More Pipes and Dup2

Computer Operating Systems, Fall 2025

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Administrivia

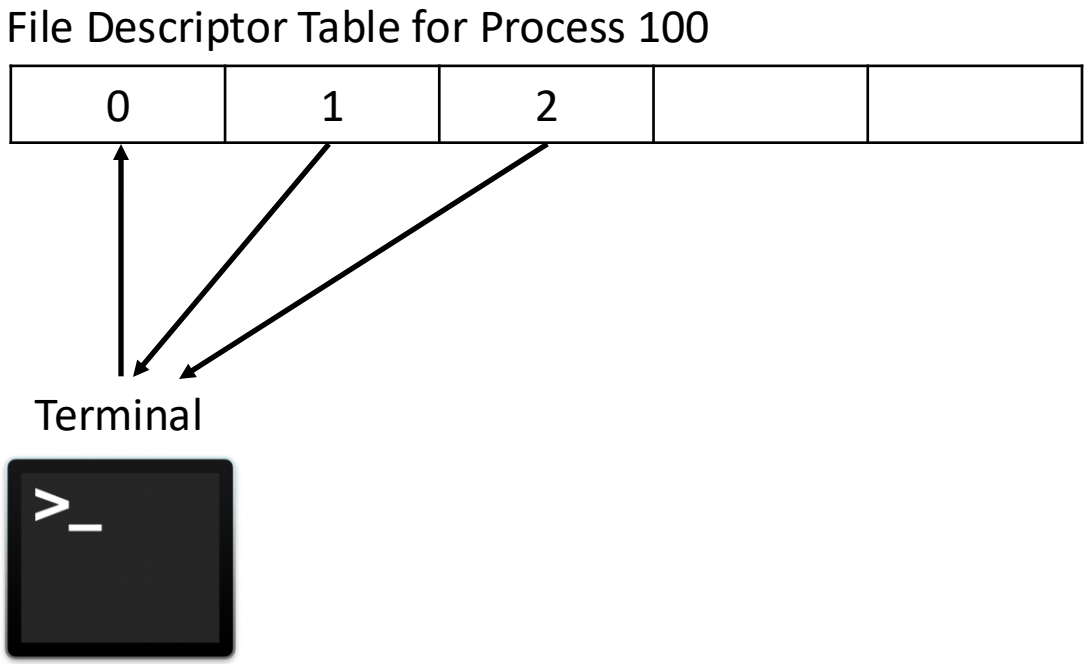
- **Penn-Vec and Penn-Shredder**
  - Due Tomorrow @ midnight! Go to office hours if you need help!
  - Late due date, with two late tokens is Tuesday @ Midnight.
- **Penn-Shell**
  - To be released on Saturday!
  - Find your partners! You will sign up with your partners as a group on Canvas and on Github when the assignment is out.
  - If you are without a partner by 09/17 at 5PM, we will automatically pair people together.
    - SO FIND SOMEONE!
  - Broken up into two milestone, the first is due @ 11:59 pm on 09/24
  - The entire assignment is due 10/03 @ midnight.
- **Project 1 Peer Evaluation goes out Saturday.**
  - Due @ 11:59 pm on 09/22
  - This is where your partner will critique your code…

Lecture Outline

- **Quick Review**
  - **File Descriptors**
  - **File Table**
  - **Open File Table**
- Pipes and Dup
- pipe2

File Descriptor Table

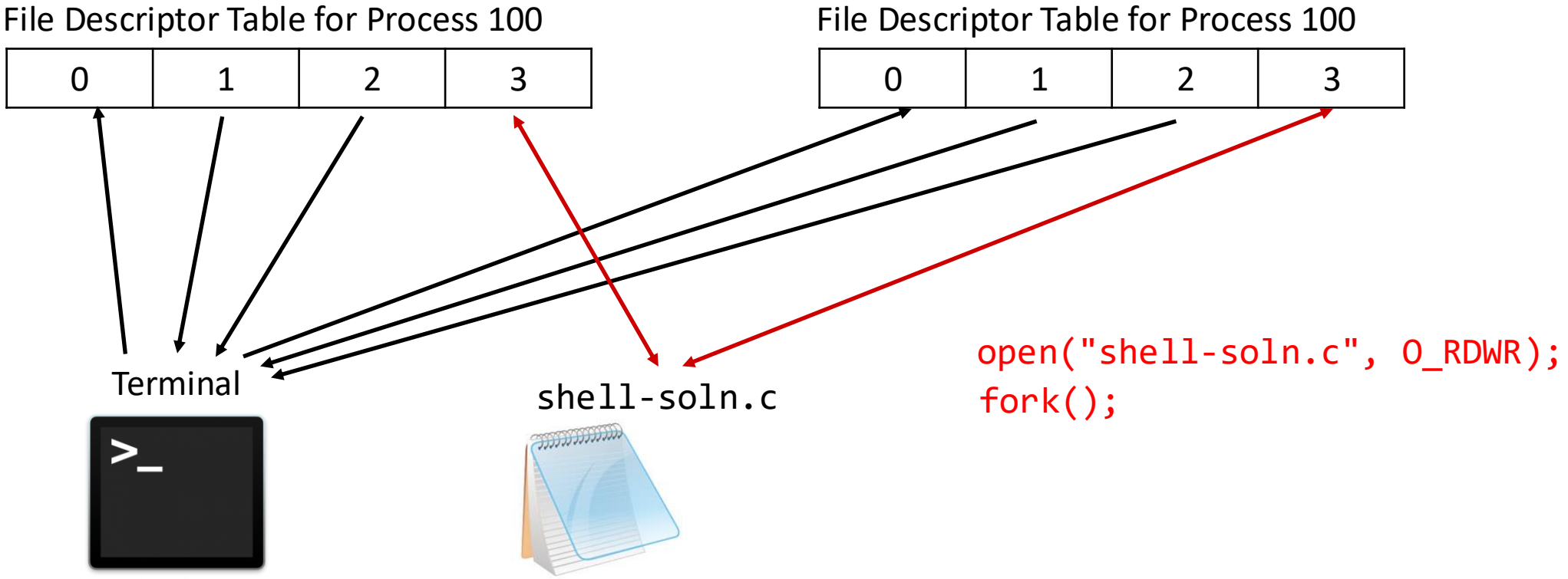
- Each process has **its own file descriptor table** managed by the OS
  - The table maintains information about the respective files the process has references to.
- A *file descriptor* is an index into a processes FD table.



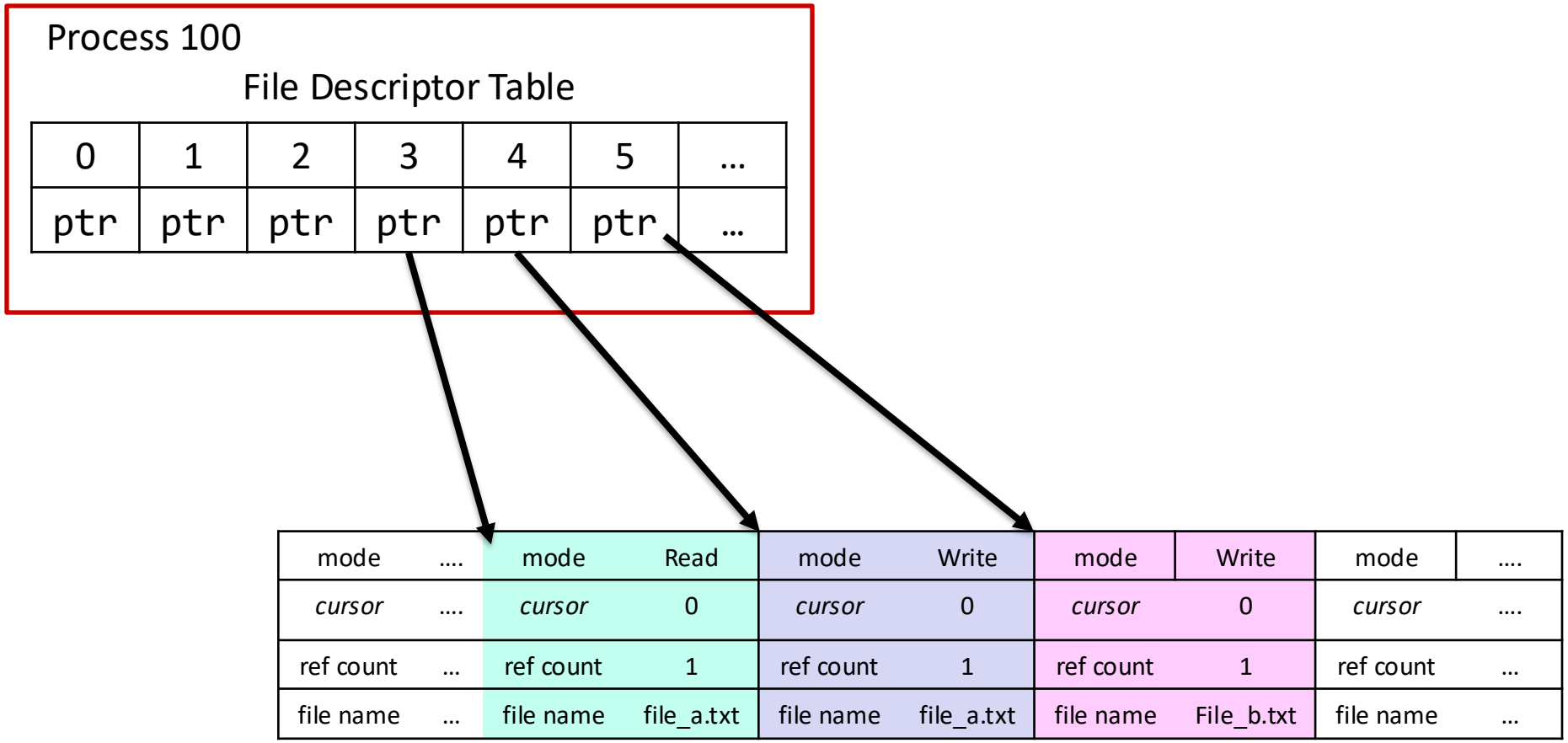
Not an accurate depiction.

File Descriptor Table w/Fork

- Fork will make ***an IDENTICAL copy of the parent's file descriptor table***
- If a file is opened before forking, child processes will inherit that file descriptor from the parent & point to same file reference!

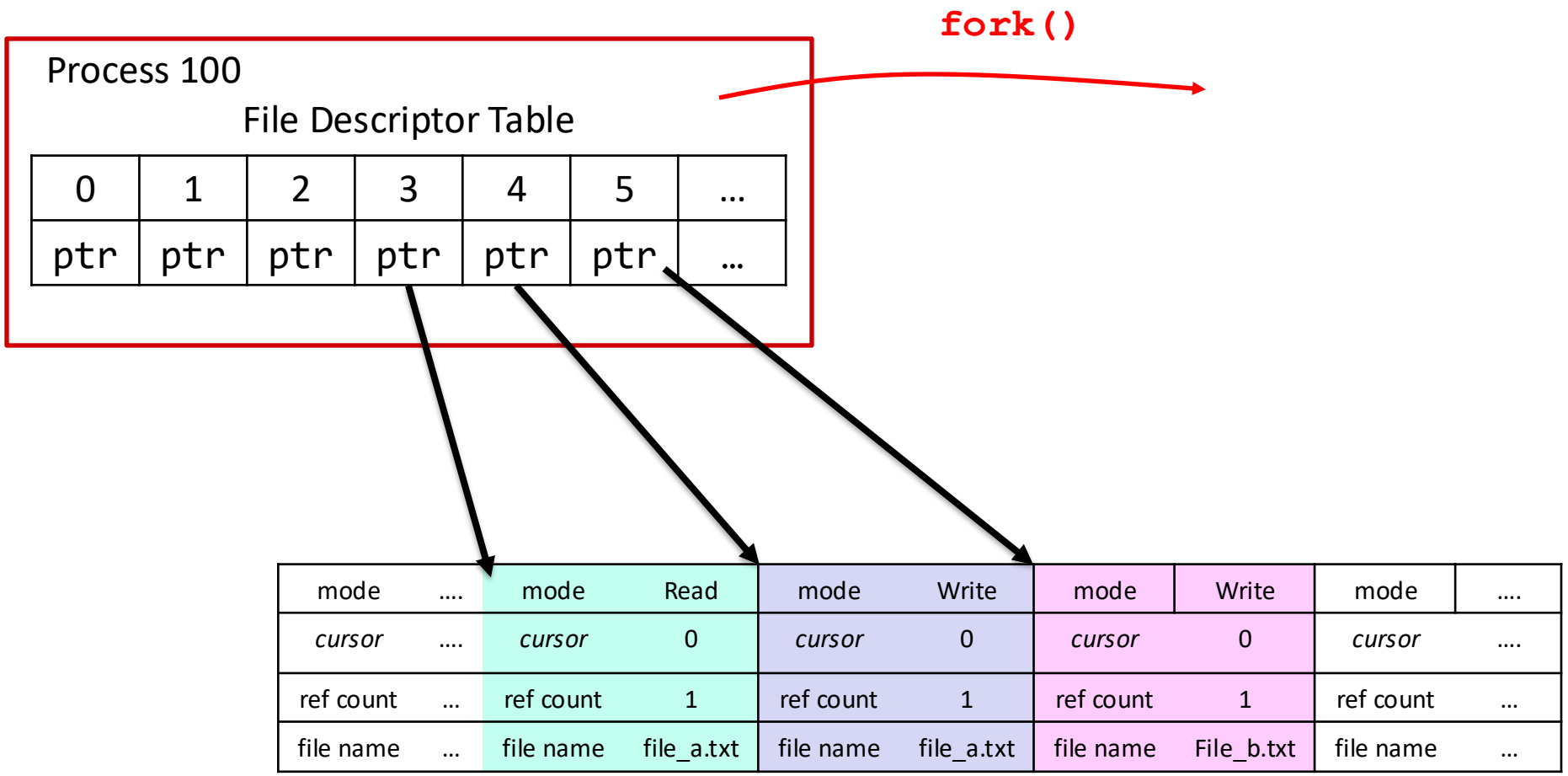


The Open File Table



*The v/inode row is removed since it's not relevant at the moment.

The Open File Table



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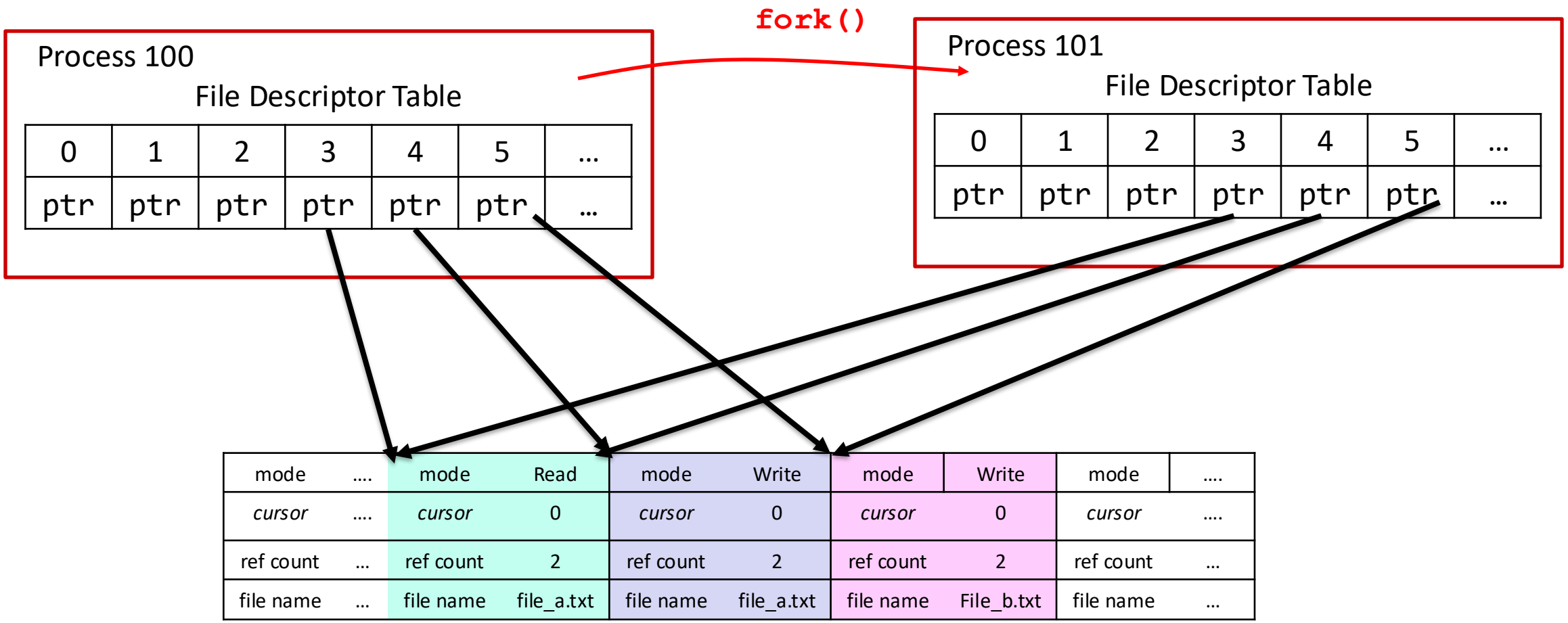
The Open File Table



reference counts are incremented with fork!

