek(file_descriptor, offset, whence)

Standard File Descriptors

```
int main( ) {
  char buf[BUFSIZE];
  int n;
  const char *note = "Write failed\n";

  while ((n = read(0, buf, sizeof(buf))) > 0)
   if (write(1, buf, n) != n) {
         write(2, note, strlen(note));
         exit(1);
   }
  return(0);
}
```

Standard I/O Library



Formatting

printf … scanf

Buffering

stdin stdout stderr …

Syscalls

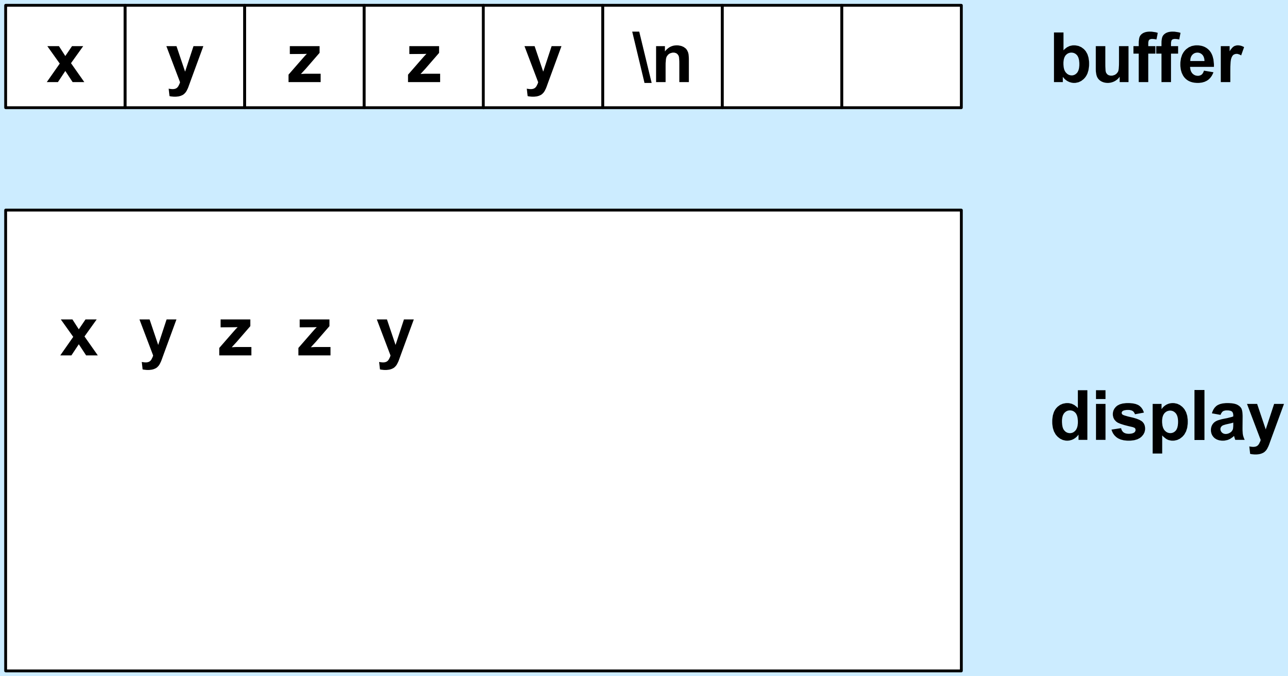
fd 0 fd 1 fd 2 …

Standard I/O

```
FILE *stdin;           // declared in stdio.h
FILE *stdout;          // declared in stdio.h
FILE *stderr;          // declared in stdio.h

scanf("%d", &in);      // read via f.d. 0
printf("%d\n", in);    // write via f.d. 1
fprintf(stderr, "there was an error\n");
     // write via f.d. 2
```

Buffered Output

```
printf("xy");
printf("zz");
printf("y\n");
```



x	y	z	z	y	\n		

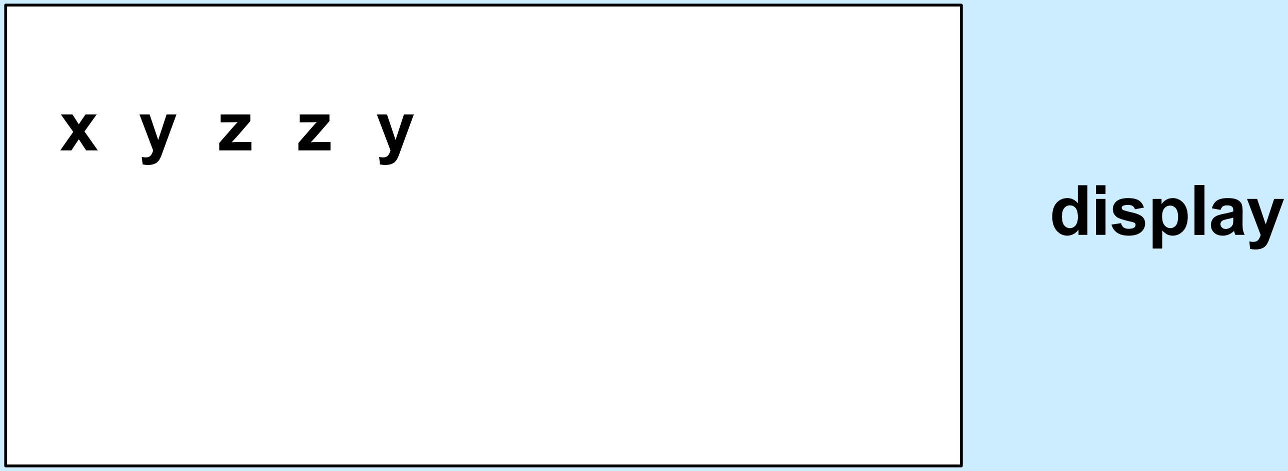
buffer

x y z z y

display

Unbuffered Output

```
fprintf(stderr, "xy");
fprintf(stderr, "zz");
fprintf(stderr, "y\n");
```



A Program

```
int main(int argc, char *argv[]) {
  if (argc != 2) {
    fprintf(stderr, "Usage: echon reps\n");
    exit(1);
  }
  int reps = atoi(argv[1]);
  if (reps > 2) {
    fprintf(stderr, "reps too large, reduced to 2\n");
    reps = 2;
  }
  char buf[256];
  while (fgets(buf, 256, stdin) != NULL)
    for (int i=0; i<reps; i++)
      fputs(buf, stdout);
  return(0);
}
```

From the Shell ...

```
$ echon 1
```

- *stdout* (fd 1) and *stderr* (fd 2) go to the display
- *stdin* (fd 0) comes from the keyboard

```
$ echon 1 > Output
```

- *stdout* goes to the file “Output” in the current directory
- *stderr* goes to the display
- *stdin* comes from the keyboard

