Pipe() & HW4

Computer Systems Programming, Spring 2024

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Logistics

- HW03 due Friday this week
  - Recitation last week had an overview of what it is doing
  - Autograder is posted
  - Travis has extra oh from 2 to 3:30 on Friday

- Project code posted
  - Due May 1st @ 11:59pm
  - There is a component that is graded by hand
  - Git repositories to be created soon
  - Beginning of this lecture helps with setup.

- Next Checkin to be released soon

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- Any questions?

Lecture Outline

- **Pipe**
- Unix Shell
- HW4

Pipes

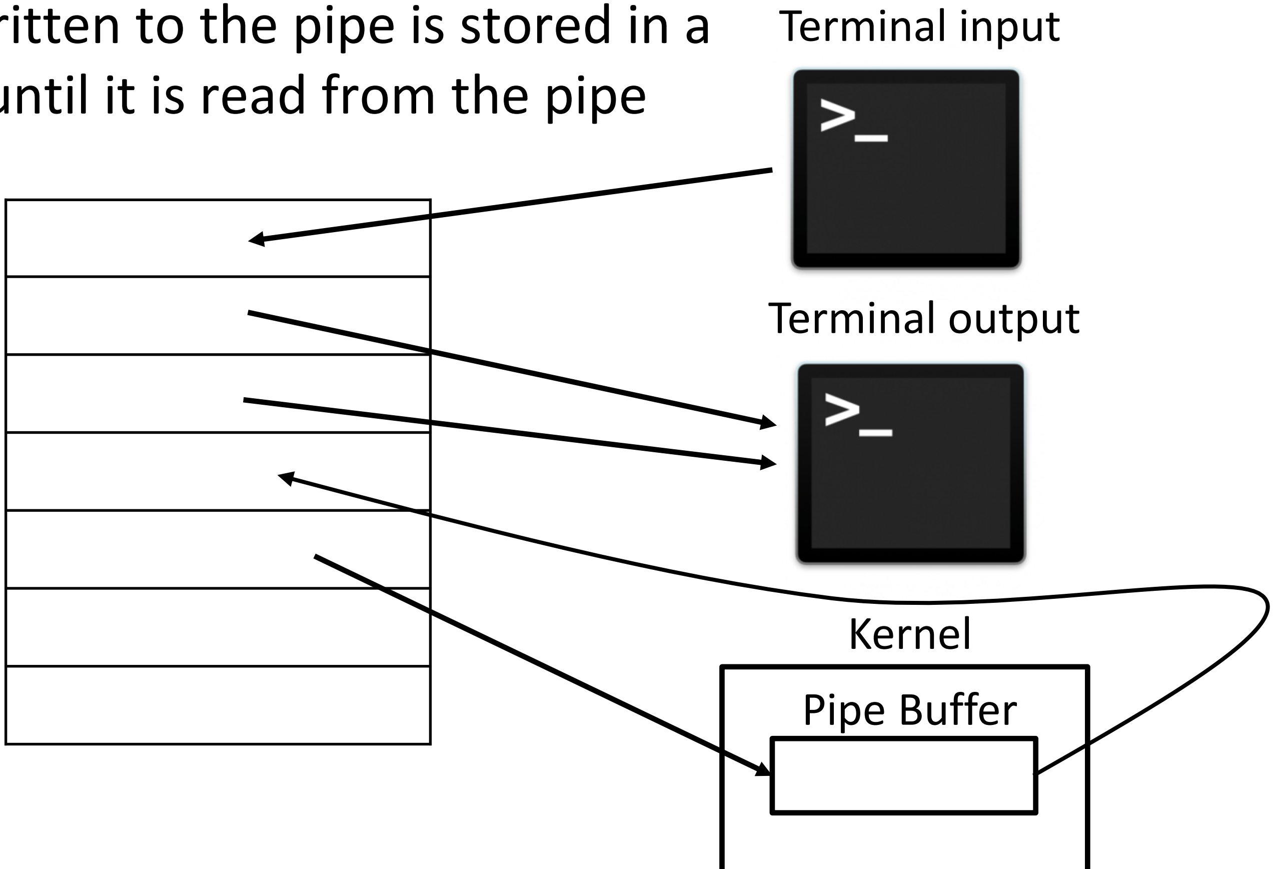
```
int pipe(int pipefd[2]);
```

- Creates a unidirectional data channel for IPC
- Communication through file descriptors! // POSIX ☺
- 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

- **In addition to copying memory, fork copies the file descriptor table of parent**
- Exec does NOT reset file descriptor table

Pipe Visualization

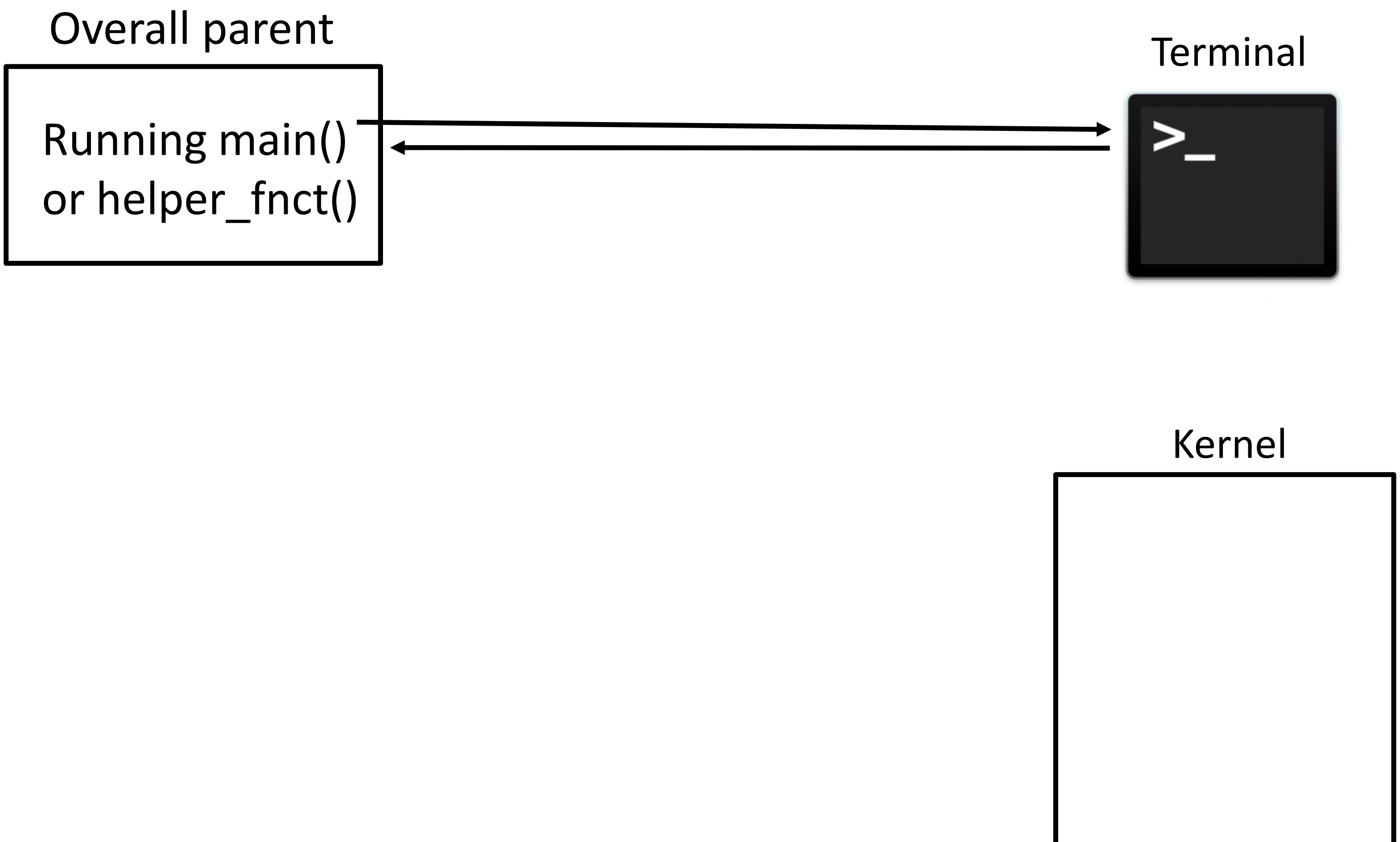
- A pipe can be thought of as a "file" that has distinct file descriptors for reading and writing. This "file" only exists as long as the pipe exists and is maintained by the OS.
  - Data written to the pipe is stored in a buffer until it is read from the pipe



Pipe Example

- Take a look at `pipe_example.cpp` on the course website.
  - Simple pipe example

pipe_example.cpp Walkthrough



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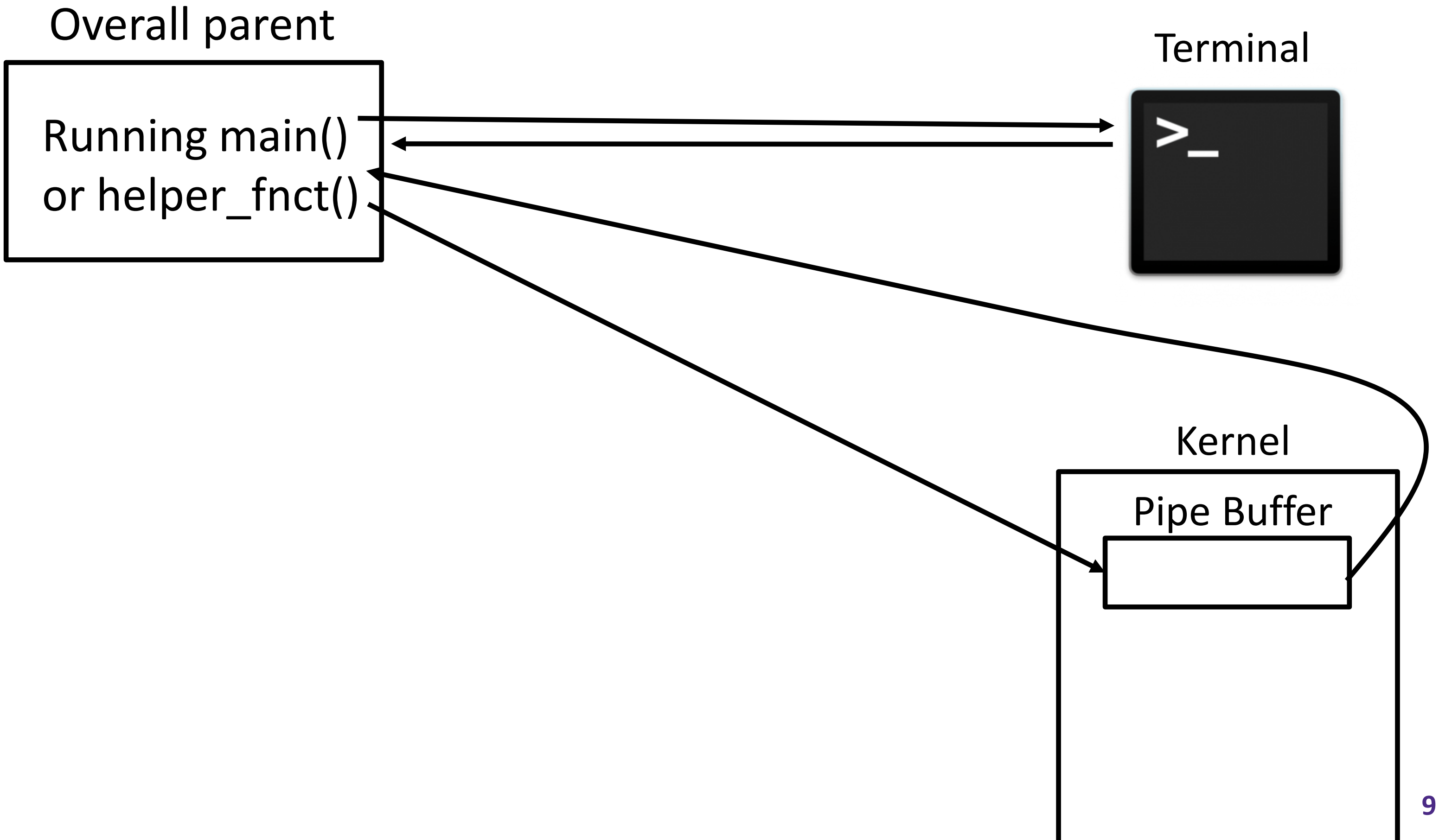

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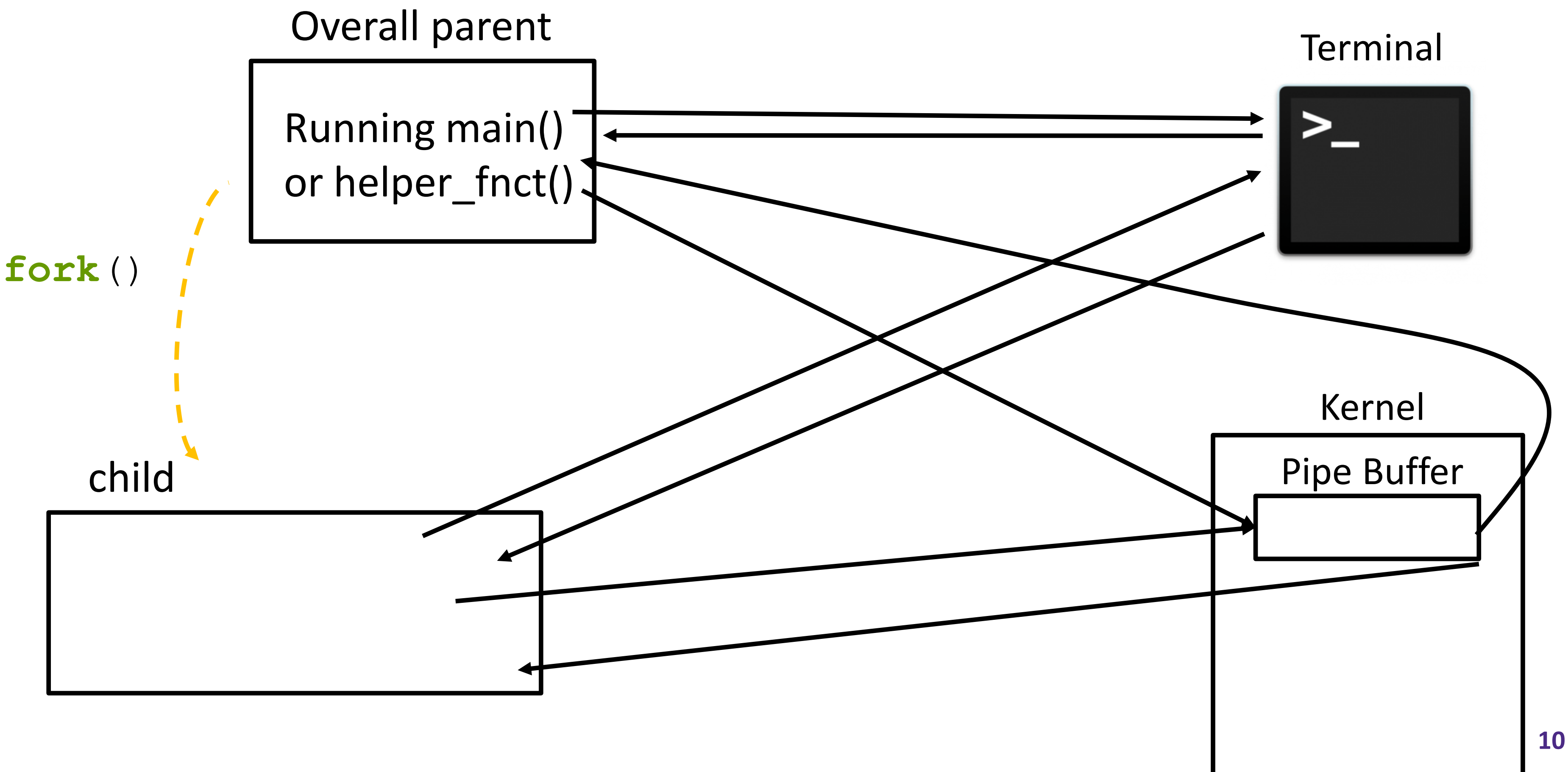