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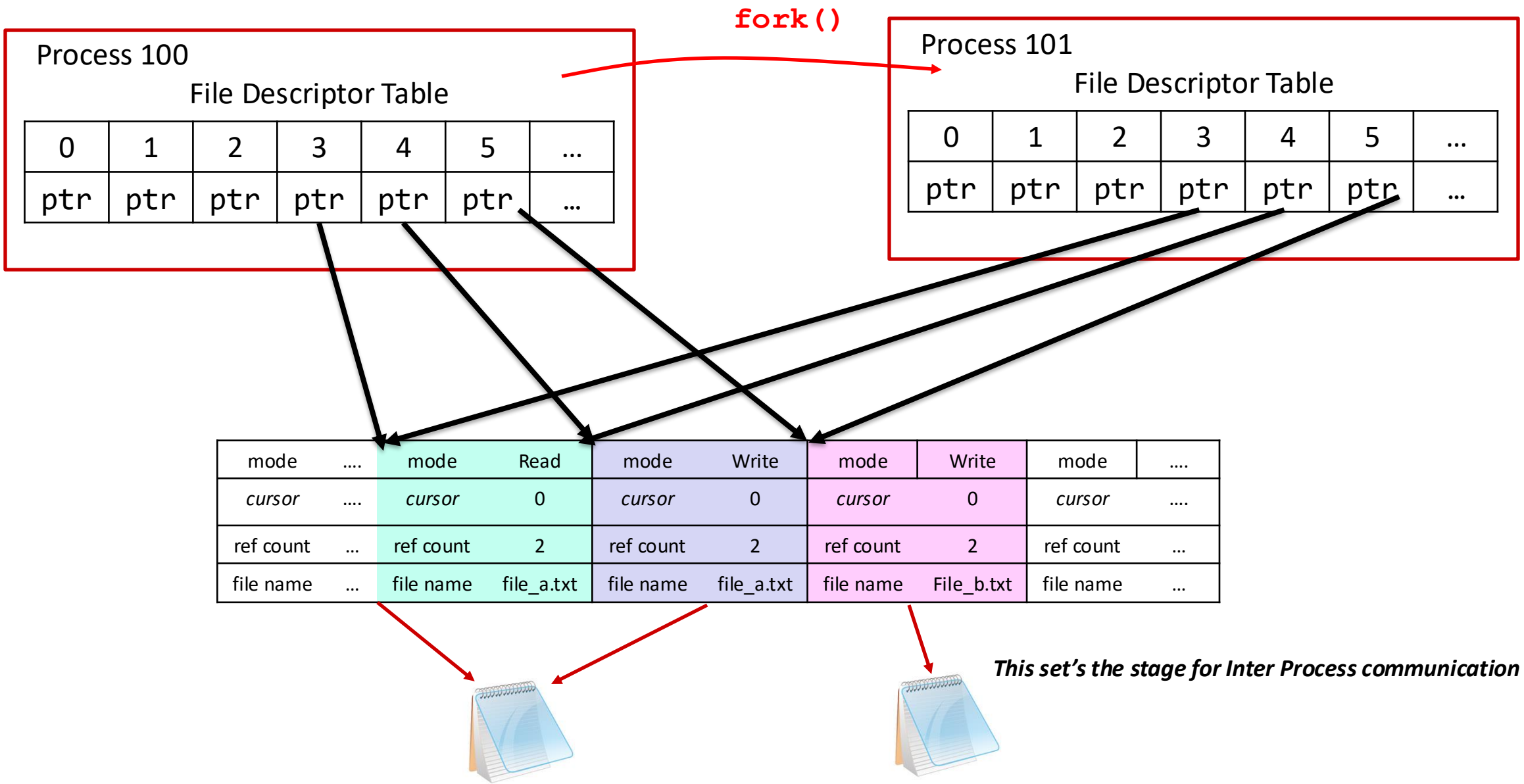
The Open File Table



This set's the stage for Inter Process communication via pipes…

Lecture Outline

- Quick Review
  - File Descriptors
  - File Table
  - Open File Table
- Pipes and Dup
- pipe2

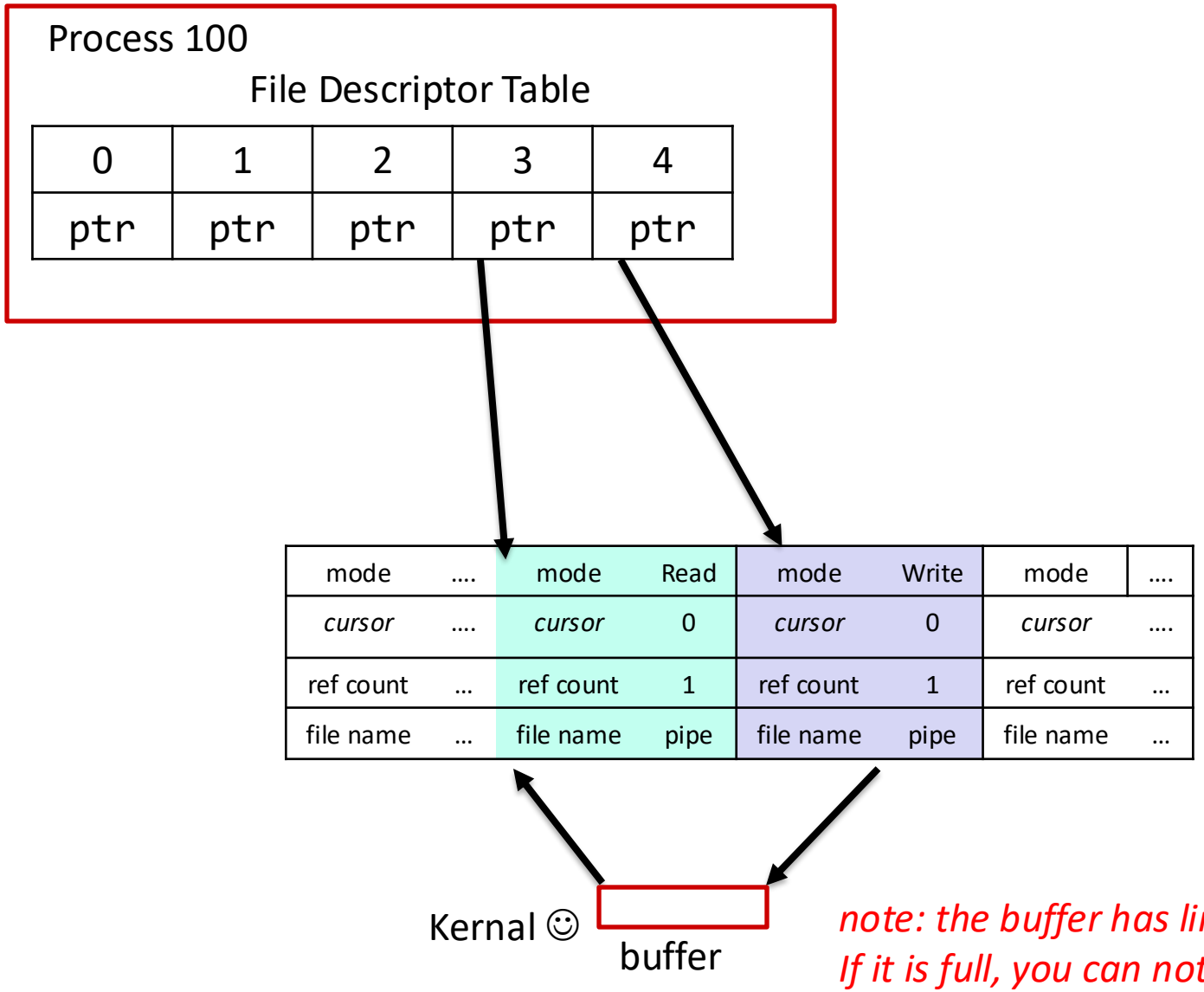
Interprocess Communication: *Pipes*

```
int pipe(int pipefd[2]);
```

- Takes in an array of two integers, and sets each integer to be a file descriptor corresponding to an "end" of the pipe
- `pipefd[0]` is the reading end of the pipe
- `pipefd[1]` is the writing end of the pipe

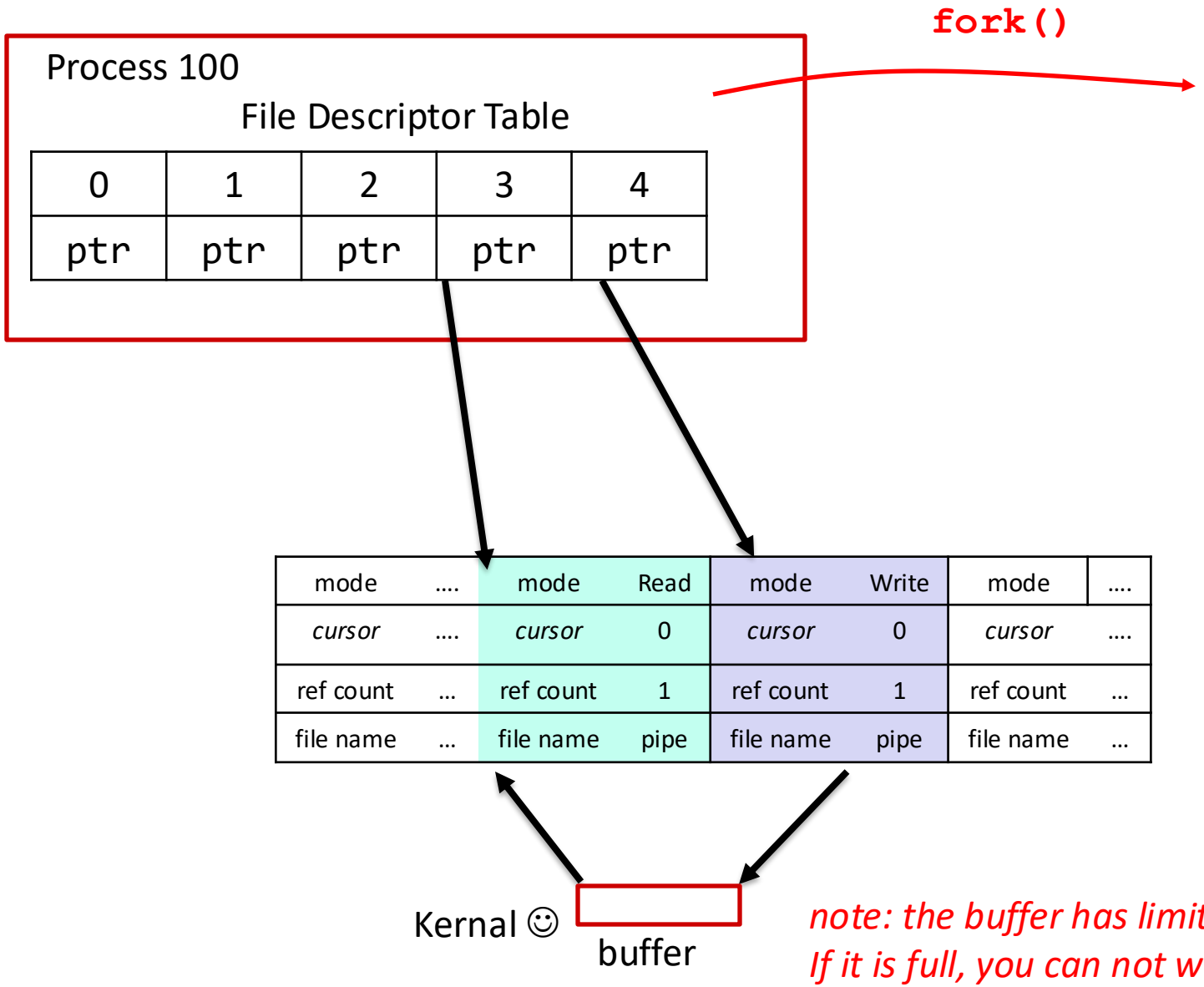
```
int pipefd[2];
int pipe(&pipefd);
```

Visualizing Pipes



note: the buffer has limited space.
If it is full, you can not write to it until you read (consume) what is there.

Visualizing Pipes with Fork



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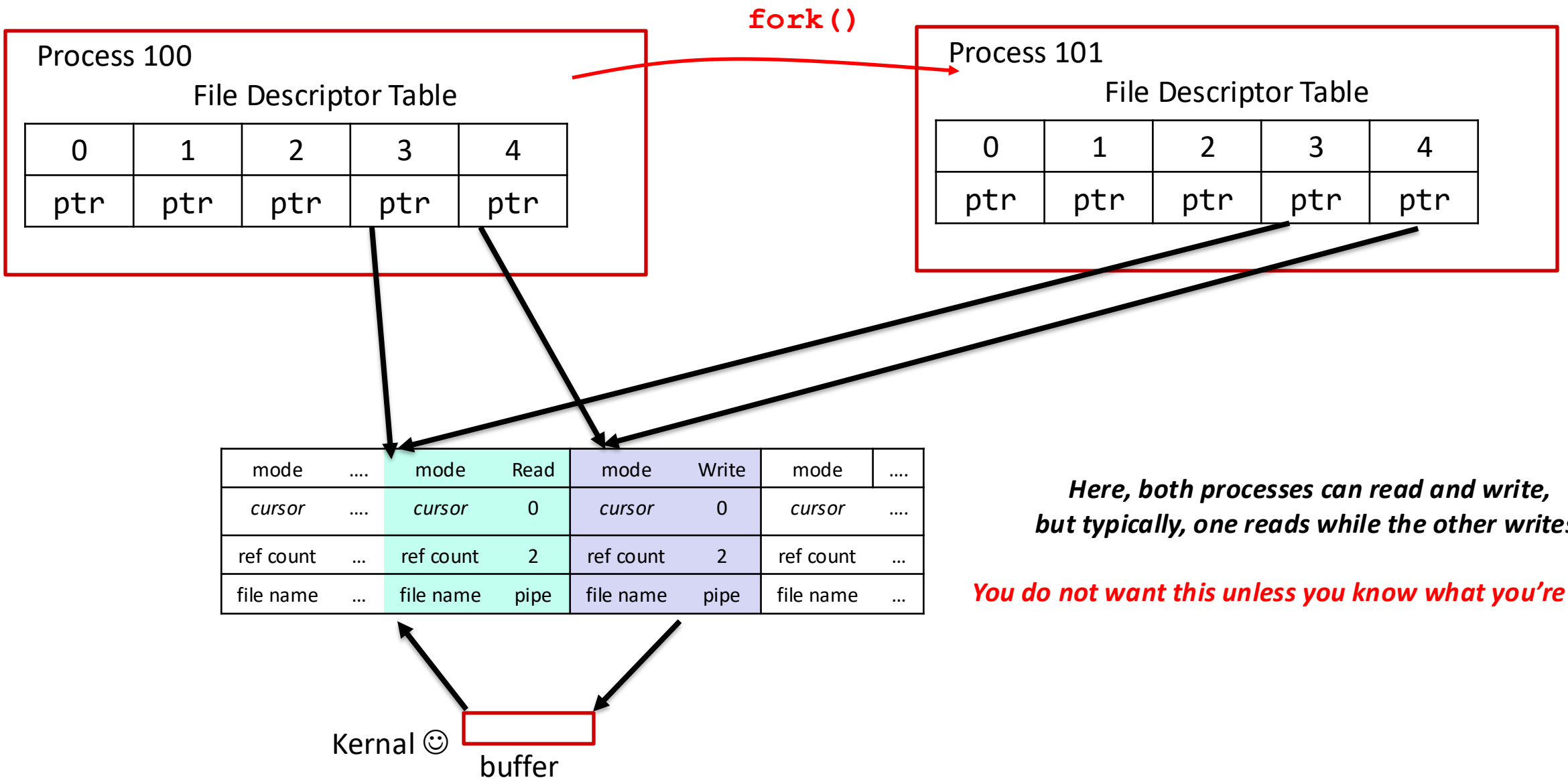
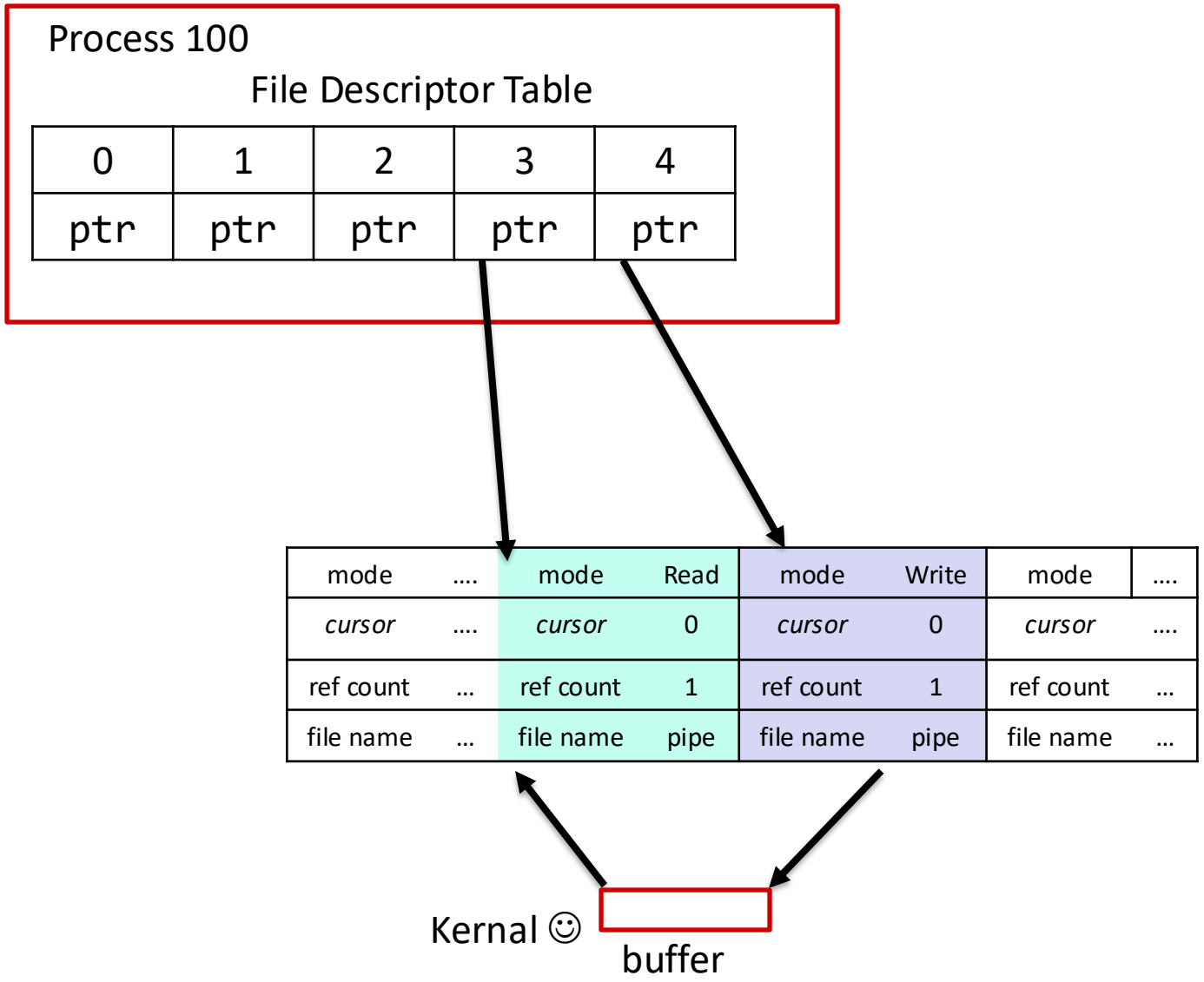
Visualizing Pipes with Fork



Here, both processes can read and write, but typically, one reads while the other writes.