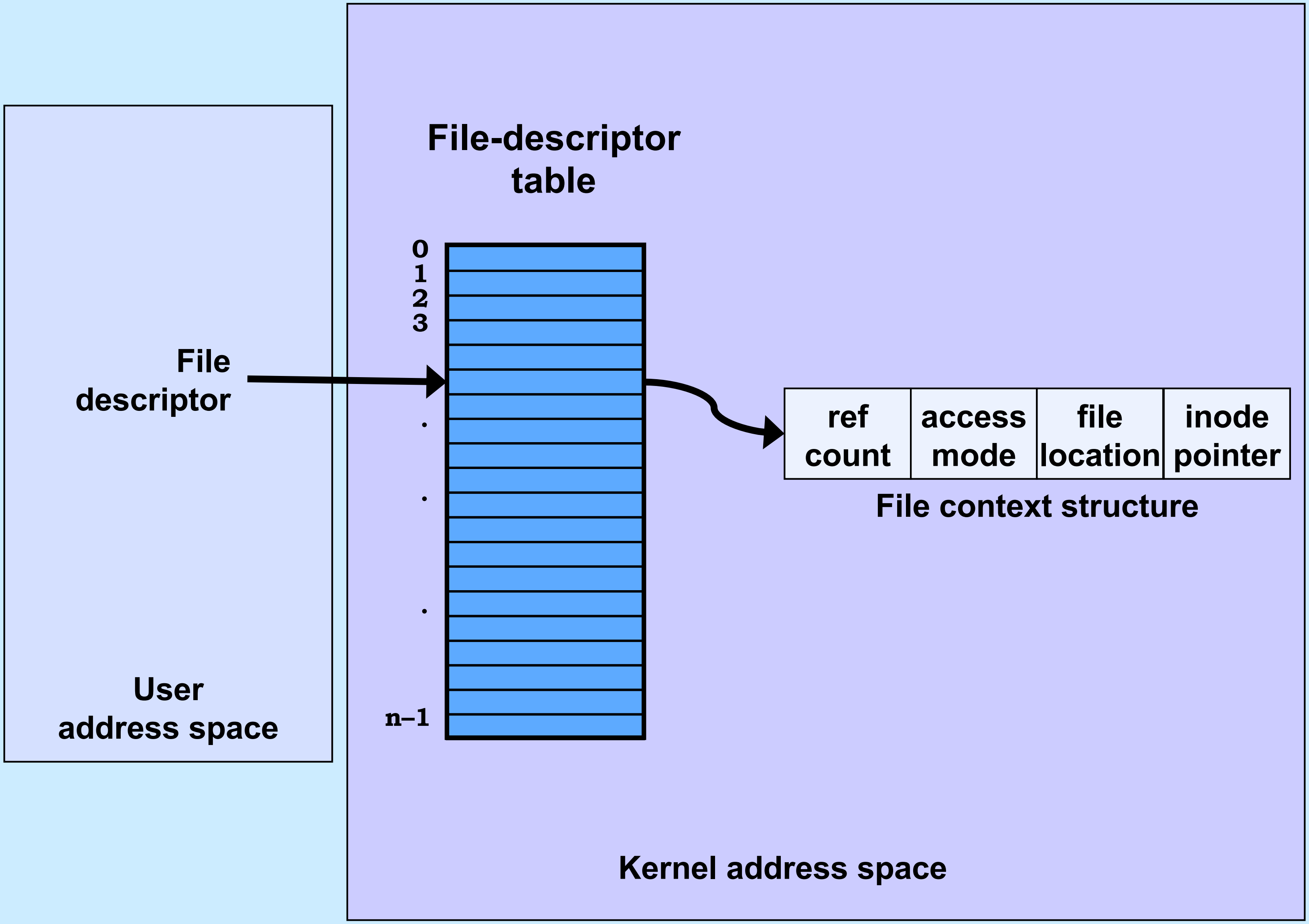
```
$ echon 1 < Input
```

- *stdin* comes from the file “Input” in the current directory

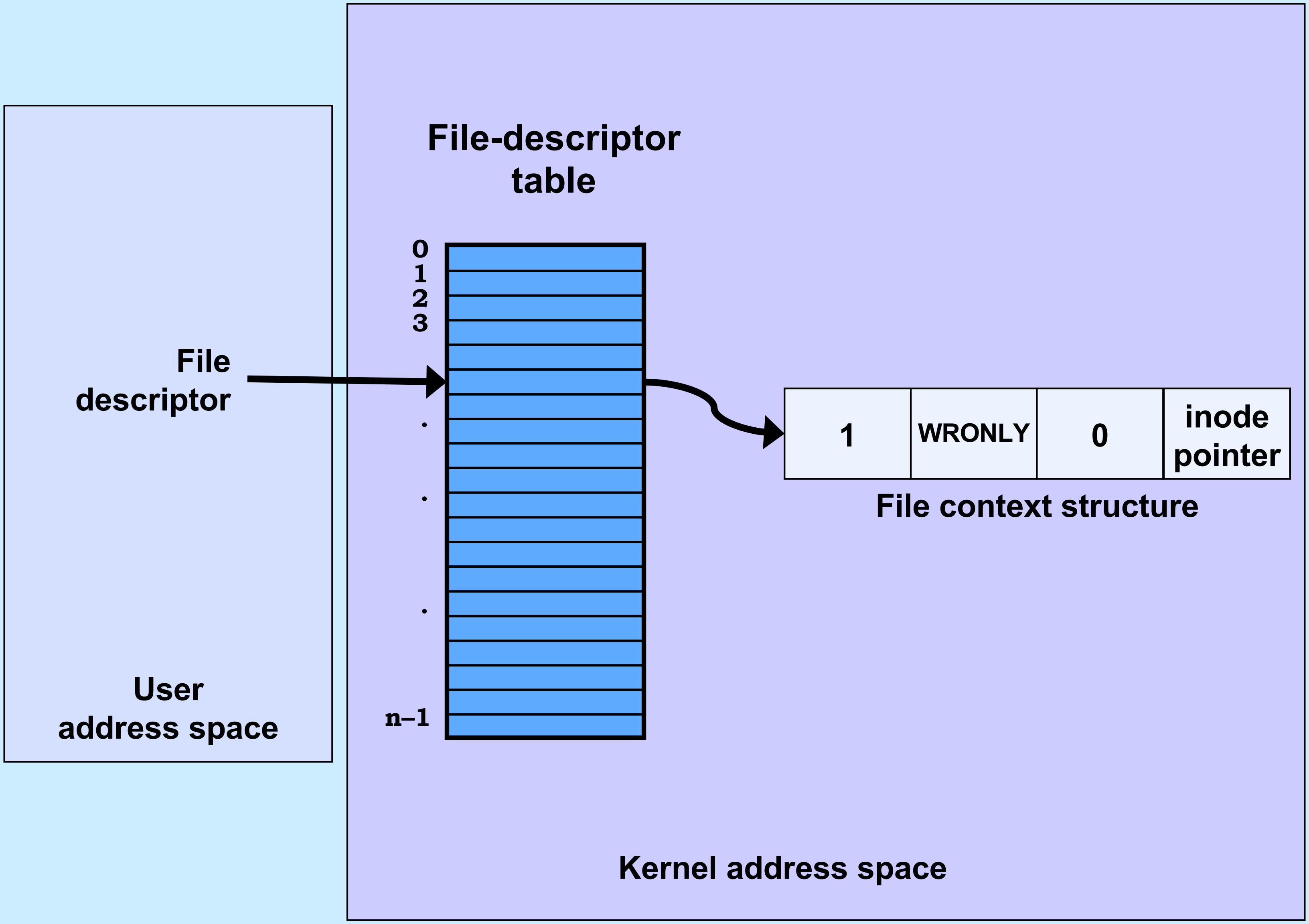
Redirecting Stdout in C

```
if ((pid = fork()) == 0) {
   /* set up file descriptor 1 in the child process */
   close(1);
   if (open("/home/twd/Output", O_WRONLY) == -1) {
      perror("/home/twd/Output");
      exit(1);
   }
   char *argv[] = {"echon", "2", NULL};
   execv("/home/twd/bin/echon", argv);
   exit(1);
}

/* parent continues here */

waitpid(pid, 0, 0);     // wait for child to terminate
```

