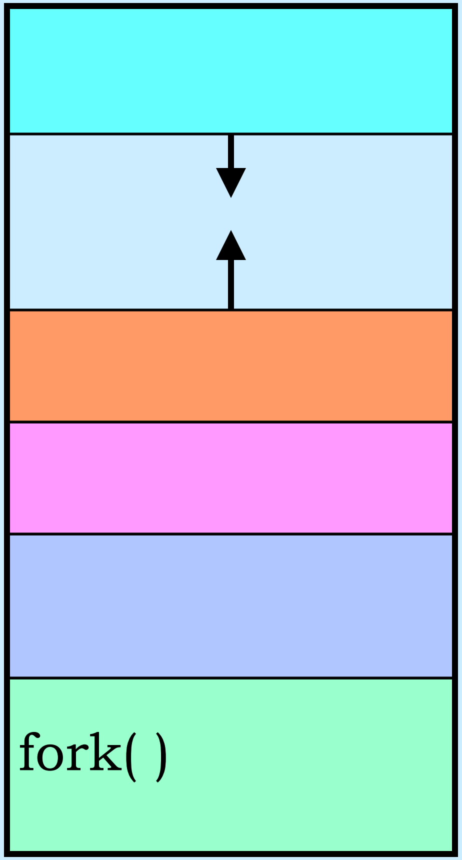
CS 33

Architecture and the OS (2)

Recap: Creating Your Own Processes

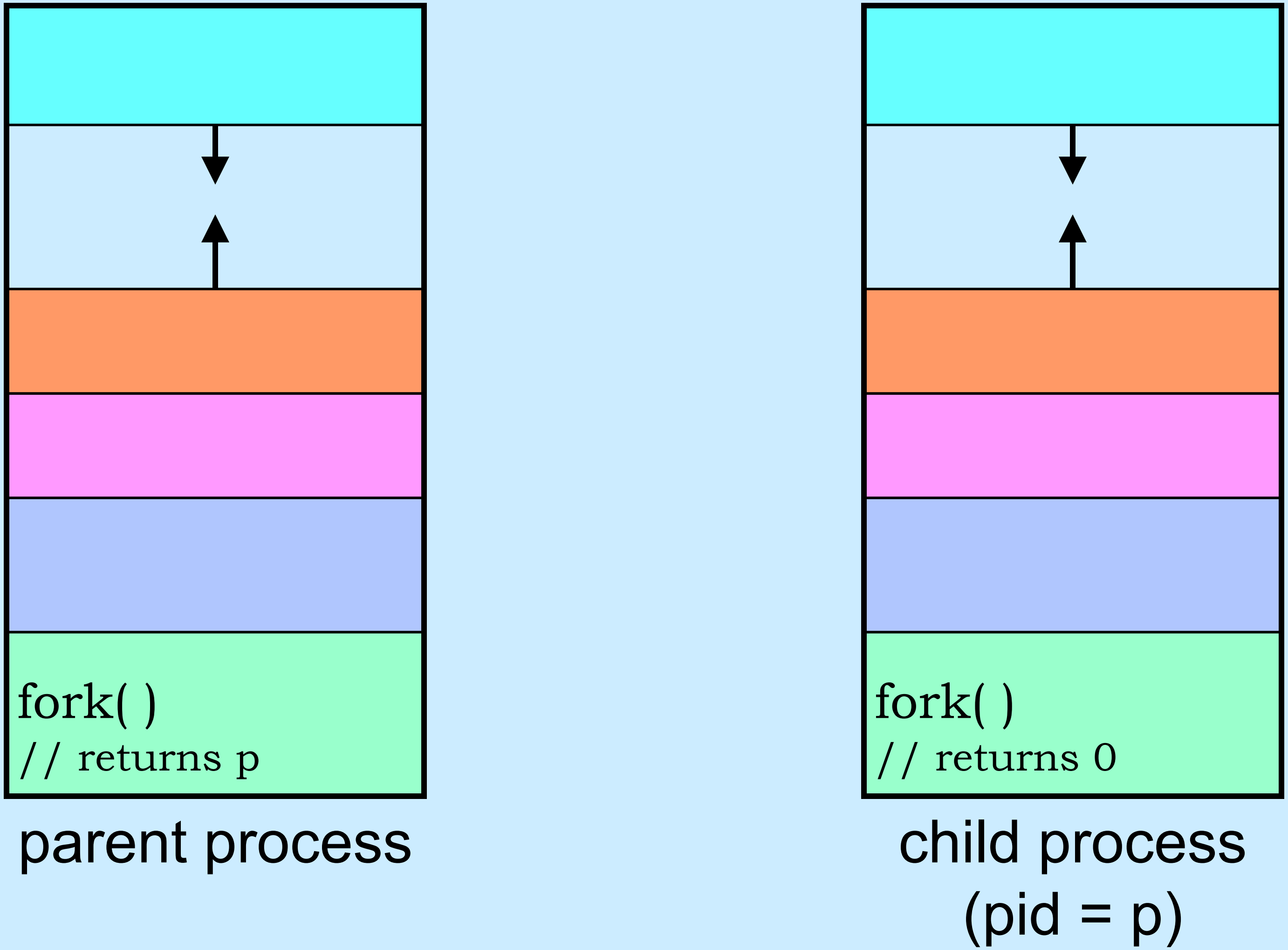
```
#include <unistd.h>
int main( ) {
  pid_t pid;
  if ((pid = fork()) == 0) {
      /* new process starts
         running here */
  }
  /* old process continues
     here */
}
```

Creating a Process: Before

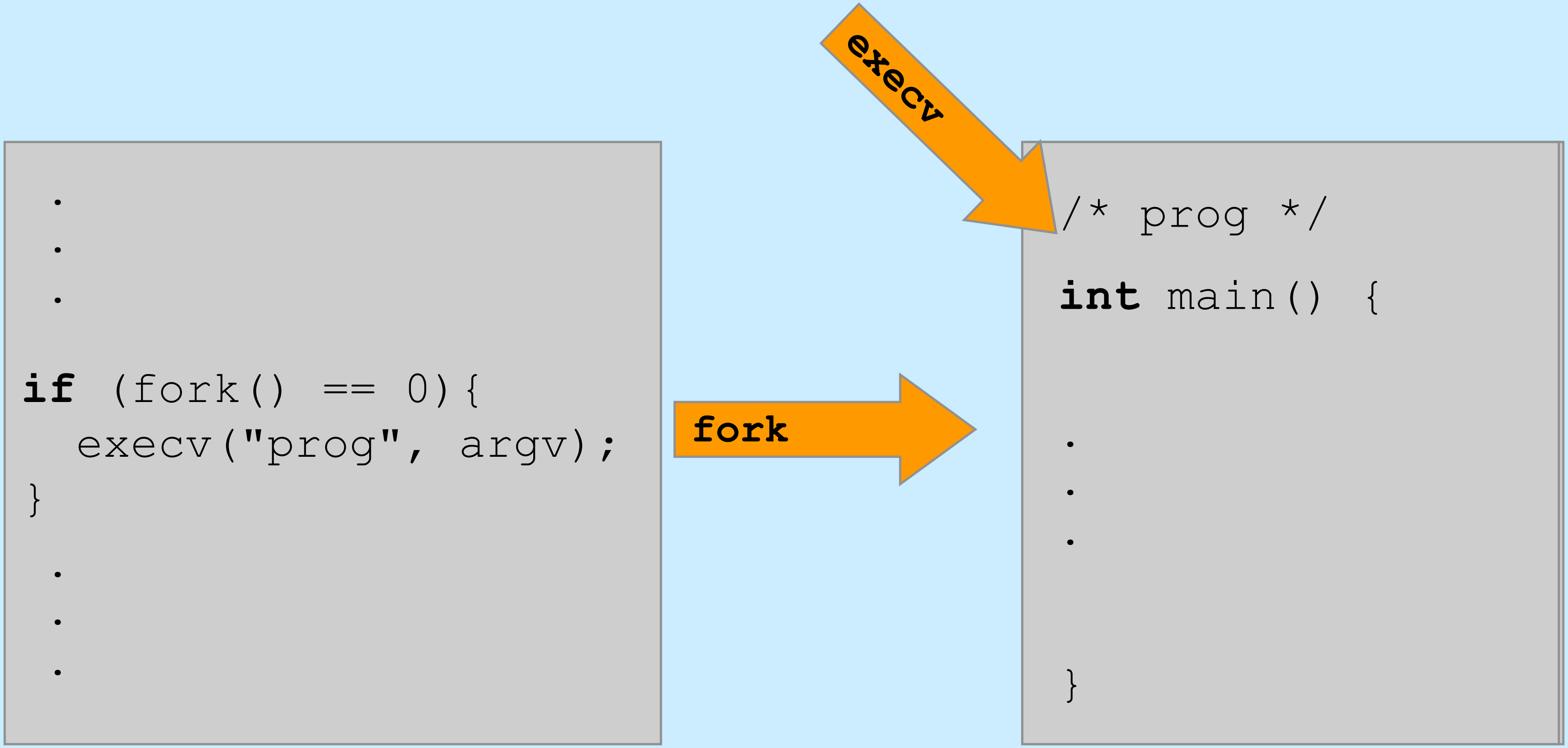


parent process

Creating a Process: After



Putting Programs into Processes

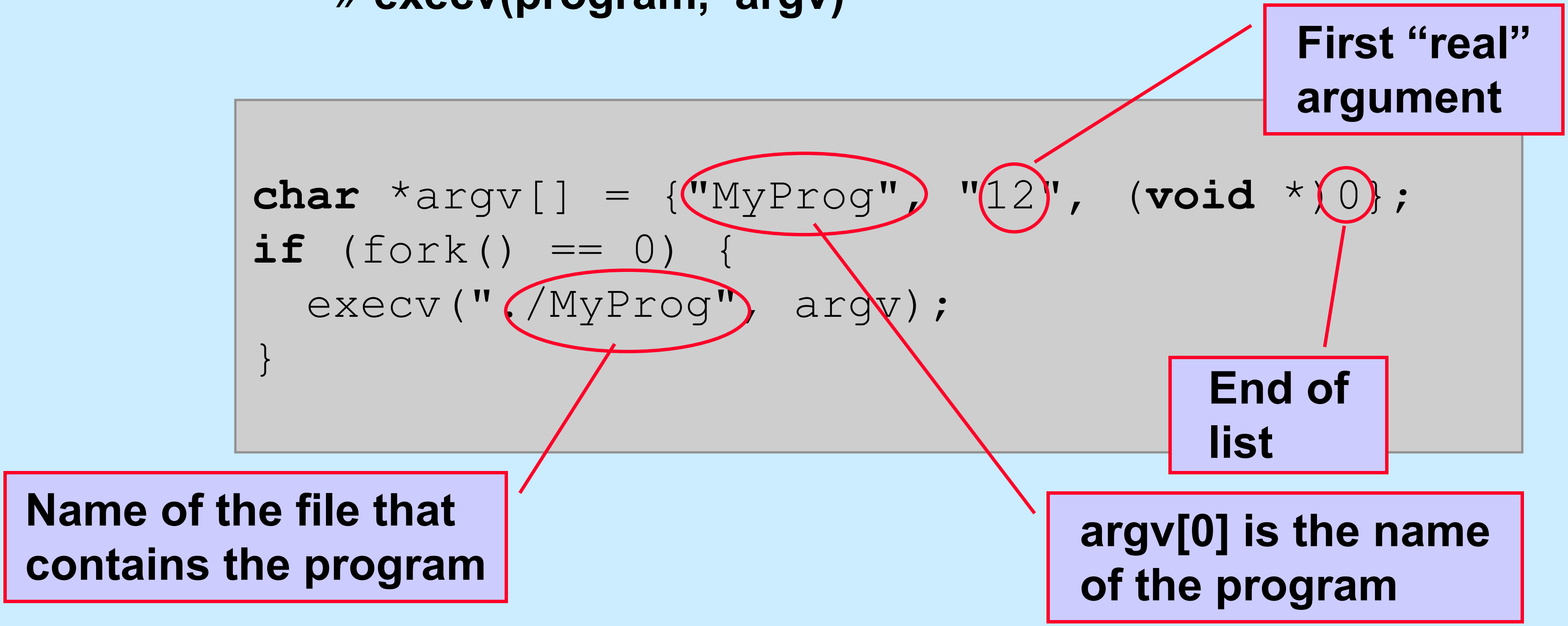


```
 .
 .
 .

if (fork() == 0){
  execv("prog", argv);
}
 .
 .
 .
```

```
/* prog */
int main() {

 .
 .
 .

}
```