You do not want this unless you know what you're doing.

Walk through short program

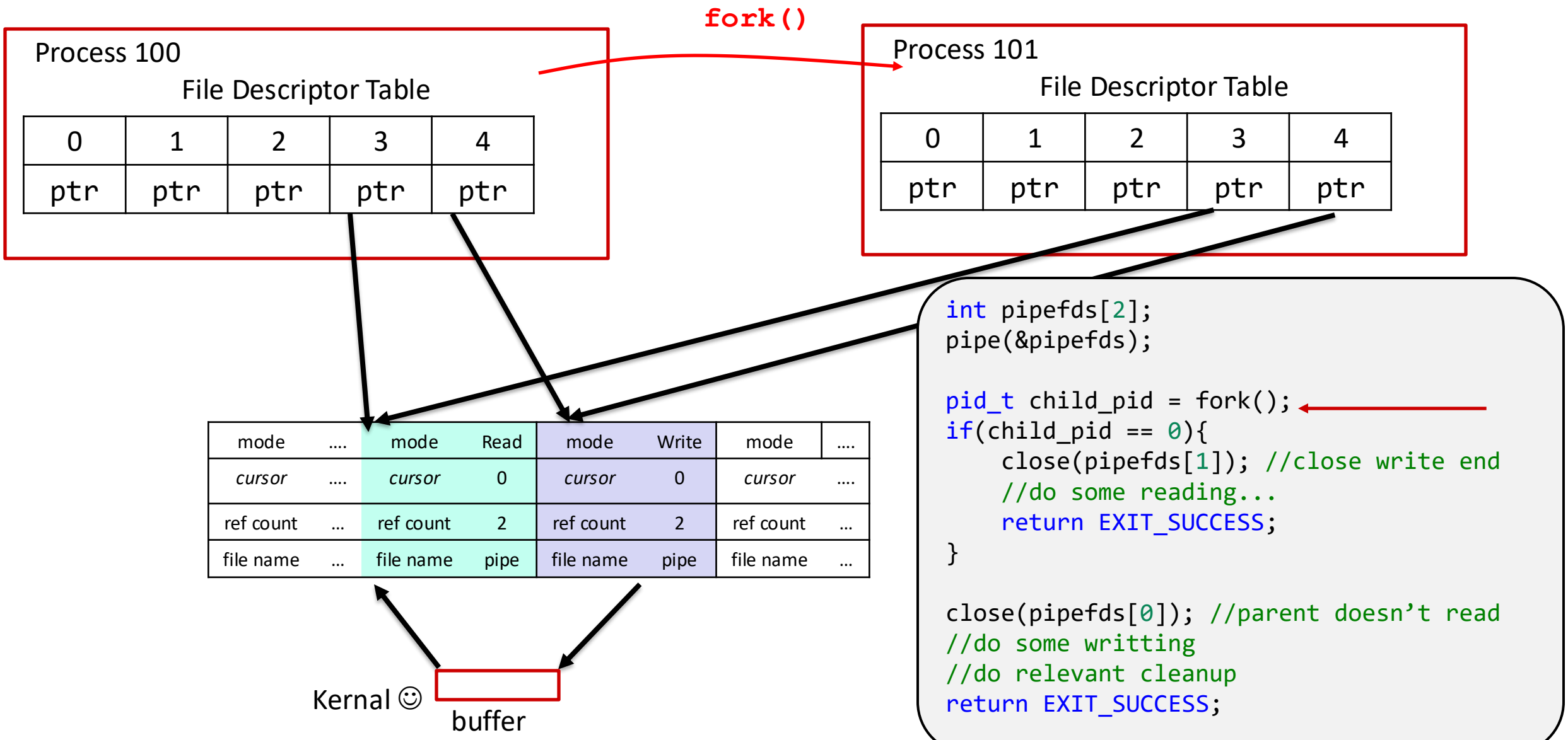



```c
int pipefds[2];
pipe(&pipefds);

pid_t child_pid = fork();
if(child_pid == 0){
    close(pipefds[1]); //close write end
    //do some reading...
    return EXIT_SUCCESS;
}

close(pipefds[0]); //parent doesn't read
//do some writting
//do relevant cleanup
return EXIT_SUCCESS;
```

Walk through short program

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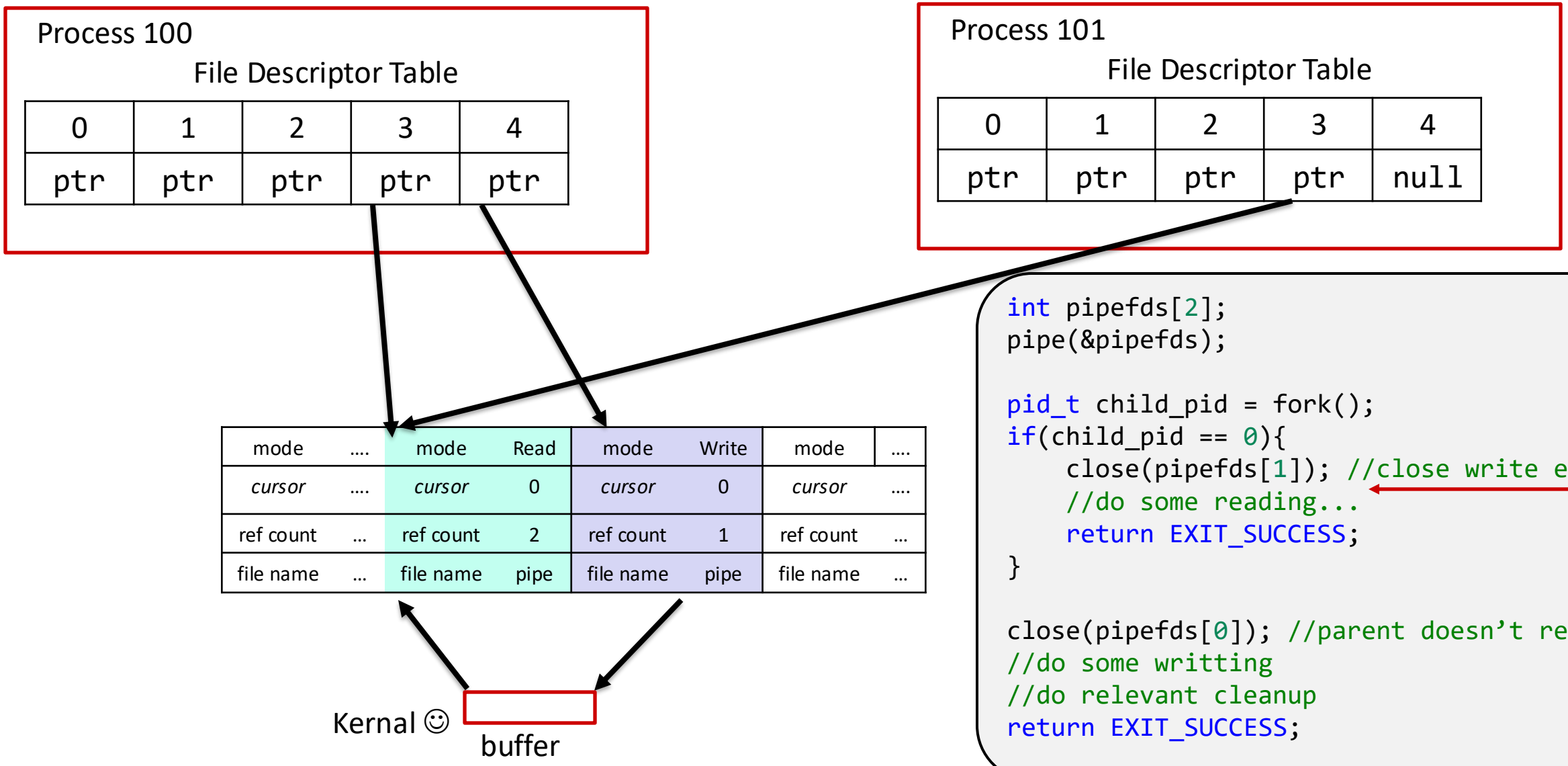
Walk through short program

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    //do some reading...
    return EXIT_SUCCESS;
}

close(pipefds[0]); //parent doesn't read
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//do relevant cleanup
return EXIT_SUCCESS;
```

Walk through short program

Process 100

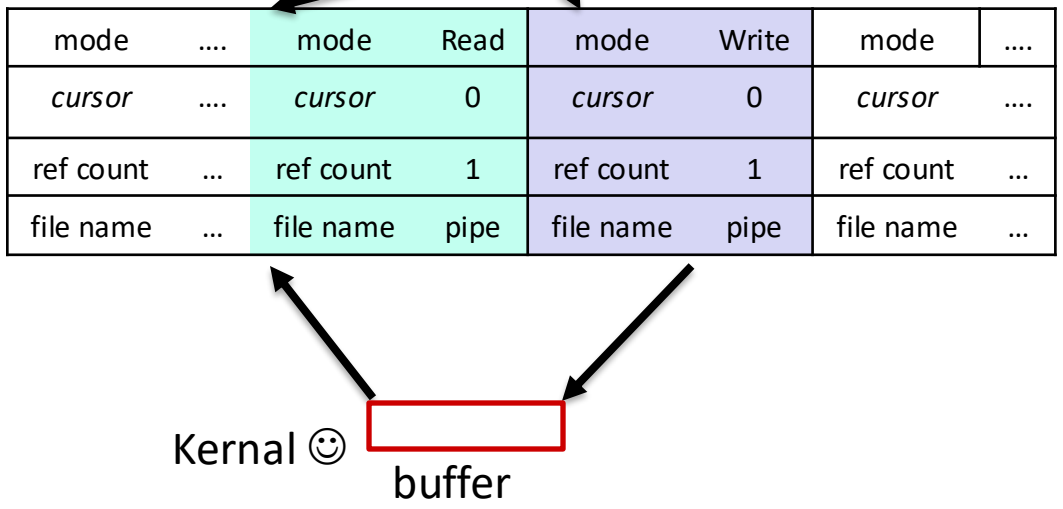
File Descriptor Table

0	1	2	3	4
ptr	ptr	ptr	null	ptr

Process 101

File Descriptor Table

0	1	2	3	4
ptr	ptr	ptr	ptr	null




```c
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if(child_pid == 0){
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//do relevant cleanup
return EXIT_SUCCESS;
```
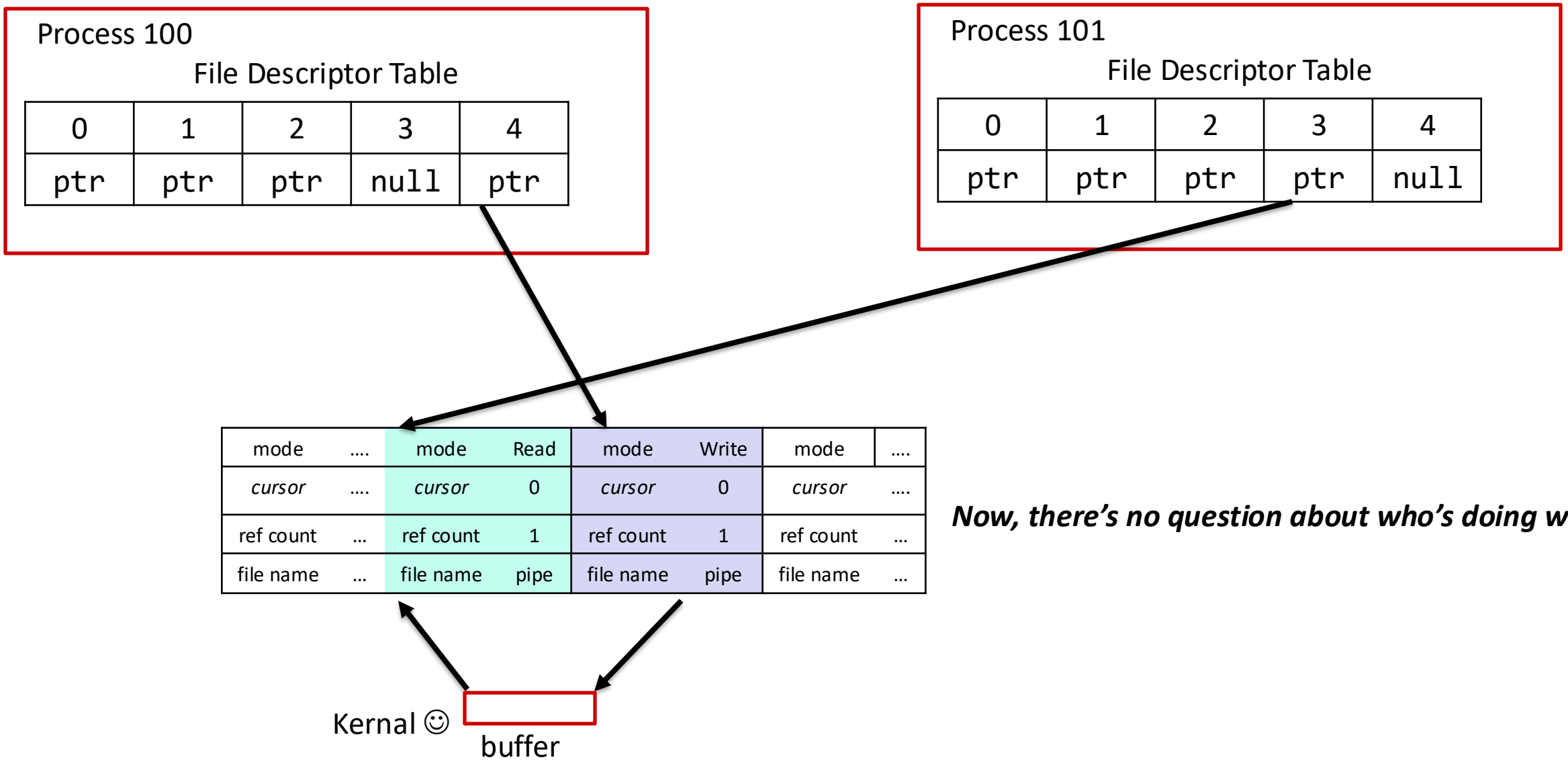

Final State of Short Program



Now, there's no question about who's doing what!

dup2: redirecting to our heart's desire

- We can manipulate the File Table so that a FD Table entry is associated with another file.
- ```
  int dup2(int oldfd, int newfd);
  ```
  - The file descriptor *newfd* is adjusted so that it now refers to the same open file description as *oldfd*. (newfd is closed silently…shh)

```
int dup2(int redirect_here, STDOUT_FILENO);
```

  - In this example, STDOUT_FILENO, no longer refers to the terminal, but rather the FILE associated with ***redirect_here***
```

Unix Shell Control Operators

- `cmd1 | cmd2`, creates a pipe so that the stdout of cmd1 is redirected to the stdin of cmd2
  - E.g. "`history | grep valgrind`"

- `cmd < file`, redirects stdin to instead read from the specified file
  - E.g. "`./penn-shredder < test_case`"

- `cmd > file`, redirects the stdout of a command to be written to the specified file
  - E.g. "`grep -r kill > out.txt`"

Piping in the Shell

```
cat bee_movie.txt | grep Barry | uniq
```

- ***cat*** first outputs the entire contents of bee_movie.txt and pipes it into ***grep***, which filters for lines containing "Barry"
- The output from ***grep*** is then piped into the ***uniq*** command, which removes duplicate lines from the output, ensuring each matching line appears only once.
- ***What would the fd table (for each process) and open file need to look like to make this feasible?***

Important: it is the shell process that forks each of these processes and intertwines their pipes together.

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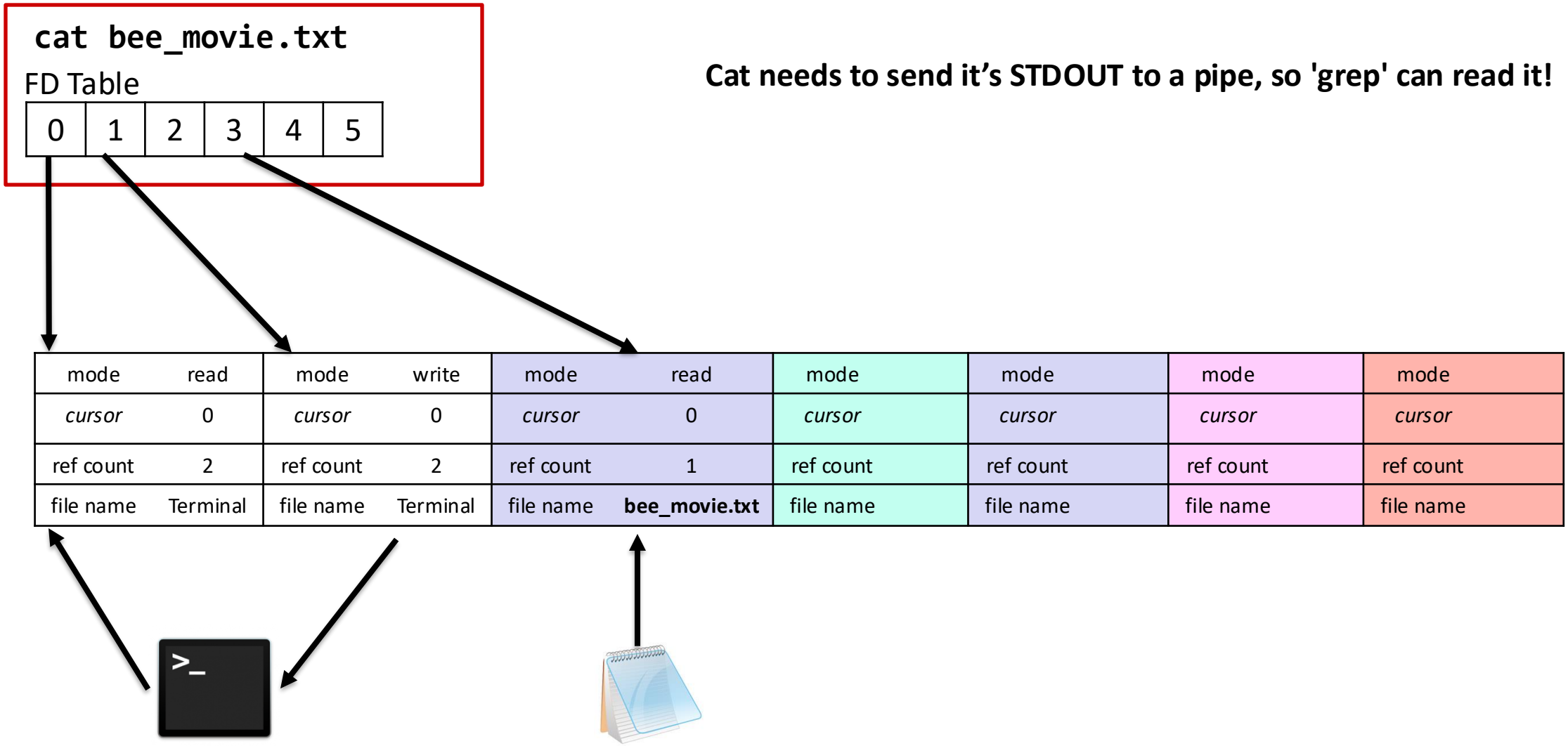
```
cat bee_movie.txt | grep Barry | uniq
```