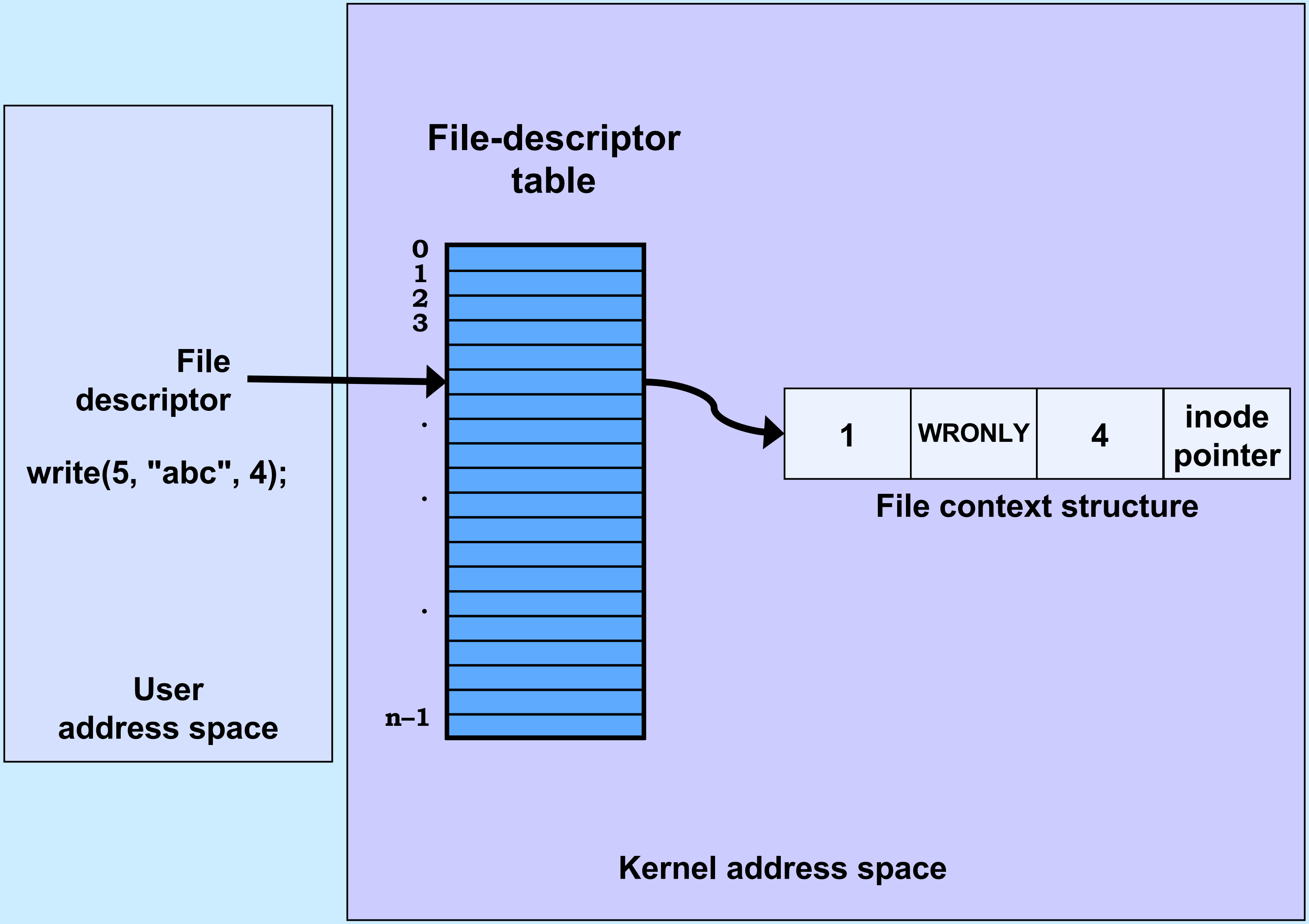
File-Descriptor Table



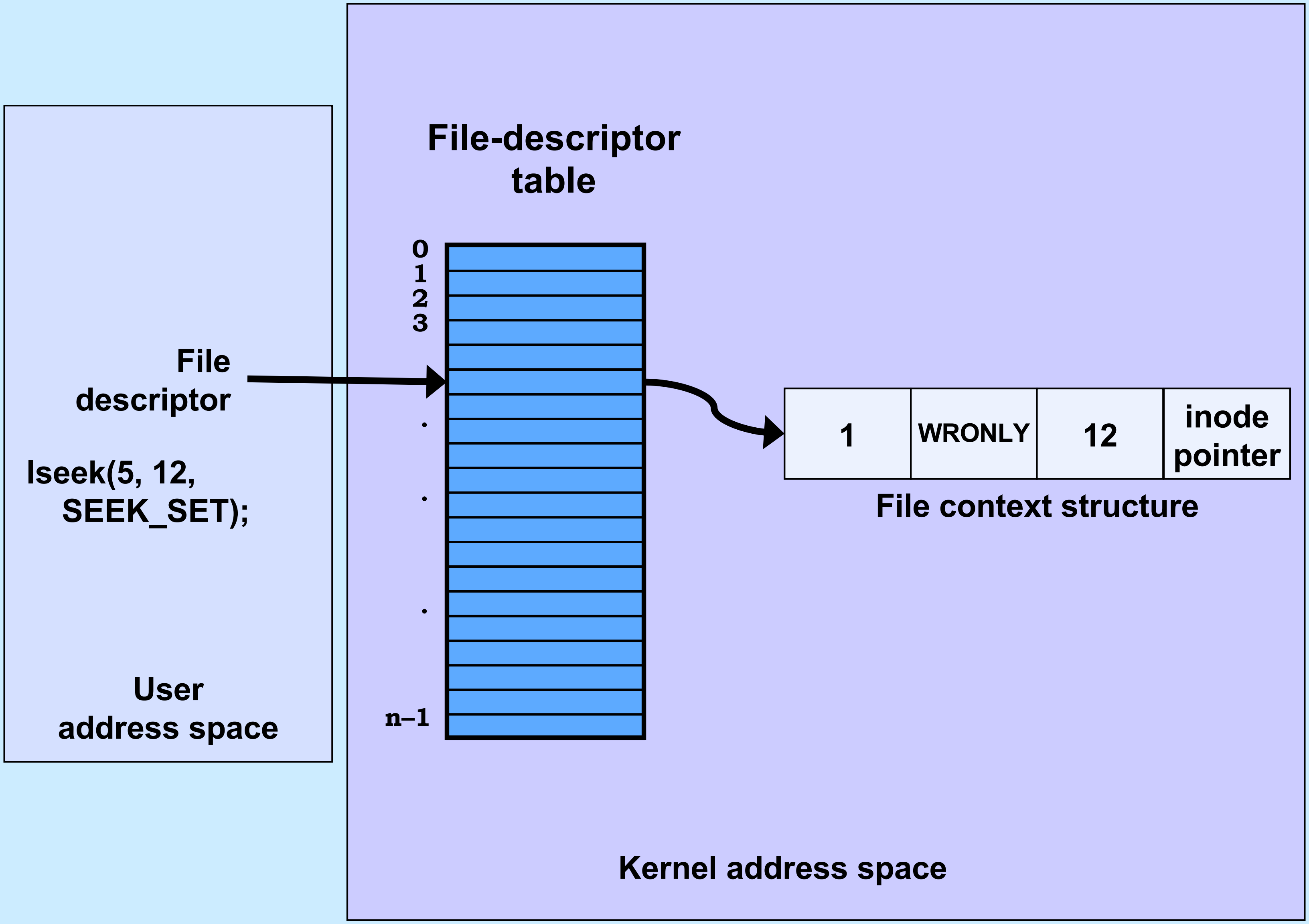
File Location



File Location



File Location



lseek(5, 12,
    SEEK_SET);