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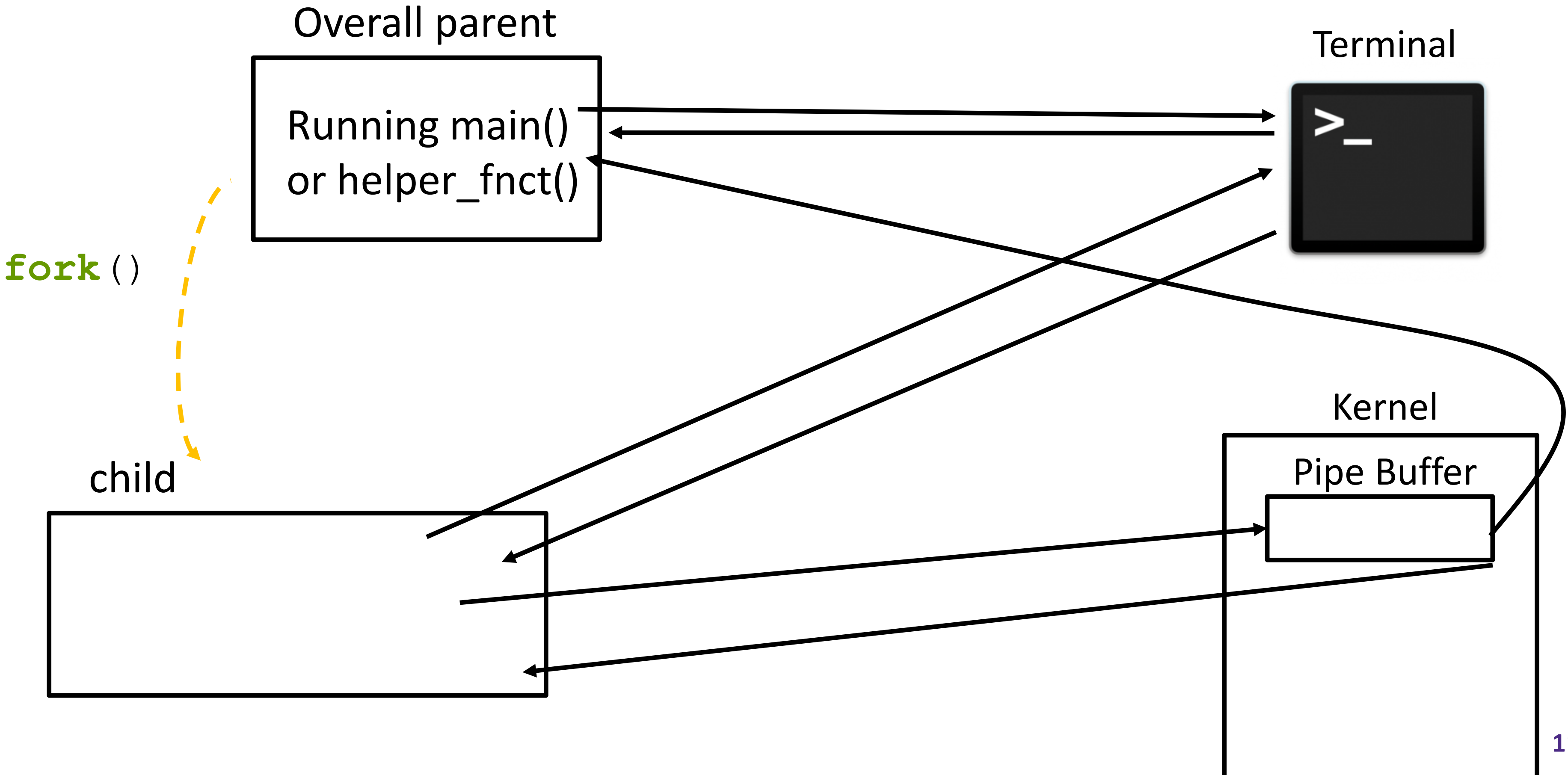

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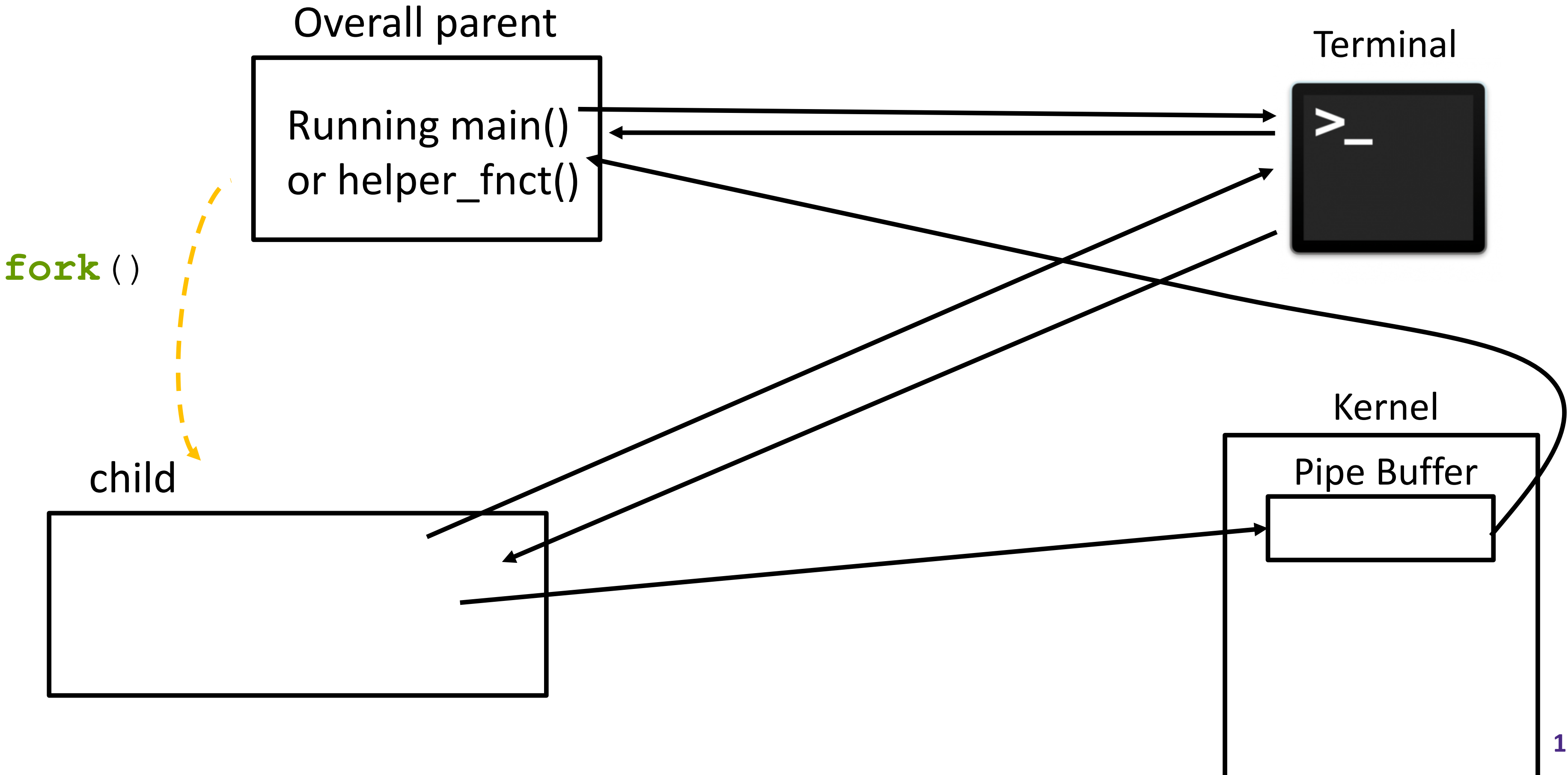

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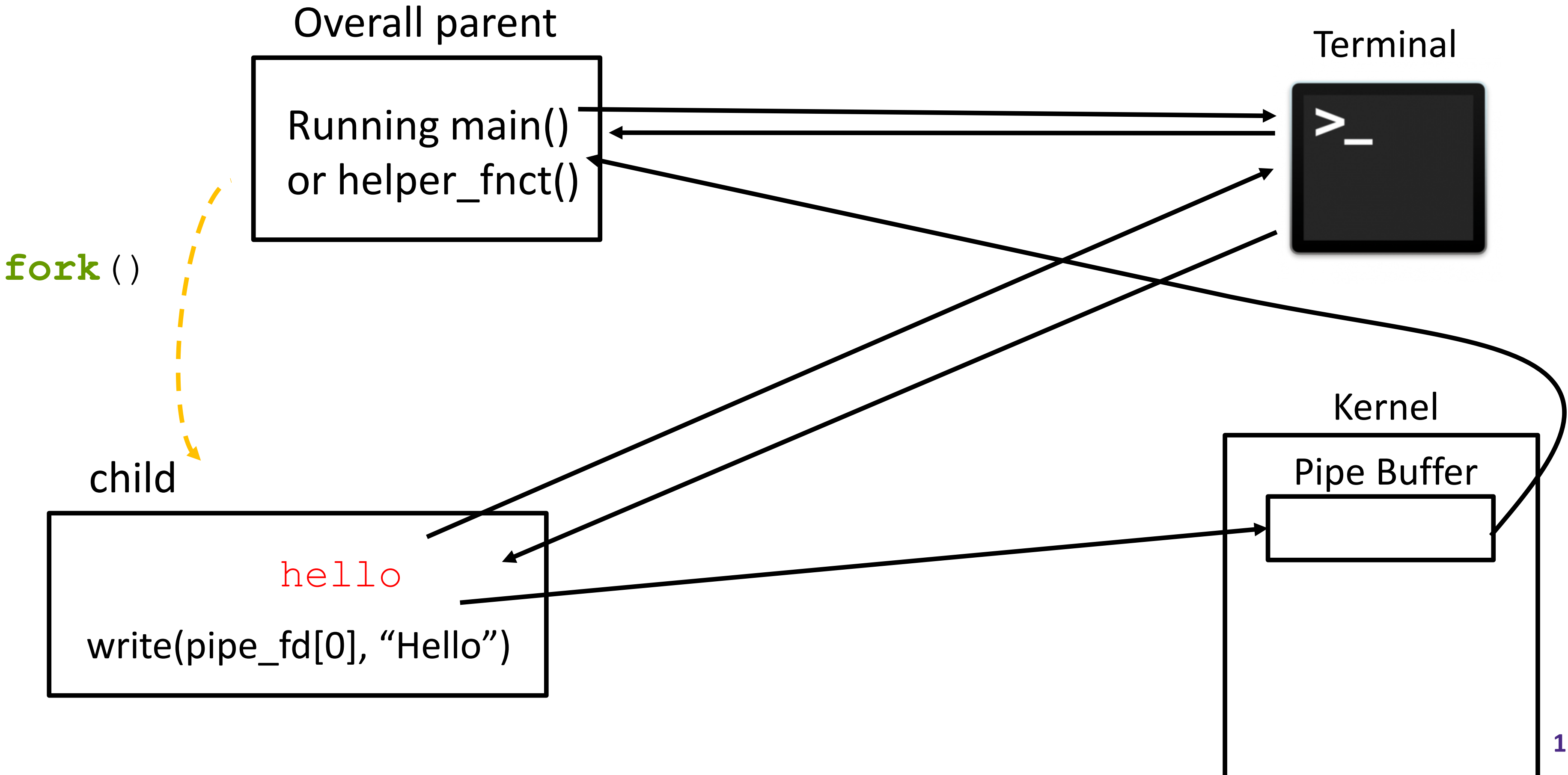

Poll Everywhere

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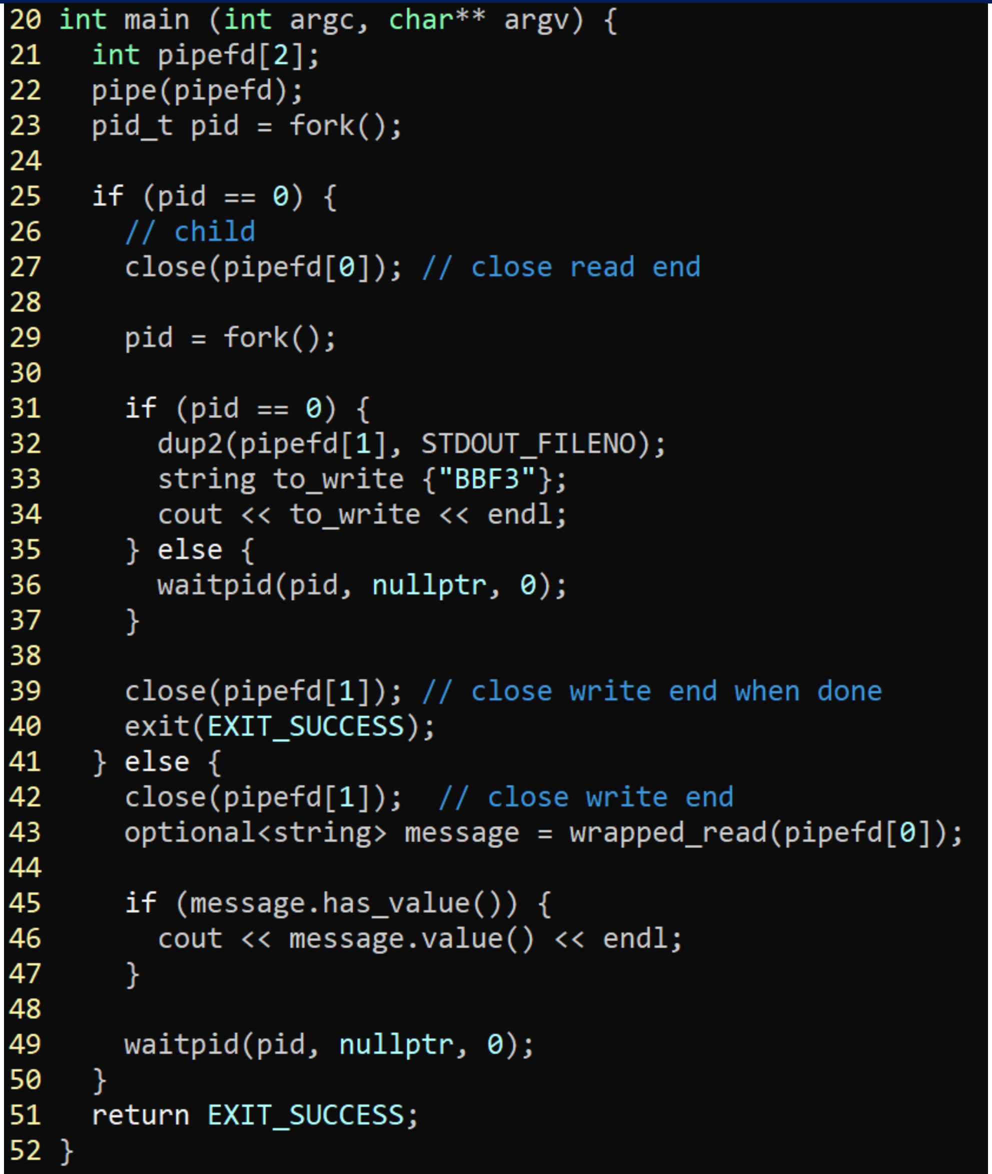

```
int main (int argc, char** argv) {
  int pipefd[2];
  pipe(pipefd);
  pid_t pid = fork();

  if (pid == 0) {
    // child
    close(pipefd[0]); // close read end

    pid = fork();

    if (pid == 0) {
      dup2(pipefd[1], STDOUT_FILENO);
      string to_write {"BBF3"};
      cout << to_write << endl;
    } else {
      waitpid(pid, nullptr, 0);
    }

    close(pipefd[1]); // close write end when done
    exit(EXIT_SUCCESS);
  } else {
    close(pipefd[1]);  // close write end
    optional<string> message = wrapped_read(pipefd[0]);

    if (message.has_value()) {
      cout << message.value() << endl;
    }

    waitpid(pid, nullptr, 0);
  }
  return EXIT_SUCCESS;
}
```

