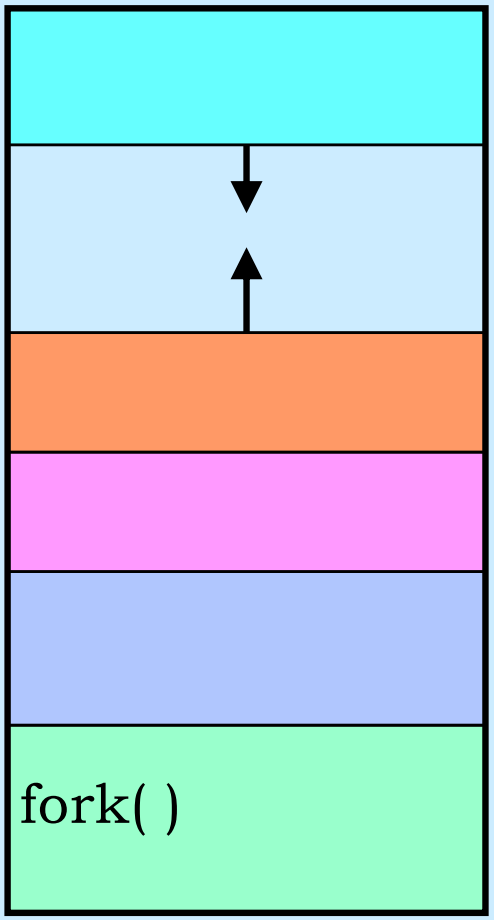
CS 33

Architecture and the OS (2)

Creating Your Own Processes

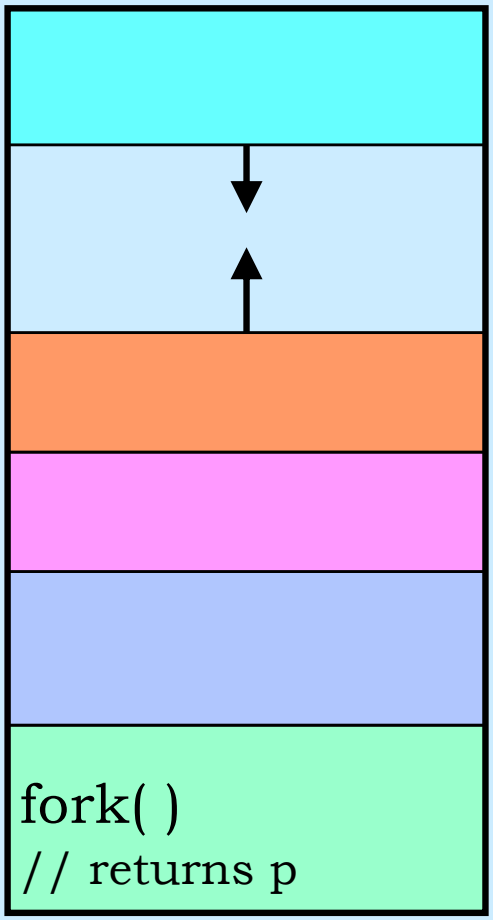
```
#include <unistd.h>
int main( ) {
  pid_t pid;
  if ((pid = fork()) == 0) {
      /* new process starts
         running here */
  }
  /* old process continues
     here */
}
```

Creating a Process: Before

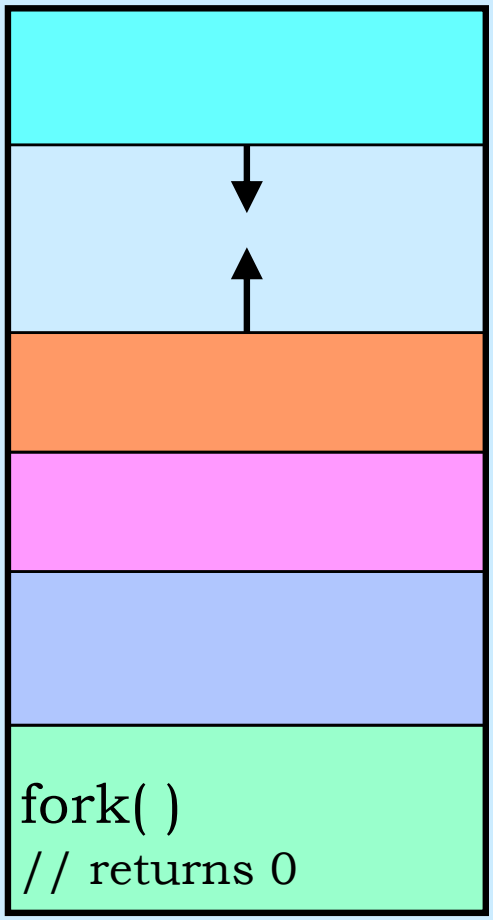


parent process

Creating a Process: After



parent process



child process
(pid = p)

Quiz 1

The following program

a) runs forever

b) terminates quickly

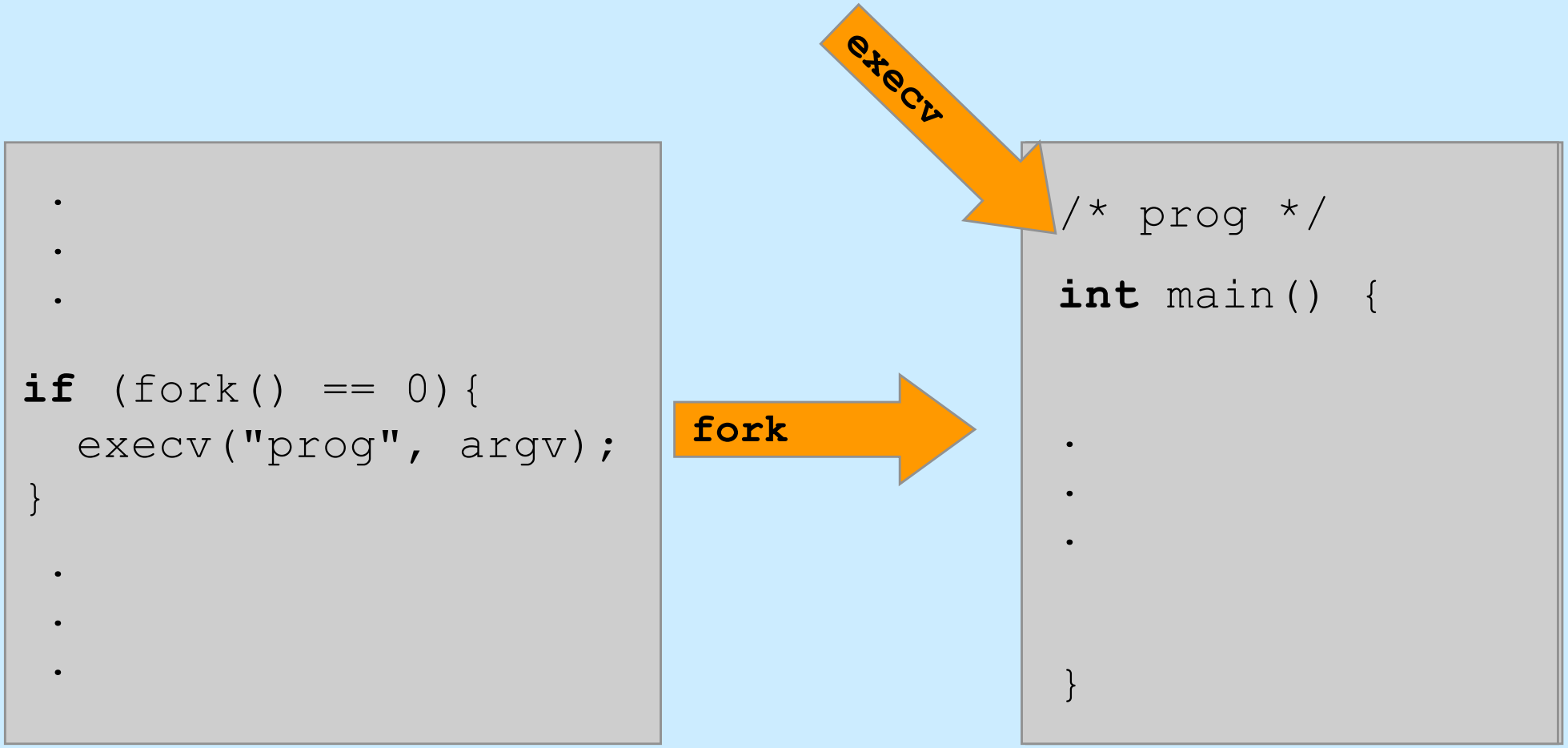
```
int flag;
int main() {
  while (flag == 0) {
    if (fork() == 0) {
      // in child process
      flag = 1;
      exit(0);  // causes process to terminate
    }
  }
}
```