How many pipes do we need to execute this command?

cat bee_movie.txt | grep Barry | uniq



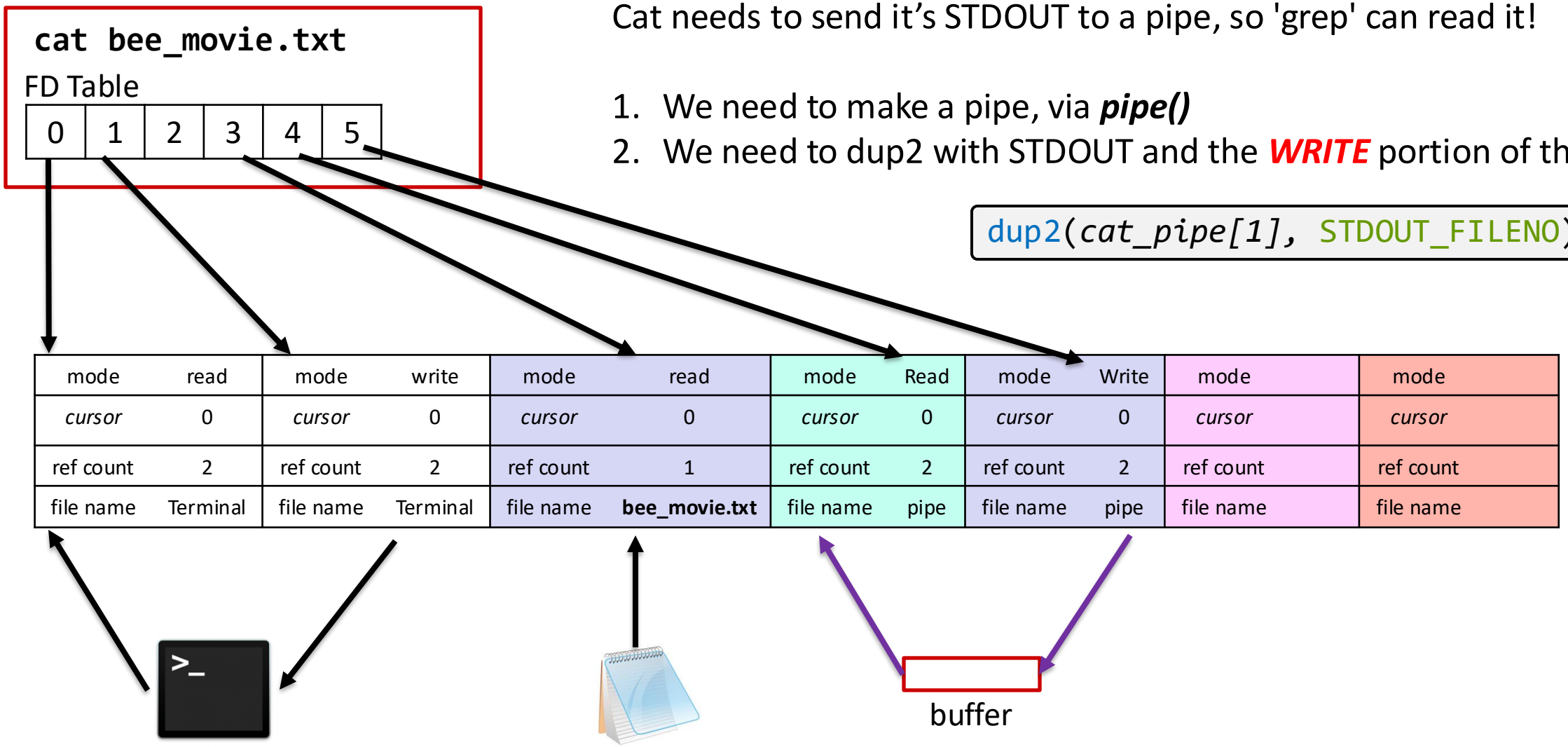
Note: the ref counts might seem inflated, but there is a shell process that exists too and forks these processes.

cat bee_movie.txt | grep Barry | uniq

Cat needs to send it's STDOUT to a pipe, so 'grep' can read it!

1. We need to make a pipe, via ***pipe()***
2. We need to dup2 with STDOUT and the ***WRITE*** portion of the pipe…

```
dup2(cat_pipe[1], STDOUT_FILENO);
```



cat bee_movie.txt | grep Barry | uniq

cat bee_movie.txt

FD Table

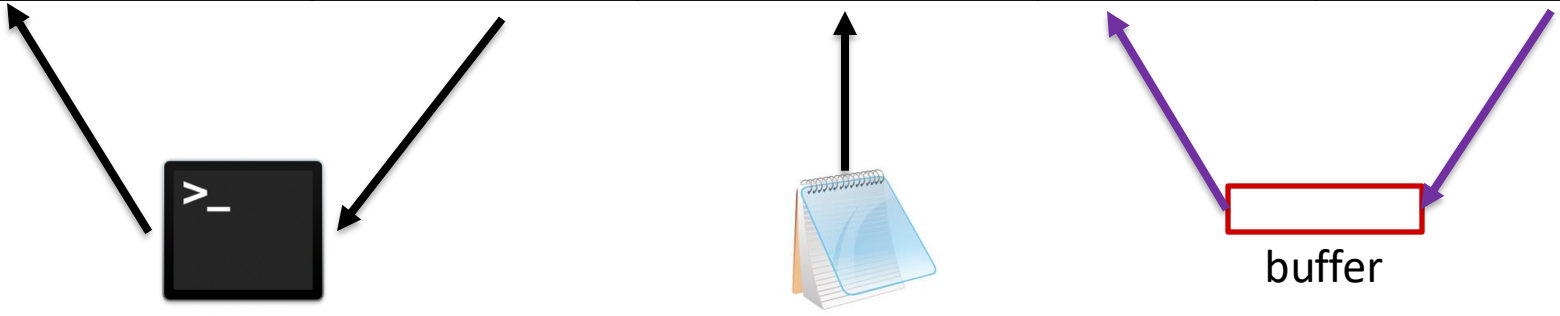
0	1	2	3	4	5

Cat needs to send it's STDOUT to a pipe, so 'grep' can read it!

1. We need to make a pipe, via ***pipe()***
2. We need to dup2 with STDOUT and the ***WRITE*** portion of the pipe before we exec!

```
dup2(cat_pipe[1], STDOUT_FILENO);
```

mode	read	mode	write	mode	read	mode	Read	mode	Write	mode	mode
cursor	0	*cursor*	0	*cursor*	0	*cursor*	0	*cursor*	0	*cursor*	*cursor*
ref count	2	ref count	1	ref count	1	ref count	2	ref count	3	ref count	ref count
file name	Terminal	file name	Terminal	file name	**bee_movie.txt**	file name	pipe	file name	pipe	file name	file name



note: cat doesn't need the write or read portions of the pipe after dup2, so I've omitted them here.

Be sure to close them when not necessary. We'll see a better trick in a bit.

Poll Everywhere

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`cat bee_movie.txt | grep Barry | uniq`

Where can we put a pipe, so both cat and grep can write and read, respectively?

```
int cat_pipe[2];

pipe(&cat_pipe); // A ←

pid_t cat_pid = fork();
pipe(&cat_pipe); // B ←
if(cat_pid == 0){
   // do cat stuff
   // maybe do some pipe stuff?
}
pipe(&cat_pipe); // C ←
pid_t grep_pid = fork();
pipe(&cat_pipe); // D ←
if(grep_pid == 0){
   // do grep stuff
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}
```

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pipe(&cat_pipe); // C ←
pid_t grep_pid = fork();
pipe(&cat_pipe); // D ←
if(grep_pid == 0){
   // do grep stuff
   // maybe do some pipe stuff?
}
```
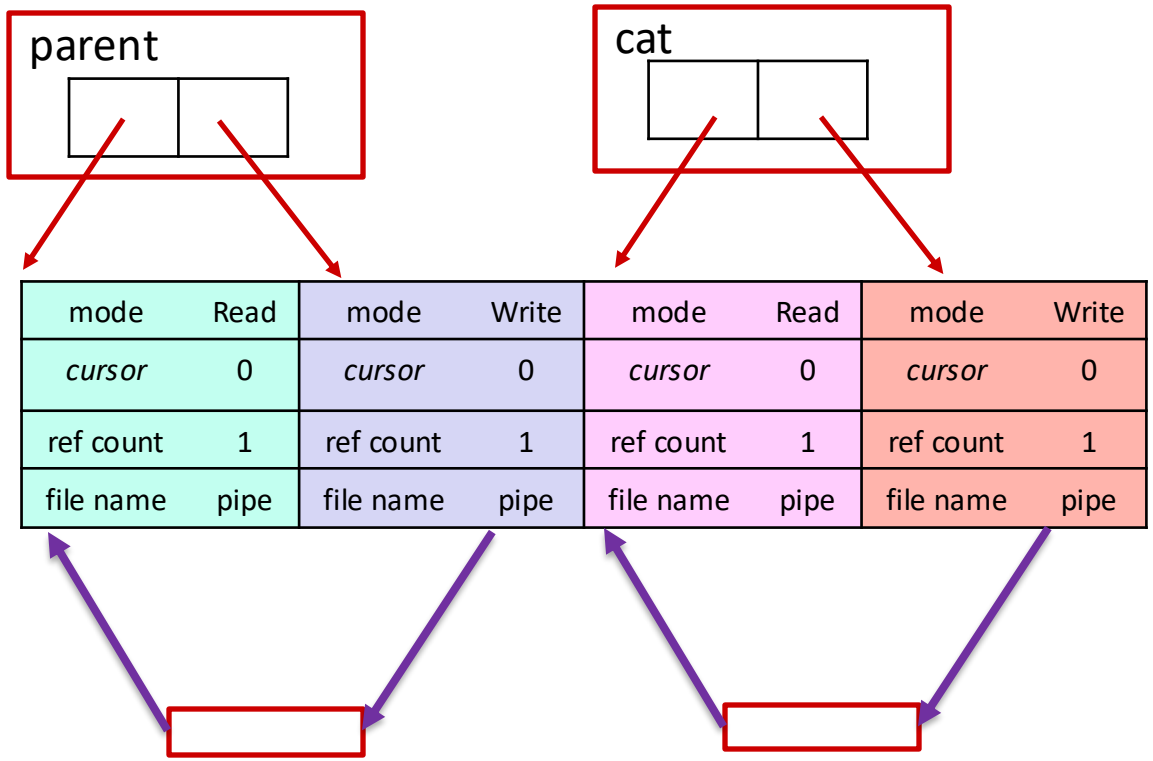

B: ***If we pipe here, we make two sperate pipes, one in the parent process, and one in the cat process, this does not allow for cat and grep to share a pipe: why? The FD are NOT SHARED!***



Poll Everywhere

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}
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pid_t grep_pid = fork();
pipe(&cat_pipe); // D ←
if(grep_pid == 0){
   // do grep stuff
   // maybe do some pipe stuff?
}
```

C: ***If we pipe here, we make only one pipe, in the parent! The cat process has already gone off on it's own. However, the grep process will inherit this pipe, just not the cat process.***

Recall: "In Cat, We need to dup2 with STDOUT and the ***WRITE*** portion of the pipe!"

How can we dup2 a pipe that never existed in the child process?

Poll Everywhere

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```
cat bee_movie.txt | grep Barry | uniq
```

Where can we put a pipe, so both cat and grep can write and read, respectively?

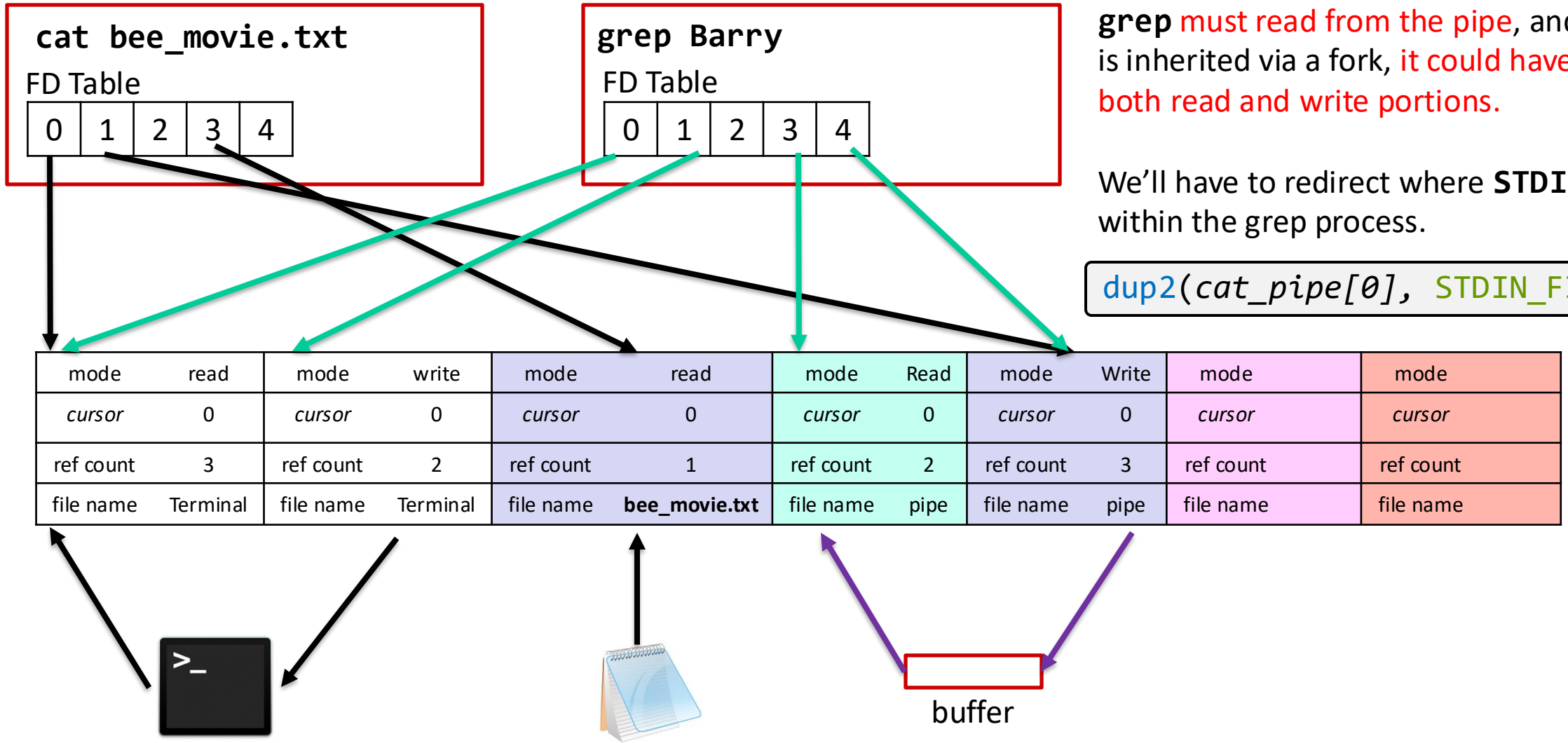
```
int cat_pipe[2];

pipe(&cat_pipe); // A ←

pid_t cat_pid = fork();
pipe(&cat_pipe); // B ←
if(cat_pid == 0){
   // do cat stuff
   // maybe do some pipe stuff?
}
pipe(&cat_pipe); // C ←
pid_t grep_pid = fork();
pipe(&cat_pipe); // D ←
if(grep_pid == 0){
   // do grep stuff
   // maybe do some pipe stuff?
}
```

D: ***This is similar to B, where we create a sepearte pipe in the parent and the grep process. No way to wrangle the pipes this way.***

`cat bee_movie.txt | grep Barry | uniq`

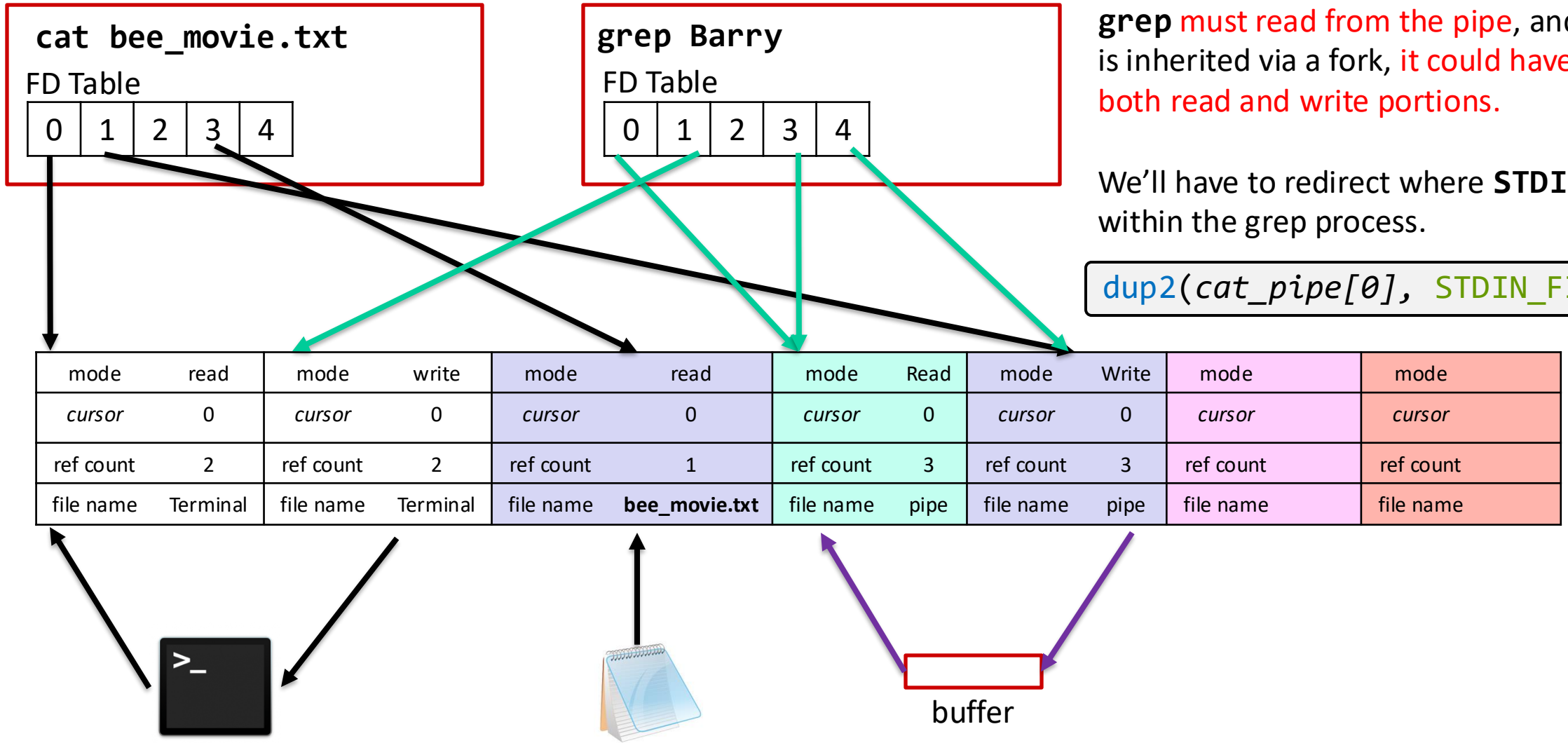


`grep` must read from the pipe, and as the pipe is inherited via a fork, it could have access to both read and write portions.

We'll have to redirect where **`STDIN`** refers to within the grep process.