- What does this code print? why? (assume pipe, close and fork succeed)
- **`pipe_poll.cpp`**

Pipes & EOF

- Many programs will read from a file until they hit EOF and will not terminate until then
- Like reading from the terminal, just because there is nothing in the pipe, does not mean nothing else will ever come through the pipe.
  - EOF is not read in this case

- EOF is only read from a pipe when:
  - There is nothing in the pipe
  - All write ends of the pipe are closed

- **Good practice: CLOSE ALL PIPE FDS YOU ARE DONE WITH**

Poll Everywhere

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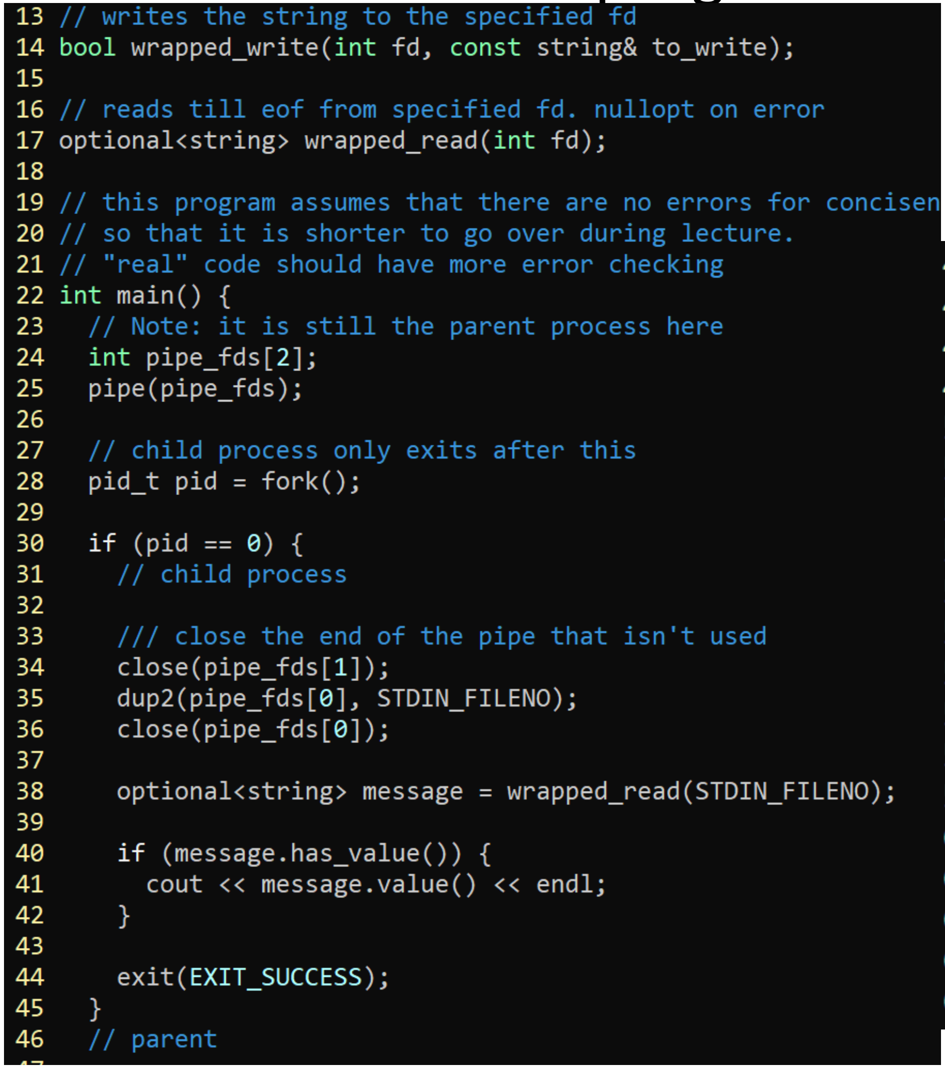
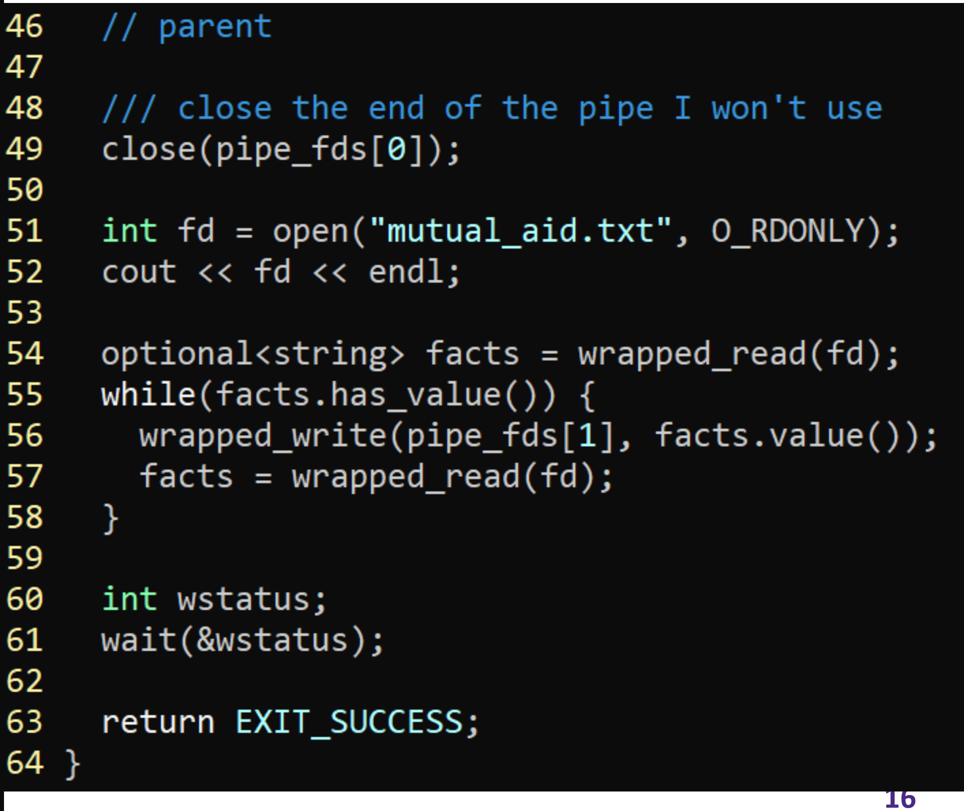
- What does this program do? (assume no system calls fail)

code is on website as **cat_pipe.cpp**



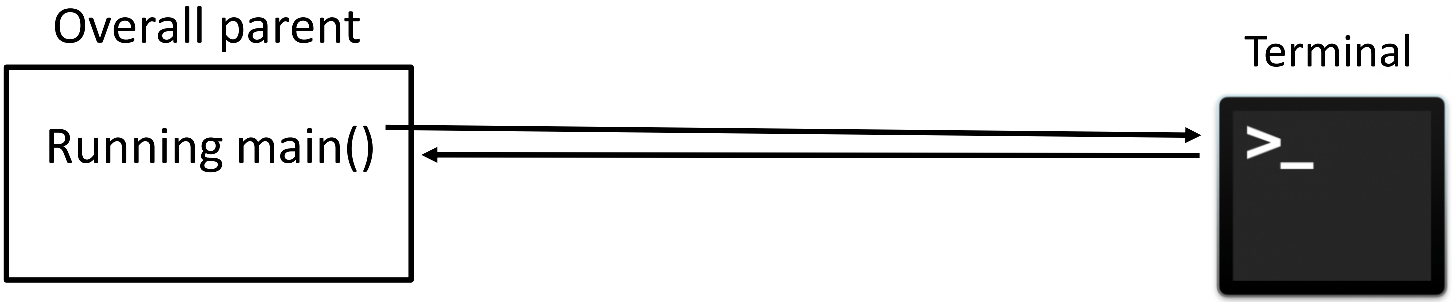
```
// writes the string to the specified fd
bool wrapped_write(int fd, const string& to_write);

// reads till eof from specified fd. nullopt on error
optional<string> wrapped_read(int fd);

// this program assumes that there are no errors for concisen
// so that it is shorter to go over during lecture.
// "real" code should have more error checking
int main() {
  // Note: it is still the parent process here
  int pipe_fds[2];
  pipe(pipe_fds);

  // child process only exits after this
  pid_t pid = fork();

  if (pid == 0) {
    // child process

    /// close the end of the pipe that isn't used
    close(pipe_fds[1]);
    dup2(pipe_fds[0], STDIN_FILENO);
    close(pipe_fds[0]);

    optional<string> message = wrapped_read(STDIN_FILENO);

    if (message.has_value()) {
      cout << message.value() << endl;
    }

    exit(EXIT_SUCCESS);
  }
  // parent
```



```
  // parent

  /// close the end of the pipe I won't use
  close(pipe_fds[0]);

  int fd = open("mutual_aid.txt", O_RDONLY);
  cout << fd << endl;

  optional<string> facts = wrapped_read(fd);
  while(facts.has_value()) {
    wrapped_write(pipe_fds[1], facts.value());
    facts = wrapped_read(fd);
  }

  int wstatus;
  wait(&wstatus);

  return EXIT_SUCCESS;
}
```

`cat_pipe.cpp` Trace

- First:
  we create a pipe



`cat_pipe.cpp` Trace

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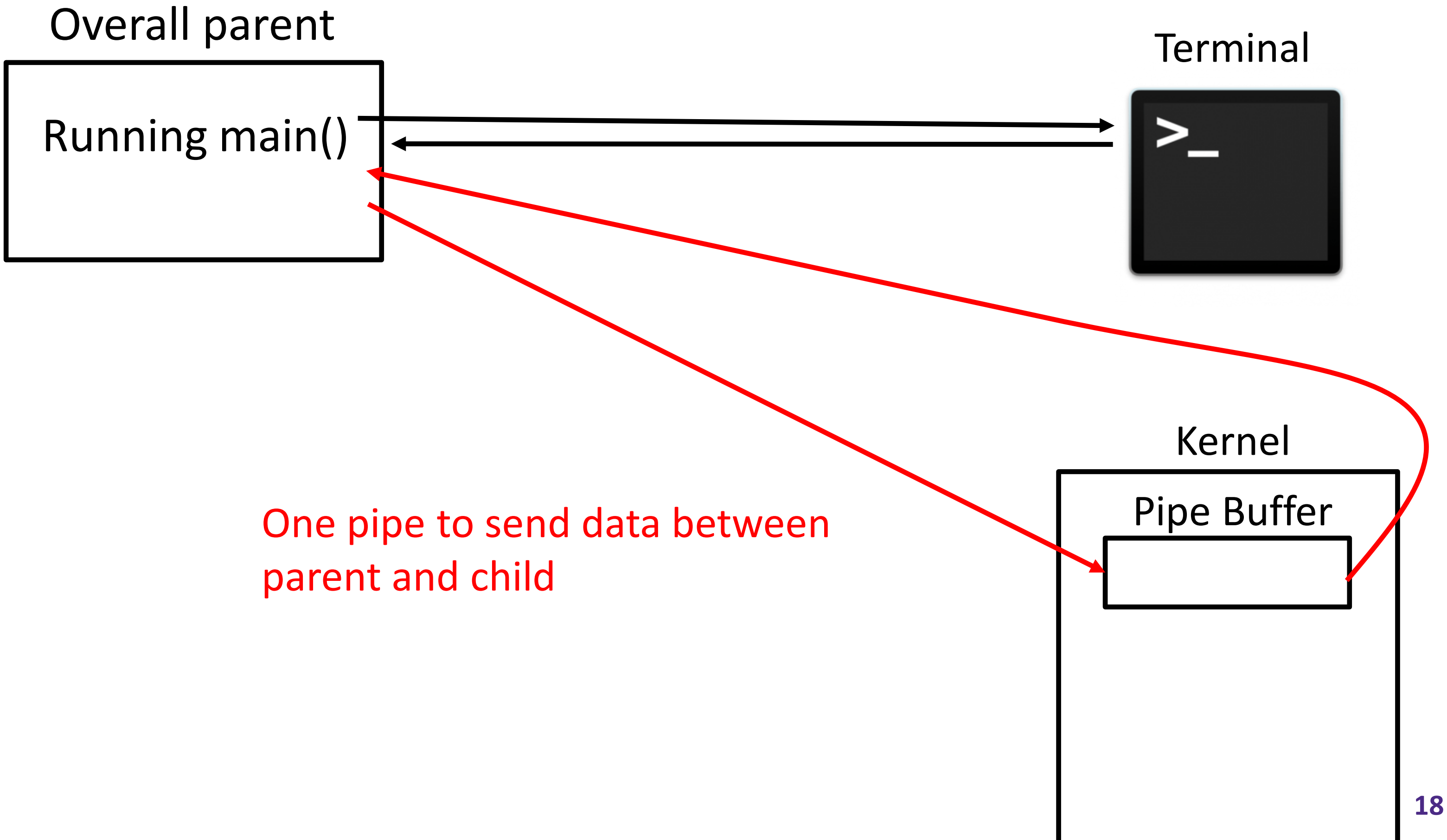
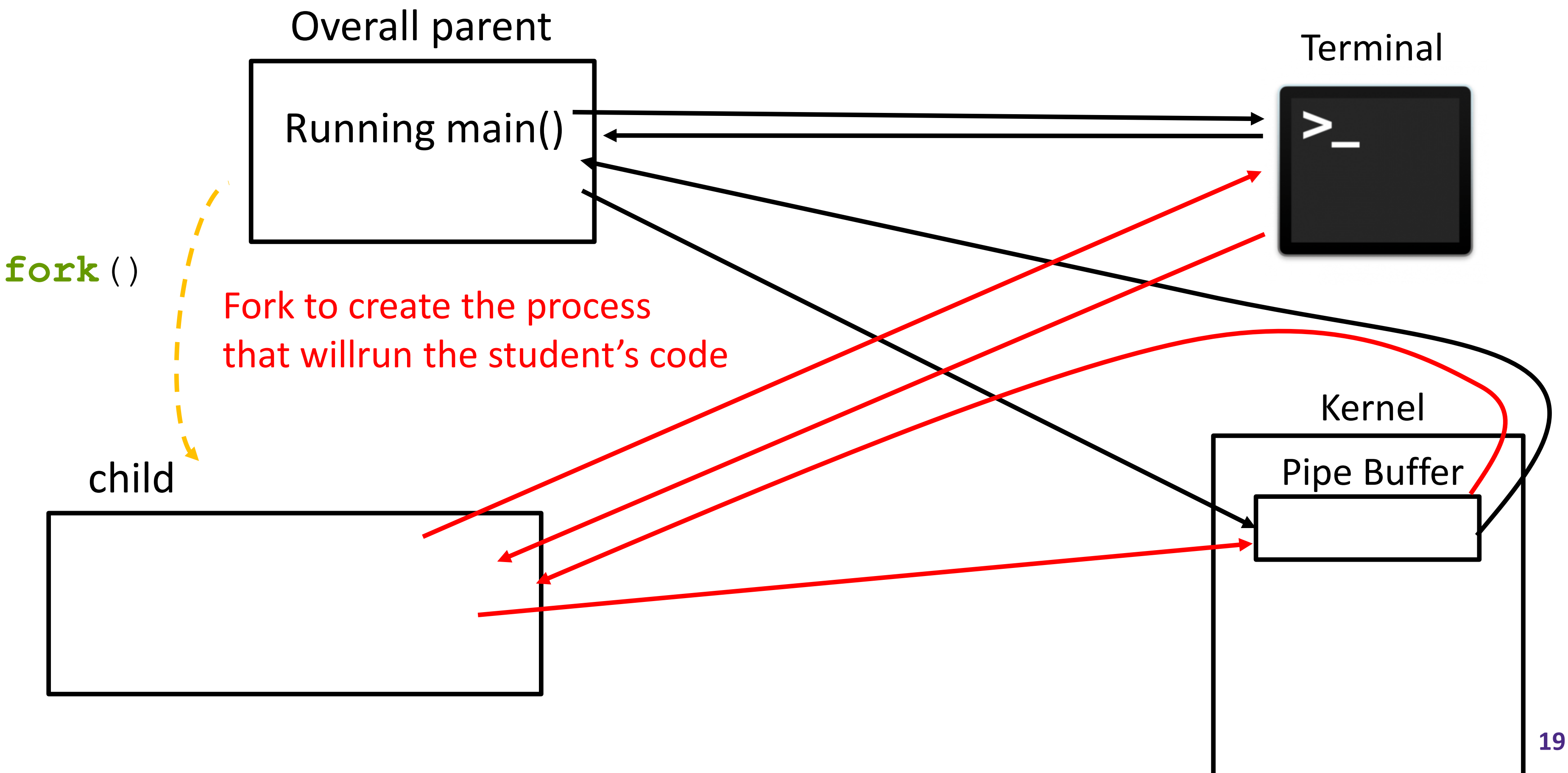