Process IDs

```
int main( ) {
  pid_t pid;
  pid_t ParentPid = getpid();

  if ((pid = fork()) == 0) {
      printf("%d, %d, %d\n",
            pid, ParentPid, getpid());
      return 0;
  }
  printf("%d, %d, %d\n",
            pid, ParentPid, getpid());
  return 0;
}
```

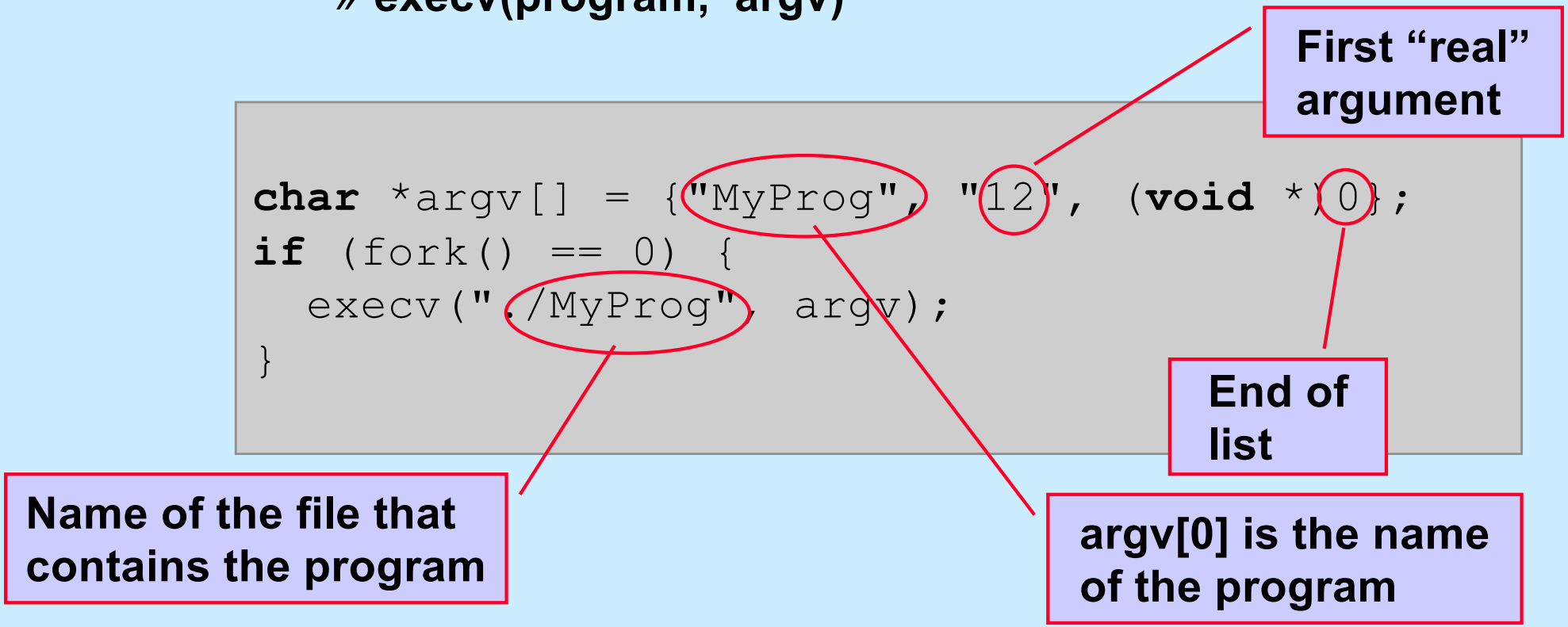
```
parent prints:
  27355, 27342, 27342

child prints:
  0, 27342, 27355
```

Putting Programs into Processes

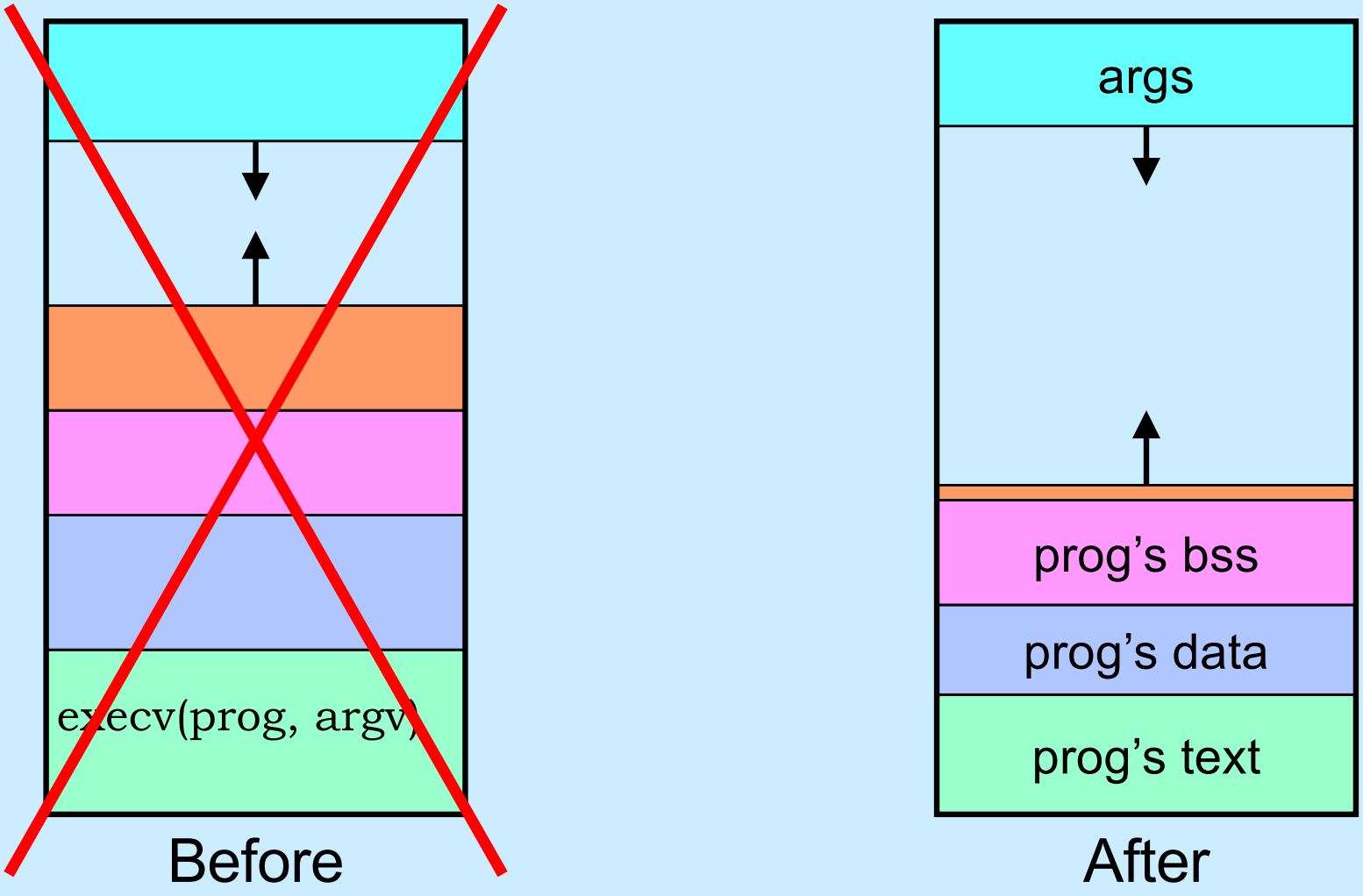


Exec

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



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

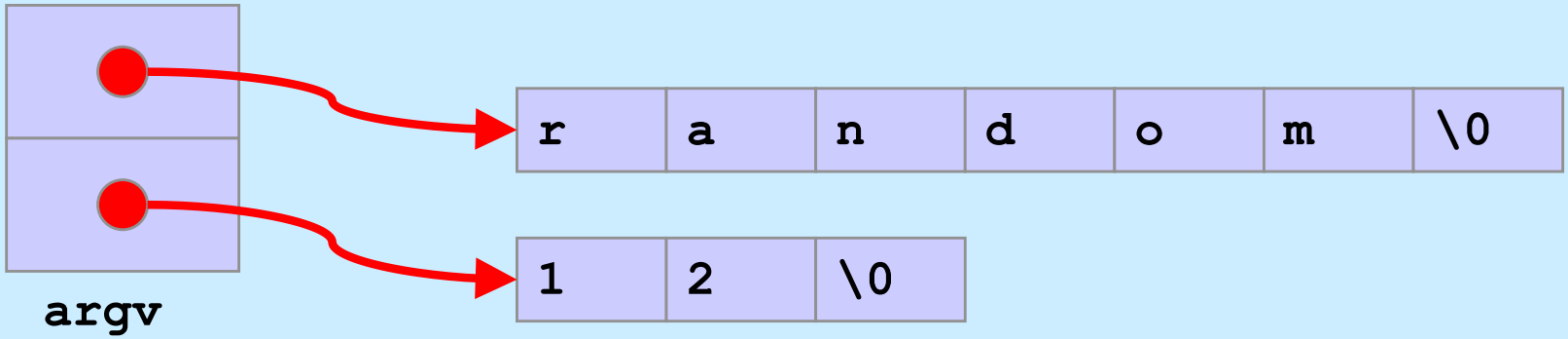
```
if (fork() == 0) {
   char *argv[] = {"random", "12", (void *)0};
   execv("./random", argv);
   printf("random done\n");
}
```