Allocation of File Descriptors

- Whenever a process requests a new file descriptor, the lowest-numbered file descriptor not already associated with an open file is selected; thus

```
#include <fcntl.h>
#include <unistd.h>

close(0);
fd = open("file", O_RDONLY);
```

  - will always associate *file* with file descriptor 0 (assuming that *open* succeeds)

Redirecting Output … Twice

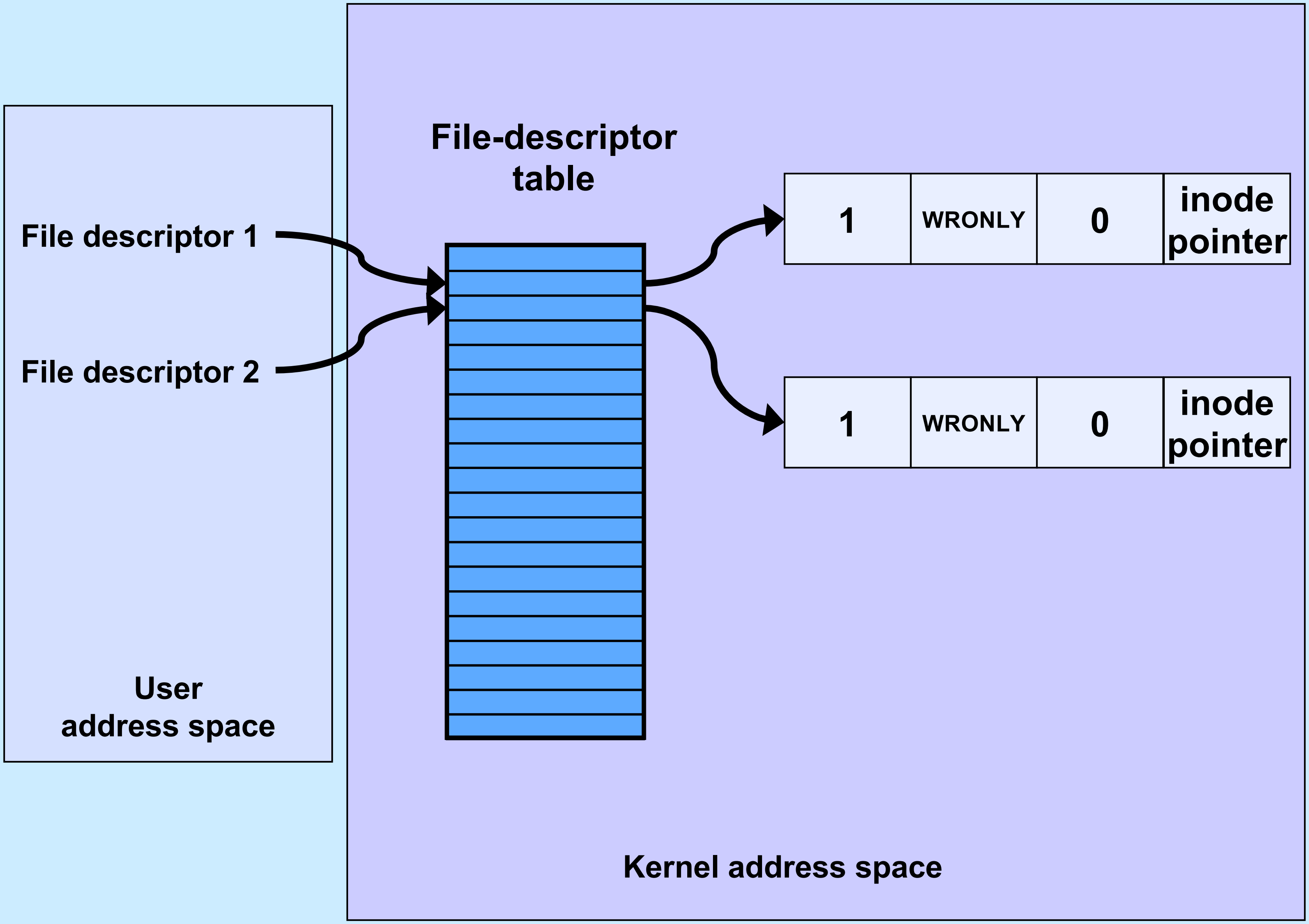
```
if (fork() == 0) {
   /* set up file descriptors 1 and 2 in the child process */
   close(1);
   close(2);
   if (open("/home/twd/Output", O_WRONLY) == -1) {
      exit(1);
   }
   if (open("/home/twd/Output", O_WRONLY) == -1) {
      exit(1);
   }
   char *argv[] = {"echon", 2, NULL};
   execv("/home/twd/bin/echon", argv);
   exit(1);
}
/* parent continues here */
```

From the Shell ...