```
dup2(cat_pipe[0], STDIN_FILENO);
```

`cat bee_movie.txt | grep Barry | uniq`



`grep` must read from the pipe, and as the pipe is inherited via a fork, it could have access to both read and write portions.

We'll have to redirect where **`STDIN`** refers to within the grep process.

```
dup2(cat_pipe[0], STDIN_FILENO);
```

cat bee_movie.txt | grep Barry | uniq

cat bee_movie.txt

FD Table

0	1	2	3	4

grep Barry

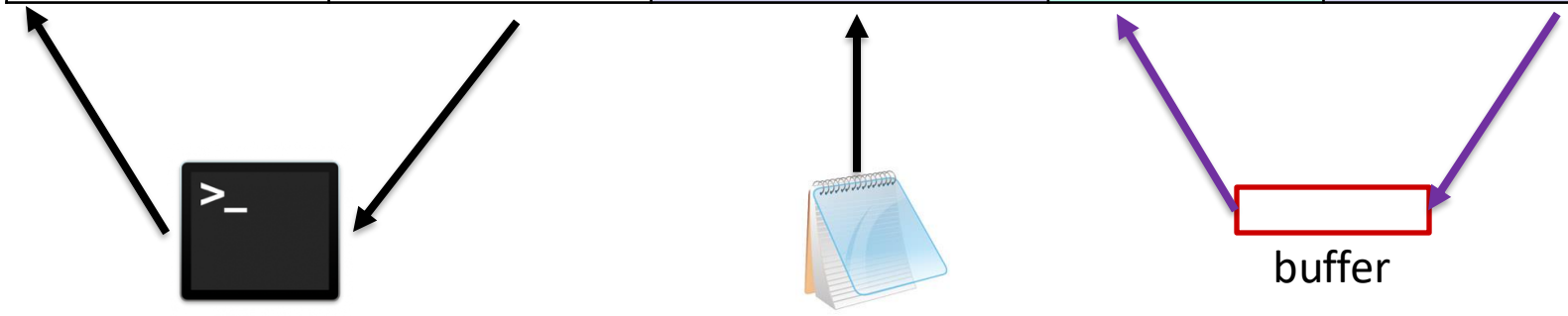
FD Table

0	1	2	3	4

```
dup2(cat_pipe[0], STDIN_FILENO);
```

After this, we can go ahead and close both sides of the pipe in ***grep***.

mode	read	mode	write	mode	read	mode	Read	mode	Write	mode	mode
cursor	0	*cursor*	0	*cursor*	0	*cursor*	0	*cursor*	0	*cursor*	*cursor*
ref count	2	ref count	2	ref count	1	ref count	3	ref count	3	ref count	ref count
file name	Terminal	file name	Terminal	file name	**bee_movie.txt**	file name	pipe	file name	pipe	file name	file name



cat bee_movie.txt | grep Barry | uniq

cat bee_movie.txt

FD Table

0	1	2	3	4

grep Barry

FD Table

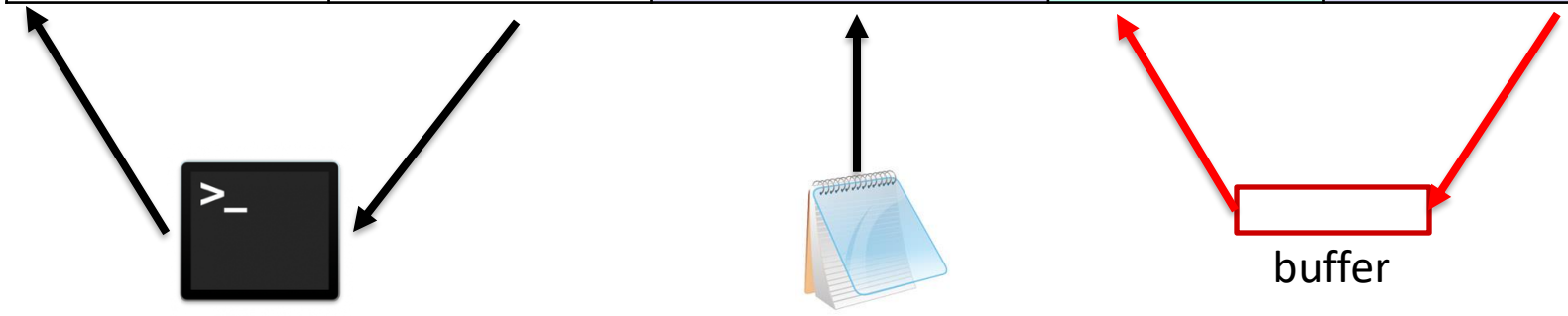
0	1	2	3	4

```
dup2(cat_pipe[0], STDIN_FILENO);
```

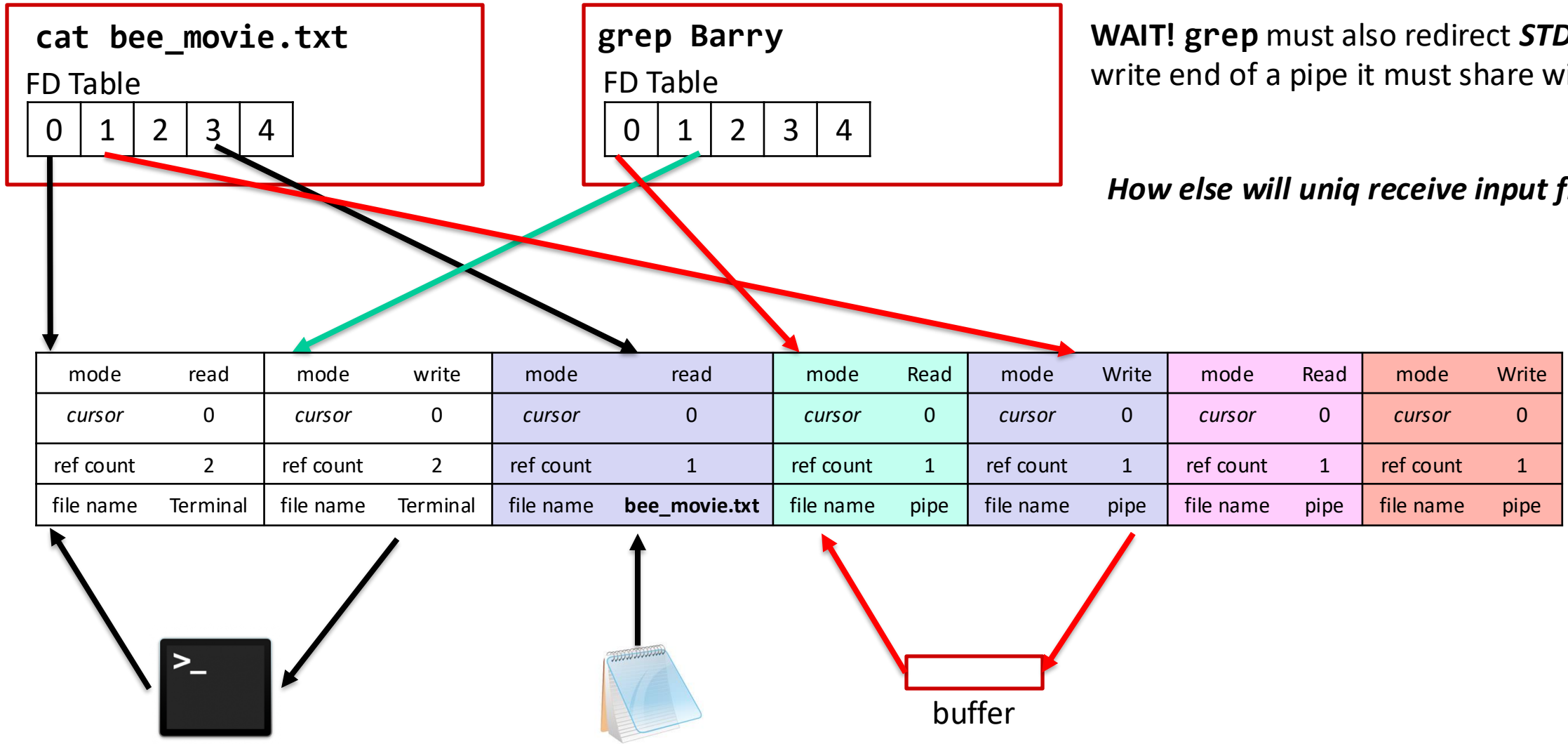
After this, we can go ahead and close both sides of the pipe in ***grep***.

Check out our first loop of pipes in red!

mode	read	mode	write	mode	read	mode	Read	mode	Write	mode	mode
cursor	0	*cursor*	0	*cursor*	0	*cursor*	0	*cursor*	0	*cursor*	*cursor*
ref count	1	ref count	1	ref count	1	ref count	1	ref count	1	ref count	ref count
file name	Terminal	file name	Terminal	file name	**bee_movie.txt**	file name	pipe	file name	pipe	file name	file name



`cat bee_movie.txt | grep Barry | uniq`



WAIT! `grep` must also redirect ***STDOUT*** to the write end of a pipe it must share with **`uniq`**

How else will uniq receive input from grep?

`cat bee_movie.txt | grep Barry | uniq`

`cat bee_movie.txt`

FD Table

0	1	2	3	4

`grep Barry`

FD Table

0	1	2	3	4

WAIT! `grep` must also redirect ***STDOUT*** to the write end of a pipe it must share with **`uniq`**

```
dup2(grep_pipe[1], STDOUT_FILENO);
```

mode	read	mode	write	mode	read	mode	Read	mode	Write	mode	Read	mode	Write
cursor	0	*cursor*	0	*cursor*	0	*cursor*	0	*cursor*	0	*cursor*	0	*cursor*	0
ref count	2	ref count	1	ref count	1	ref count	1	ref count	1	ref count	1	ref count	1
file name	Terminal	file name	Terminal	file name	**bee_movie.txt**	file name	pipe	file name	pipe	file name	pipe	file name	pipe

buffer

buffer

Poll Everywhere

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```
pipe(&grep_fds); // A ←
pid_t cat_pid = fork();
pipe(&grep_fds); // B ←
if(cat_pid == 0){
   // do cat stuff
   // maybe do some pipe stuff?
}
pipe(&grep_fds); // C ←
pid_t grep_pid = fork();
pipe(&grep_fds); // D ←
if(grep_pid == 0){
   // do grep stuff
   // maybe do some pipe stuff?
}
pipe(&grep_fds); // E ←
pid_t uniq_pid = fork();
pipe(&grep_fds); // F ←
if(uniq_pid == 0){
   // do uniq stuff
 }
```

`cat bee_movie.txt | grep Barry | uniq`

Where is the ***best place*** to put a pipe, so both grep and uniq can write and read, respectively?

*yes, this is a completely different pipe from the one shared by cat and grep

Poll Everywhere

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pipe(&grep_fds); // E ←
pid_t uniq_pid = fork();
pipe(&grep_fds); // F ←
if(uniq_pid == 0){
   // do uniq stuff
 }
```

`cat bee_movie.txt | grep Barry | uniq`

F: This creates two sperate pipes, in the `uniq` & parent process only. This pipe does not exist in the FD Table of `grep`! No way to communicate.

Poll Everywhere

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   // do uniq stuff
 }
```

`cat bee_movie.txt | grep Barry | uniq`

E: This creates one pipe, that is shared by both the parent process and uniq! However, still inaccessible by both uniq and grep.

Poll Everywhere

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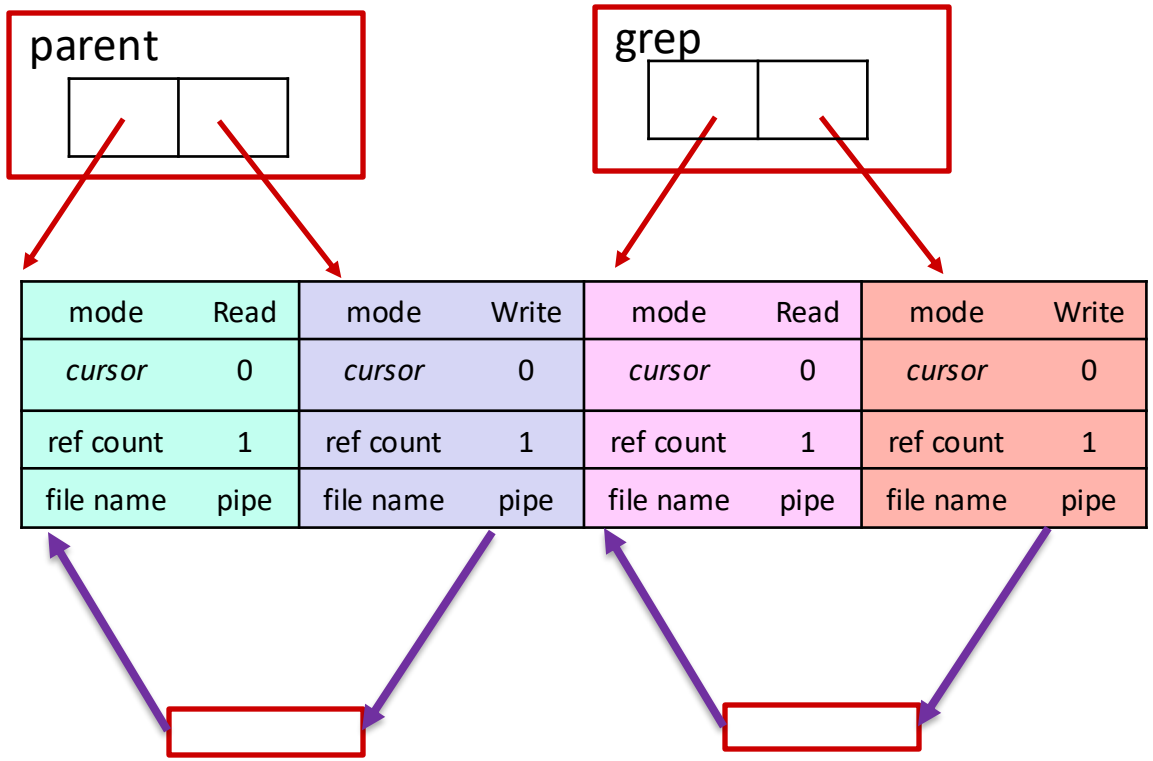
```
pipe(&grep_fds); // A ←
pid_t cat_pid = fork();
pipe(&grep_fds); // B ←
if(cat_pid == 0){
   // do cat stuff
   // maybe do some pipe stuff?
}
pipe(&grep_fds); // C ←
pid_t grep_pid = fork();
pipe(&grep_fds); // D ←
if(grep_pid == 0){
   // do grep stuff
   // maybe do some pipe stuff?
}
pipe(&grep_fds); // E ←
pid_t uniq_pid = fork();
pipe(&grep_fds); // F ←
if(uniq_pid == 0){
   // do uniq stuff
 }
```

`cat bee_movie.txt | grep Barry | uniq`

D: This creates two separate pipes, one in the parent and one in the grep process. However, still inaccessible by both uniq and grep. Why…