The *printf* statement will be executed

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

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 */
```

Shell: To Wait or Not To Wait ...

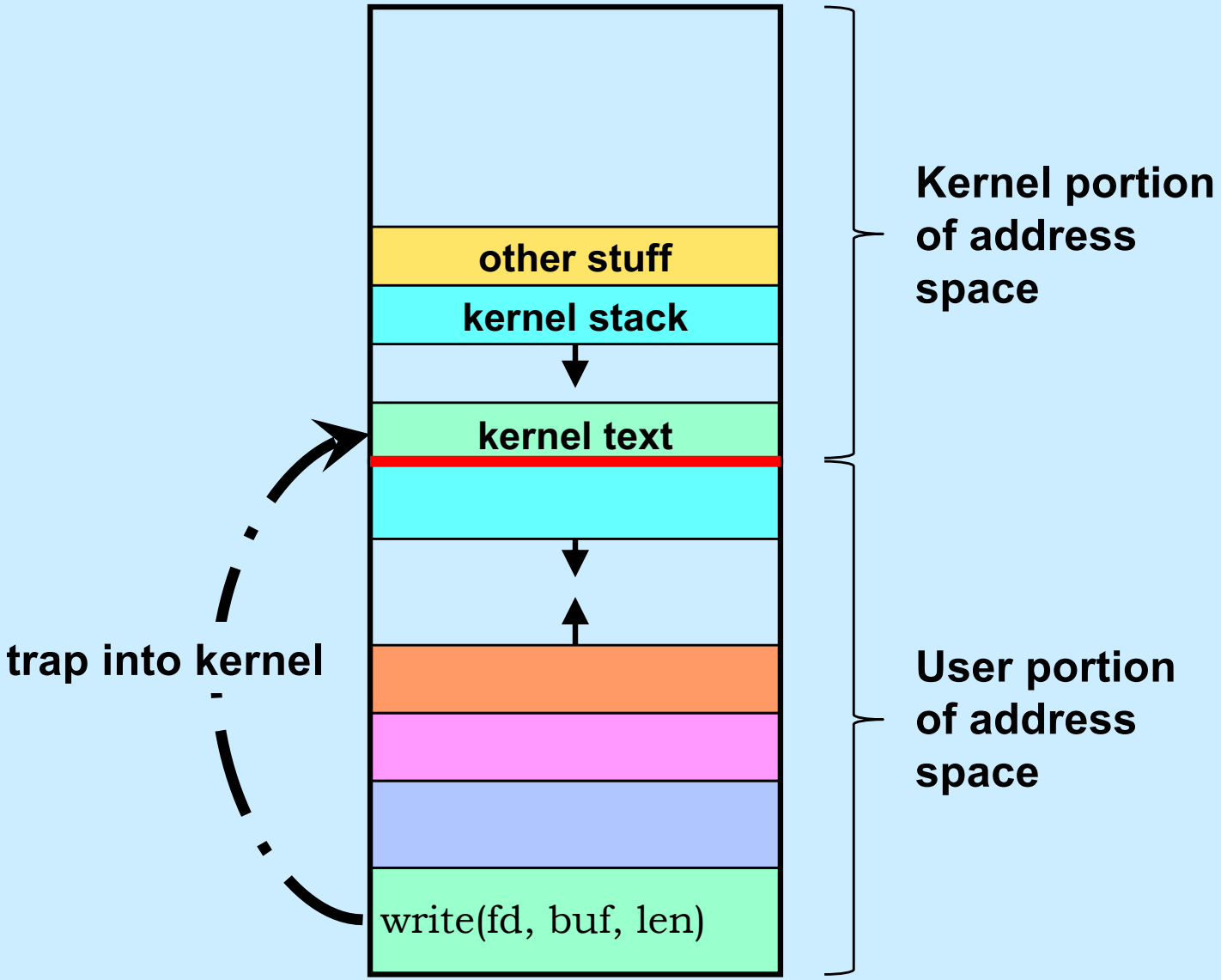
```
$ who
    if ((pid = fork()) == 0) {
        char *argv[] = {"who", 0};
        execv("who", argv);
    }
    waitpid(pid, &status, 0);
    …

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

System Calls

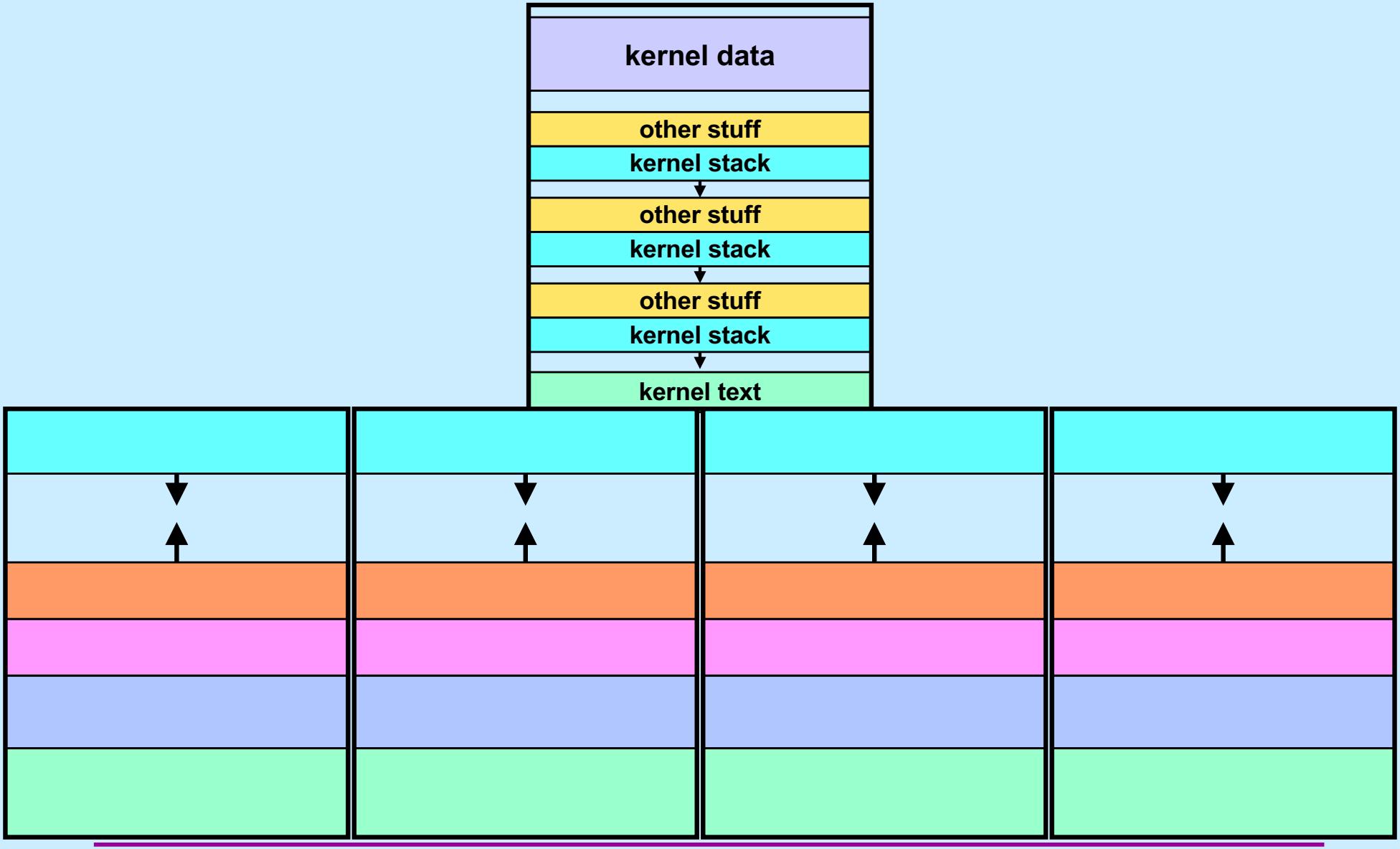
- **Sole direct interface between user and kernel**
- **Implemented as library functions that execute *trap* instructions to enter kernel**
- **Errors indicated by returns of –1; error code is in global variable *errno***

```
if (write(fd, buffer, bufsize) == -1) {
   // error!
   printf("error %d\n", errno);
   // see perror
}
```