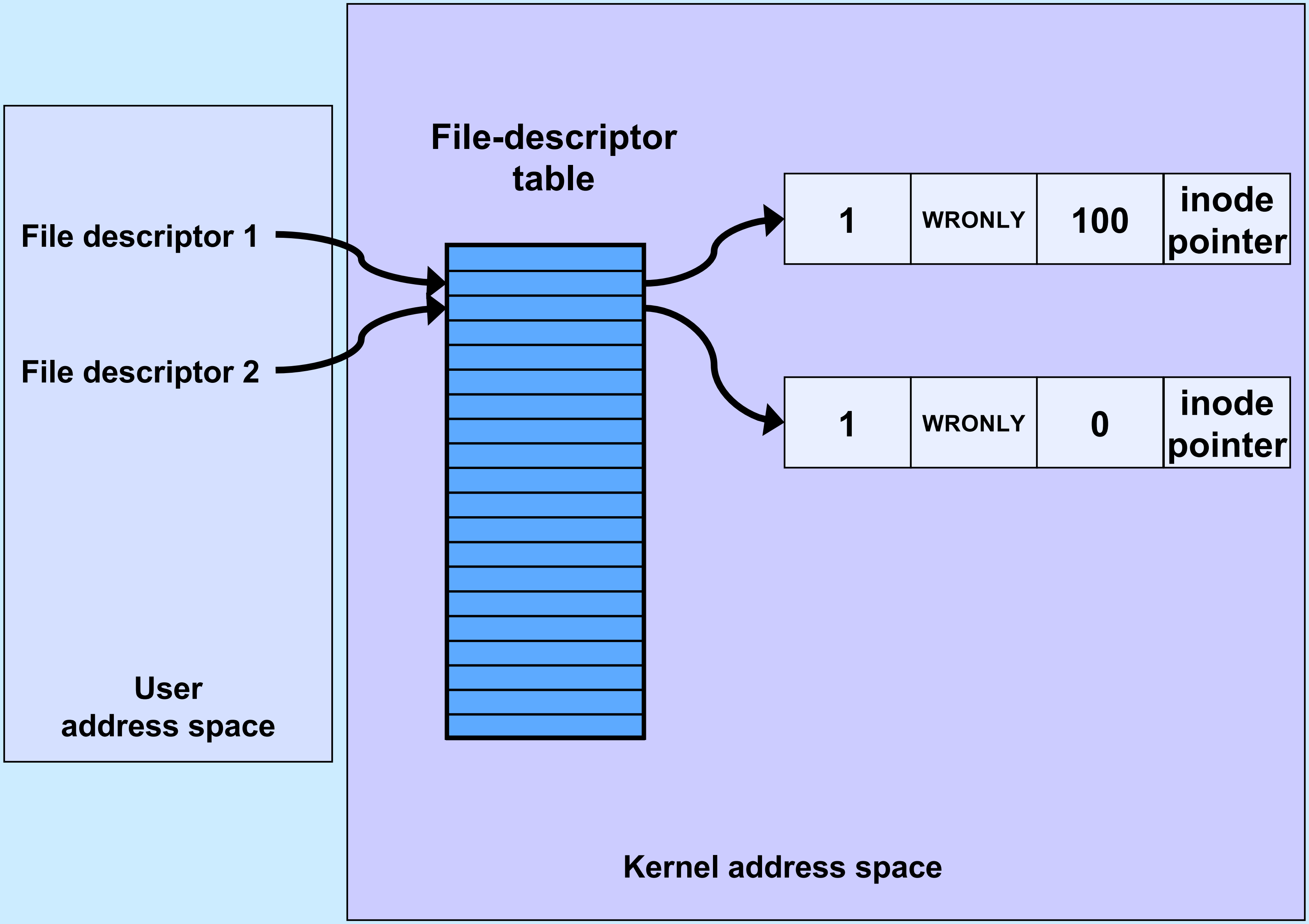
```
$ echon 1 >Output 2>Output
```

- both stdout and stderr go to Output file

Redirected Output



Redirected Output After Write



Quiz 1

- Suppose we run

```
$ echon 3 >Output 2>Output
```

- The input line is

```
X
```

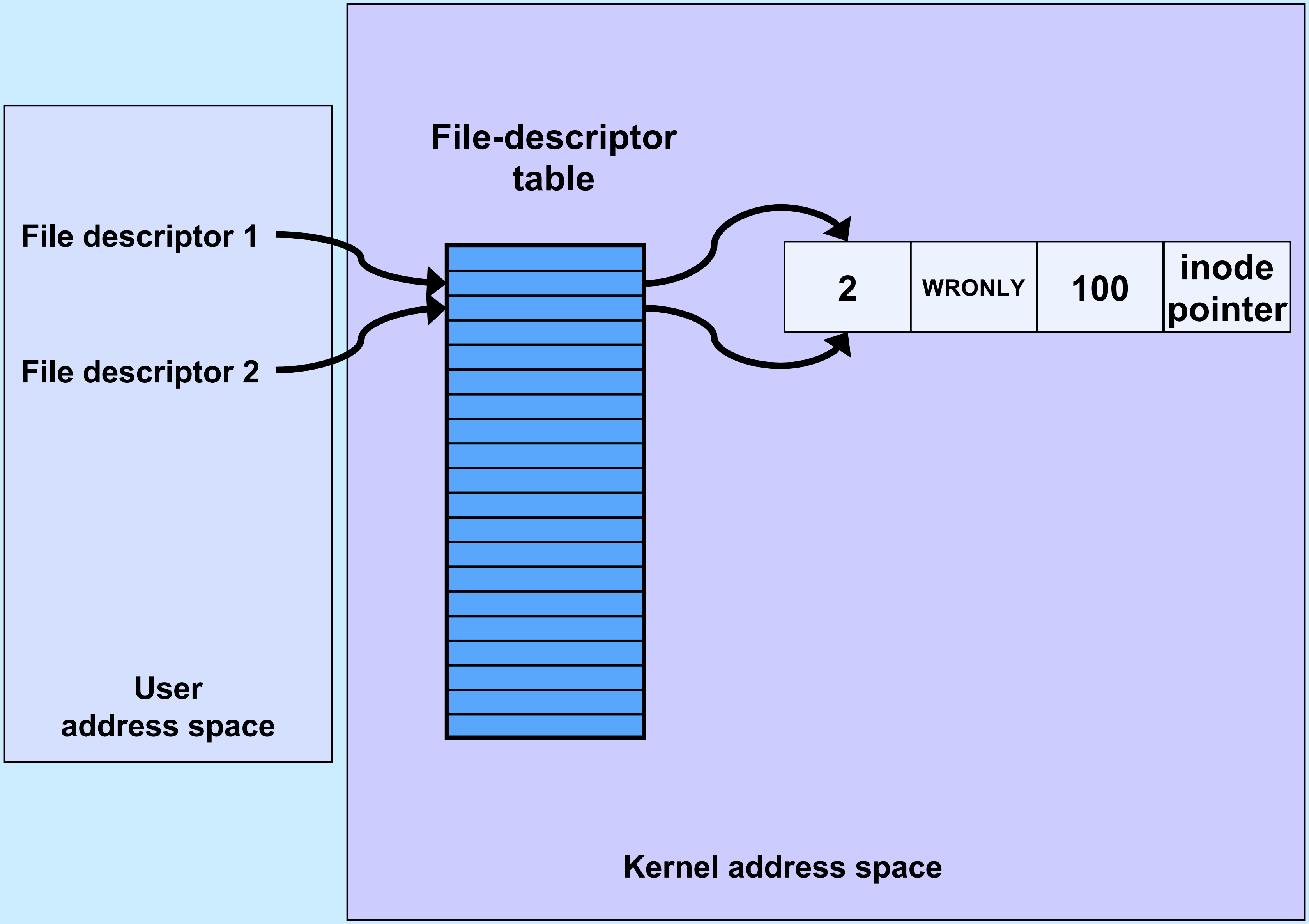
- What is the final content of Output?

```
a) X\nX\nreps too large, reduced to 2\n
b) X\nX\n too large, reduced to 2\n
c) reps too large, reduced to 2\nX\nX\n
```

Sharing Context Information

```
if (fork() == 0) {
   /* set up file descriptors 1 and 2 in the child process */
   close(1);
   close(2);
   if (open("/home/twd/Output", O_WRONLY) == -1) {
      exit(1);
   }
   dup(1); /* set up file descriptor 2 as a duplicate of 1 */
   char *argv[] = {"echon", 2};
   execv("/home/twd/bin/echon", argv);
   exit(1);
}
/* parent continues here */
```