Exec

- **Family of related system functions**
  - we concentrate on one:
    - » execv(program, argv)



```
char *argv[] = {"MyProg", "12", (void *)0};
if (fork() == 0) {
  execv("./MyProg", argv);
}
```

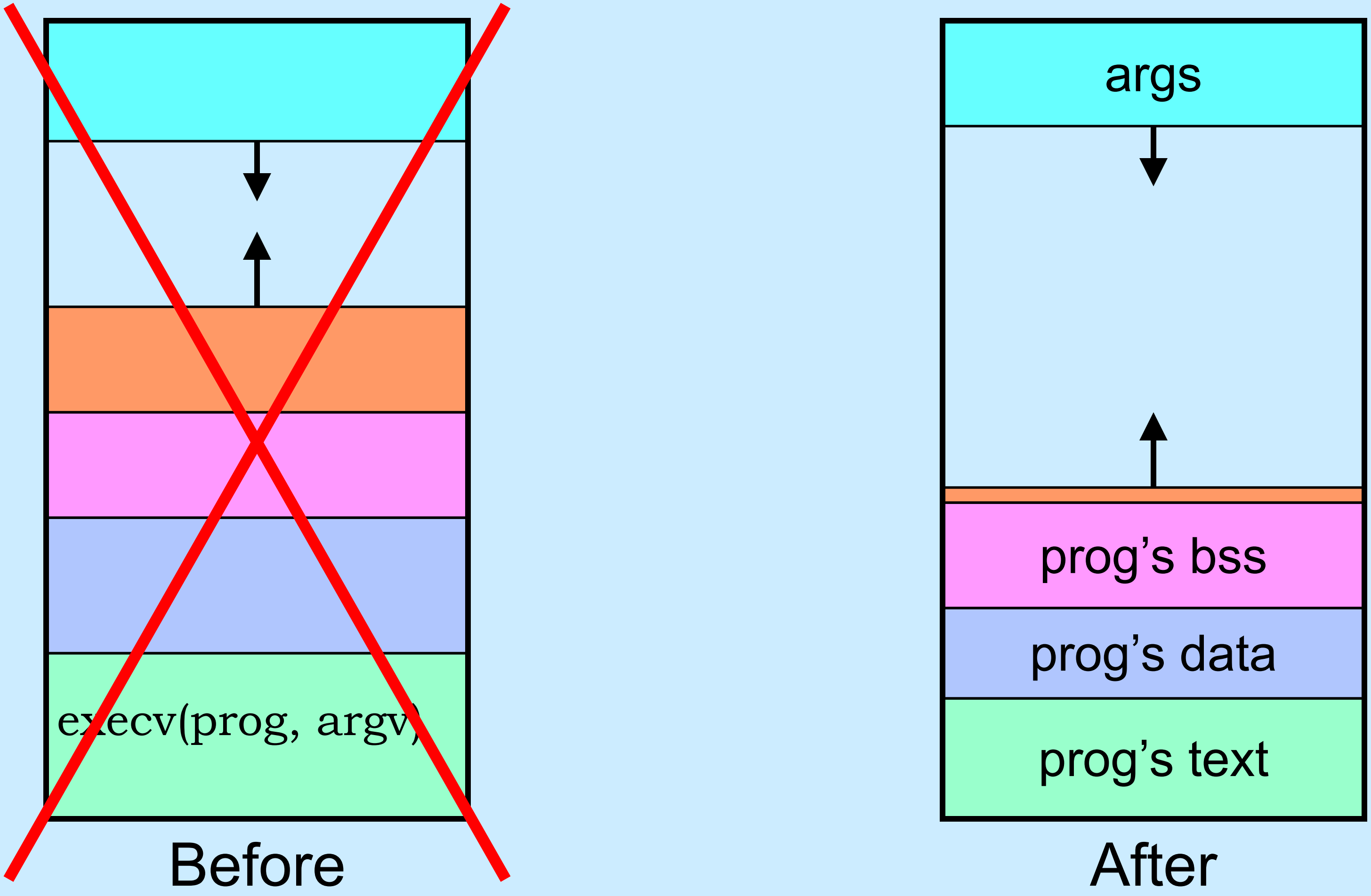
First “real” argument

End of list

Name of the file that contains the program

argv[0] is the name of the program

Loading a New Image



A Random Program …

```
int main(int argc, char *argv[]) {
 if (argc != 2) {
    fprintf(stderr, "Usage: random count\n");
    exit(1);
  }
  int stop = atoi(argv[1]);
  for (int i = 0; i < stop; i++)
    printf("%d\n", rand());
  return 0;
}
```

Passing It Arguments

- **From the shell**

```
$ random 12
```

- **From a C program**

```
if (fork() == 0) {
  char *argv[] = {"random", "12", (void *)0};
  execv("./random", argv);
}
```

Quiz 2

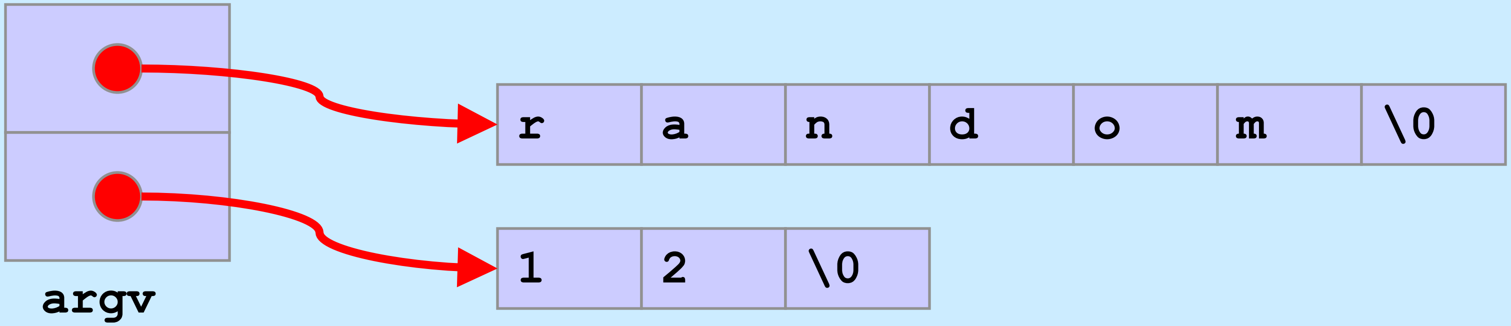
```
if (fork() == 0) {
  char *argv[] = {"random", "12", (void *)0};
  execv("./random", argv);
  printf("random done\n");
}
```

The *printf* statement will be executed

a) always
b) only if execv fails
c) only if execv succeeds

Receiving Arguments

```
int main(int argc, char *argv[]) {
  if (argc != 2) {
    fprintf(stderr, "Usage: random count\n");
    exit(1);
  }
  int stop = atoi(argv[1]);
  for (int i = 0; i < stop; i++)
    printf("%d\n", rand());

  return 0;
}
```



Not So Fast …

- **How does the shell invoke your program?**

```
if (fork() == 0) {
  char *argv = {"random", "12", (void *)0};
  execv("./random", argv);
}
/* what does the shell do here??? */
```

Wait

```
#include <unistd.h>
#include <sys/wait.h>
…
  pid_t pid;
  int status;
  …
  if ((pid = fork()) == 0) {
    char *argv[] = {"random", "12", (void *)0};
    execv("./random", argv);
  }
  waitpid(pid, &status, 0);
```

Exit

```
#include <unistd.h>
#include <stdlib.h>
#include <sys/wait.h>
int main( ) {
  pid_t pid;
  int status;
  if ((pid = fork()) == 0) {
    if (do_work() == 1)
      exit(0); /* success! */
    else
      exit(1); /* failure … */
  }
  waitpid(pid, &status, 0);
  /* low-order byte of status contains exit code.
     WEXITSTATUS(status) extracts it */
```

exit code

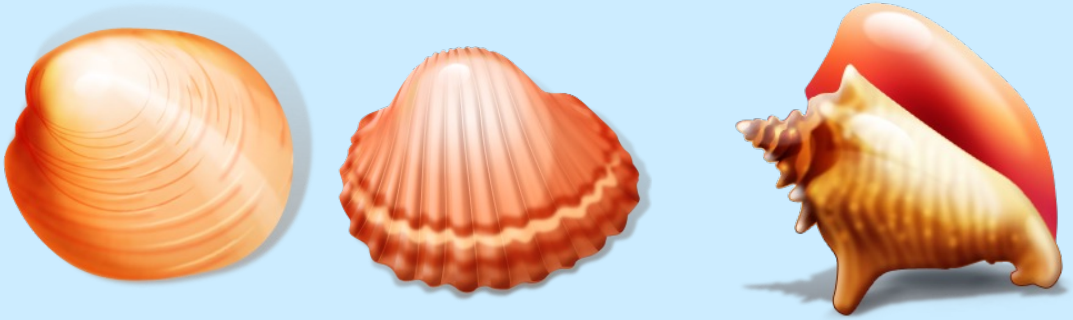
Shell: To Wait or Not To Wait ...

```
$ who

   if ((pid = fork()) == 0) {
      char *argv[] = {"who", 0};
      execv("who", argv);
   }
   waitpid(pid, &status, 0);
   …

$ who &

   if ((pid = fork()) == 0) {
      char *argv[] = {"who", 0};
      execv("who", argv);
   }
   …
```

CS 33

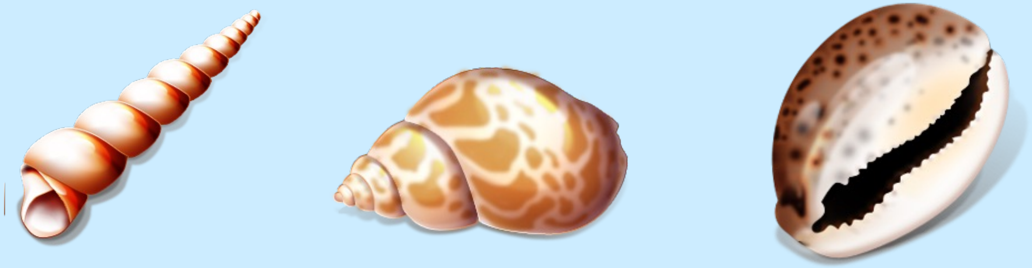
Shells and Files

Shells



- Command and scripting languages for Unix
- First shell: Thompson shell
  - sh, developed by Ken Thompson
  - released in 1971
- Bourne shell
  - also sh, developed by Steve Bourne
  - released in 1977
- C shell
  - csh, developed by Bill Joy
  - released in 1978
  - tcsh, improved version by Ken Greer

More Shells



- Bourne-Again Shell
  - bash, developed by Brian Fox
  - released in 1989
  - found to have a serious security-related bug in 2014
    - » shellshock
- Almquist Shell
  - ash, developed by Kenneth Almquist
  - released in 1989
  - similar to bash
  - dash (debian ash) used for scripts in Debian Linux
    - » faster than bash
    - » less susceptible to shellshock vulnerability

Roadmap

- We explore the file abstraction
  - what are files
  - how do you use them
  - how does the OS represent them
- We explore the shell
  - how does it launch programs
  - how does it connect programs with files
  - how does it control running programs

shell 1

shell 2

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.