System Calls



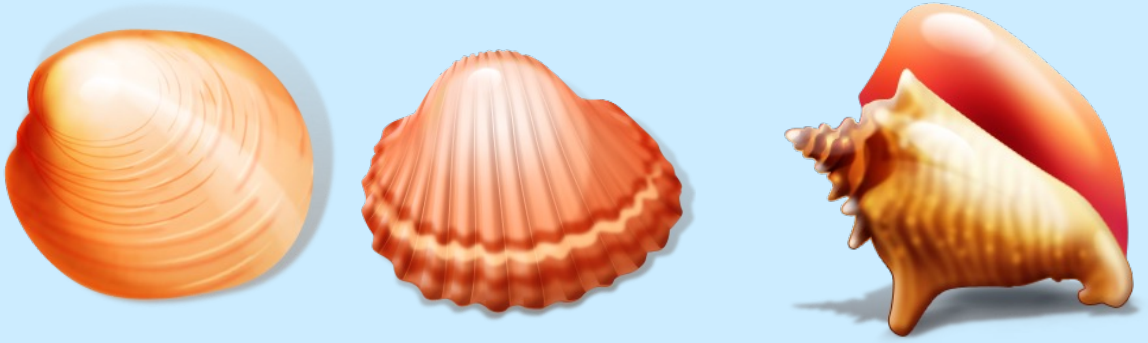
Multiple Processes



CS 33

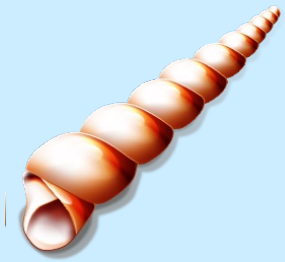
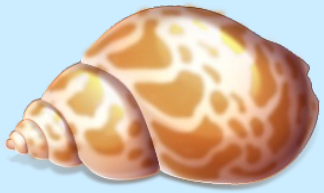
Shells and Files

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.