One pipe to send data between parent and child

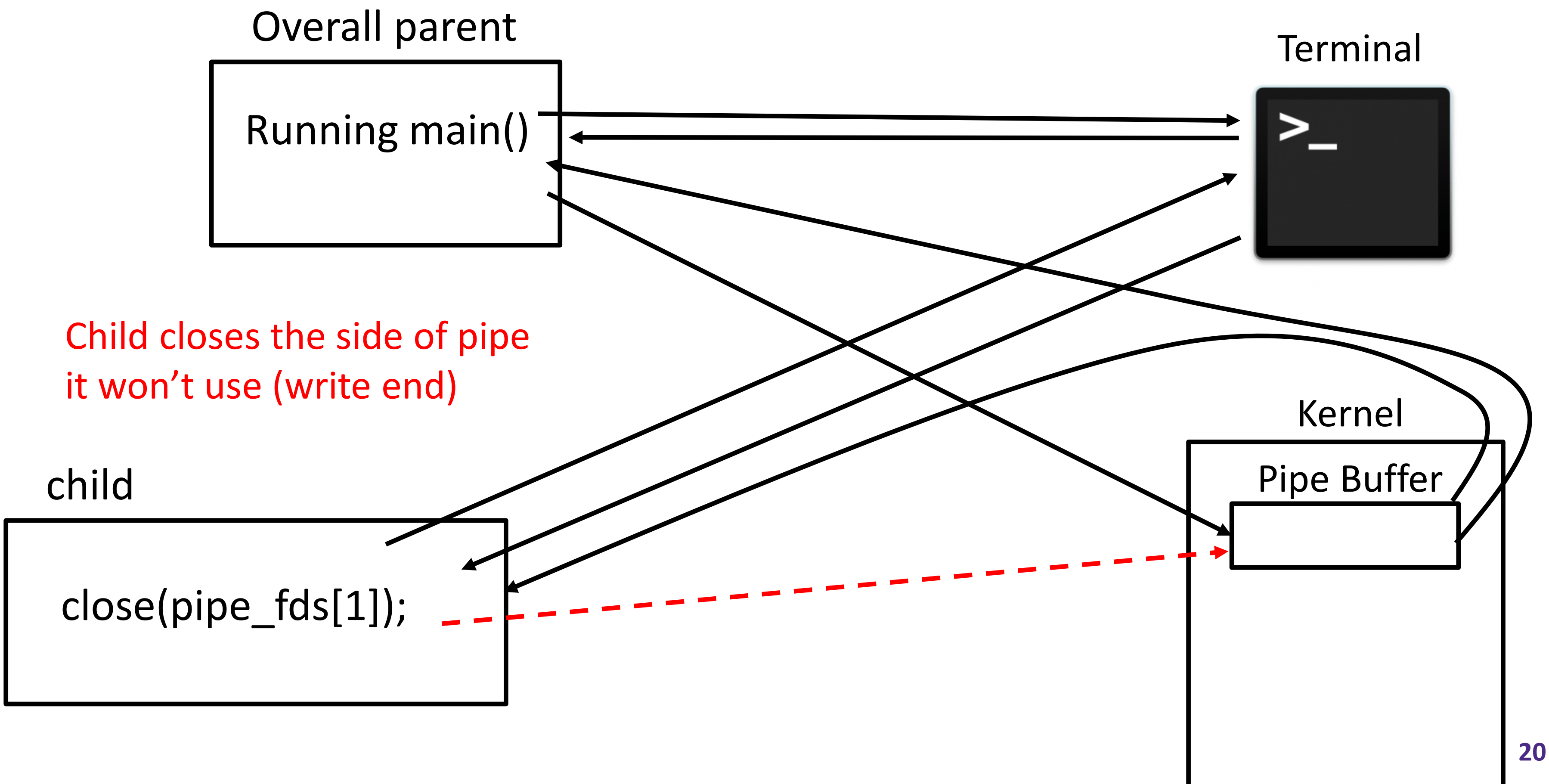
`cat_pipe.cpp` Trace

- second
  Fork



cat_pipe.cpp Trace

- Walking through child, but parent could be running first, after, or at the same time



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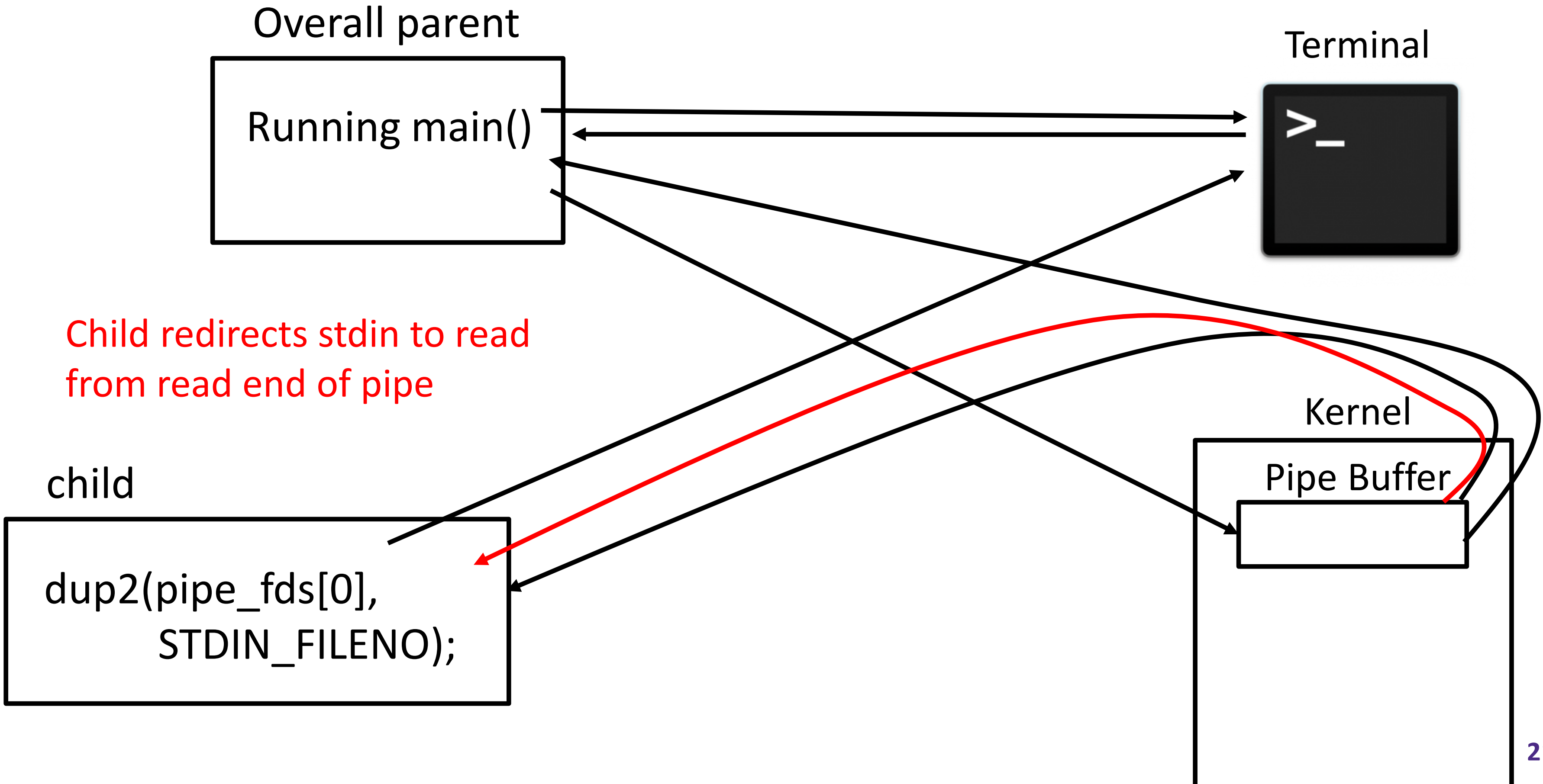

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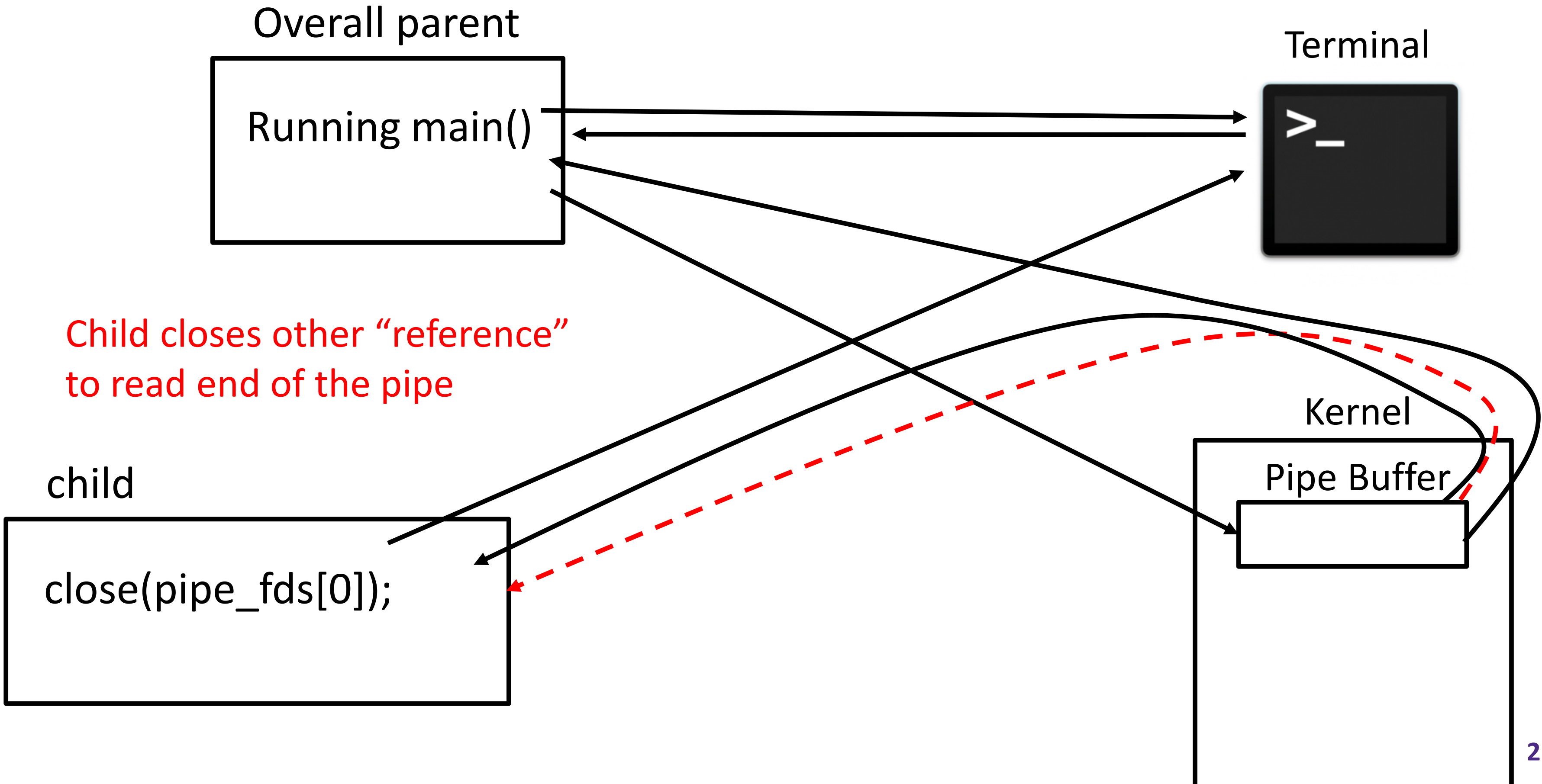