Redirected Output After Dup



From the Shell ...

```
$ echon 3 >Output 2>&1
```

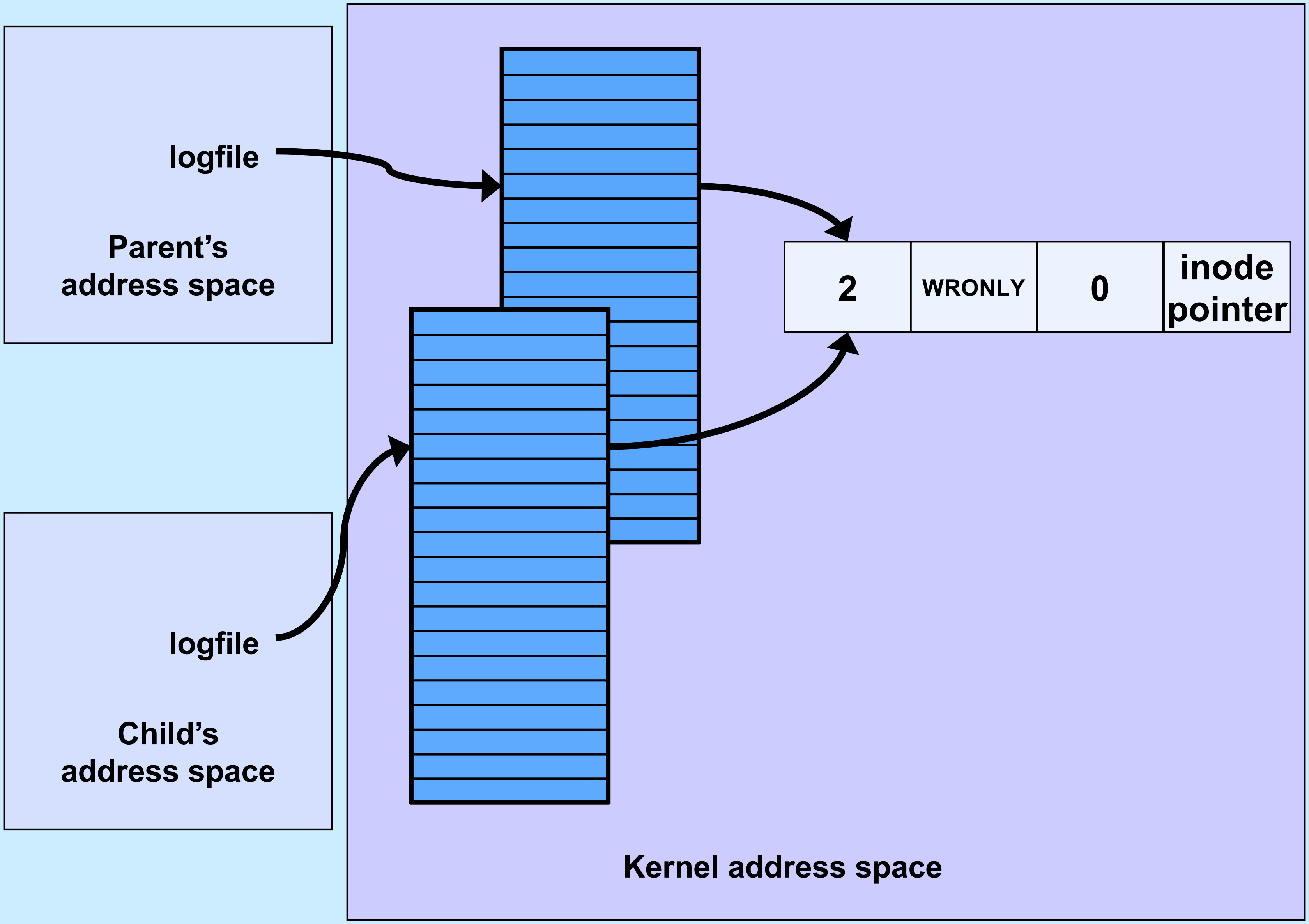
- stdout goes to Output file, stderr is the dup of fd 1
- with input “X\n” it now produces in Output:

```
reps too large, reduced to 2\nX\nX\n
```

Fork and File Descriptors

```
int logfile = open("log", O_WRONLY);
if (fork() == 0) {
   /* child process computes something, then does: */
   write(logfile, LogEntry, strlen(LogEntry));
   …
   exit(0);
}

/* parent process computes something, then does: */

write(logfile, LogEntry, strlen(LogEntry));
…
```

File Descriptors After Fork



Quiz 2

```
int main() {
  if (fork() == 0) {
    fprintf(stderr, "Child");
    exit(0);
  }
  fprintf(stderr, "Parent");
}
```

Suppose the program is run as:

```
$ prog >file 2>&1
```

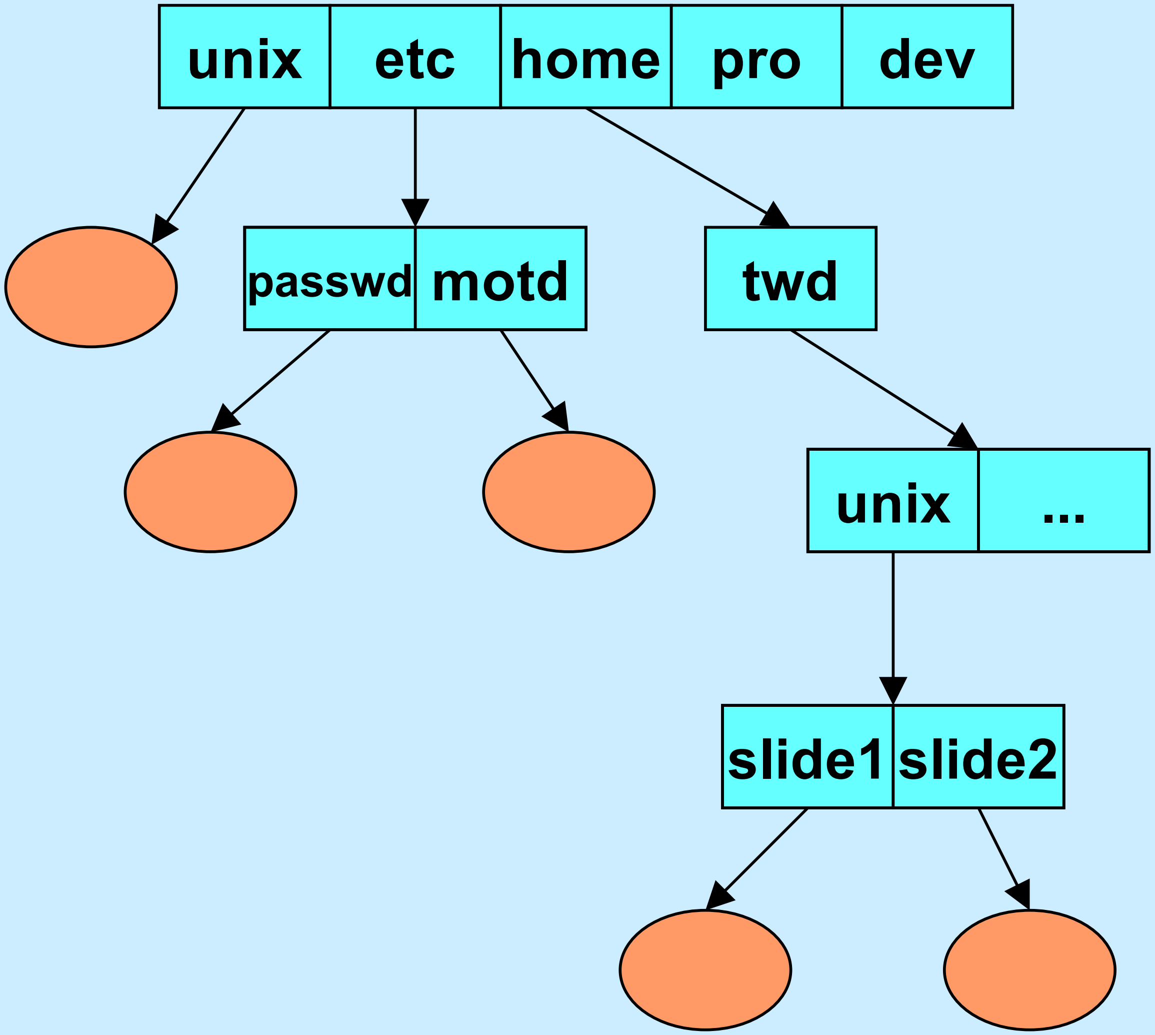
What is the final content of file? (Assume writes are “atomic”.)