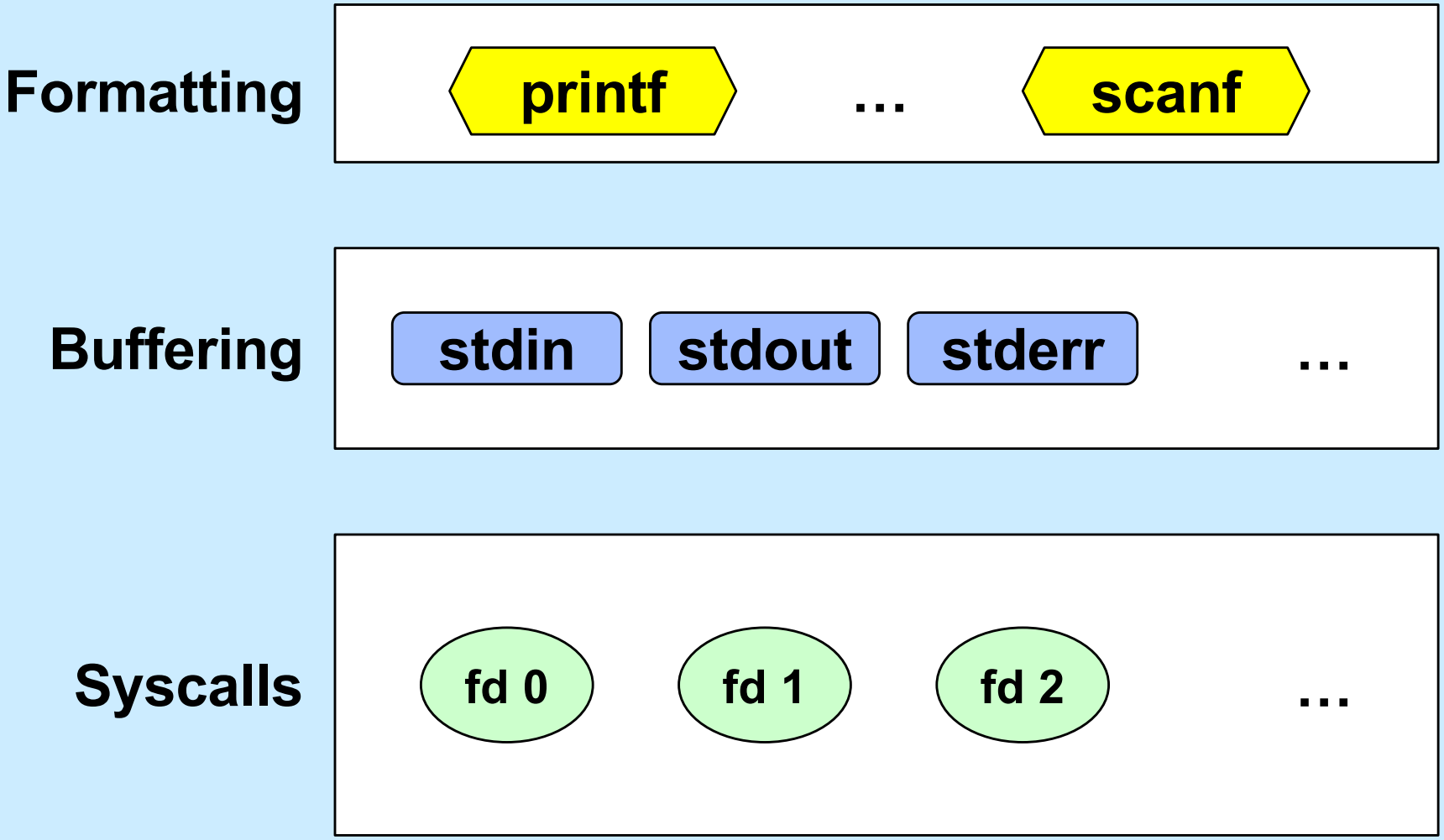
I/O System Calls

- `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

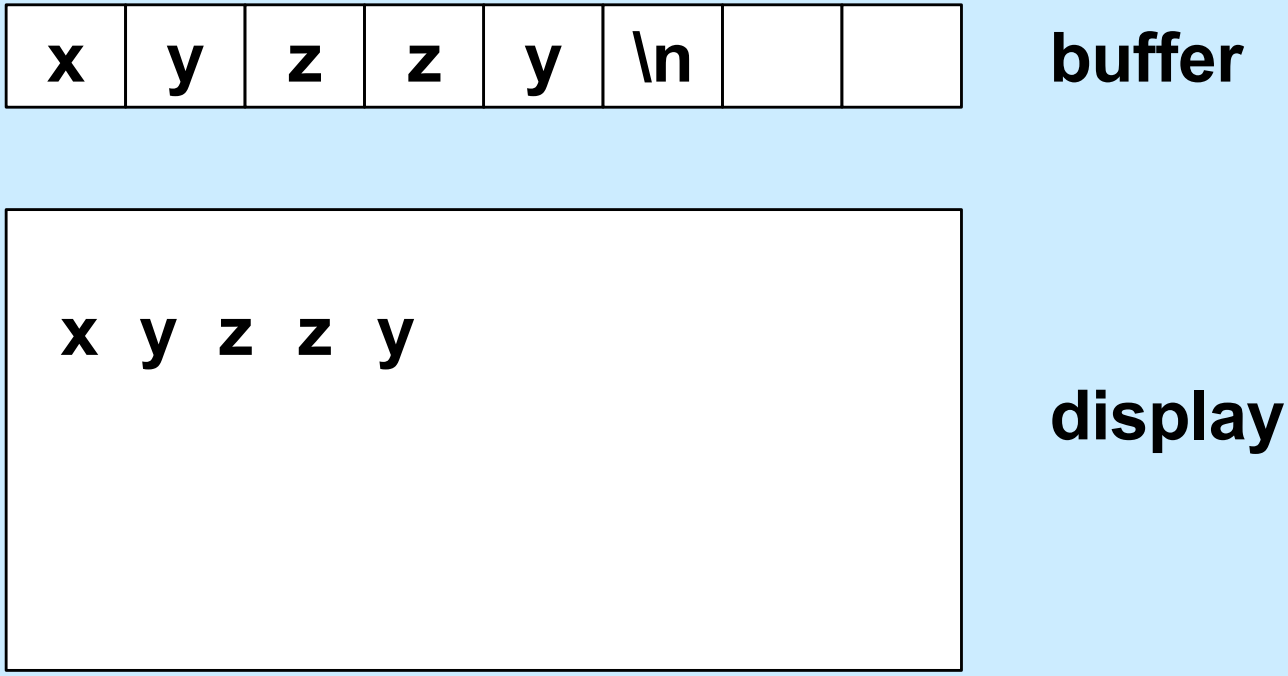


Standard I/O

```
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
```

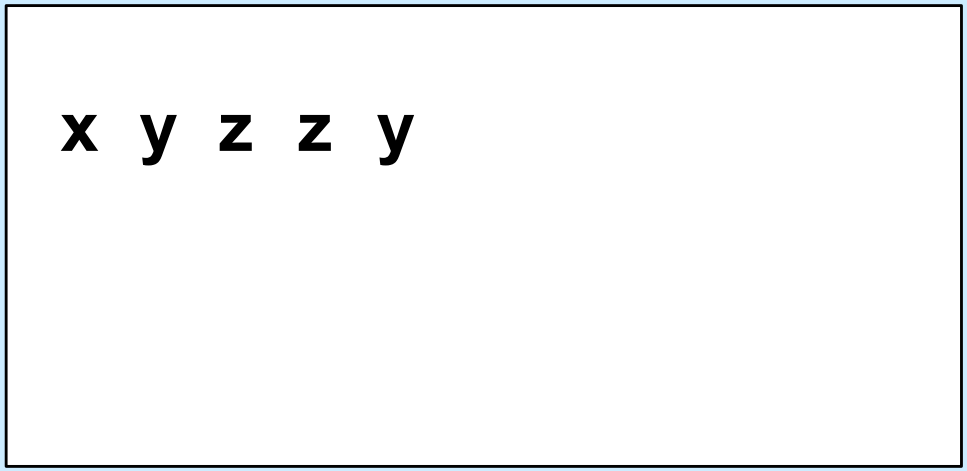
Buffered Output

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



Unbuffered Output