Child closes other "reference" to read end of the pipe

`cat_pipe.cpp` Trace

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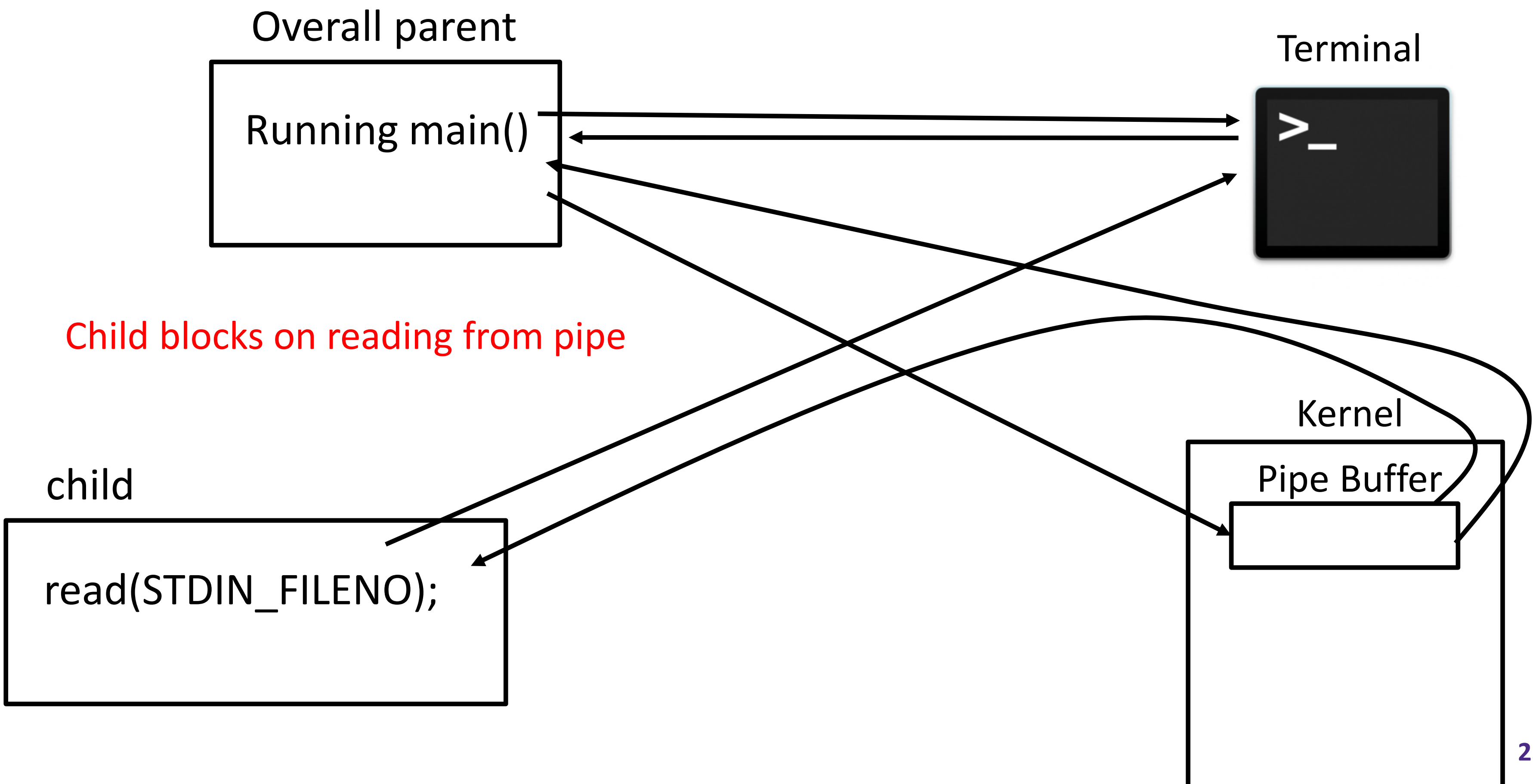

Child blocks on reading from pipe

`cat_pipe.cpp` Trace

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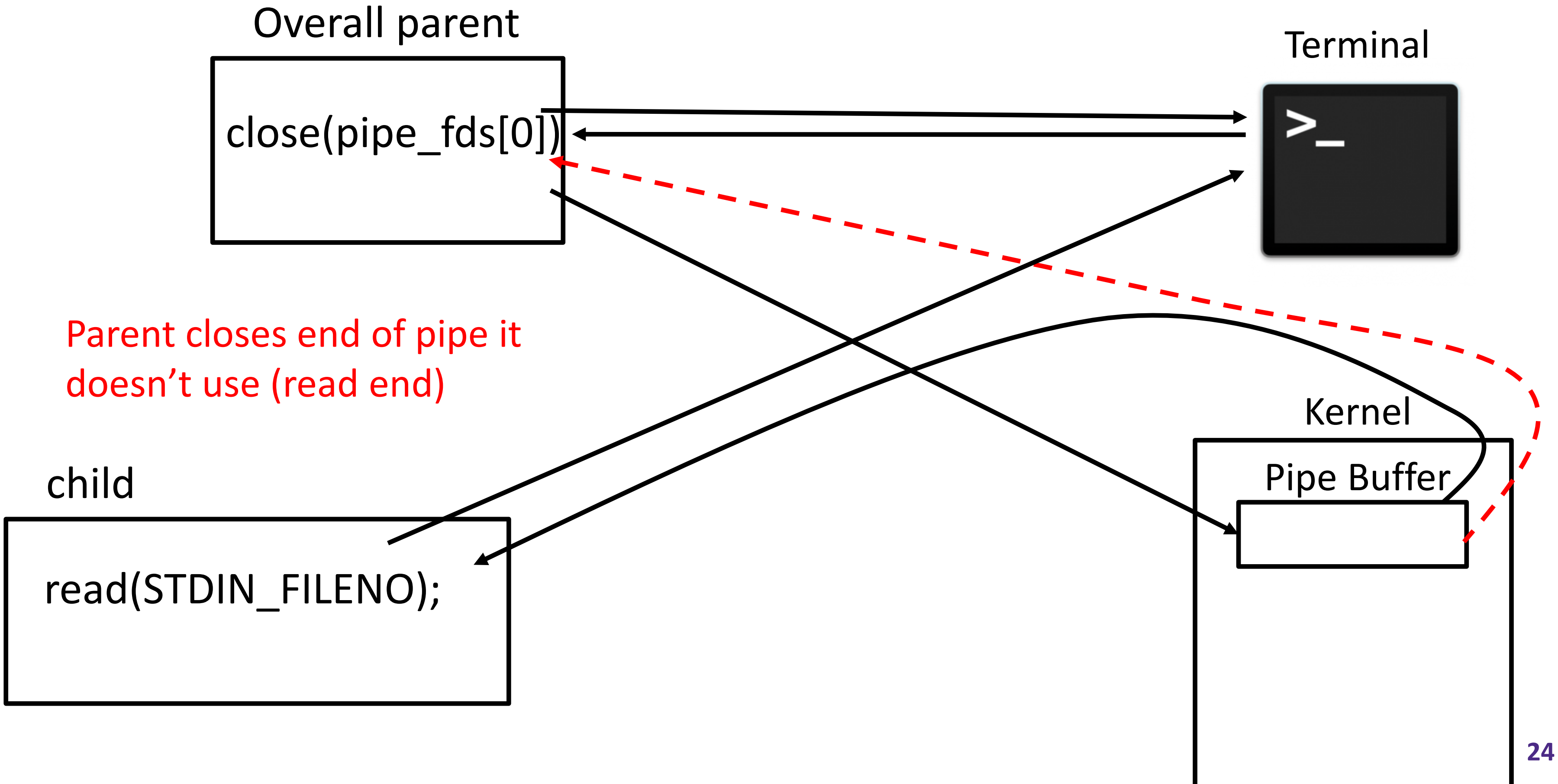

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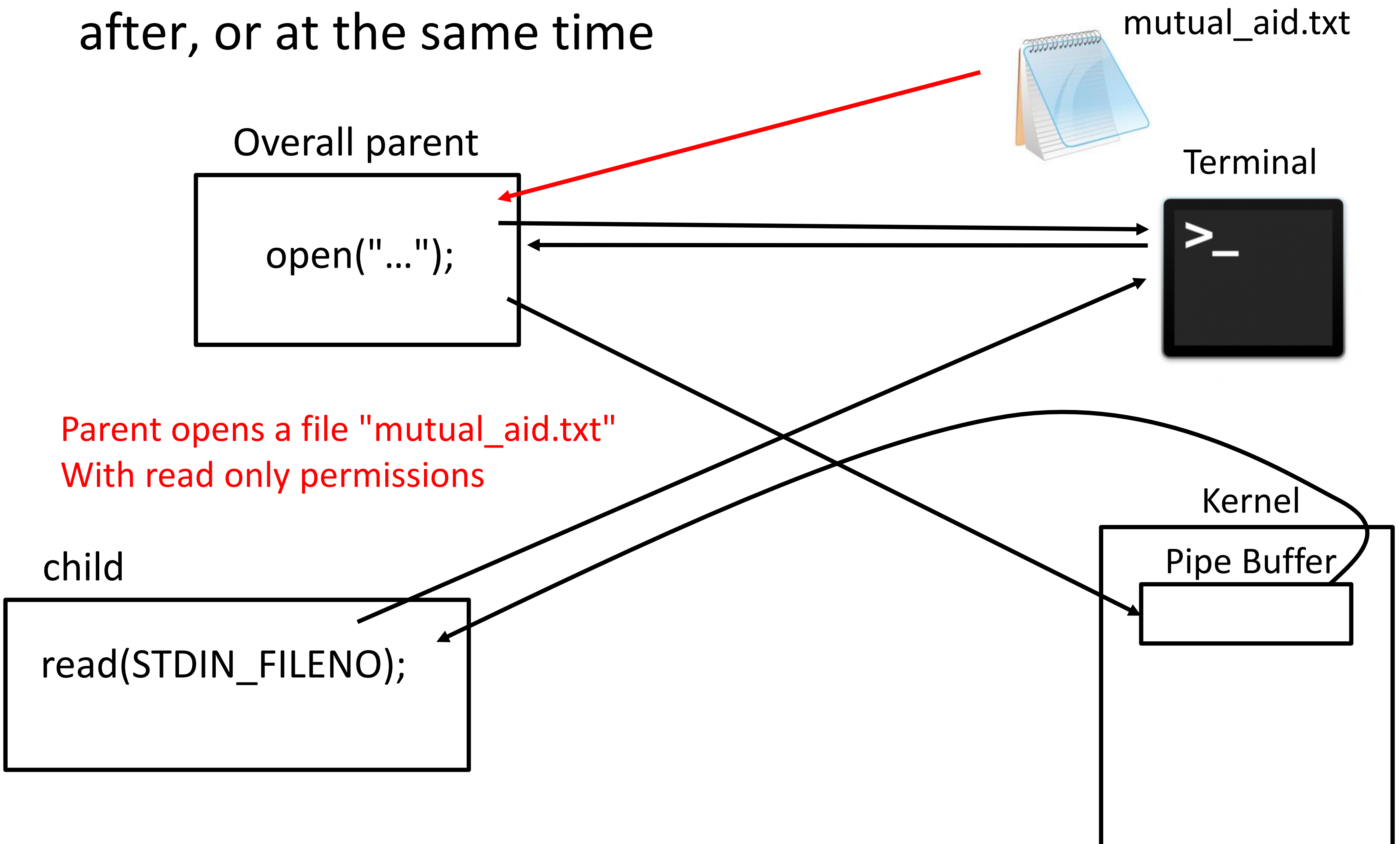

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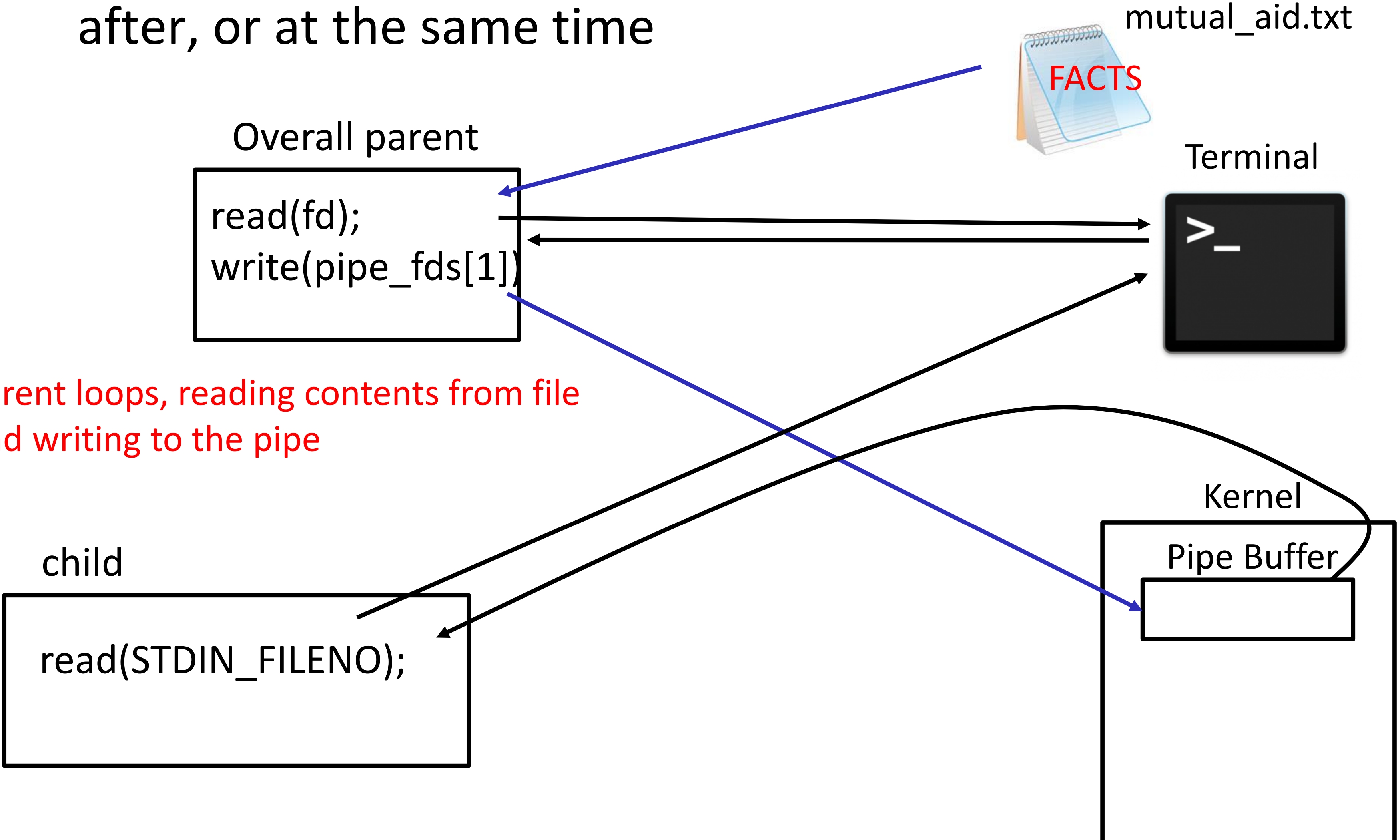