a) either “Childt” or “Parent”

b) either “Child” or “Parent”

c) either “ChildParent” or “ParentChild”

Directories



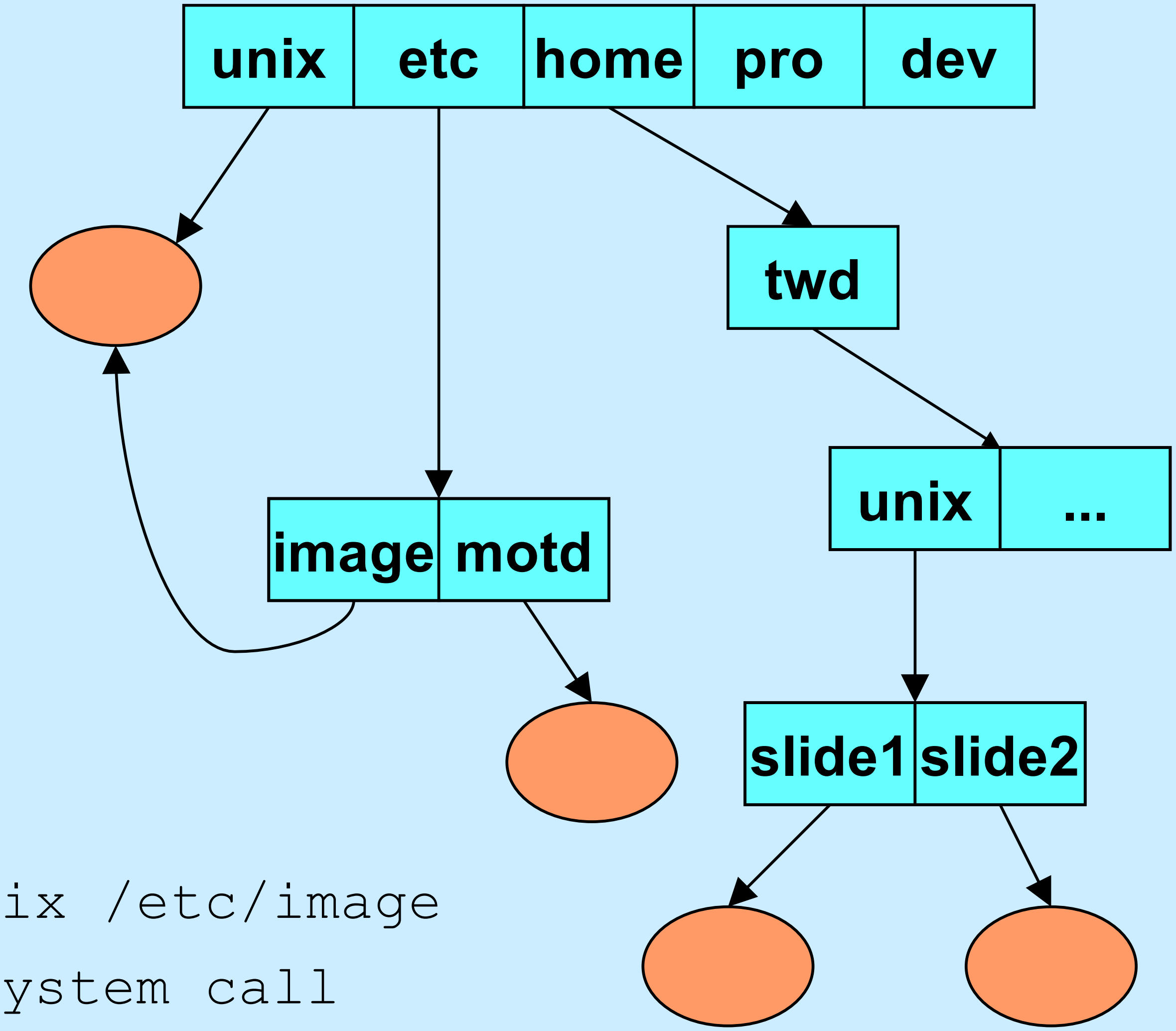
Directory Representation

Component Name	Inode Number

directory entry

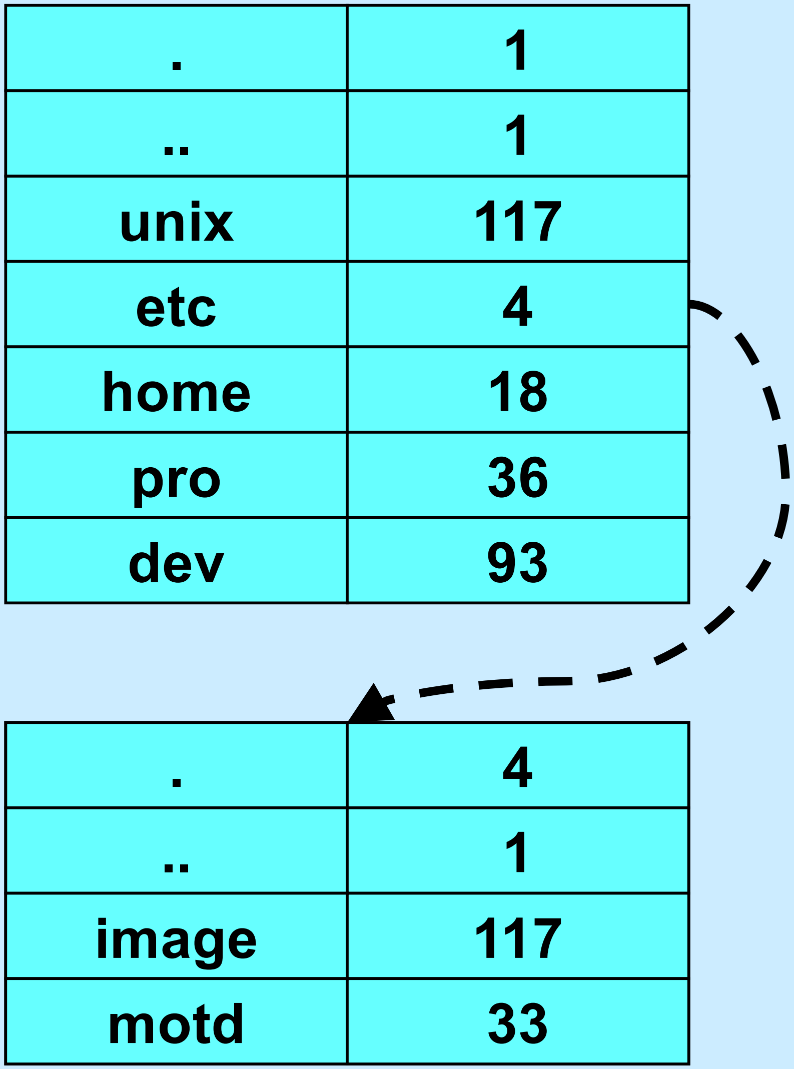
.	1
..	1
unix	117
etc	4
home	18
pro	36
dev	93