***Which of these will uniq inherit*?**



Poll Everywhere

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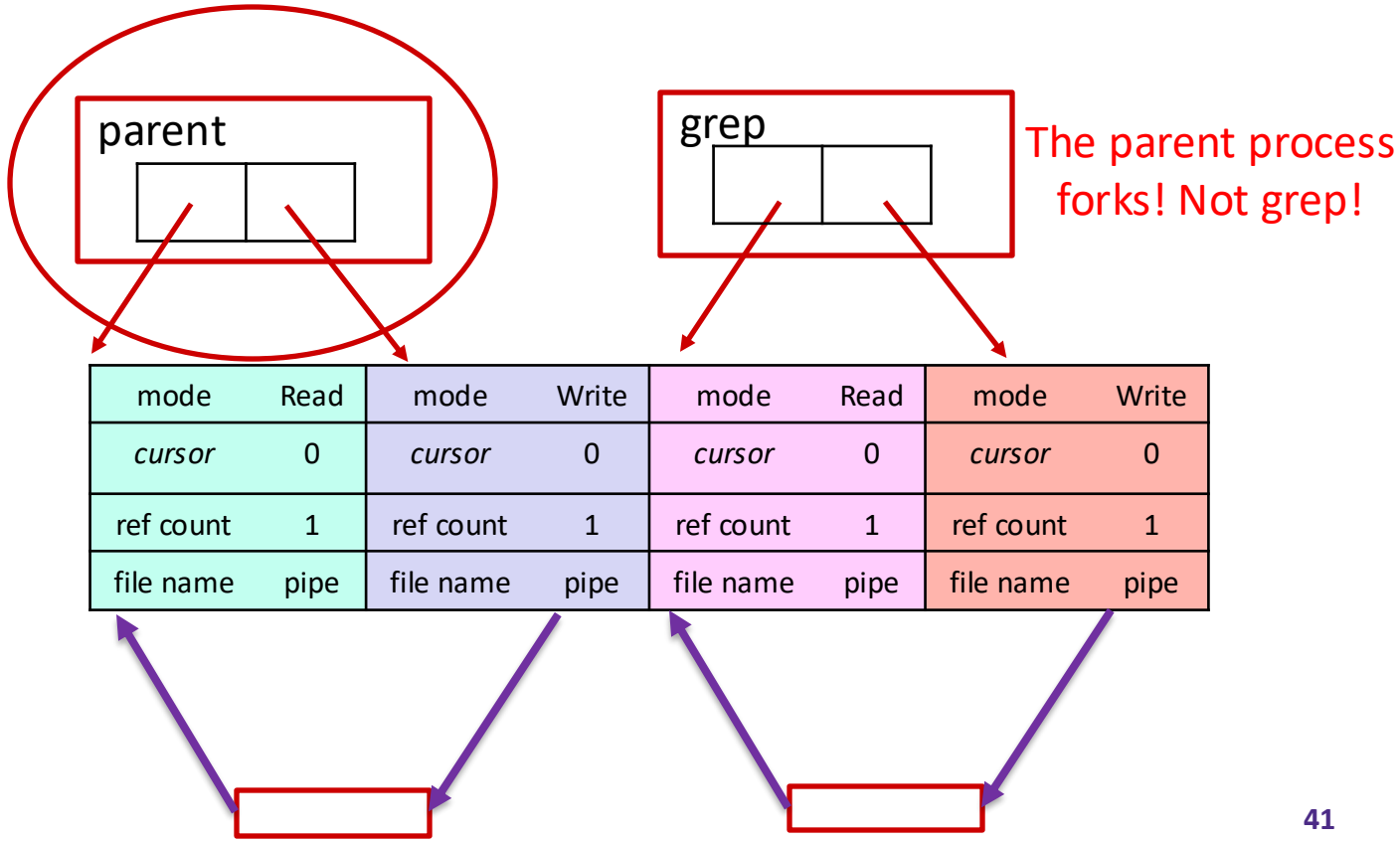
```
pipe(&grep_fds); // A ←
pid_t cat_pid = fork();
pipe(&grep_fds); // B ←
if(cat_pid == 0){
   // do cat stuff
   // maybe do some pipe stuff?
}
pipe(&grep_fds); // C ←
pid_t grep_pid = fork();
pipe(&grep_fds); // D ←
if(grep_pid == 0){
   // do grep stuff
   // maybe do some pipe stuff?
}
pipe(&grep_fds); // E ←
pid_t uniq_pid = fork();
pipe(&grep_fds); // F ←
if(uniq_pid == 0){
   // do uniq stuff
 }
```

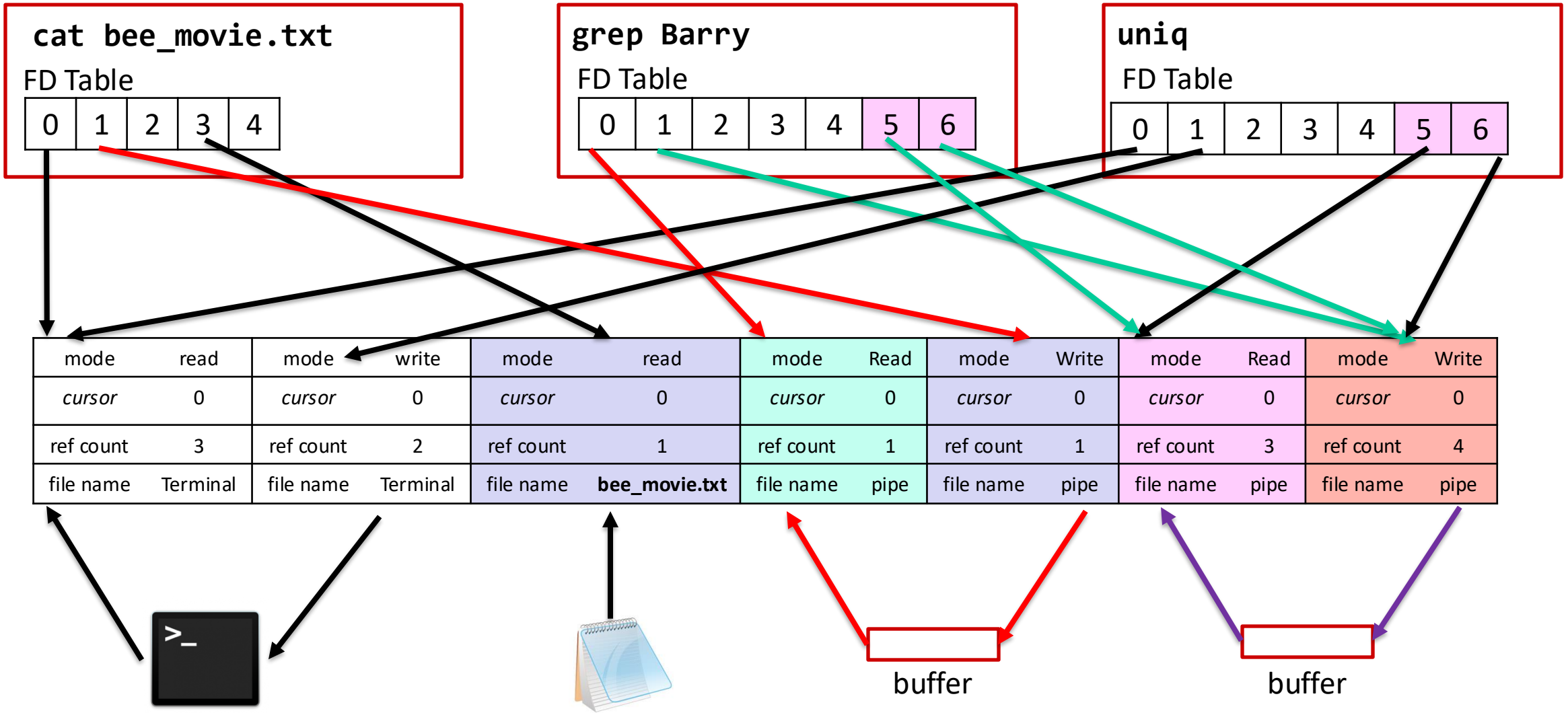
`cat bee_movie.txt | grep Barry | uniq`

D: This creates two separate pipes, one in the parent and one in the grep process. However, still inaccessible by both uniq and grep. Why…***Which of these will uniq inherit***?



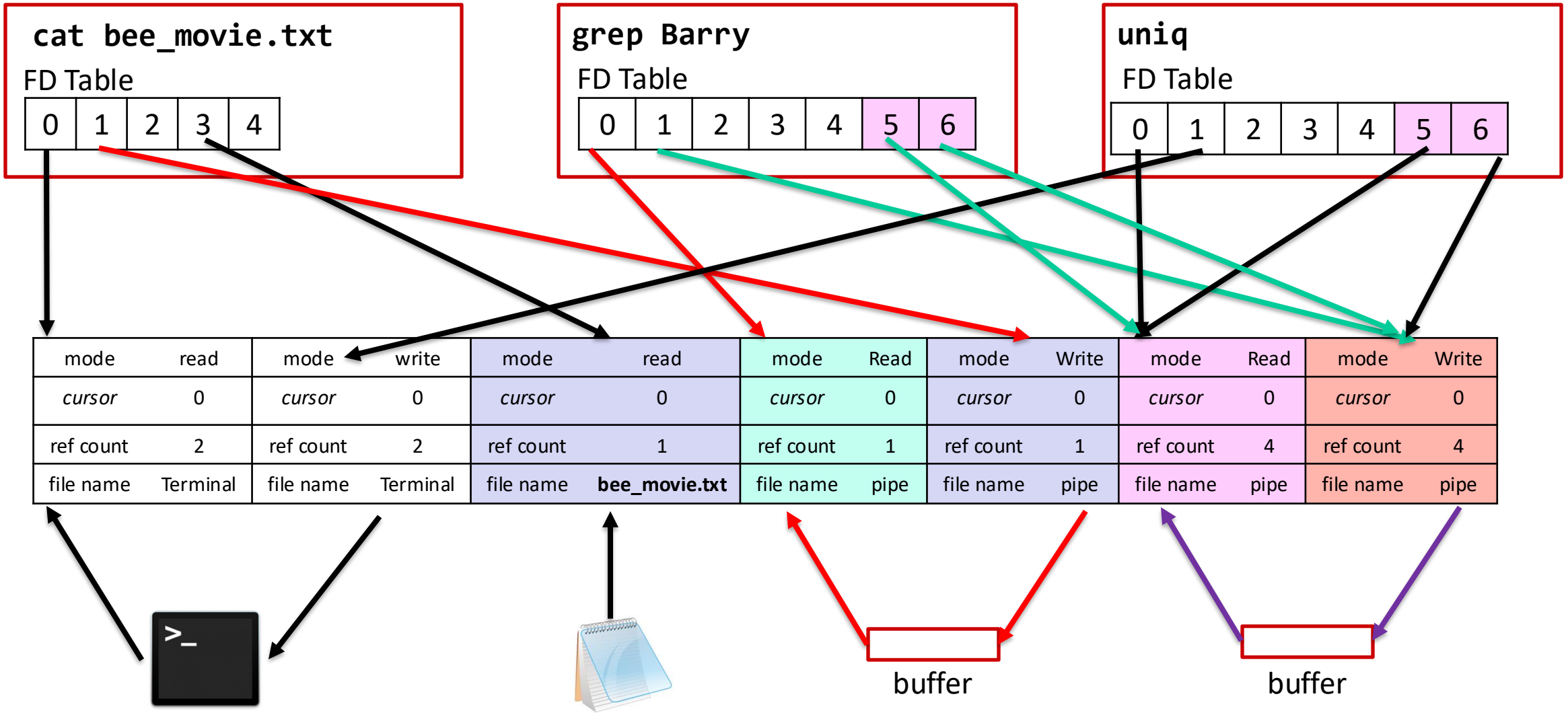
`cat bee_movie.txt | grep Barry | uniq`

Finally, uniq reads from pipe shared with 'grep' via dup2



`cat bee_movie.txt | grep Barry | uniq`

Let's close all unnecessary FDs so we can see the beauty…



`cat bee_movie.txt | grep Barry | uniq`

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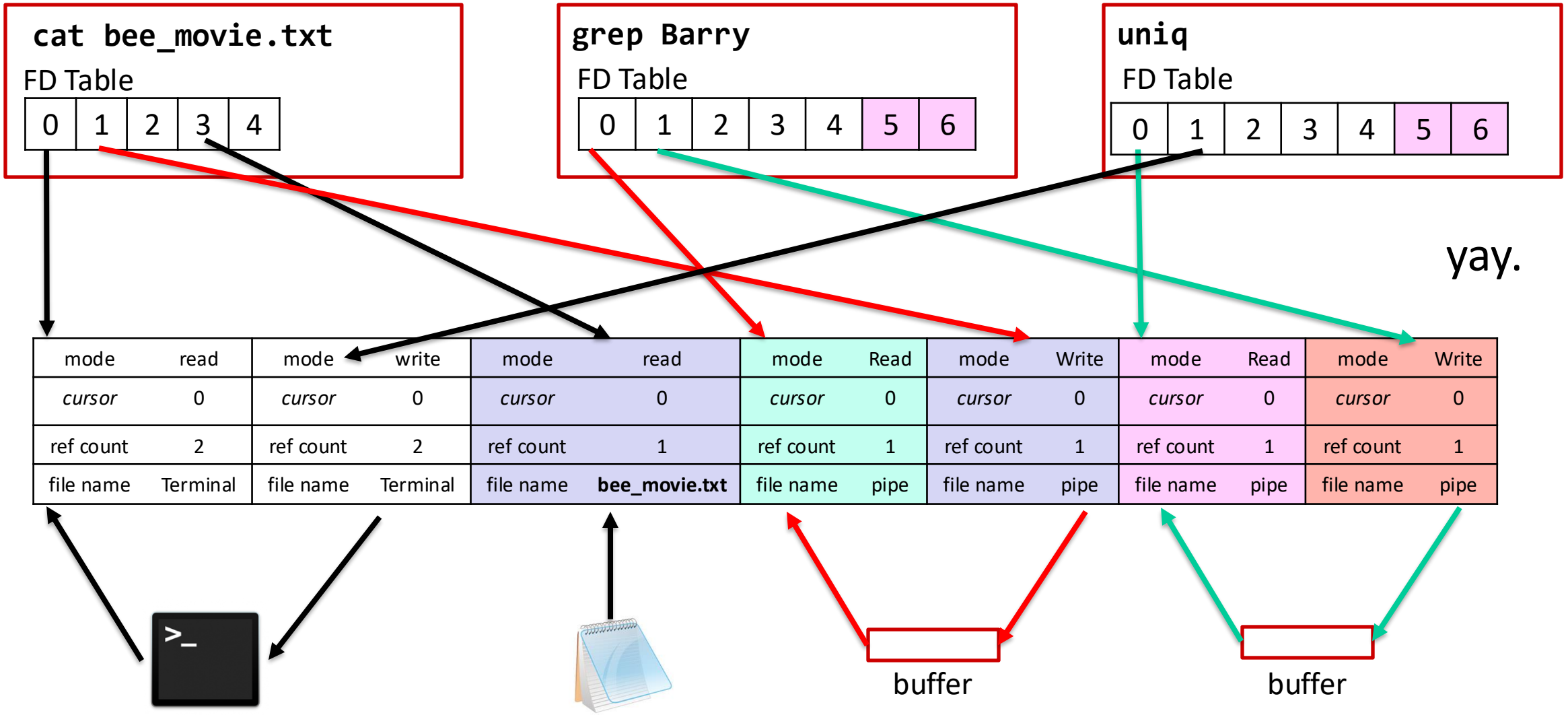
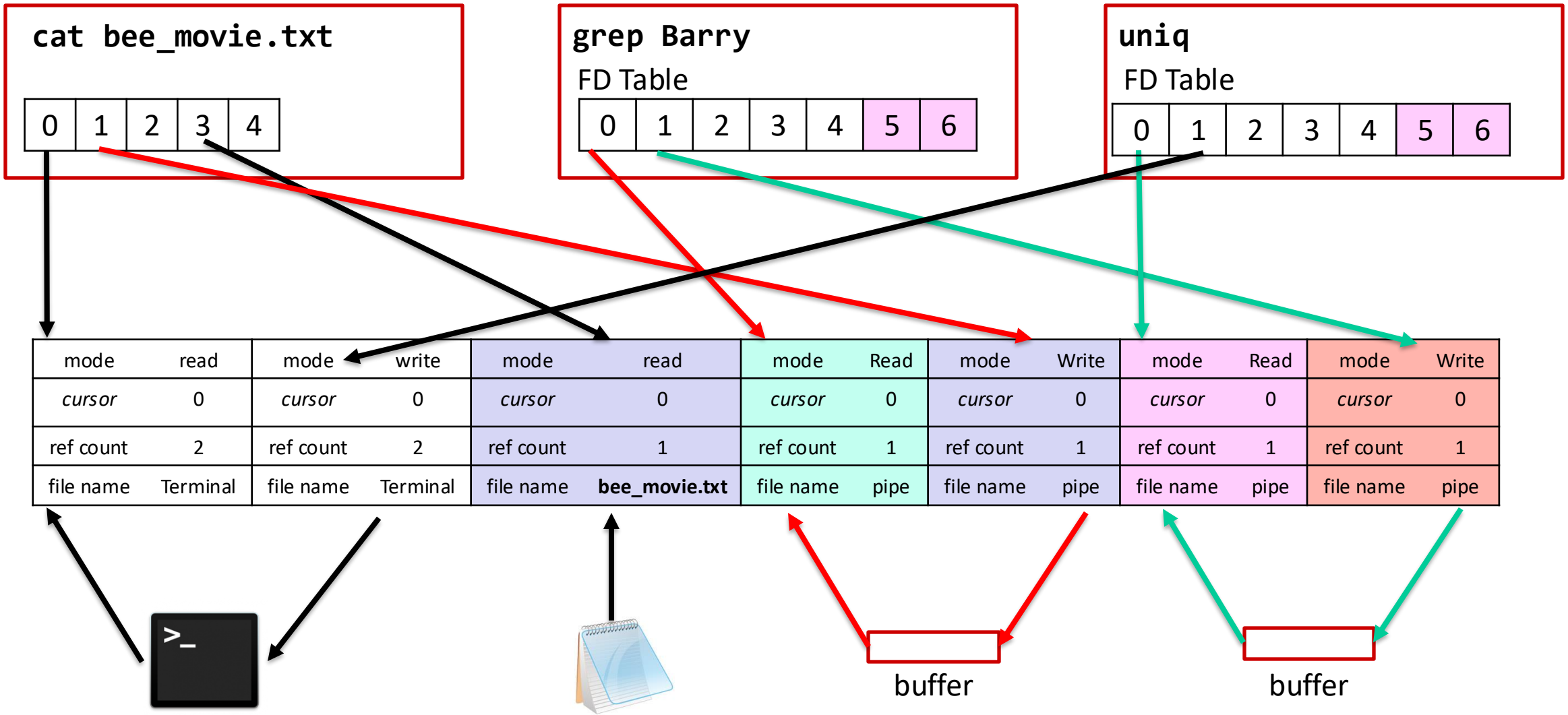


Poll Everywhere

Discuss Quicklyyy

Why doesn't uniq need to redirect it's STDOUT?