Parent loops, reading contents from file and writing to the pipe

cat_pipe.cpp Trace

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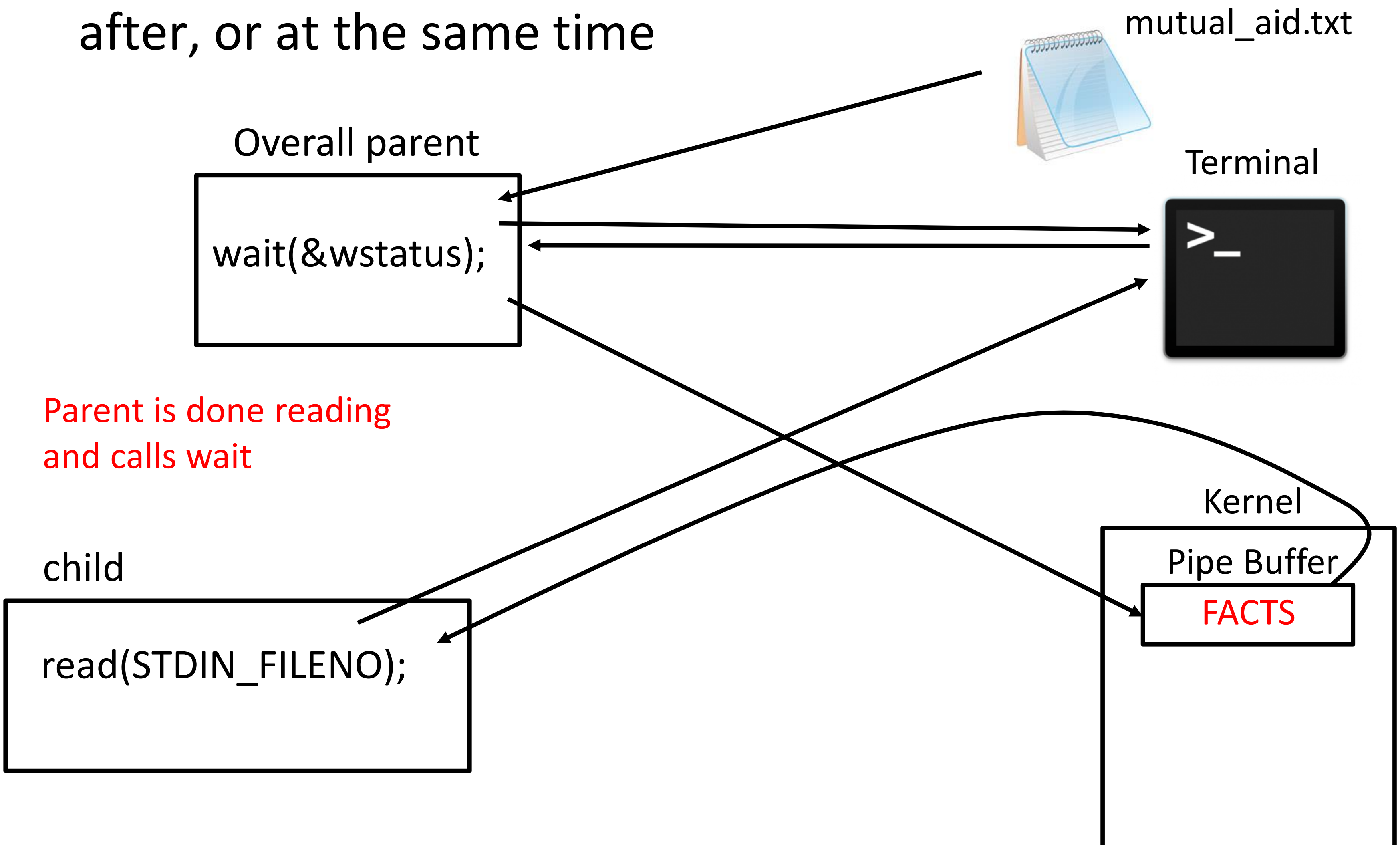

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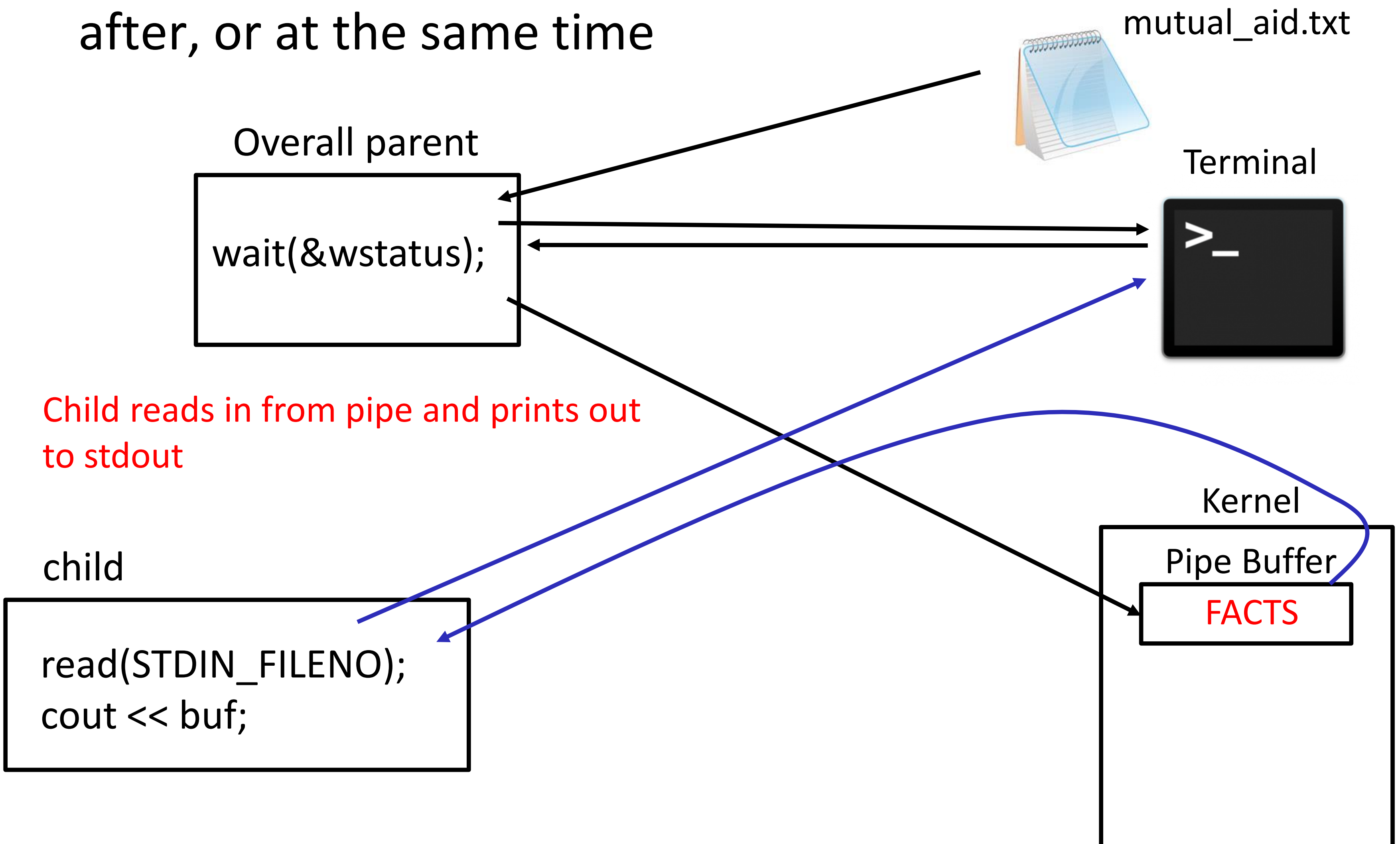

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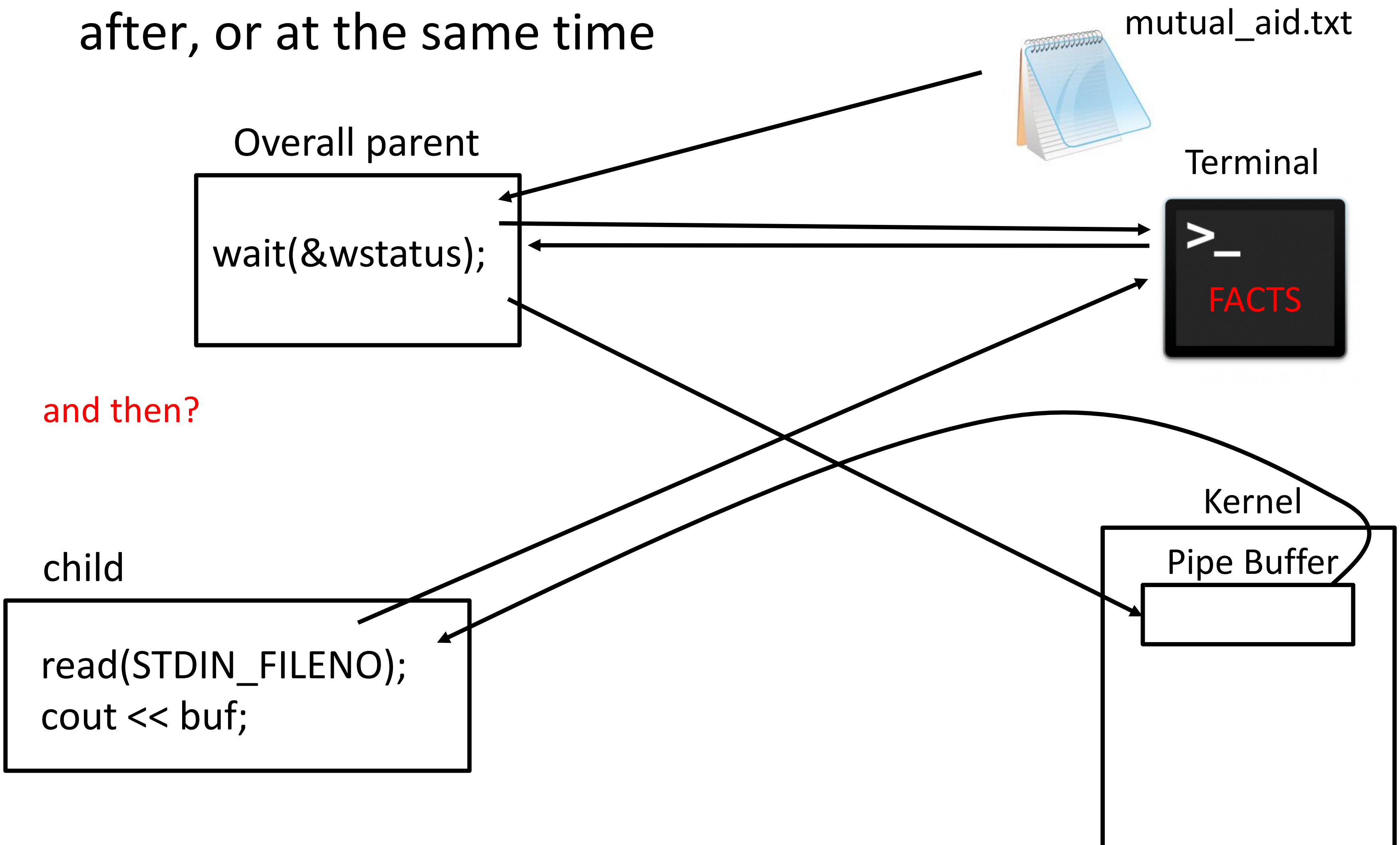
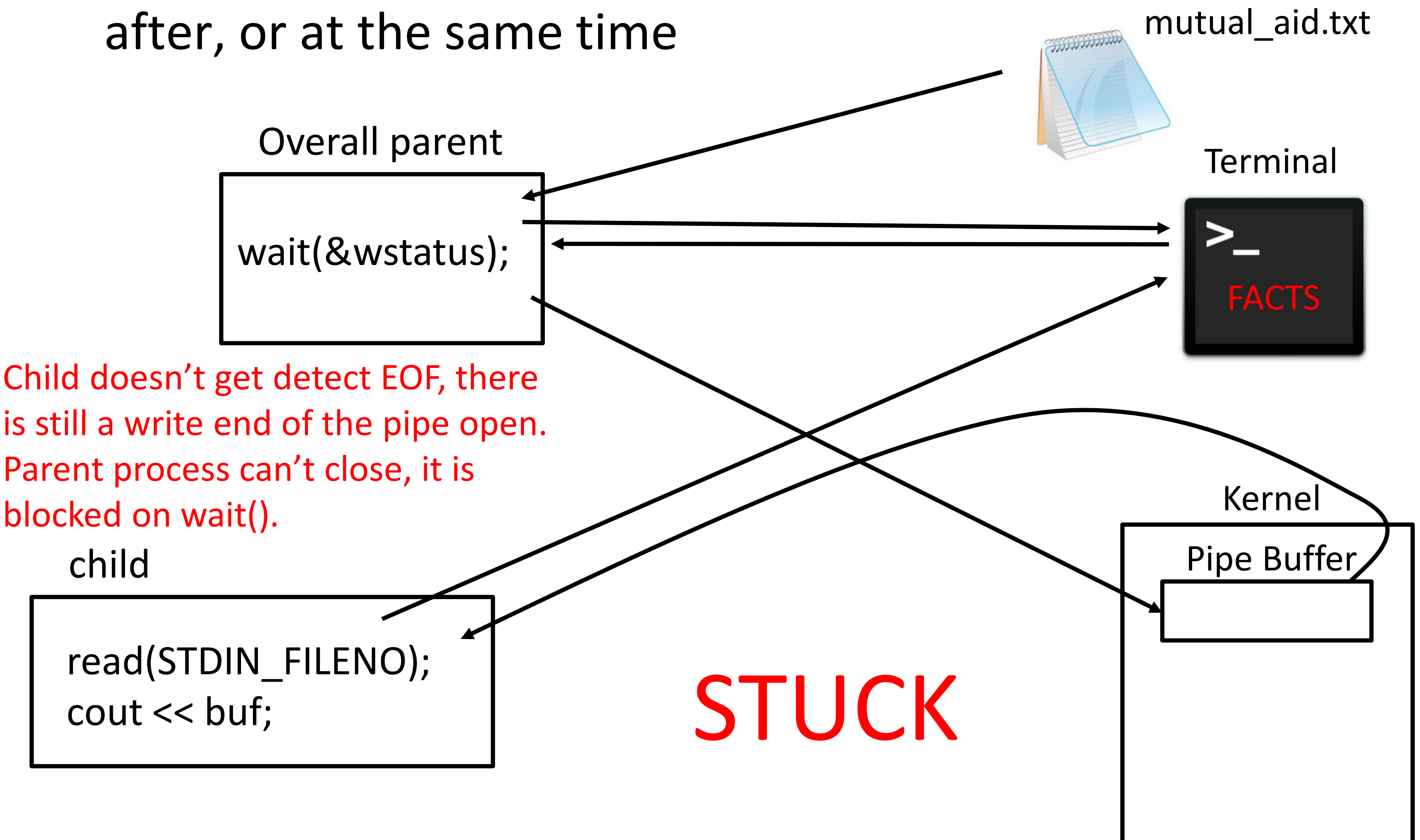


and then?

cat_pipe.cpp Trace

- Walking through **parent**, but child could be running first, after, or at the same time



Child doesn't get detect EOF, there is still a write end of the pipe open. Parent process can't close, it is blocked on wait().