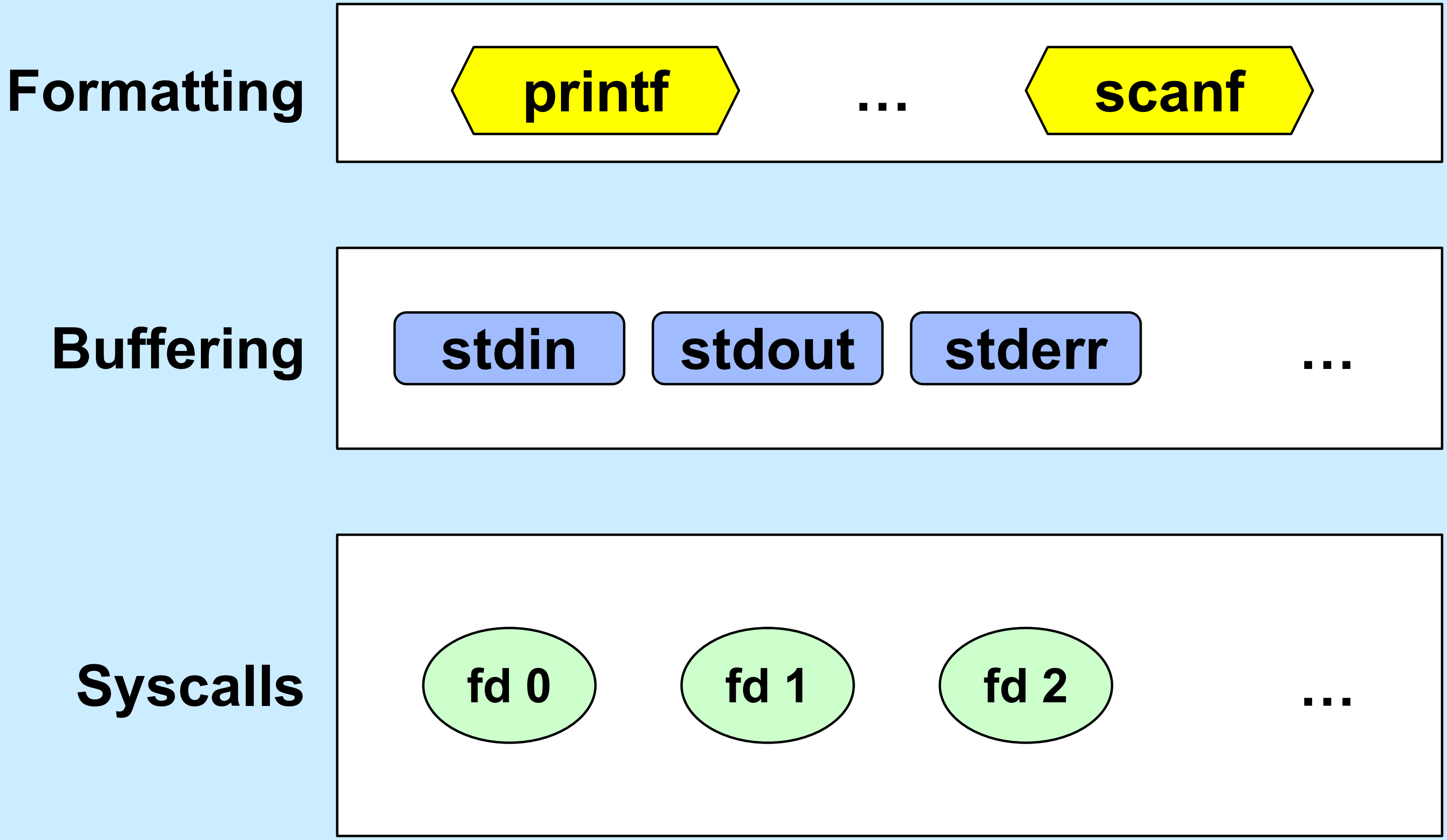
I/O System Calls

- **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

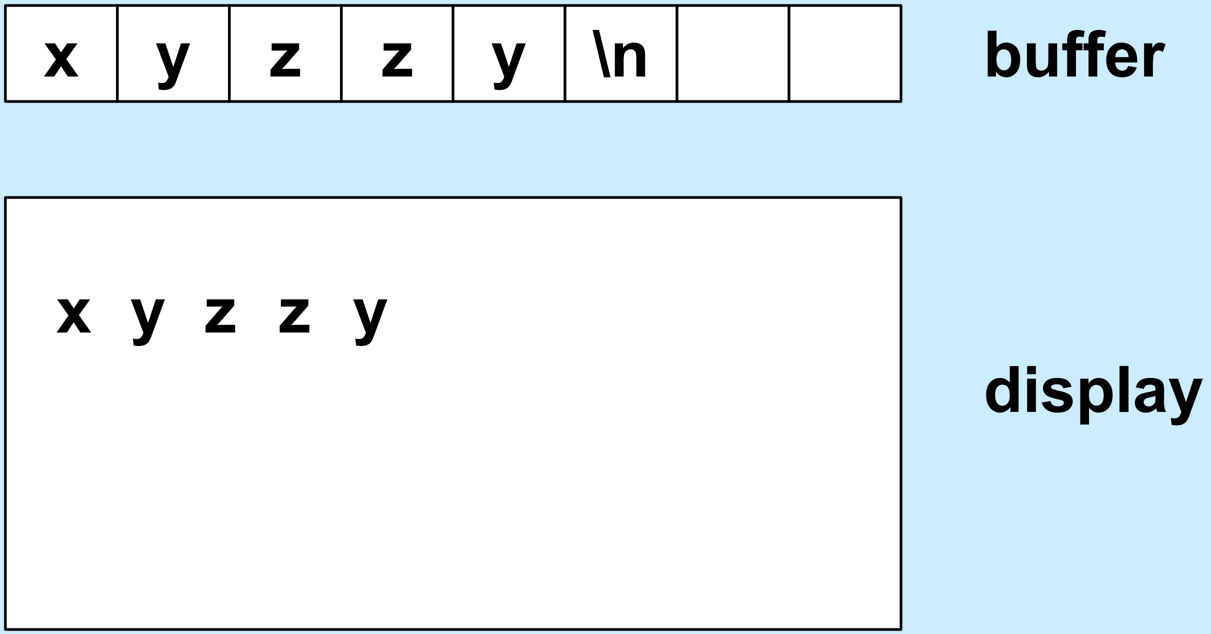


Standard I/O

```
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		

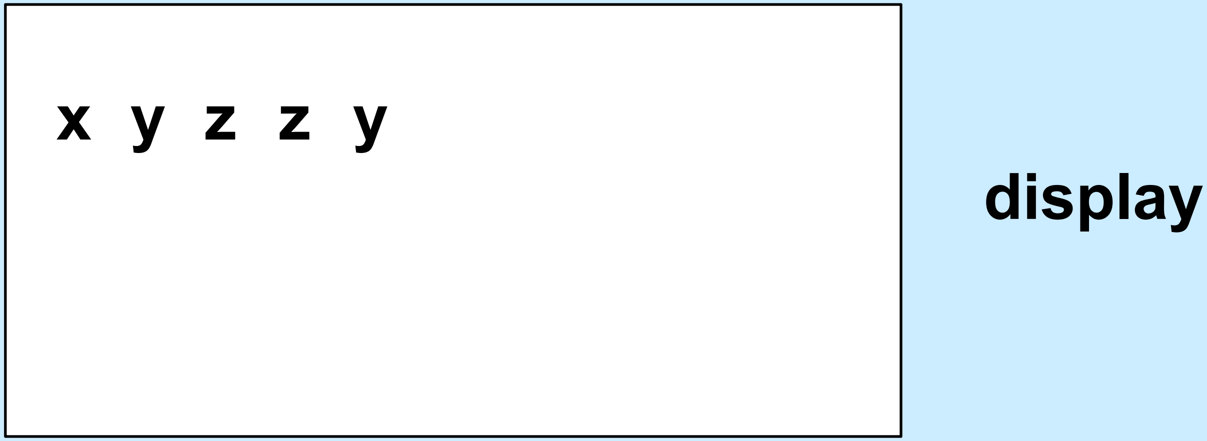
buffer

x y z z y

display

Unbuffered Output

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



x y z z y

display

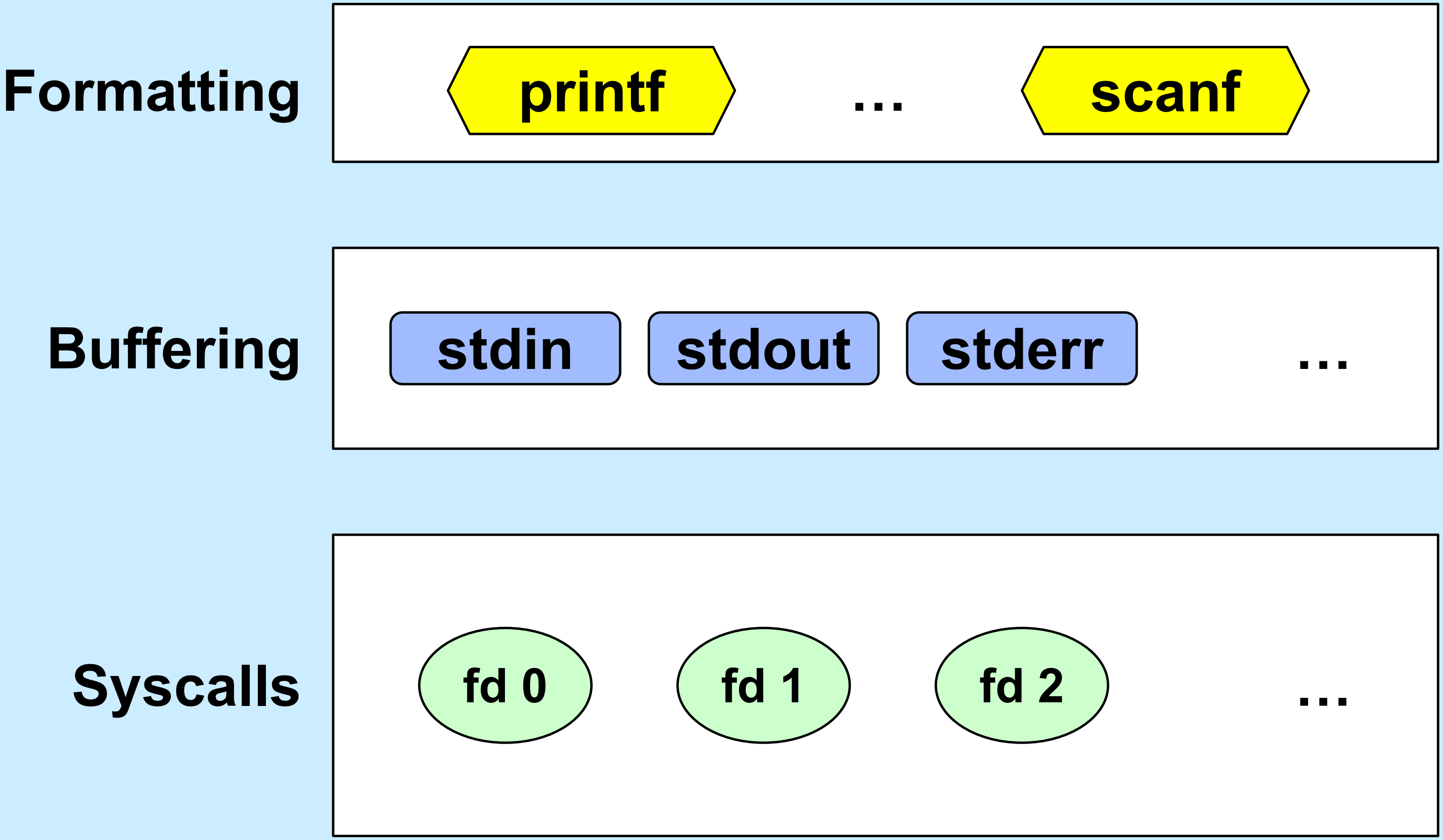
I/O System Calls

- **int** file_descriptor = open(pathname, mode [, permissions])
- **int** close(file_descriptor)
- **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

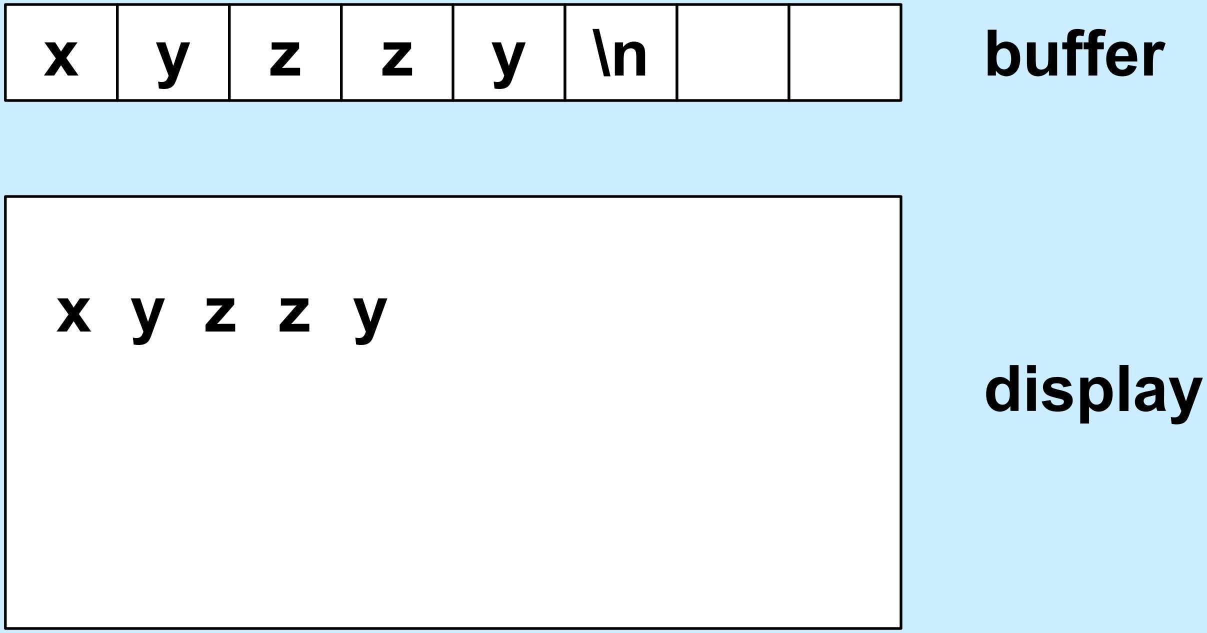


Standard I/O