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



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**

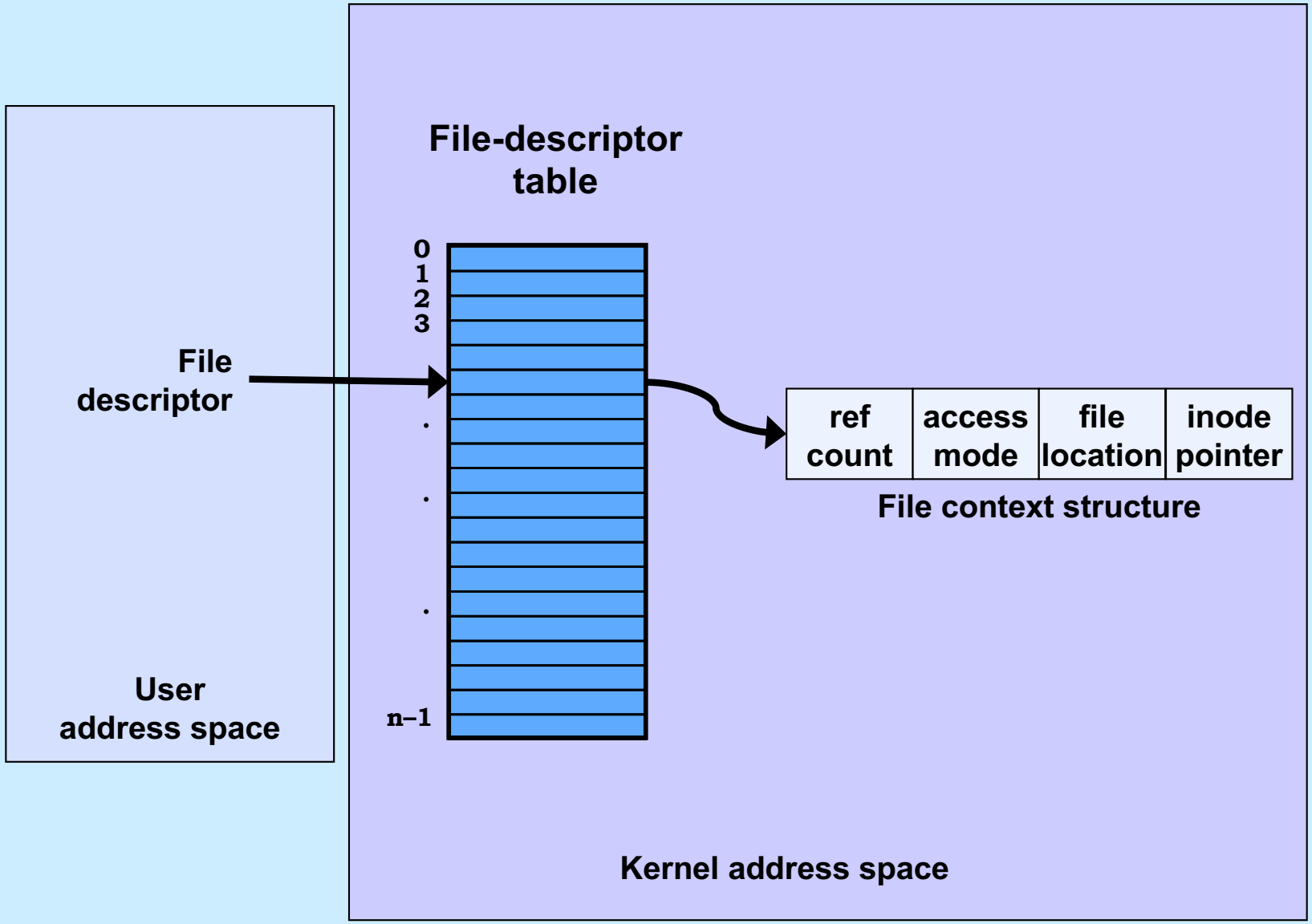
```
$ echon 1 < Input
```

- ***stdin*** **comes from the file "Input" in the current directory**

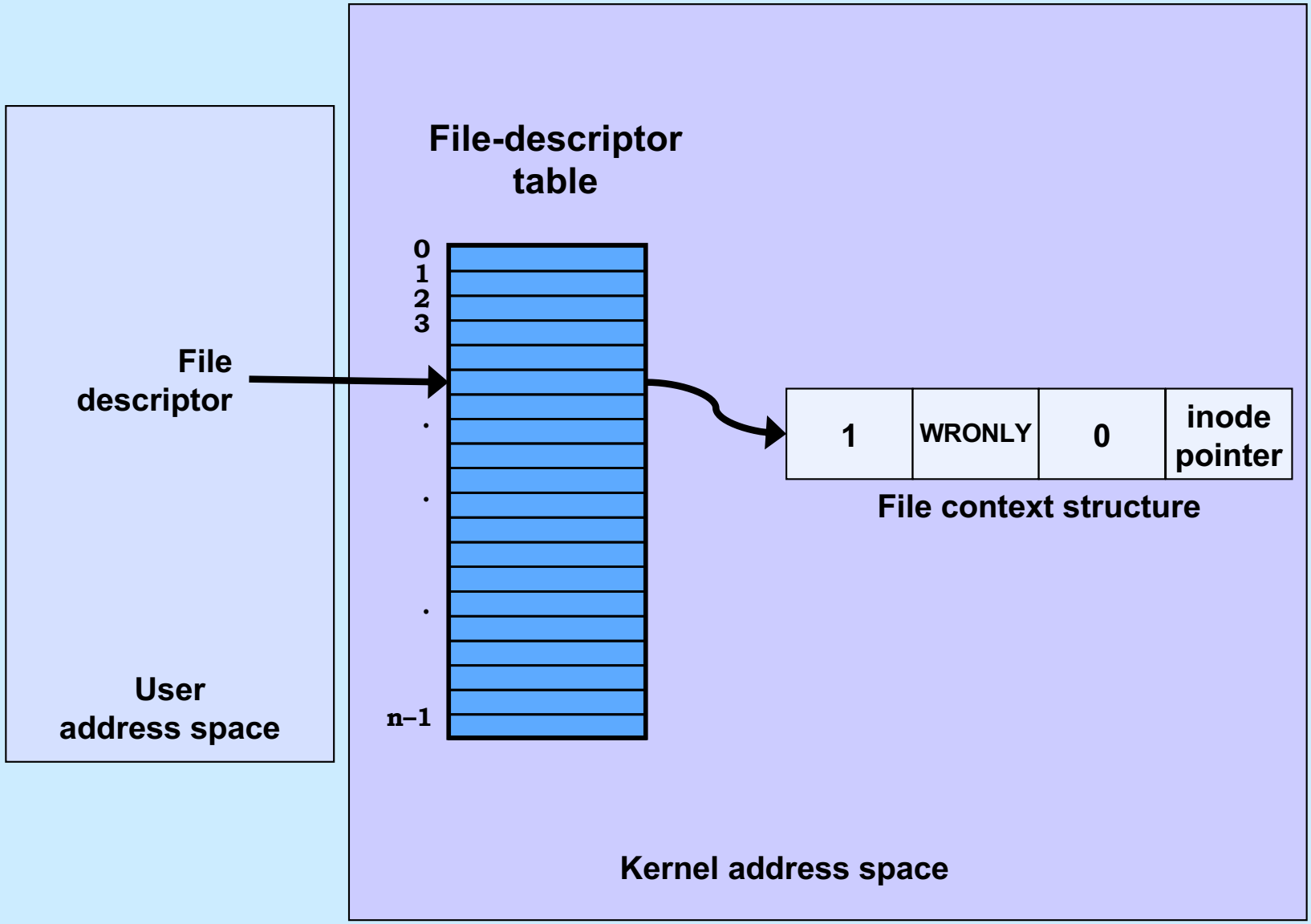
Redirecting Stdout in C

```
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
```