Pipes & EOF

- Many programs will read from a file until they hit EOF and will not terminate until then
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  - EOF is not read in this case

- EOF is only read from a pipe when:
  - There is nothing in the pipe
  - All write ends of the pipe are closed

- **Good practice: CLOSE ALL PIPE FDS YOU ARE DONE WITH**

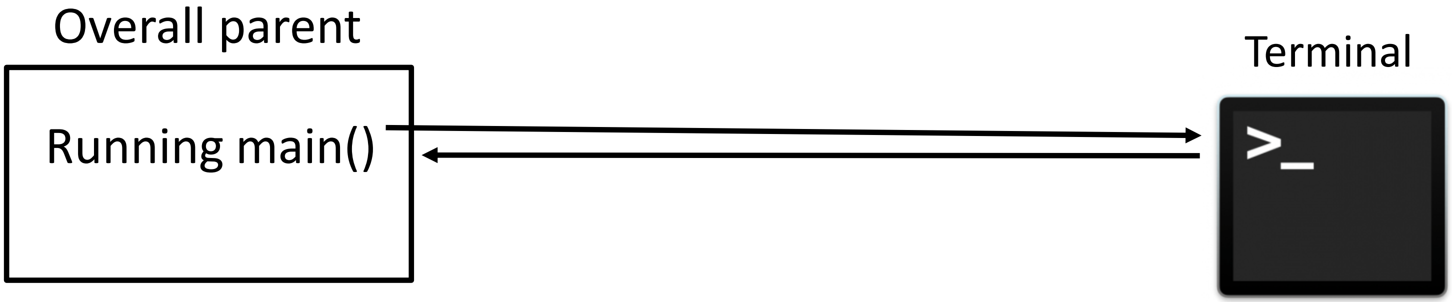
Exec & Pipe Demo

- See `autograder.cpp`
  - Example of using exec and fork

- See `io_autograder.cpp`
  - How could we take advantage of exec and pipe to do something useful?
  - Combine usage of fork and exec so our program can do multiple things

`io_autograder.cpp` Trace

- First:
  we compile the program with the gcc command



Overall parent

Running main()

Terminal

`io_autograder.cpp` Trace

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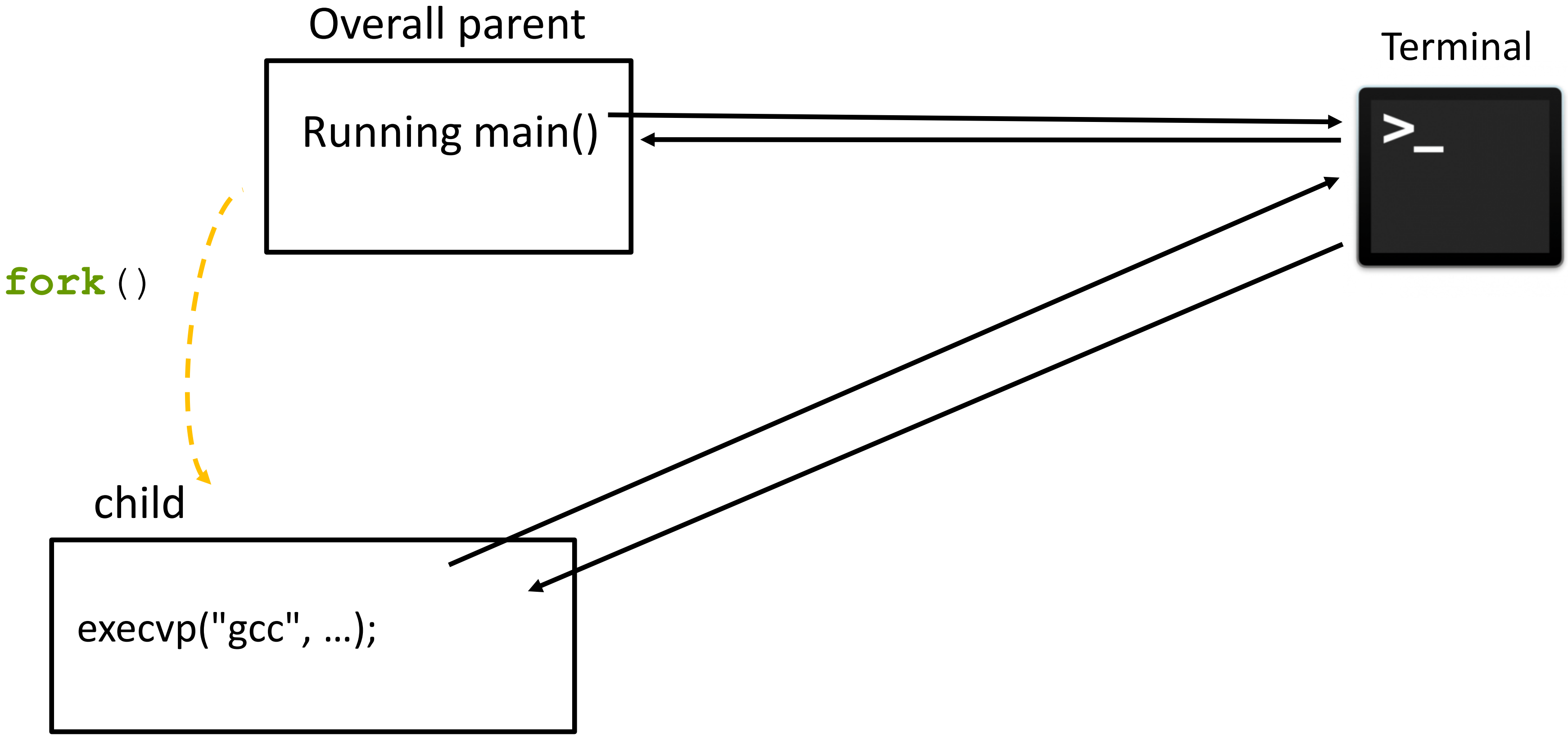

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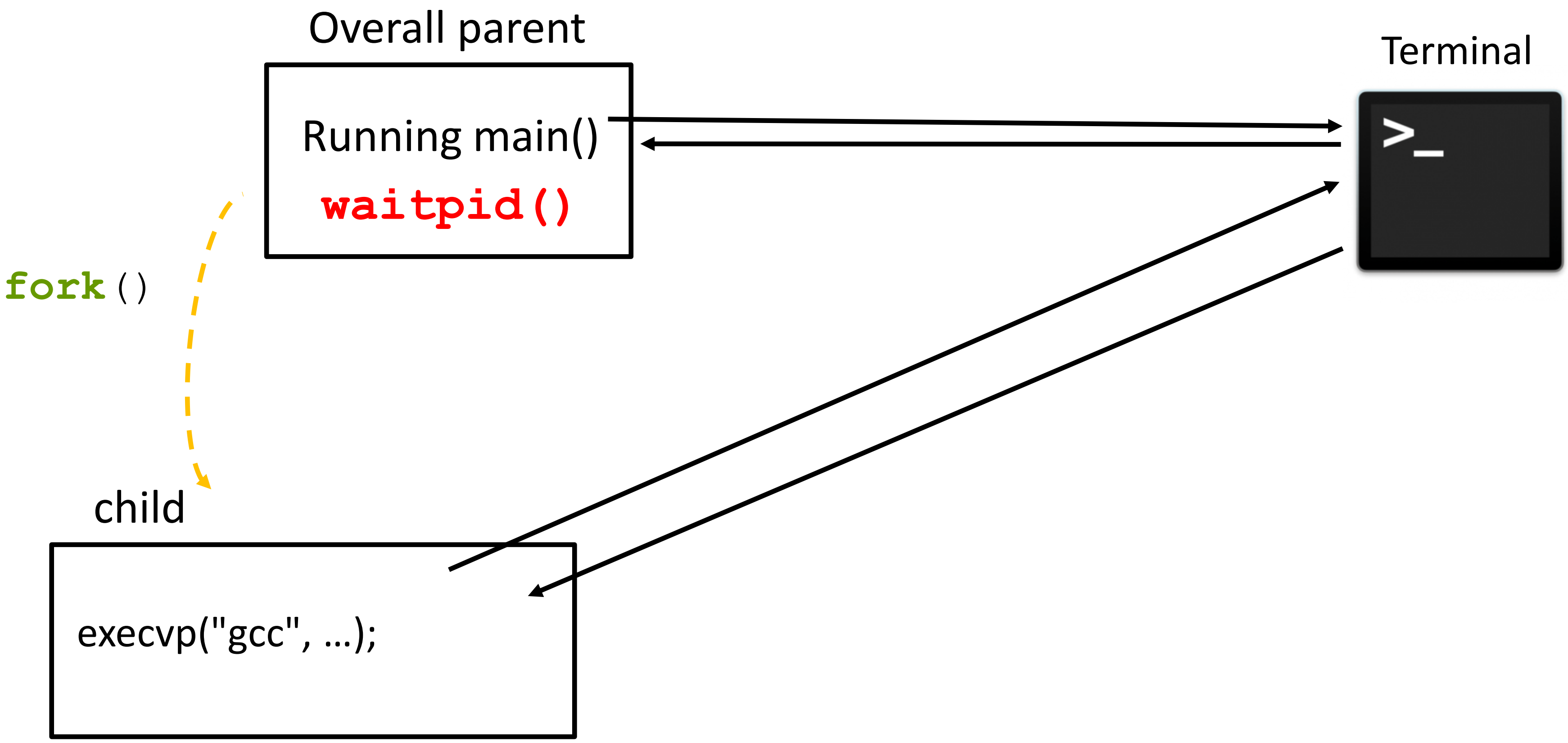
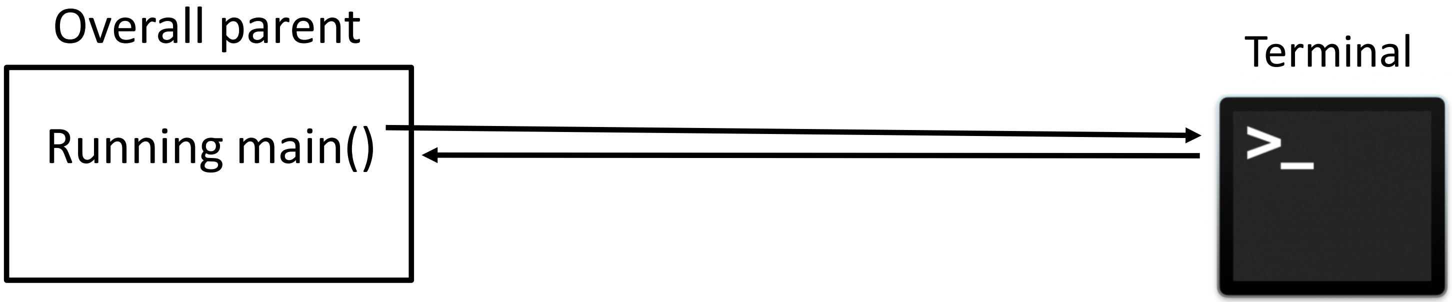


`io_autograder.cpp` Trace

- Compilation done! Run the compiled program…
  BUT send autograder input and capture output



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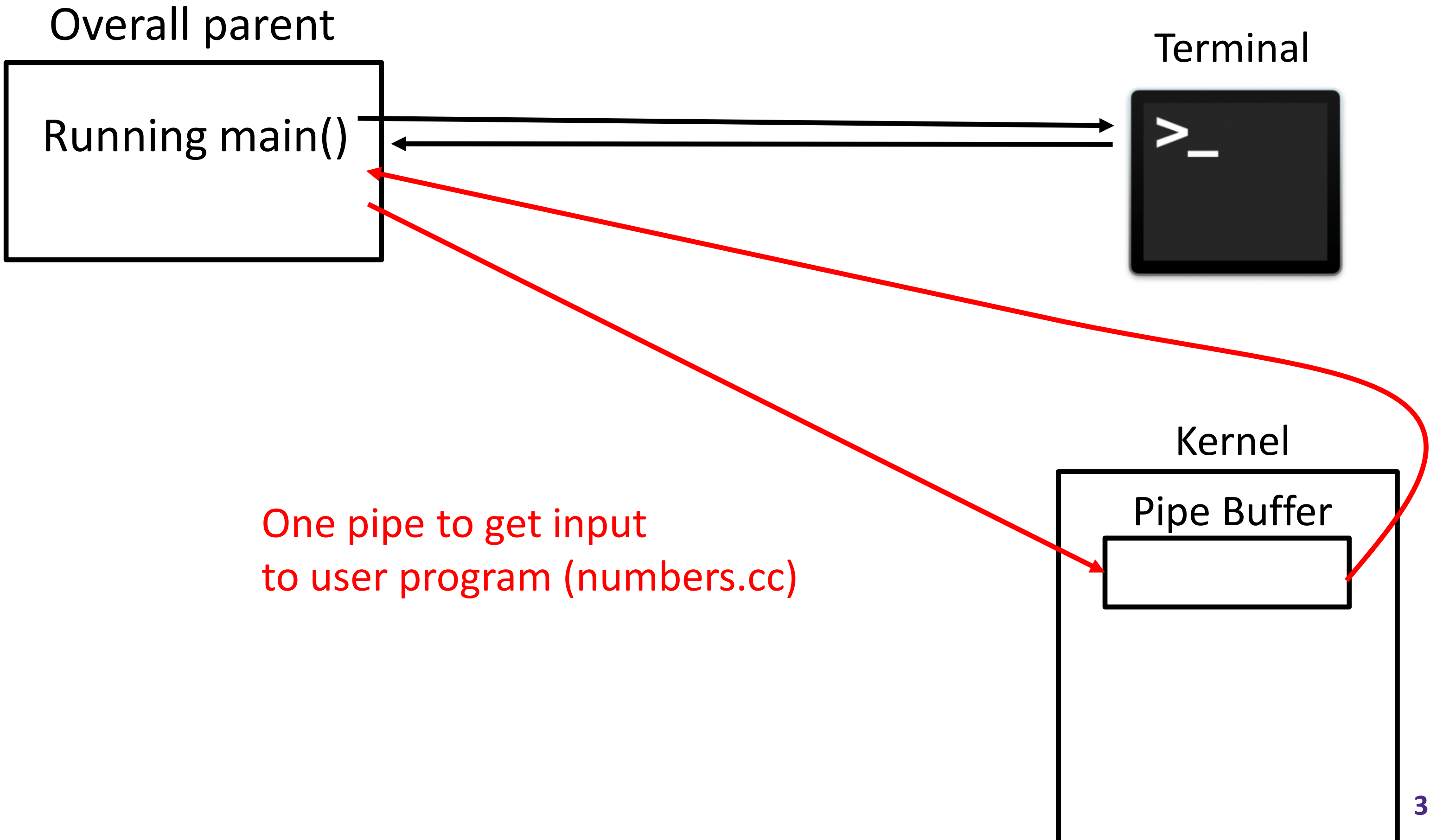