```
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
```

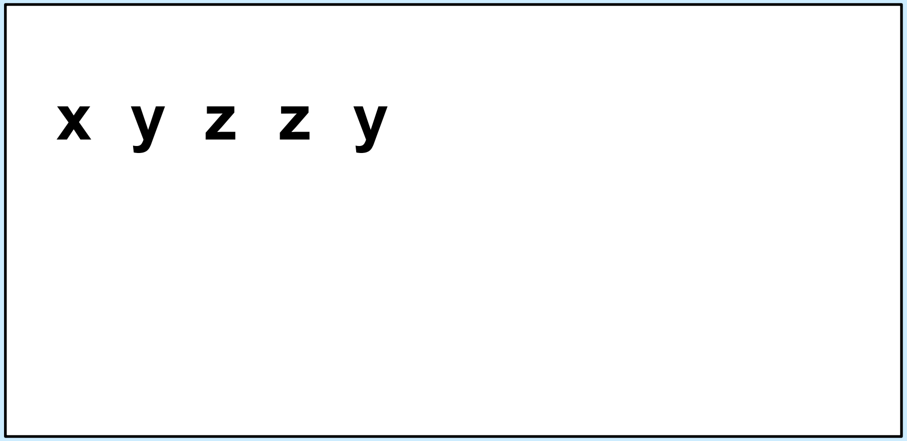
Buffered Output

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



Unbuffered Output

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



x y z z y

display

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

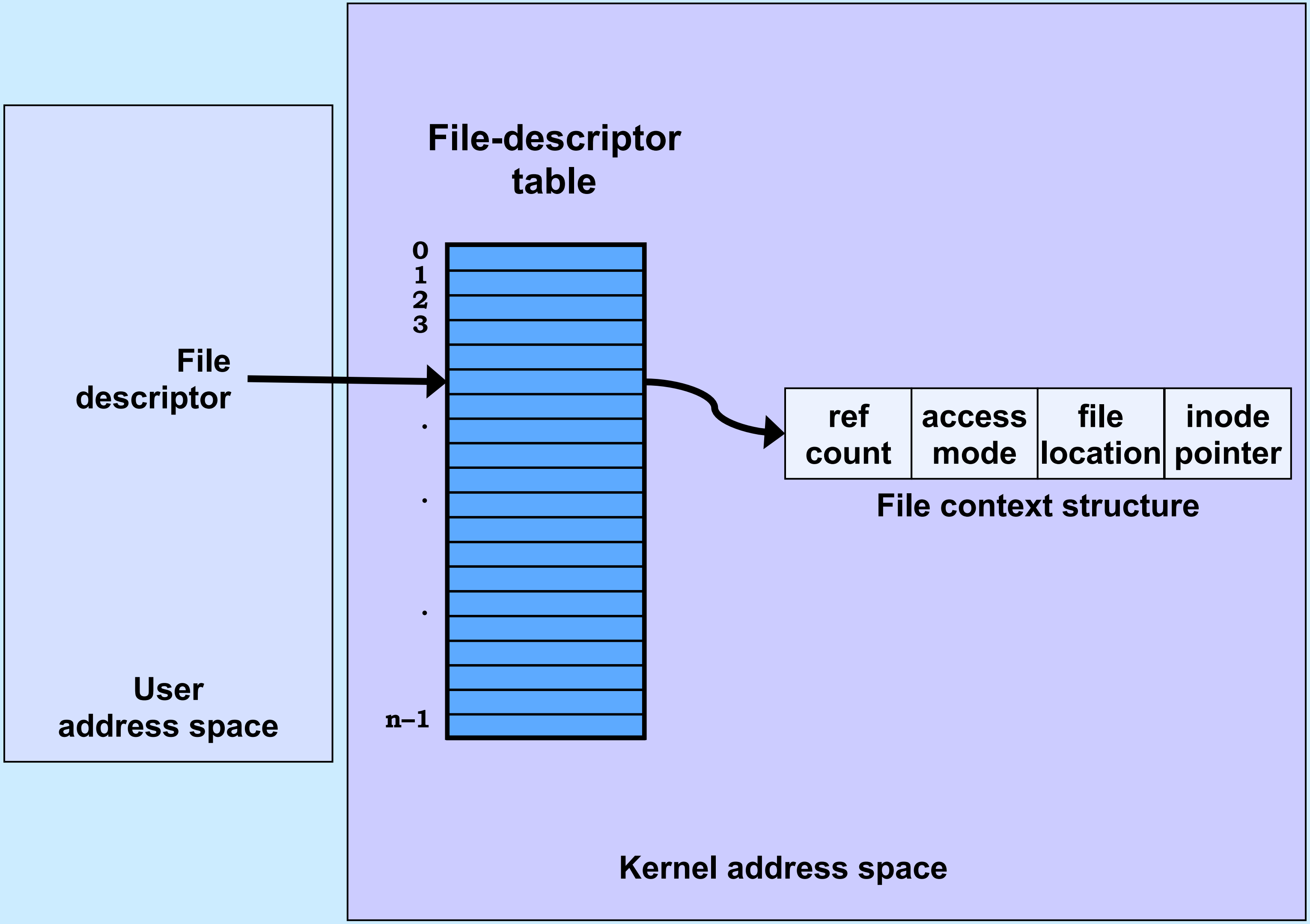
```
$ echon 1 < Input
```

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

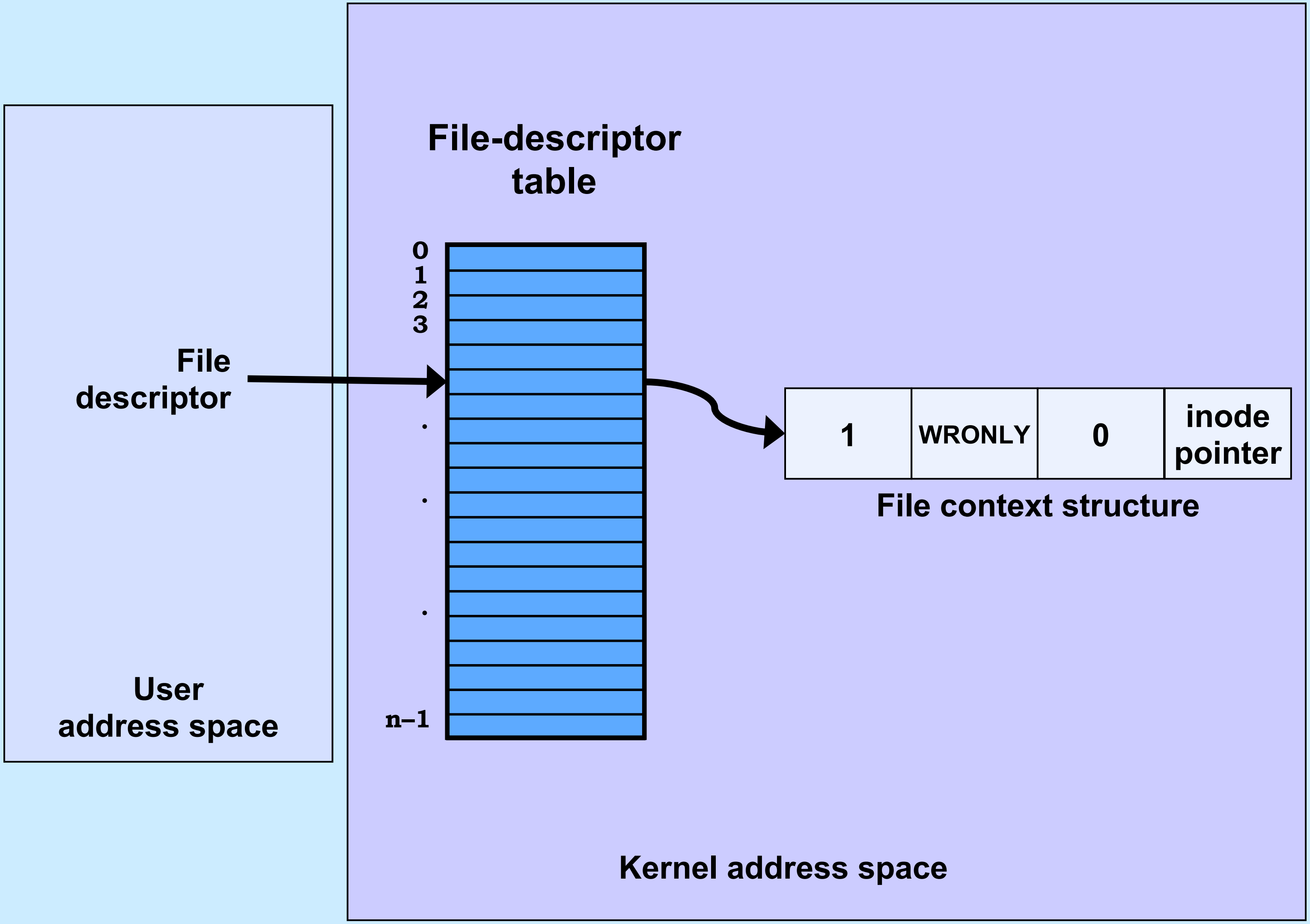
Redirecting Stdout in C