Hard Links



```
$ ln /unix /etc/image
# link system call
```

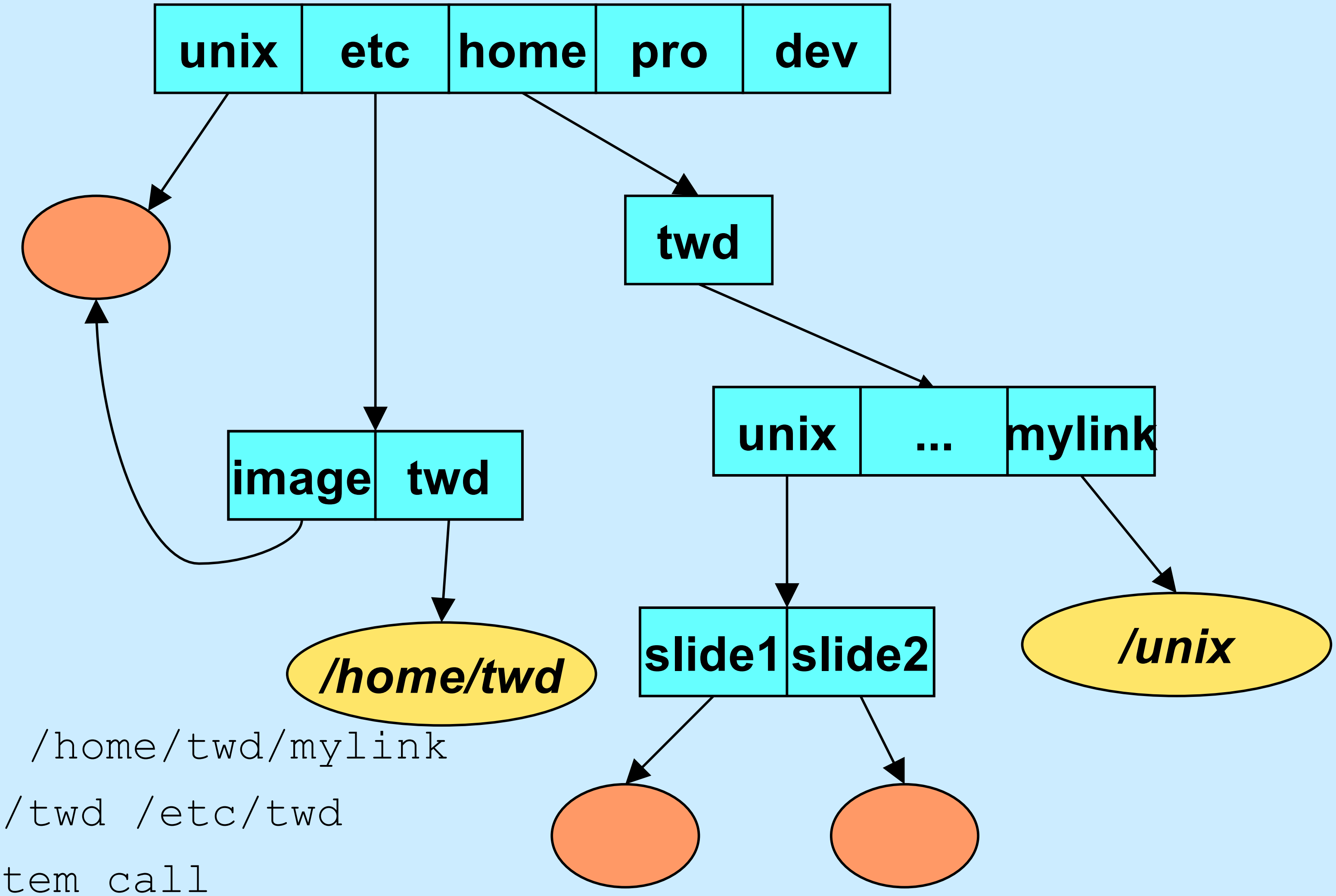
Directory Representation



.	1
..	1
unix	117
etc	4
home	18
pro	36
dev	93

.	4
..	1
image	117
motd	33

Symbolic Links



```
% ln -s /unix /home/twd/mylink
% ln -s /home/twd /etc/twd
# symlink system call
```

Working Directory

- Maintained in kernel for each process
  - paths not starting from “/” start with the working directory
  - changed by use of the *chdir* system call
    - *cd* shell command
  - displayed (via shell) using “pwd”
    - how is this done?

Open

```
#include <sys/types.h>
#include <sys/stat.h>
#include <fcntl.h>
int open(const char *path, int options [, mode_t mode])
```

- options
  - » O_RDONLY open for reading only
  - » O_WRONLY open for writing only
  - » O_RDWR open for reading and writing
  - » O_APPEND set the file offset to *end of file* prior to each *write*
  - » O_CREAT if the file does not exist, then create it, setting its mode to *mode* adjusted by *umask*
  - » O_EXCL if O_EXCL and O_CREAT are set, then *open* fails if the file exists
  - » O_TRUNC delete any previous contents of the file

Appending Data to a File (1)

```
int fd = open("file", O_WRONLY);
lseek(fd, 0, SEEK_END);
    // sets the file location to the end
write(fd, buffer, bsize);
    // does this always write to the
    // end of the file?
```

Appending Data to a File (2)

```
int fd = open("file", O_WRONLY | O_APPEND);
write(fd, buffer, bsize);
    // this is guaranteed to write to the
    // end of the file
```

In the Shell ...

```
% program >> file
```

File Access Permissions

- Who’s allowed to do what?
  - who
    - user (owner)
    - group
    - others (rest of the world)
  - what
    - read
    - write
    - execute

Permissions Example

adm group:
joe, angie

```
$ ls -lR
.:
total 2
drwxr-x--x  2 joe    adm    1024 Dec 17 13:34 A
drwxr-----  2 joe    adm    1024 Dec 17 13:34 B

./A:
total 1
-rw-rw-rw-  1 joe    adm     593 Dec 17 13:34 x

./B:
total 2
-r--rw-rw-  1 joe    adm     446 Dec 17 13:34 x
-rw----rw-  1 angie  adm     446 Dec 17 13:45 y
```

Setting File Permissions

```
#include <sys/types.h>
#include <sys/stat.h>
int chmod(const char *path, mode_t mode)
```

- sets the file permissions of the given file to those specified in *mode*
- only the owner of a file and the superuser may change its permissions
- nine combinable possibilities for *mode* (*read/write/execute* for *user*, *group*, and *others*)
  - » `S_IRUSR (0400), S_IWUSR (0200), S_IXUSR (0100)`
  - » `S_IRGRP (040), S_IWGRP (020), S_IXGRP (010)`
  - » `S_IROTH (04), S_IWOTH (02), S_IXOTH (01)`

Permission Bits

- It’s worth your while to remember this!
  - read: 4
  - write: 2
  - execute: 1
  - read/write: 6
  - read/write/execute: 7

  - user:group:others
    - » 0751
      - rwx for user, rx for group, x for others
    - » 0640
      - rw for user, r for group, nothing for others

Umask

- Standard programs create files with “maximum needed permissions” as mode
  - compilers: 0777
  - editors: 0666
- Per-process parameter, *umask*, used to turn off undesired permission bits
  - e.g., turn off all permissions for others, write permission for group: set umask to 027
    - compilers: permissions = 0777 & ~(027) = 0750
    - editors: permissions = 0666 & ~(027) = 0640
  - set with *umask* system call or (usually) shell command

Quiz 3

You get the following message when you attempt to execute ./program (a file that you own):

```
bash: ./program: Permission denied
```

Your first response should be:

a) execute the shell command
   `chmod 0644 program`

b) execute the shell command
   `chmod 0755 program`

c) find the source code for program and recompile it

d) make an Ed post

Creating a File

- Use either *open* or *creat*
  - `open(const char *pathname, int flags, mode_t mode)`
    - » flags must include O_CREAT
  - `creat(const char *pathname, mode_t mode)`
    - » open is preferred
- The *mode* parameter helps specify the permissions of the newly created file
  - permissions = mode & ~umask