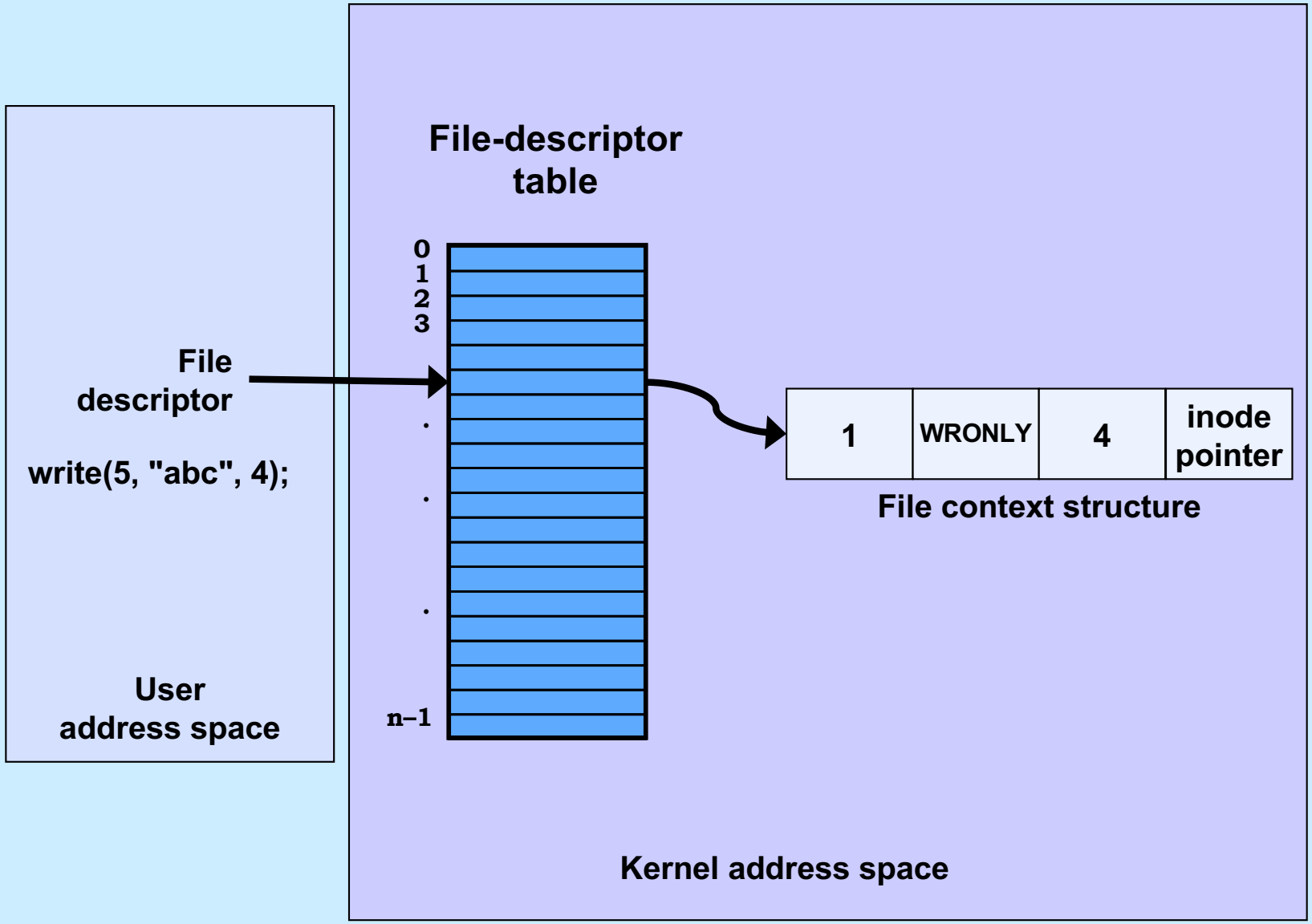
File-Descriptor Table



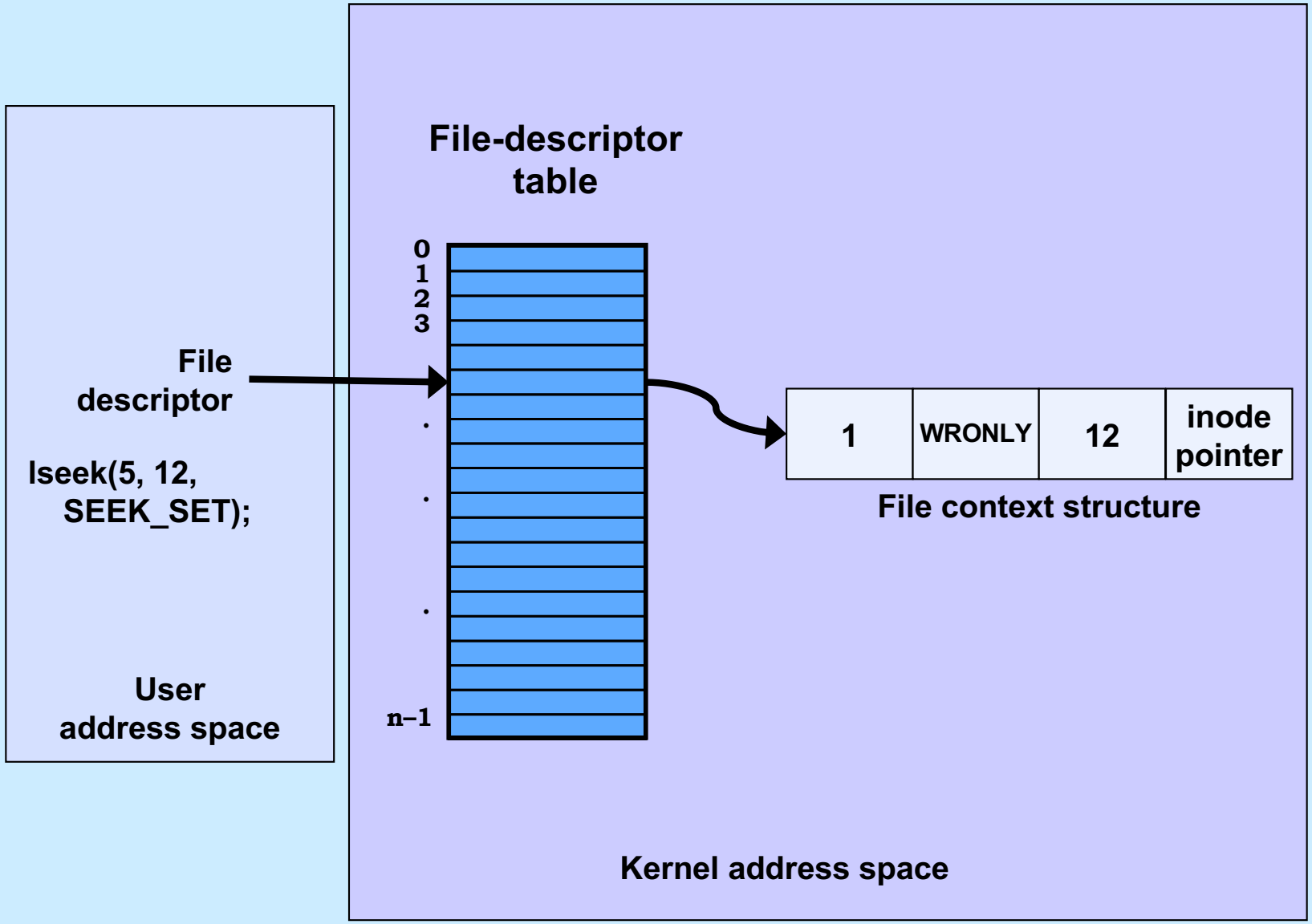
File Location



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

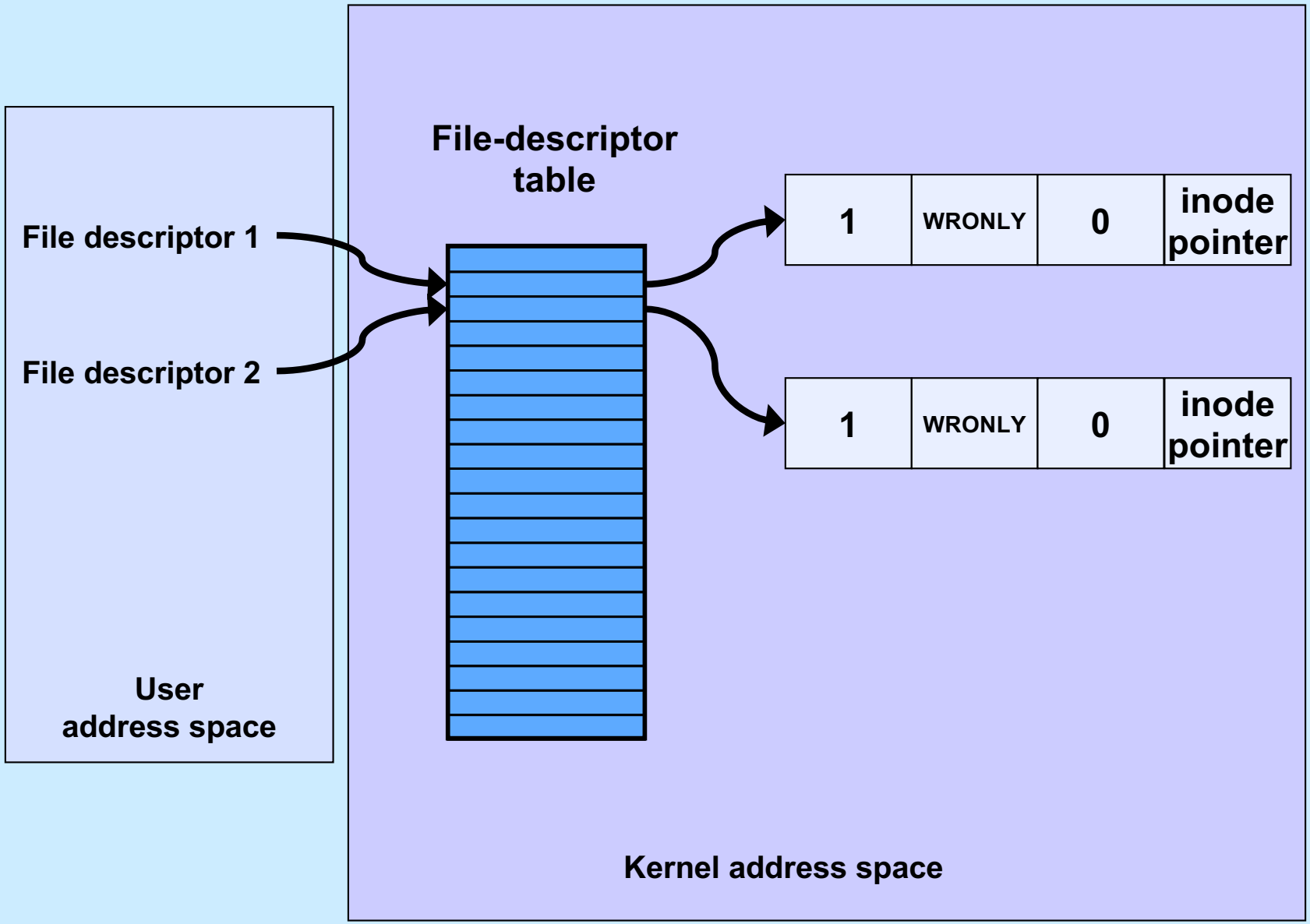
```
if (fork() == 0) {
   /* set up file descriptors 1 and 2 in the child process */
   close(1);
   close(2);
   if (open("/home/twd/Output", O_WRONLY) == -1) {
      exit(1);
   }
   if (open("/home/twd/Output", O_WRONLY) == -1) {
      exit(1);
   }
   char *argv[] = {"echon", 2, NULL};
   execv("/home/twd/bin/echon",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

From the Shell ...

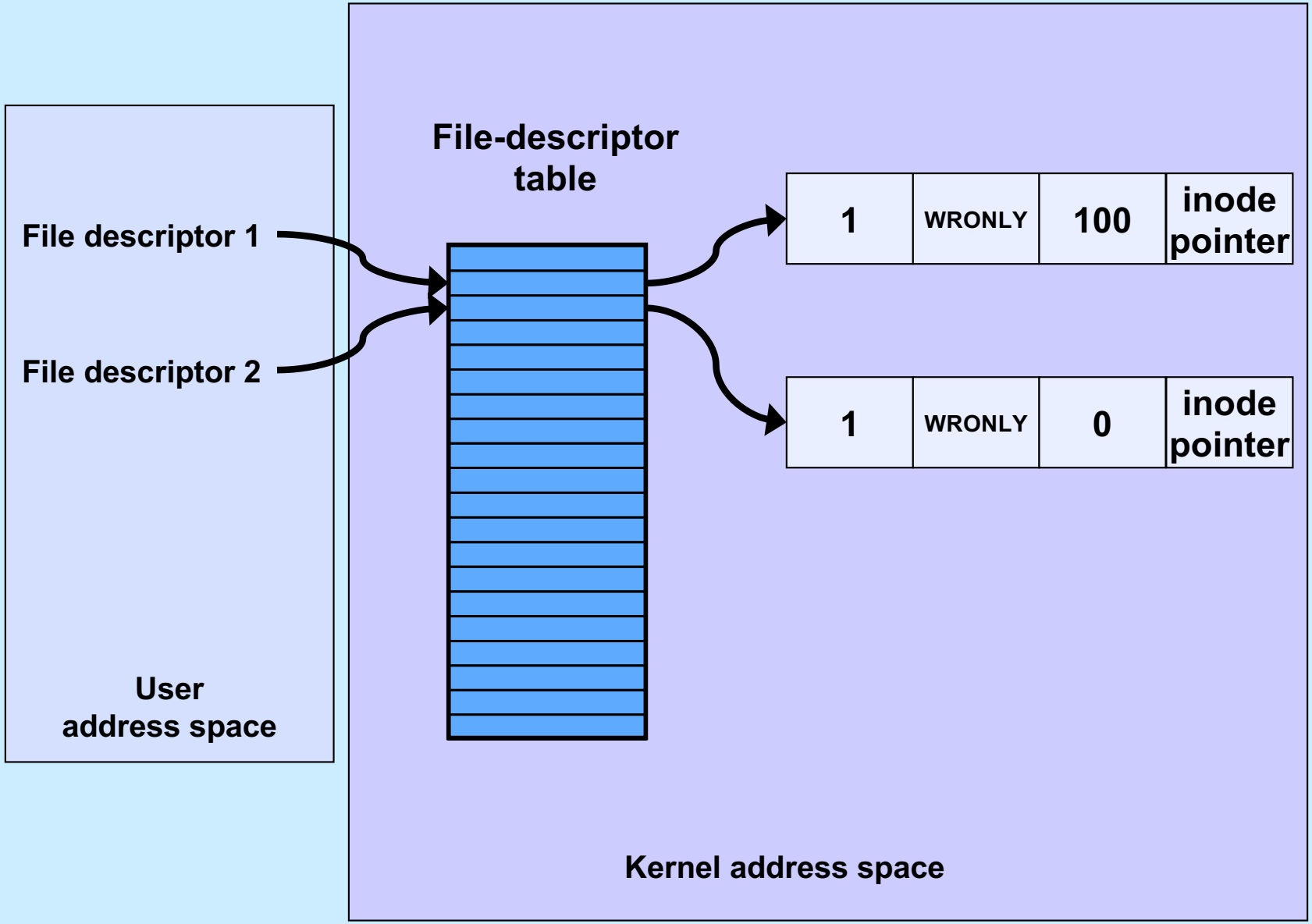
```
$ echon 1 >Output 2>Output
```

- **both stdout and stderr go to Output file**

Redirected Output



Redirected Output After Write



Quiz 3

- **Suppose we run**

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

- **The input line is**