Poll Everywhere

Discuss Quicklyyy

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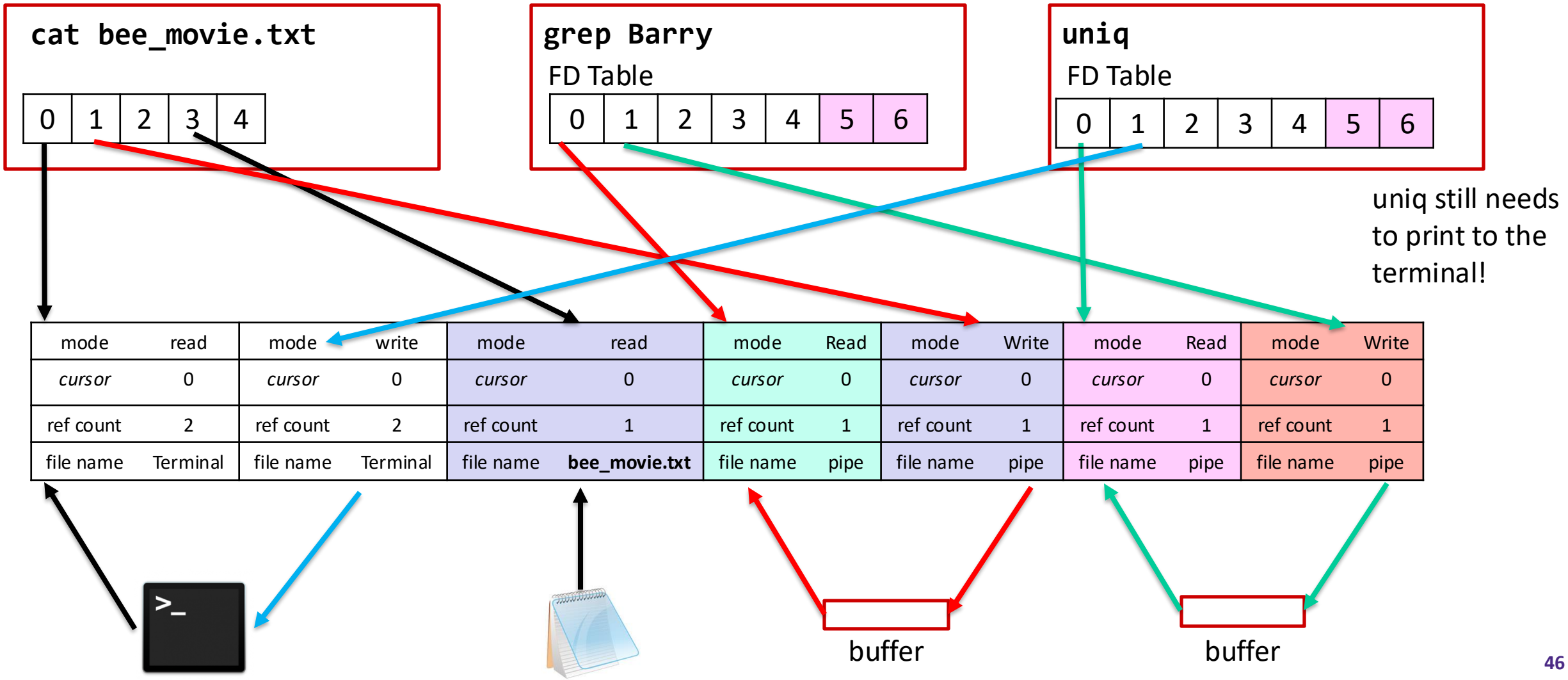
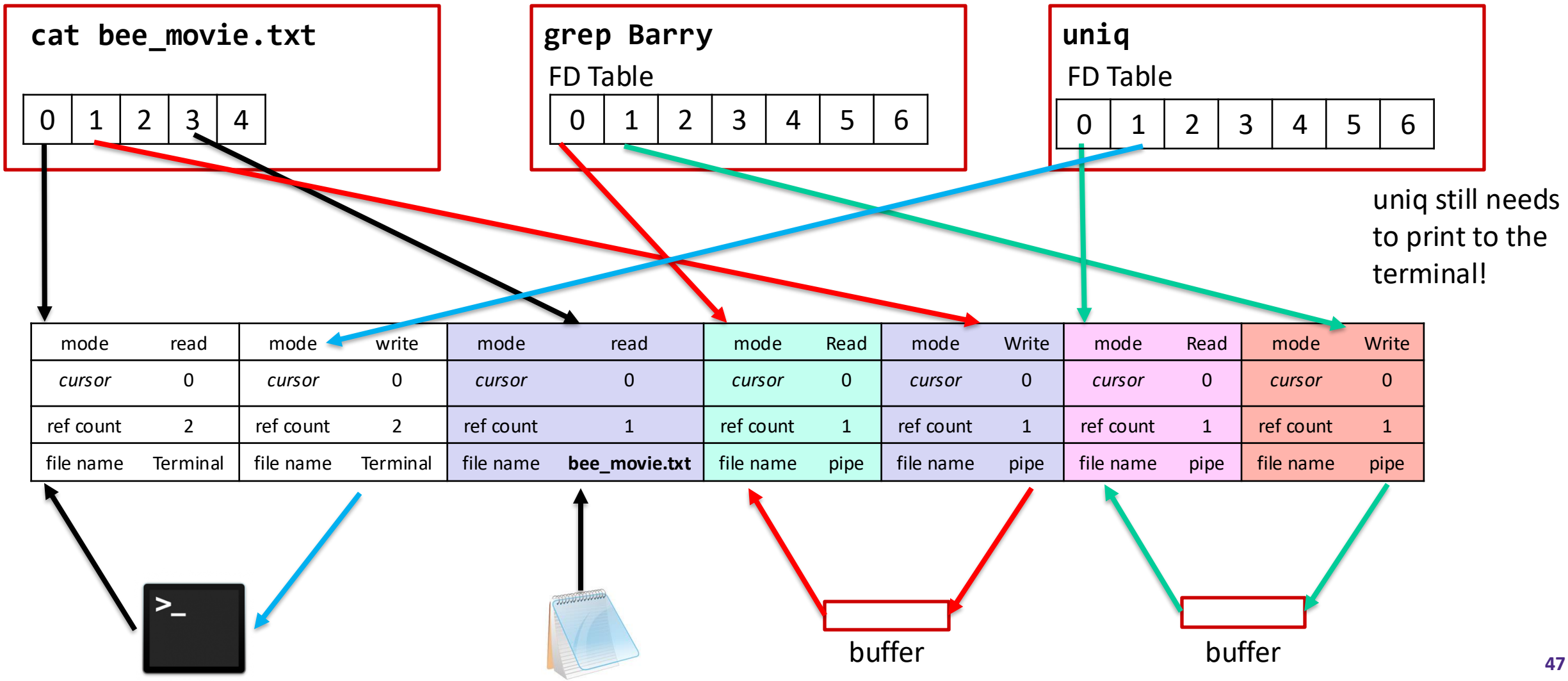


Let's see it in code! Cool.



Poll Everywhere

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```
close(cat_pipe[READ_END]);
//close(grep_pipe[WRITE_END]);

pid_t uniq_pid = fork();
if(uniq_pid == 0){
    dup2(grep_pipe[READ_END],STDIN_FILENO);
    close(grep_pipe[READ_END]);
    execvp(uniq_argv[0], uniq_argv);
    _exit(EXIT_FAILURE);
}


wait(NULL);
wait(NULL);
wait(NULL);

}
```

What happens if you forget to close a write portion of the pipe, before waiting in the parent?

Forgetting to Close Pipes

```
close(cat_pipe[READ_END]);
//close(grep_pipe[WRITE_END]);

pid_t uniq_pid = fork();
if(uniq_pid == 0){
        dup2(grep_pipe[READ_END],STDIN_FILENO);
        close(grep_pipe[READ_END]);
        execvp(uniq_argv[0], uniq_argv);
        _exit(EXIT_FAILURE);
}


wait(NULL);
wait(NULL);
wait(NULL);
```

Grep must read from STDIN ***but it does not stop reading from STDIN until it receives an EOF!***

The bigger issue is in the parent as that tends to be the one which has access to all write ends of the pipe. Make sure to close them as soon as you don't need them.

FDs are closed when a program is terminated. The trick is to make sure it terminates and doesn't hang!

Poll Everywhere

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```
close(cat_pipe[READ_END]);

pid_t uniq_pid = fork();

if(uniq_pid == 0){
        dup2(grep_pipe[READ_END],STDIN_FILENO);
        close(grep_pipe[READ_END]);
        execvp(uniq_argv[0], uniq_argv);
        _exit(EXIT_FAILURE);
}

close(grep_pipe[WRITE_END]);

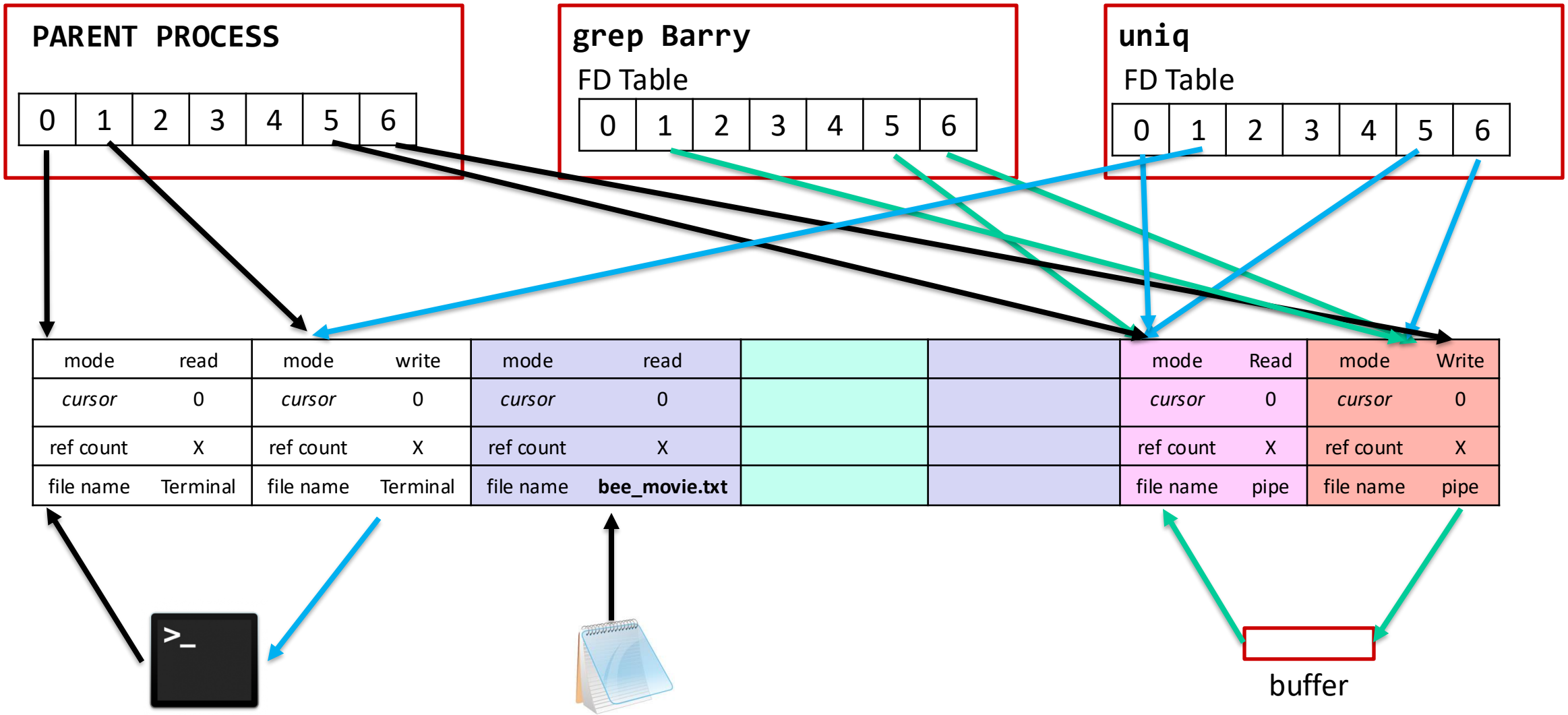
wait(NULL);
wait(NULL);
wait(NULL);
```

Exam Style Question:

In office hours a student, Shayla, attempts to fix the previous code by adding the close here. Does this work? Why or why not?

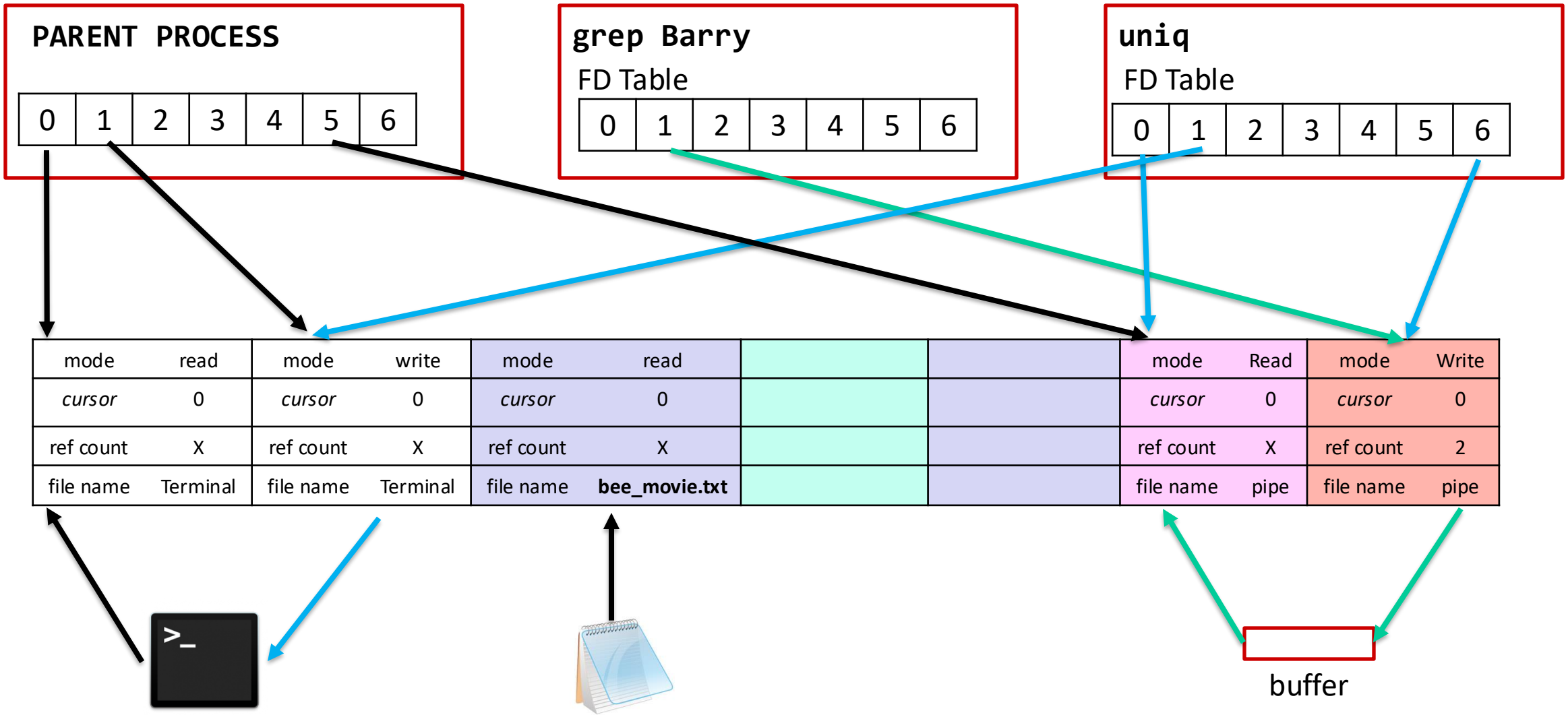
Exam-Style Question Walkthrough

We start off with grep and uniq having both references to the pipe!

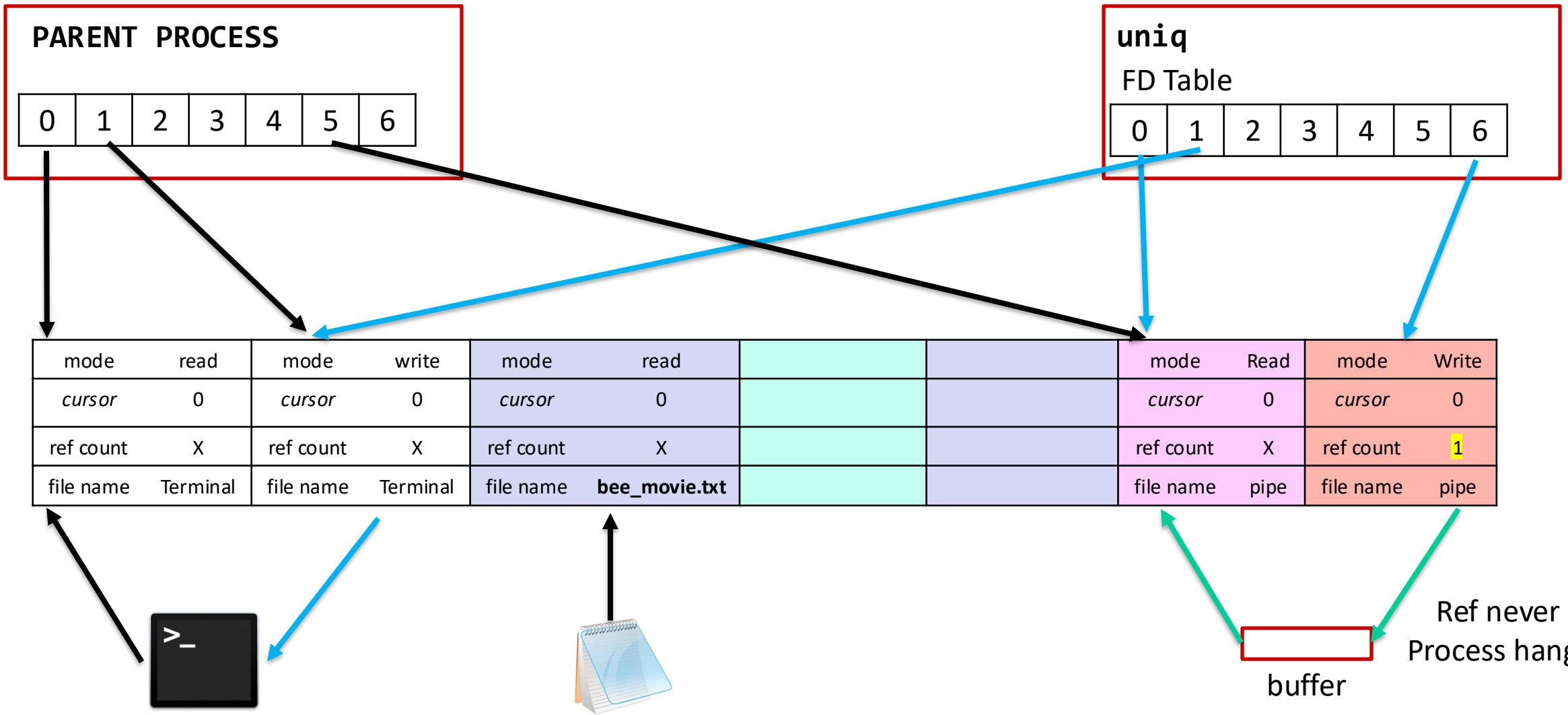


Exam-Style Question Walkthrough

Then Grep will terminate…



Exam-Style Question Walkthrough



pipe2

```
int pipe2(int pipefd[2], int flags);
```

- Still creates a pipe, similar to pipe, but we can now specify behavior!
- flags
  - O_CLOEXEC, your new friend.
  - This ***closes all file descriptors that refer to this pipe when we exec in a process.***
  - These file descriptors are only closed in the process that execs.
  - File descriptors that are ***dup2'd*** with these are not closed.
- Requires "#define _GNU_SOURCE"
  - Check the man page!
  - pipe2() is Linux-specific

pipe2

```
int pipe2(int pipefd[2], int flags);
```

- Here's an equivalent macro, for those not on linux machines.