```
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
```

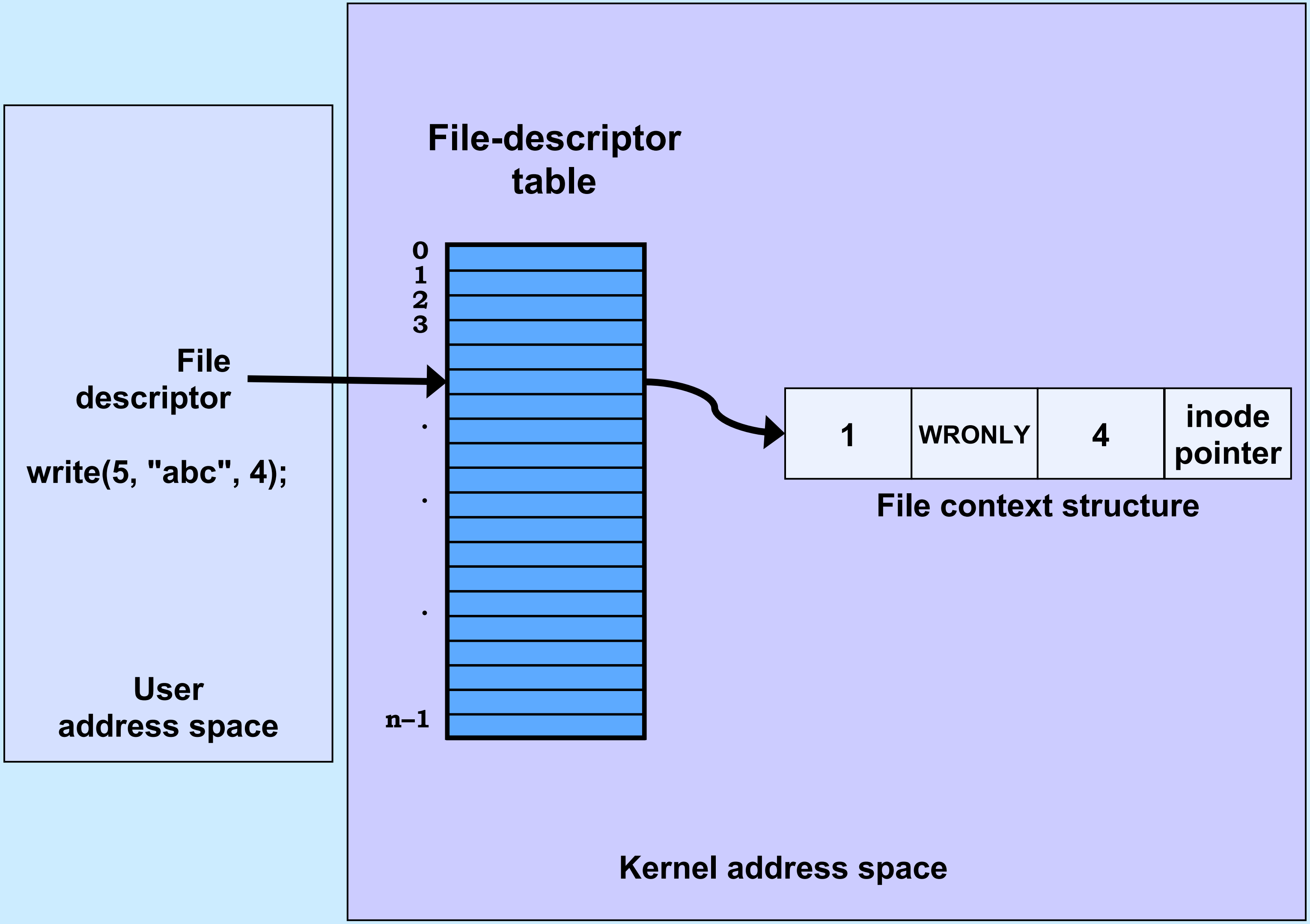
File-Descriptor Table



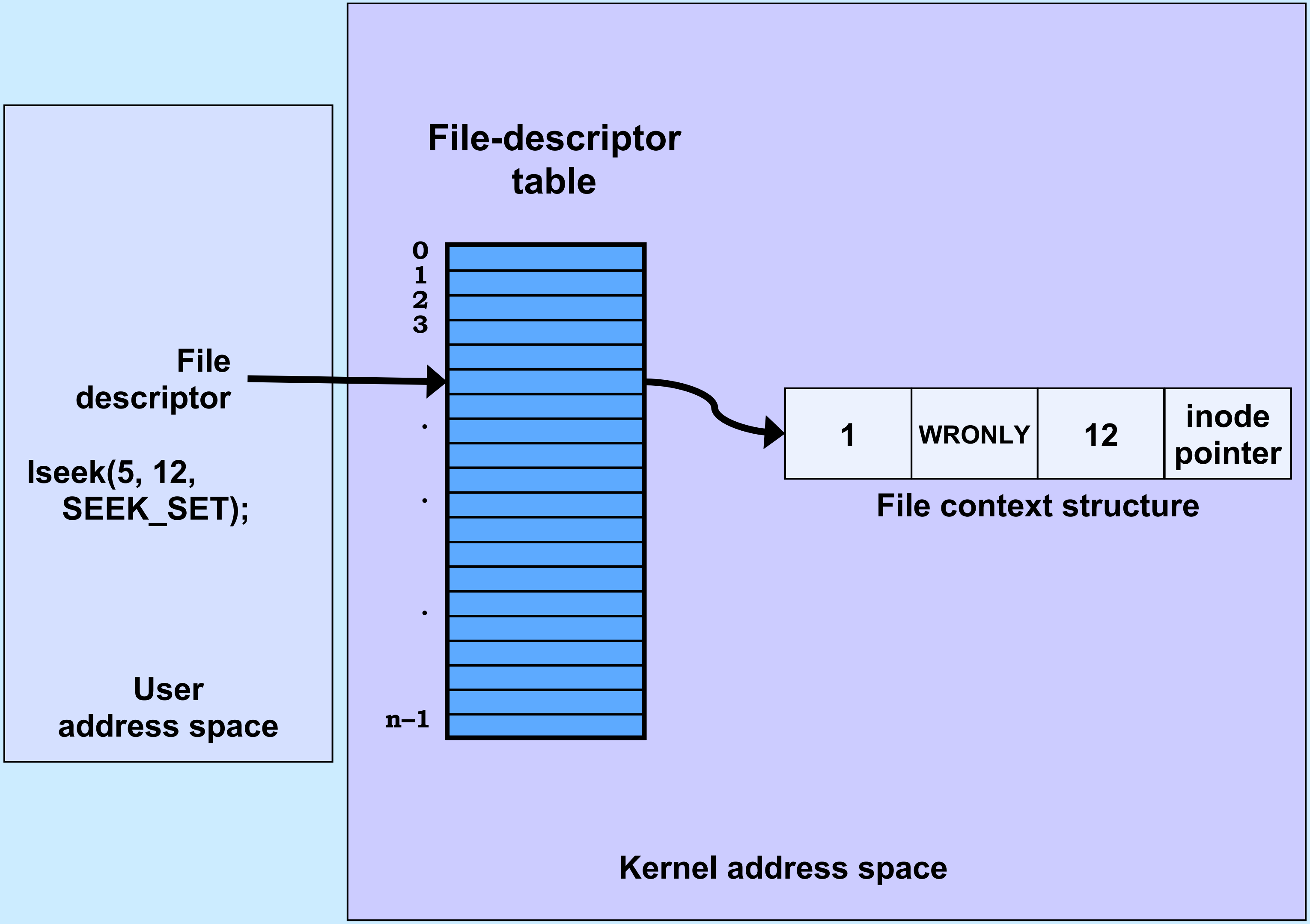
File Location



File Location



File Location



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

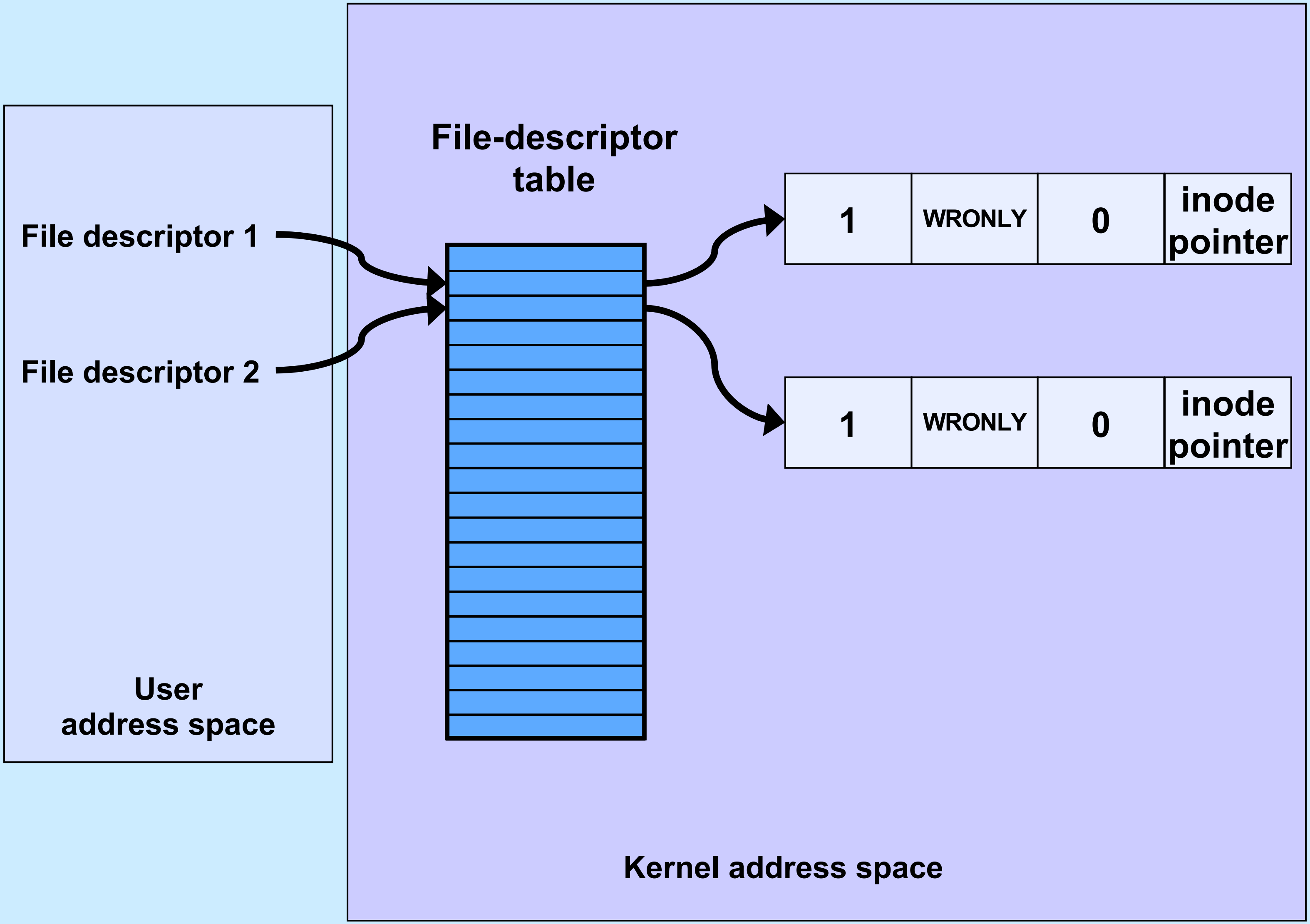
```
if (fork() == 0) {
   /* set up file descriptors 1 and 2 in the child process */
   close(1);
   close(2);
   if (open("/home/twd/Output", O_WRONLY) == -1) {
      exit(1);
   }
   if (open("/home/twd/Output", O_WRONLY) == -1) {
      exit(1);
   }
   char *argv[] = {"echon", 2, NULL};
   execv("/home/twd/bin/echon",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

From the Shell ...