```
X
```

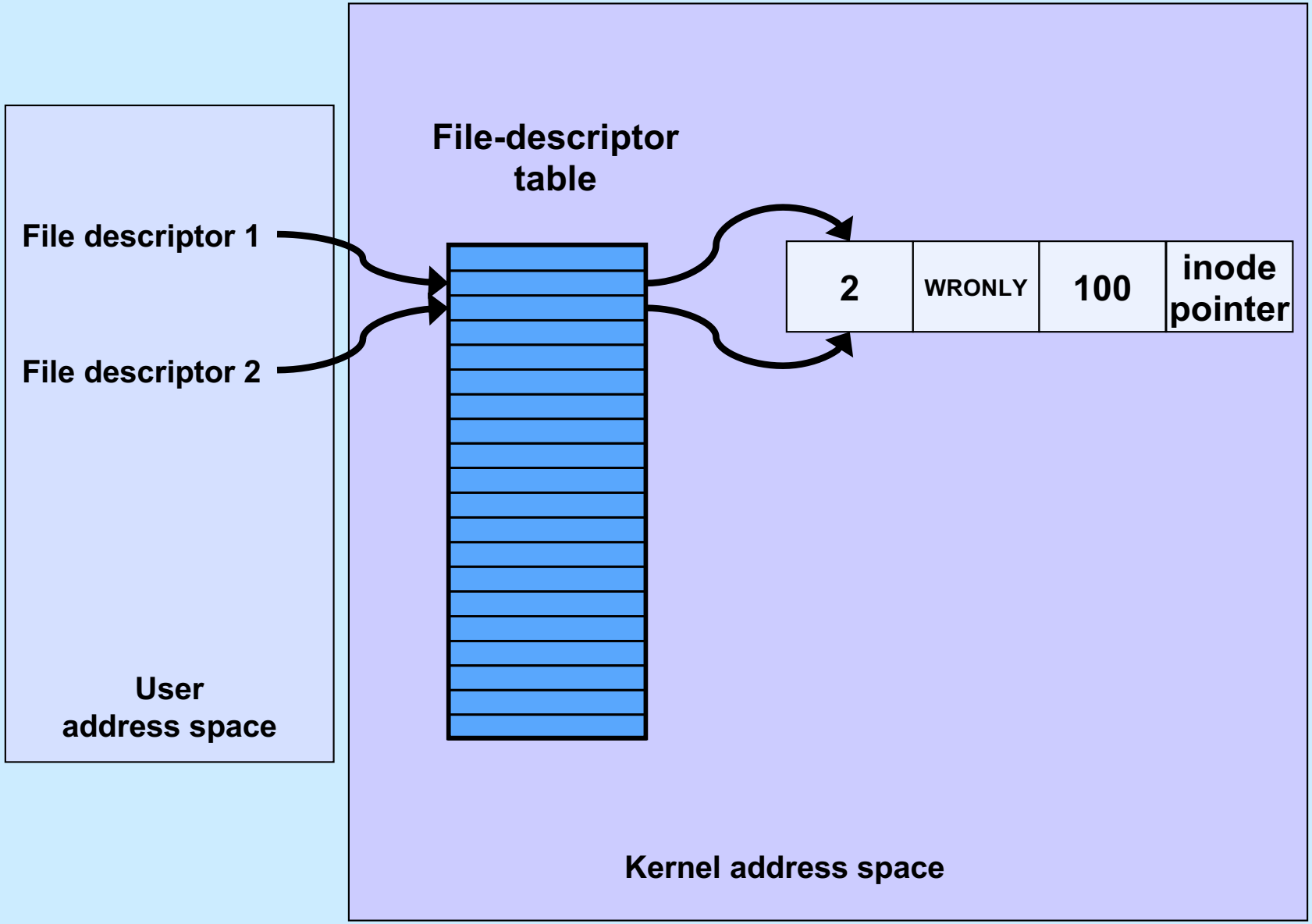
- **What is the final content of Output?**

```
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
```

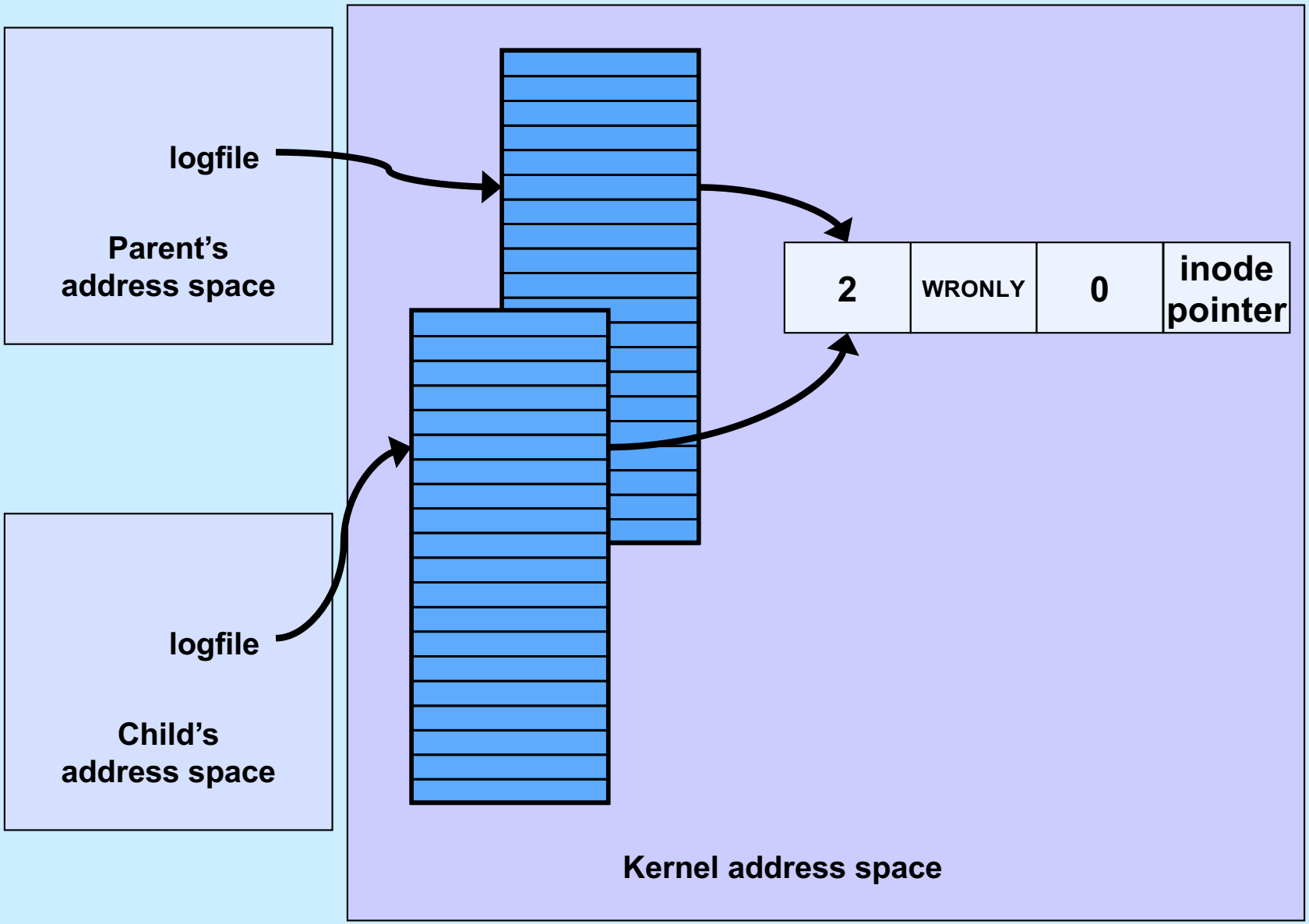
- **stdout goes to Output file, stderr is the dup of fd 1**
- **with input "X\n" it now produces in Output:**

```
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 4

```
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"