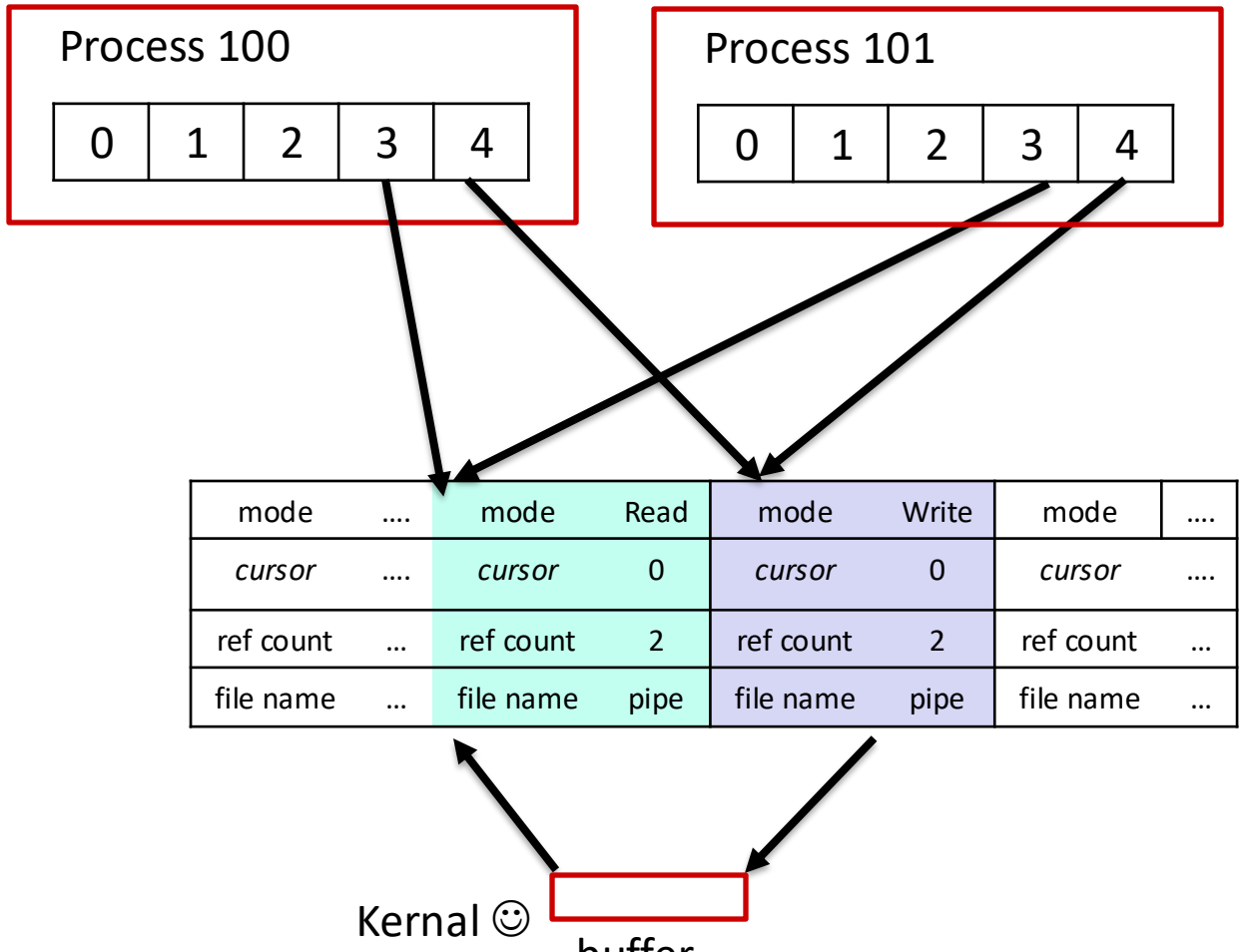
```
#define pipe2(FD, FLAG) \
pipe((FD)); \
fcntl((FD)[0], F_SETFD, FD_CLOEXEC); \
fcntl((FD)[1], F_SETFD, FD_CLOEXEC)
```

O_CLOEXEC Behavior

```
int pipe_fds[2];
pipe2(&pipe_fds, O_CLOEXEC);
pid_t cat_pid = fork();

if(cat_pid == 0){
    execvp(…);
}
// parent does some stuff.
```

- Prior to the execvp, both processes refer to the same pipe!



O_CLOEXEC Behavior

```
int pipe_fds[2];
pipe2(&pipe_fds, O_CLOEXEC);
pid_t cat_pid = fork();

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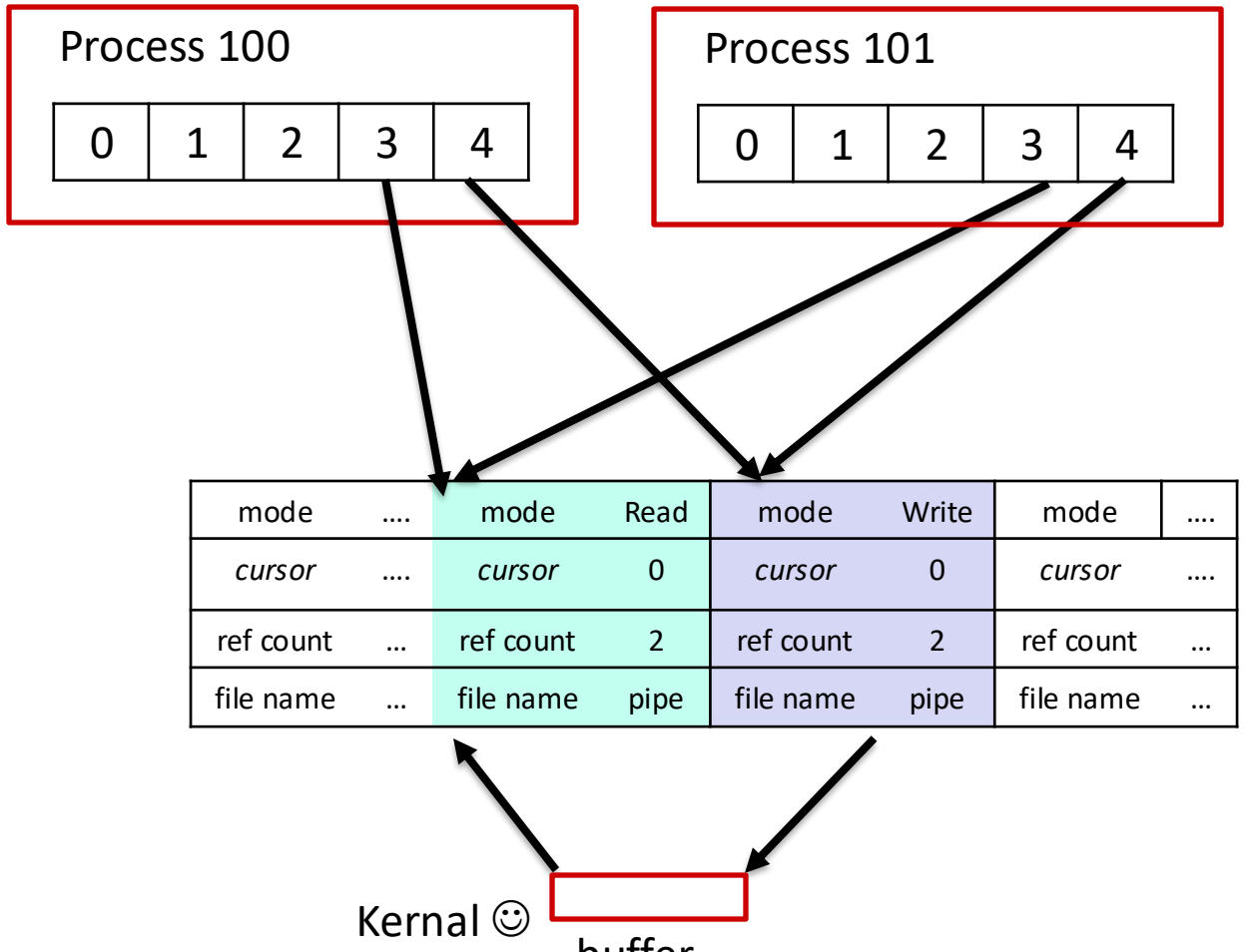
- Prior to the execvp, both processes refer to the same pipe!
- Once the child execs, the pipe_fds are closed!



O_CLOEXEC Behavior

```
int pipe_fds[2];
pipe2(&pipe_fds, O_CLOEXEC);
pid_t cat_pid = fork();

if(cat_pid == 0){
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}
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```

- Prior to the execvp, both processes refer to the same pipe!
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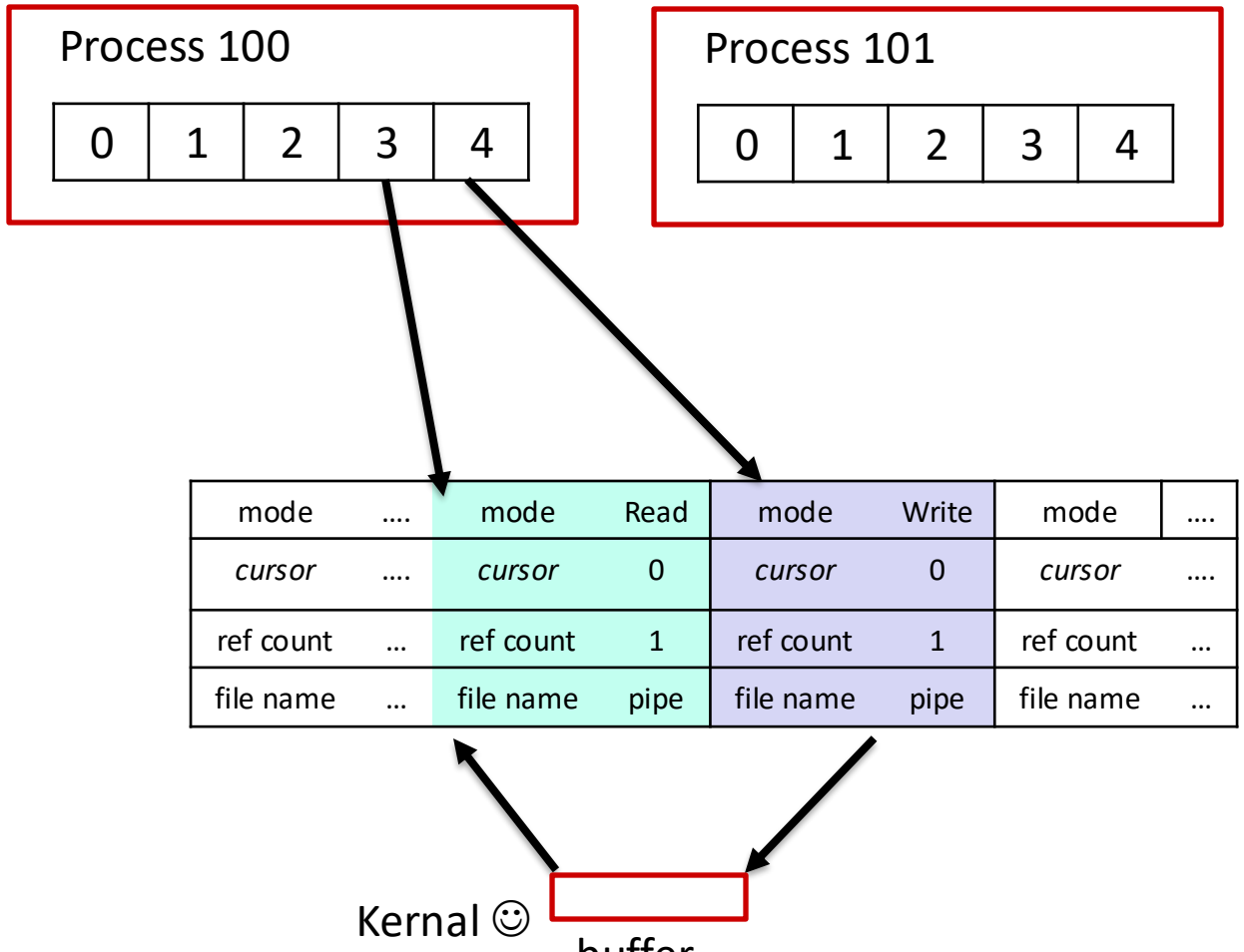
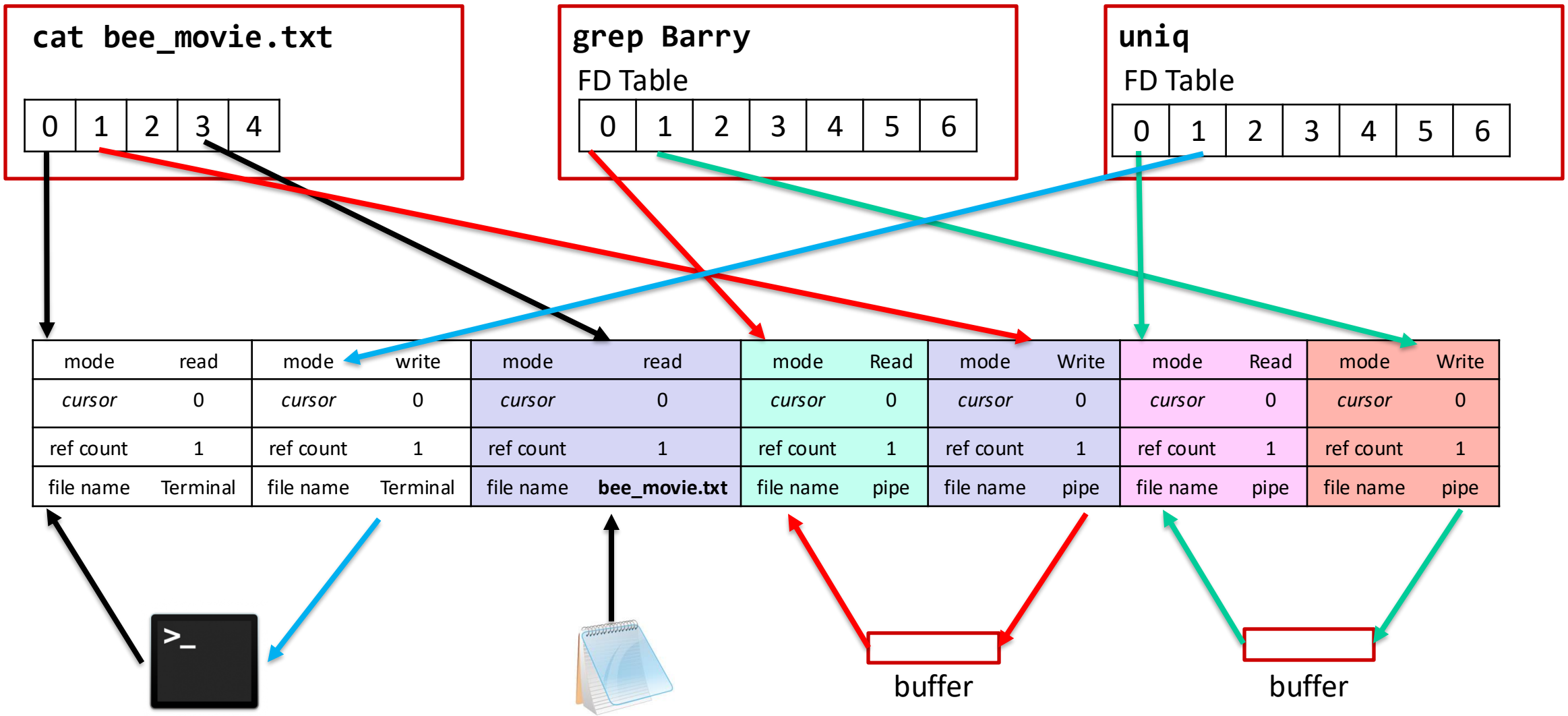


Let's see how pipe2 changes our code…



If time, how would we implement these?

- `cmd1 | cmd2`, creates a pipe so that the stdout of cmd1 is redirected to the stdin of cmd2
  - E.g. "`history | grep valgrind`"

- `cmd < file`, redirects stdin to instead read from the specified file
  - E.g. "`./penn-shredder < test_case`"

- `cmd > file`, redirects the stdout of a command to be written to the specified file
  - E.g. "`grep -r kill > out.txt`"

If time, how would we implement these?

- To use < and >, you would have to open these files on behalf of the executable, and then dup2 STDIN or STDOUT.

```
cat bee_movie.txt > copy_bee_movie.txt
```

Here, the output from *cat* that would normally go to STDOUT, now needs to be written to this new file, we must make or ***clobber.***

If it already exists, we just overwrite what is there.

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```
cat bee_movie.txt > copy_bee_movie.txt
```

To make this a possibility, what should the arguments to open be? Check the ***man*** Page…

```
char *bee_file_output = "copy_bee_movie.txt";

int bee_cpy_fd = open(bee_file_output, ???????, 0644);
```

"Here, the output from *cat* that would normally go to STDOUT,
now needs to be written to this new file, ***we must make*** or ***clobber (rewrite from scratch).***"

Poll Everywhere

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```
cat bee_movie.txt > copy_bee_movie.txt
```

To make this a possibility, what should the arguments to open be? Check the ***man*** Page…

```
char *bee_file_output = "copy_bee_movie.txt";

int bee_cpy_fd = open(bee_file_output, ???????, 644);
```

"Here, the output from *cat* that would normally go to STDOUT,
now needs to be written to this new file, ***we must make*** or ***clobber (rewrite from scratch).***"

O_CREAT | O_TRUNC | O_WRONLY

Create the file (or open it if it exists)

Truncate the file, set its length to 0, before writing

We are only writing to it, so Write only.

Time for Penn Shell Demo!

- Ask Rania all questions. Don’t be shy pls.