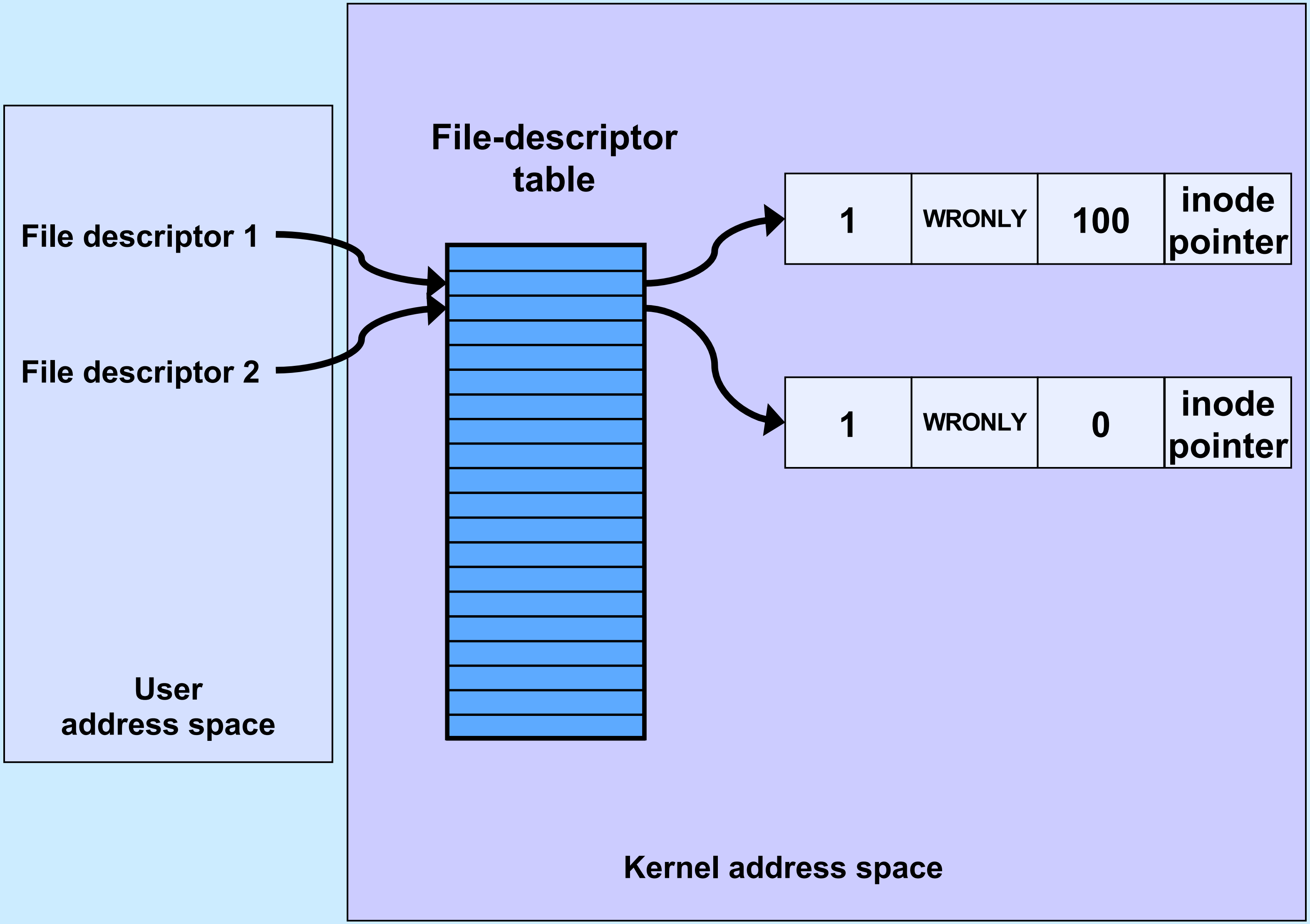
```
$ echon 1 >Output 2>Output
```

- **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
```

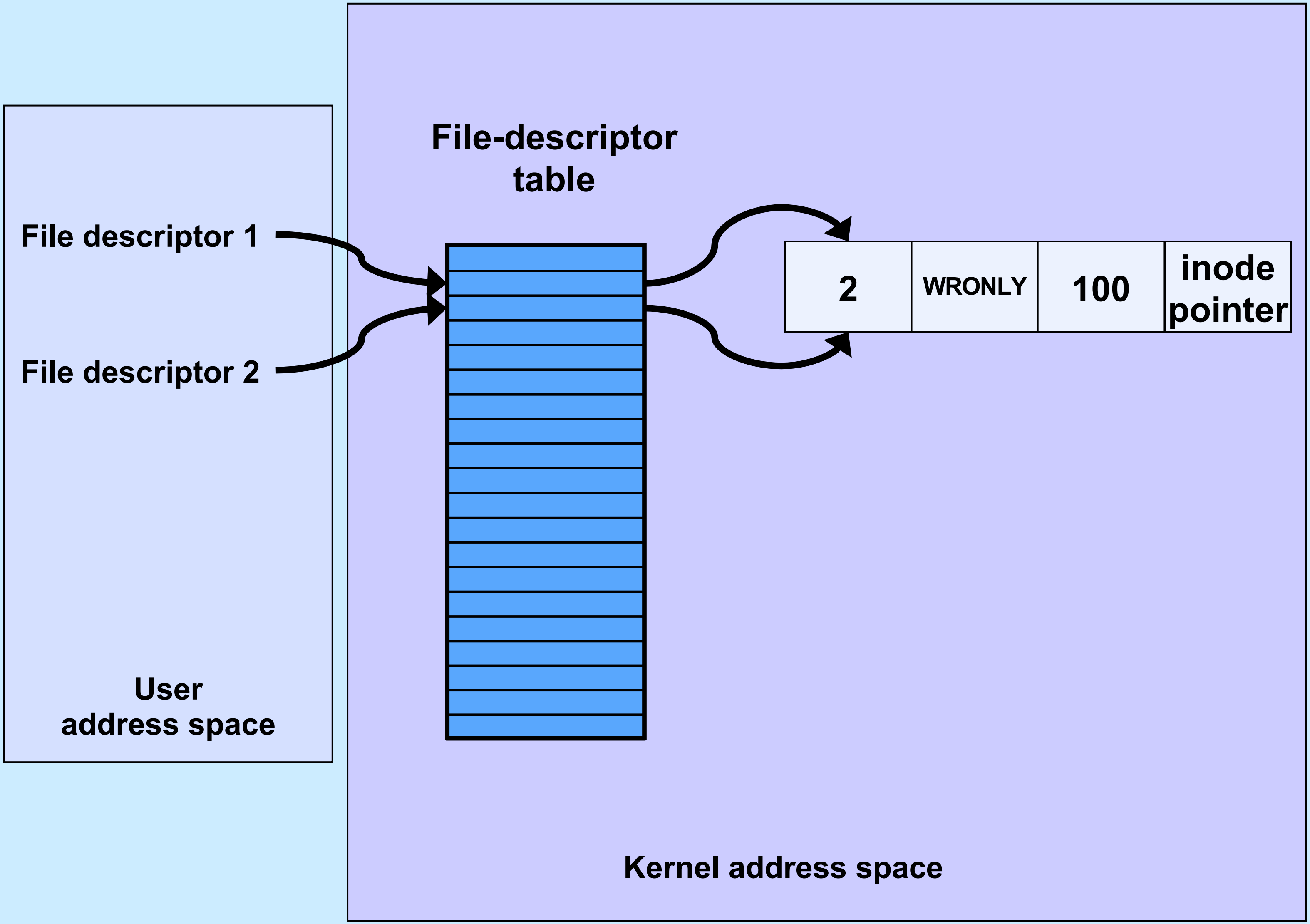
- **What is the final content of Output?**

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

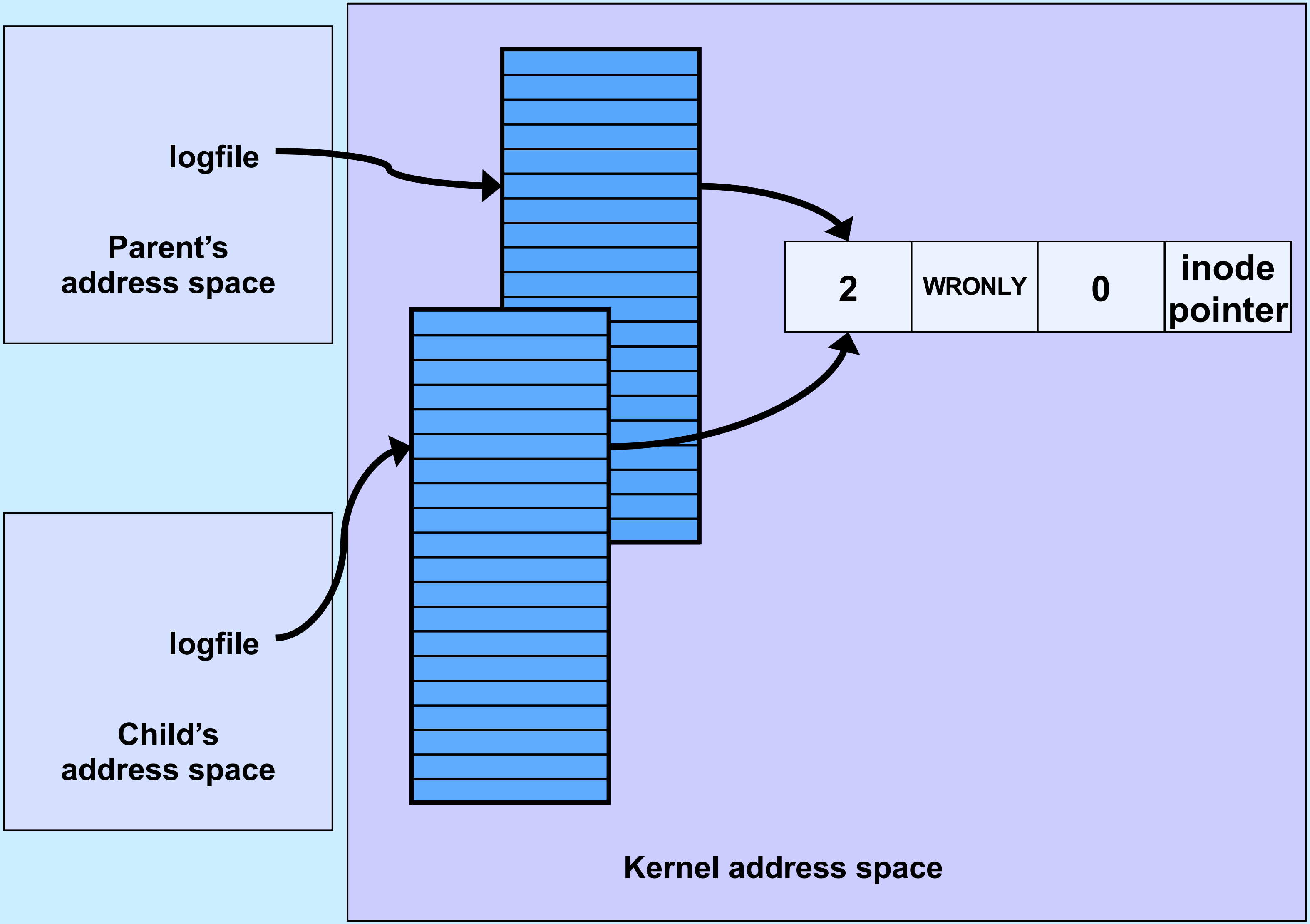
- stdout goes to Output file, stderr is the dup of fd 1
- with input “X\n” it now produces in Output:

```
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");
}
```

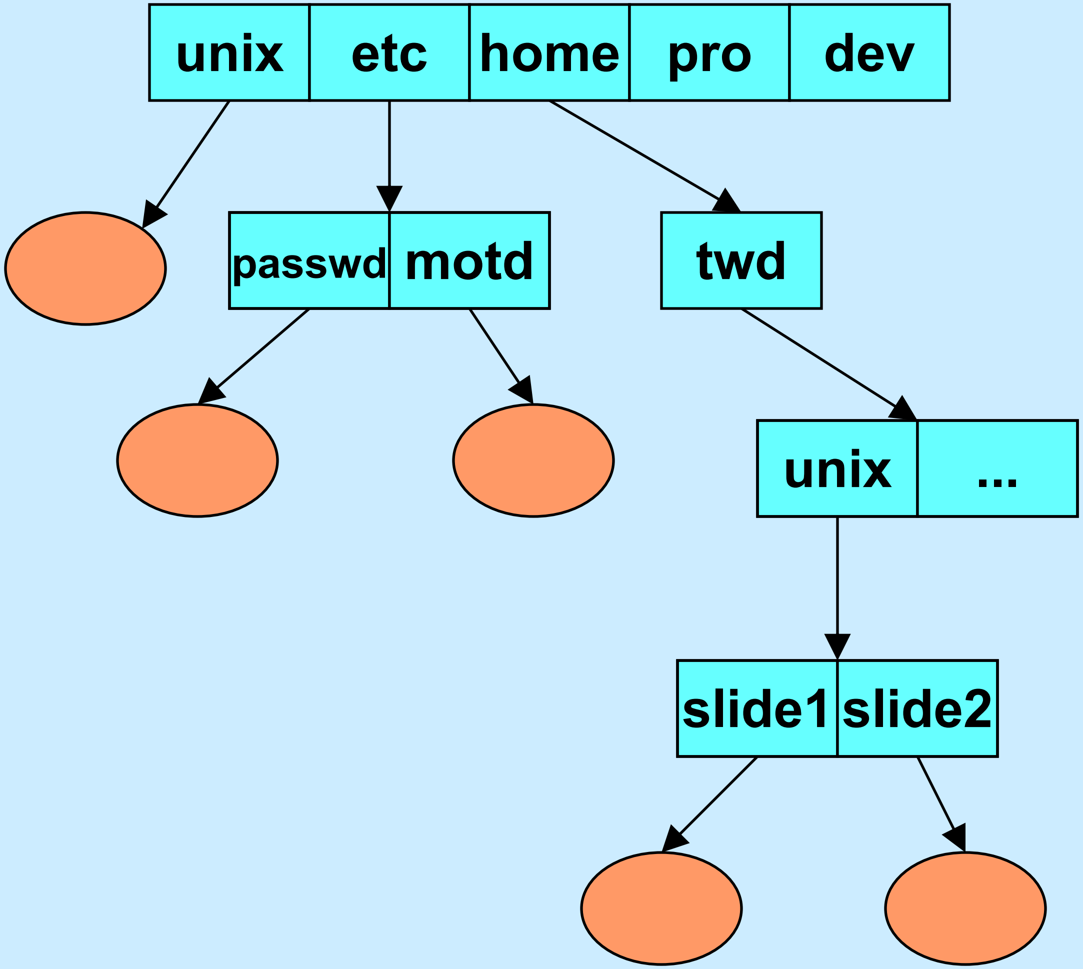
Suppose the program is run as:

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

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

- **a) either “ChildParent” or “ParentChild”**
- **b) either “Childt” or “Parent”**
- **c) either “Child” or “Parent”**

Directories



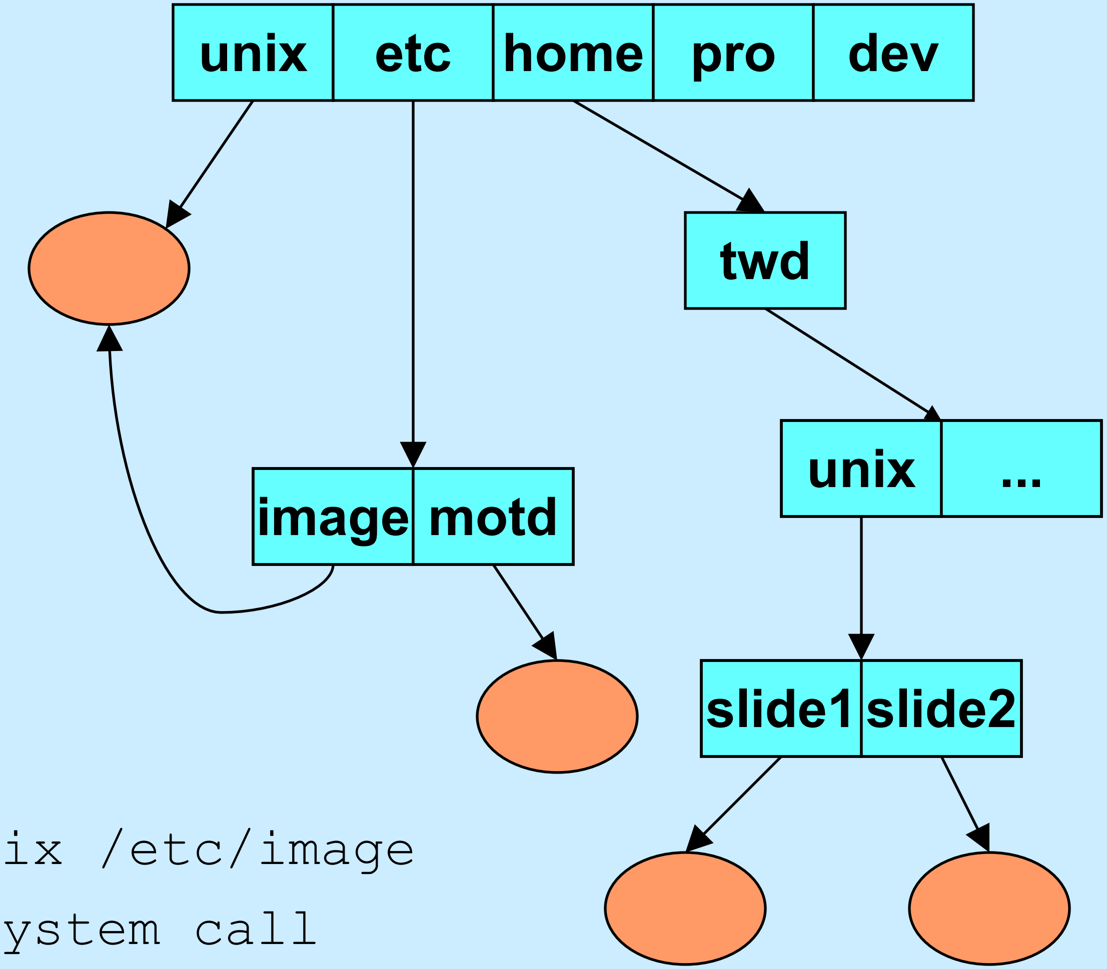
Directory Representation

Component Name	Inode Number

directory entry

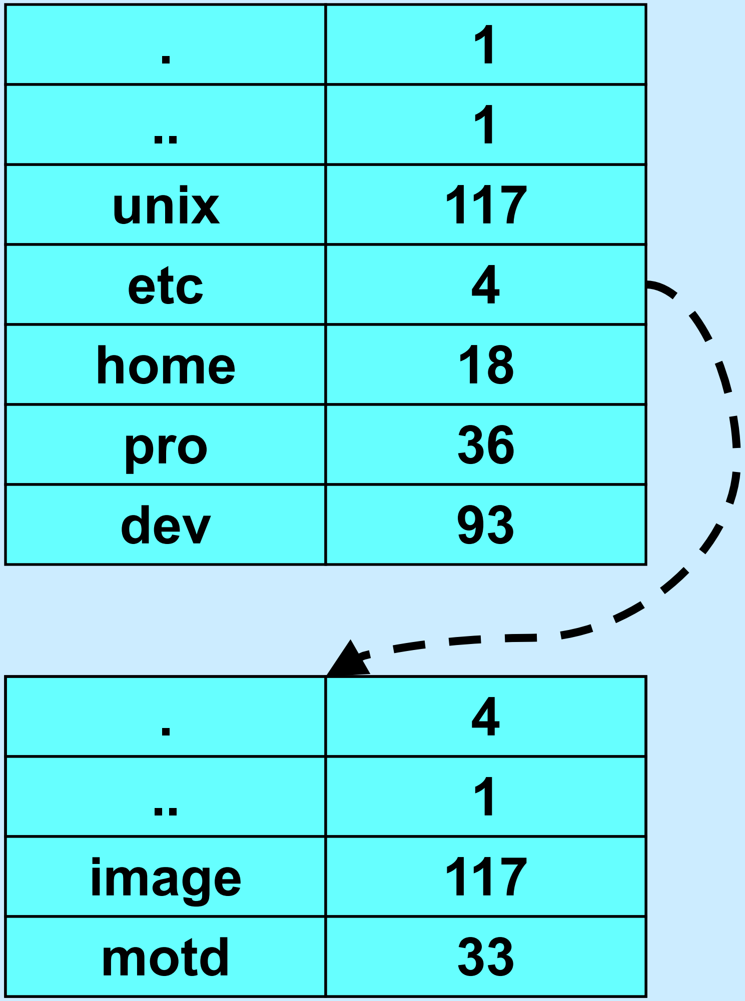
.	1
..	1
unix	117
etc	4
home	18
pro	36
dev	93

Hard Links



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

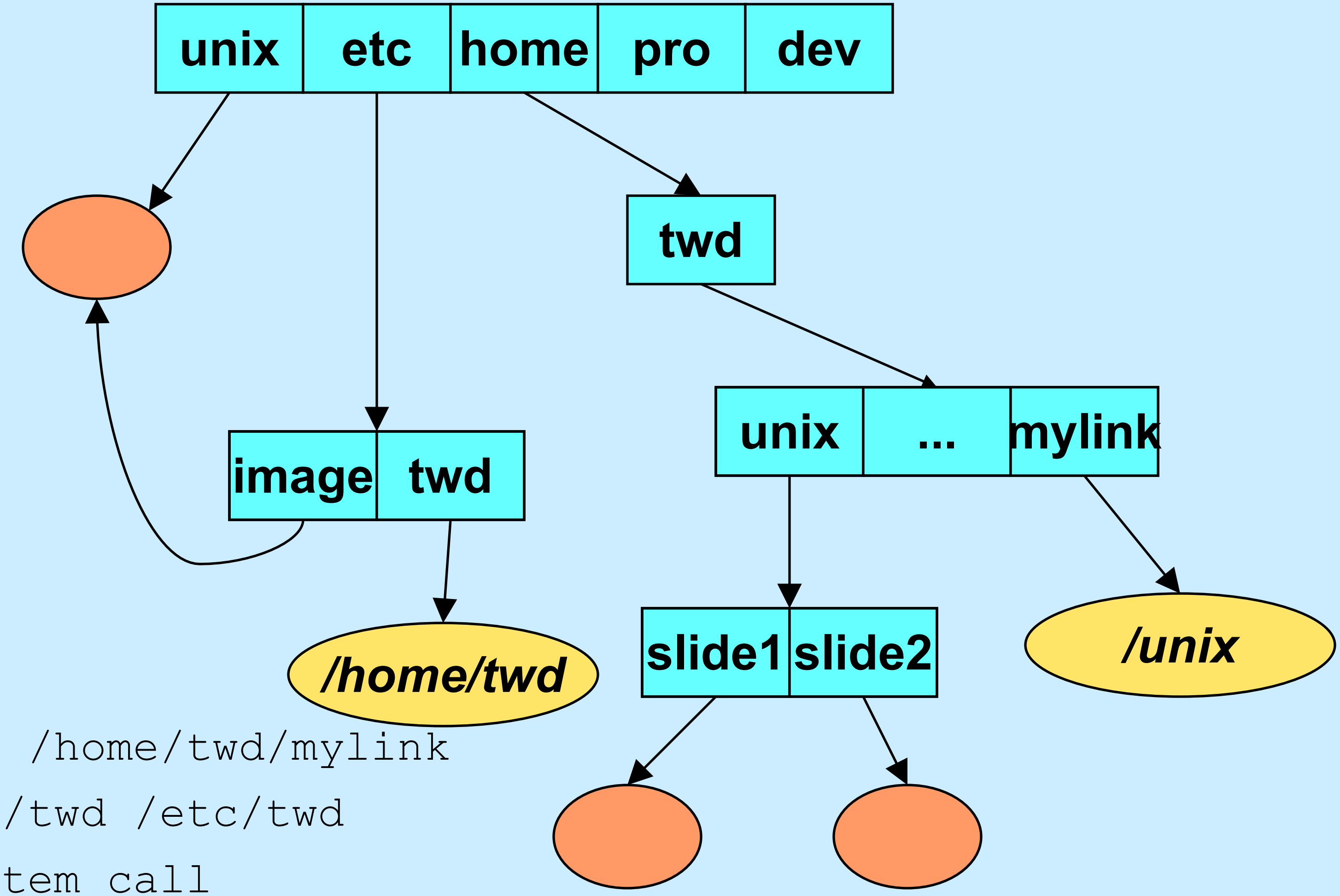
Directory Representation



.	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)`

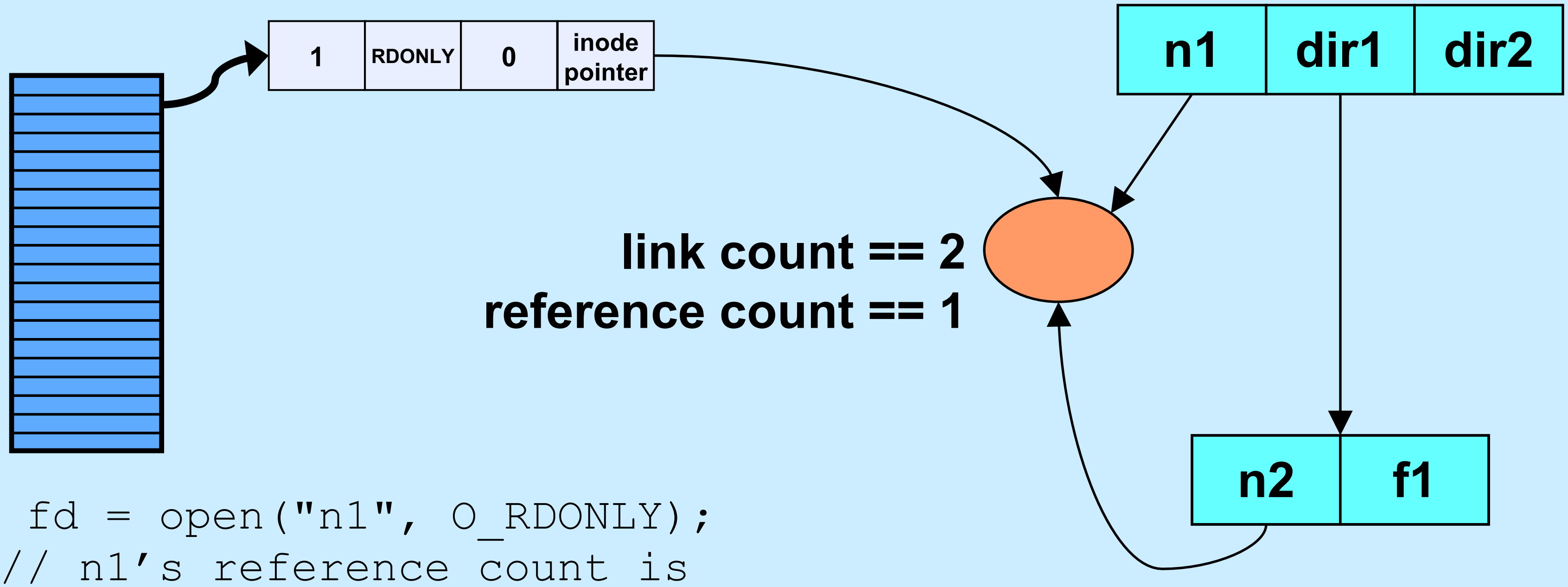
Umask

- 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

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

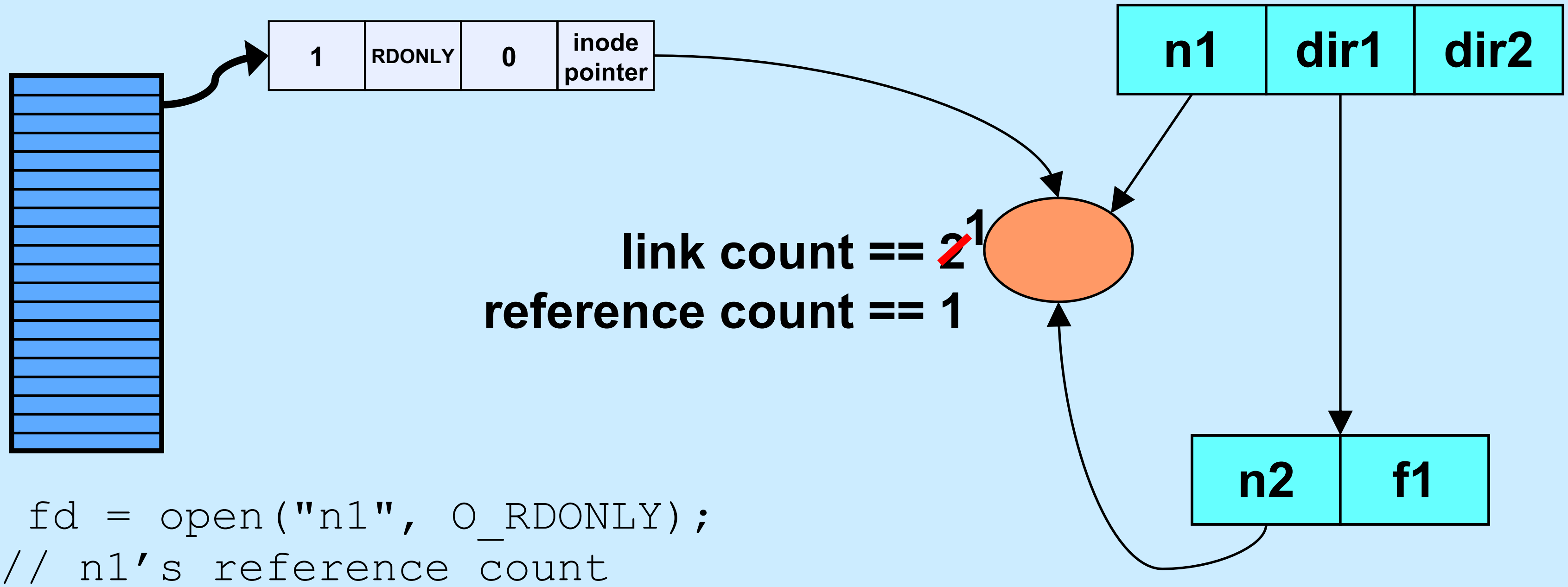
Link and Reference Counts



link count == 2
reference count == 1

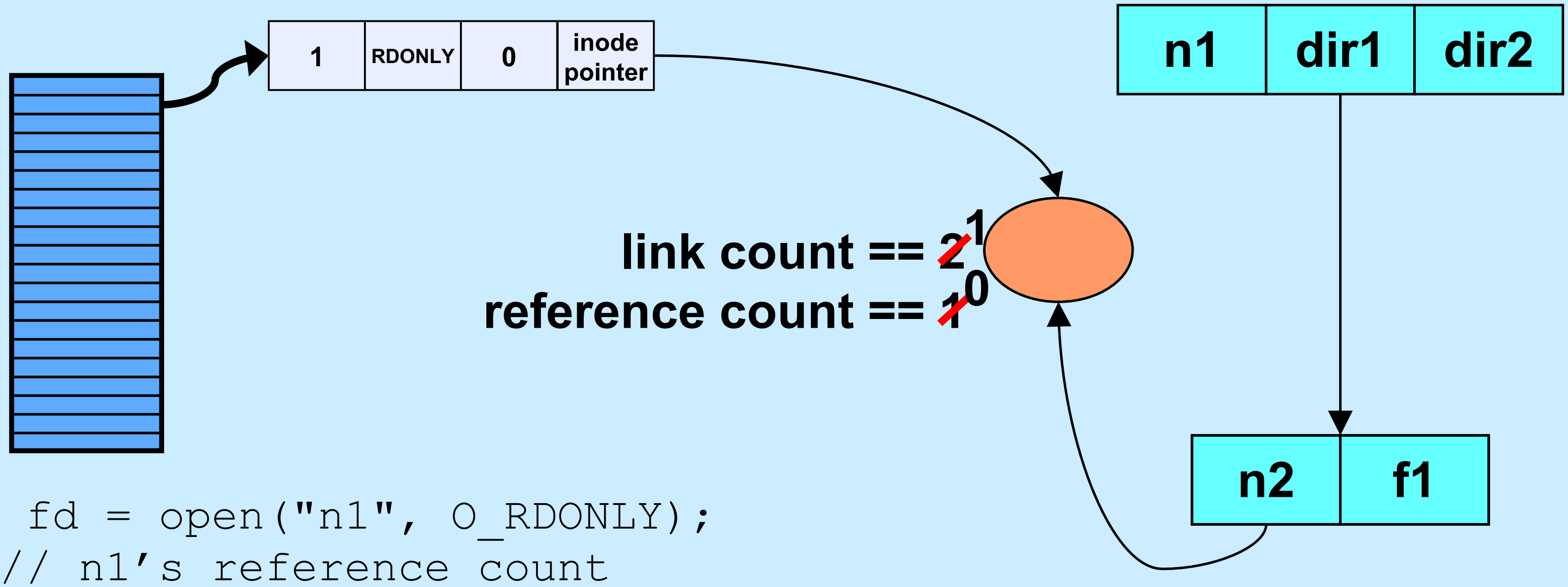
```
int fd = open("n1", O_RDONLY);
   // n1's reference count is
   // incremented by 1
```

Link and Reference Counts



```
int fd = open("n1", O_RDONLY);
   // n1’s reference count
   // incremented by 1

unlink("n1");
   // link count decremented by 1
   // same effect in shell via “rm n1”
```

Link and Reference Counts

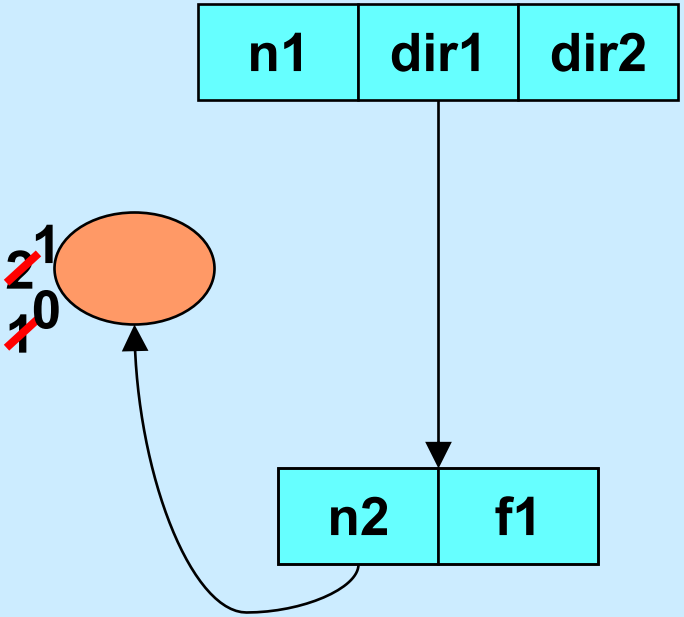


link count == ~~2~~1

reference count == ~~1~~0

```
int fd = open("n1", O_RDONLY);
   // n1’s reference count
   // incremented by 1

unlink("n1");
   // link count decremented by 1

close(fd);
   // reference count decremented by 1
```

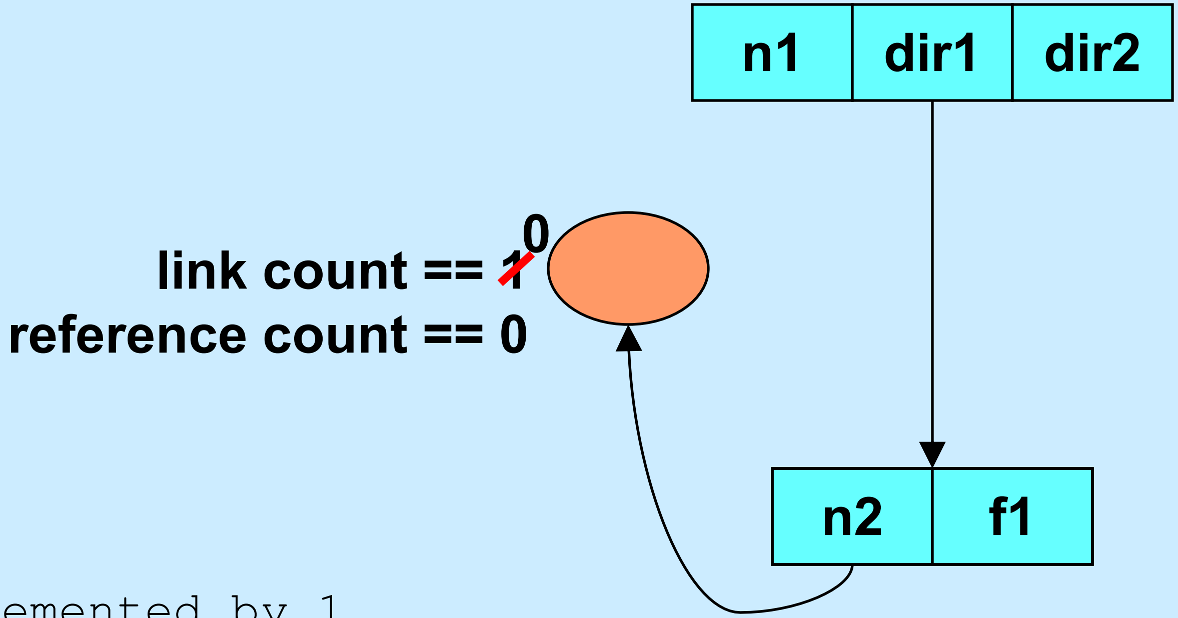
Link and Reference Counts



link count == ~~2~~ 1
reference count == ~~1~~ 0

```
int fd = open("n1", O_RDONLY);
   // n1's reference count
   // incremented by 1

unlink("n1");
   // link count decremented by 1

close(fd);
   // reference count decremented by 1
```

Link and Reference Counts



n1 | dir1 | dir2

link count == ~~1~~ 0

reference count == 0

n2 | f1

```
unlink("dir1/n2");
   // link count decremented by 1
```

Quiz 3

```
int main() {
  int fd = open("file", O_RDWR|O_CREAT, 0666);
  unlink("file");
  PutStuffInFile(fd);
  GetStuffFromFile(fd);
  return 0;
}
```

Assume that *PutStuffInFile* writes to the given file, and *GetStuffFromFile* reads from the file.

a) This program is doomed to failure, since the file is deleted before it's used

b) The file will be deleted when the program terminates

c) Because the file is used after the unlink call, it won't be deleted