One pipe to get input to user program (numbers.cc)

`io_autograder.cpp` Trace

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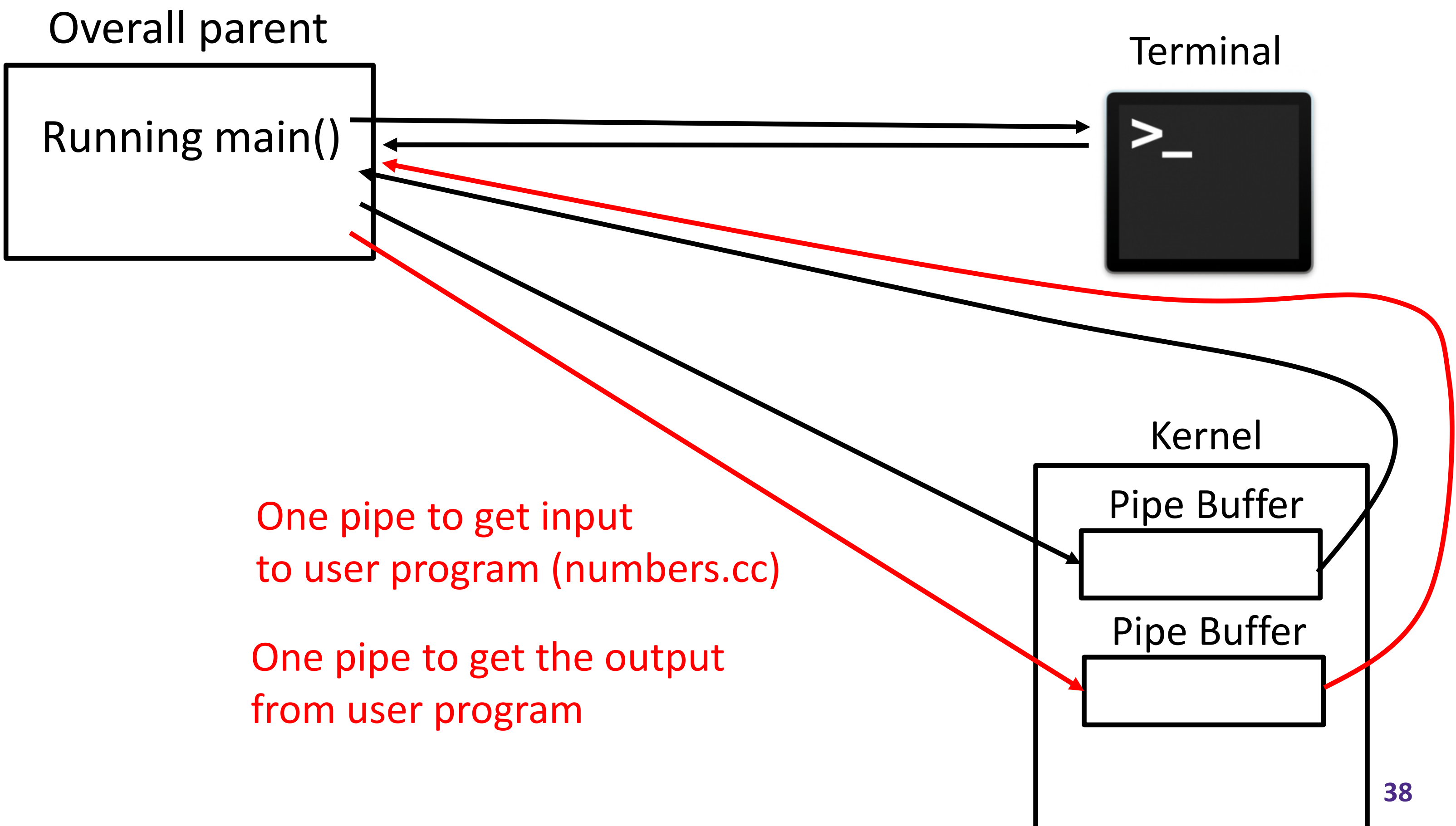

One pipe to get input to user program (numbers.cc)

One pipe to get the output from user program

io_autograder.cpp Trace

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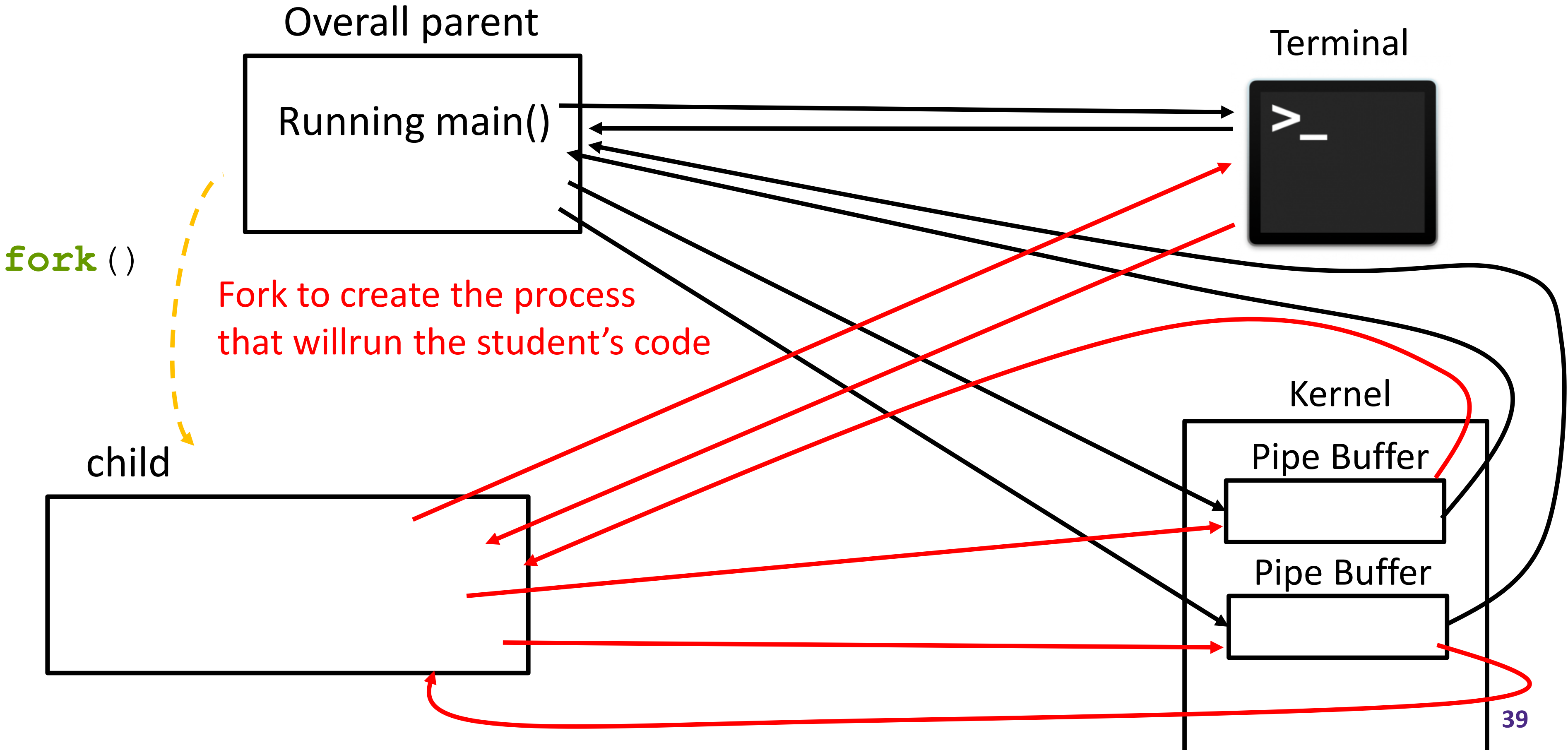

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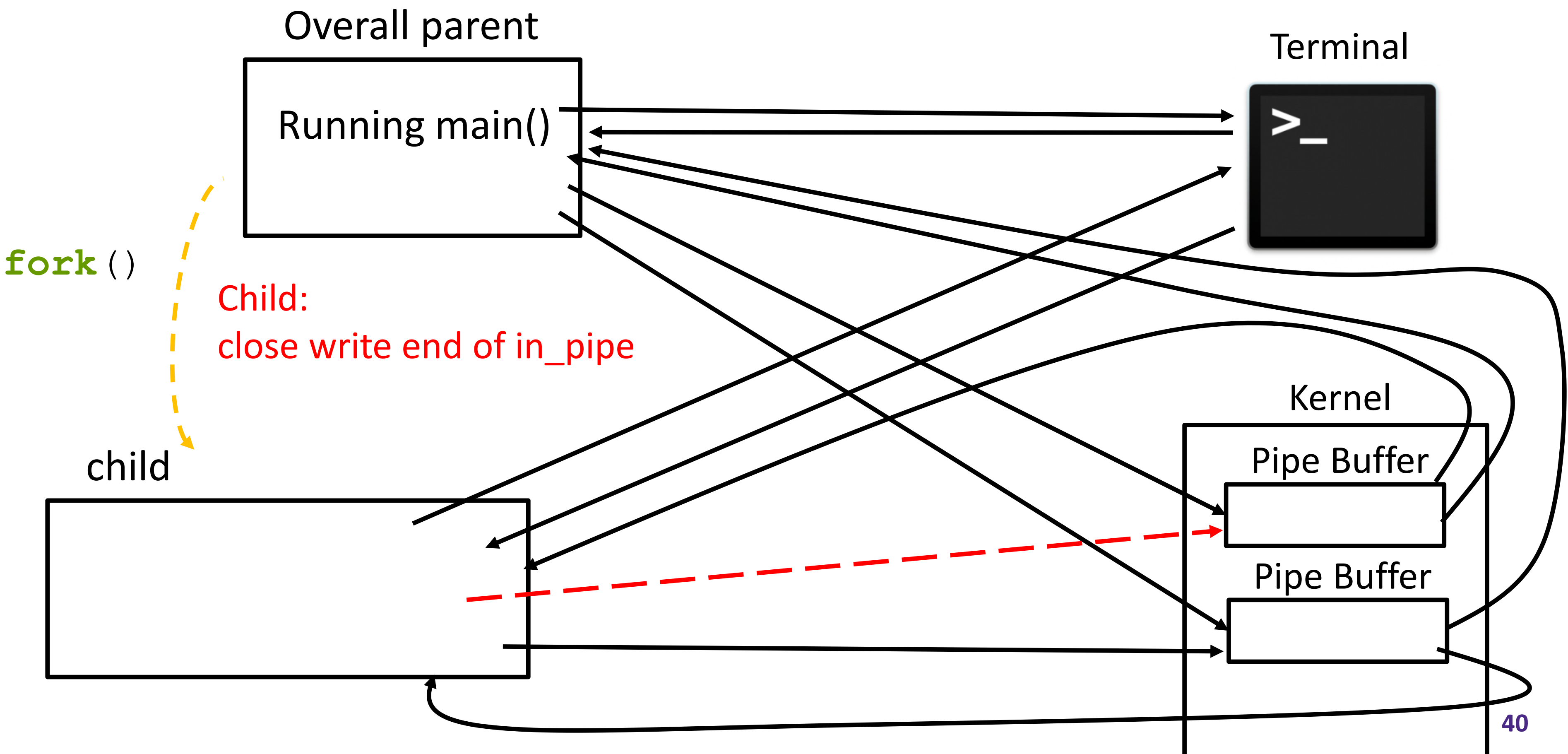

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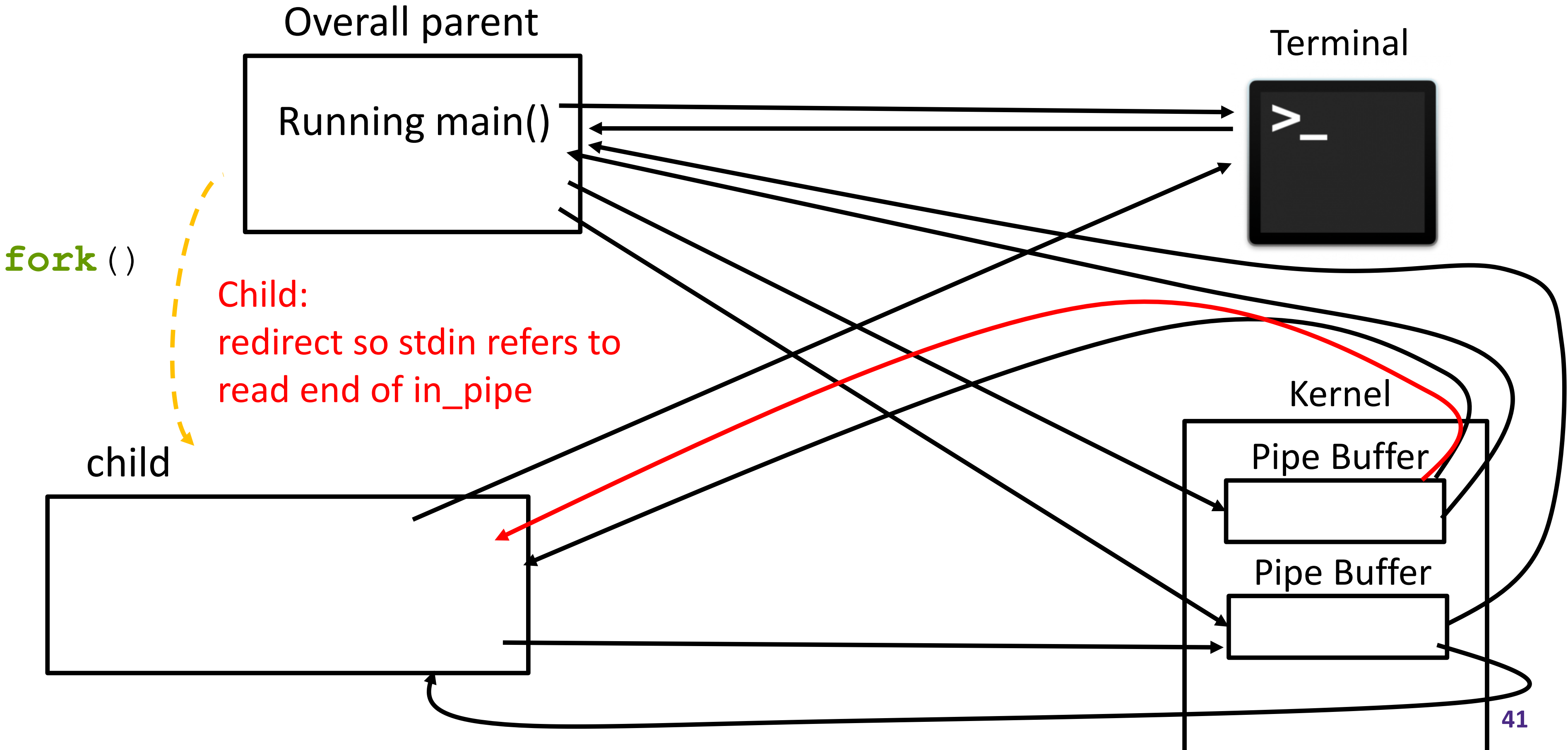

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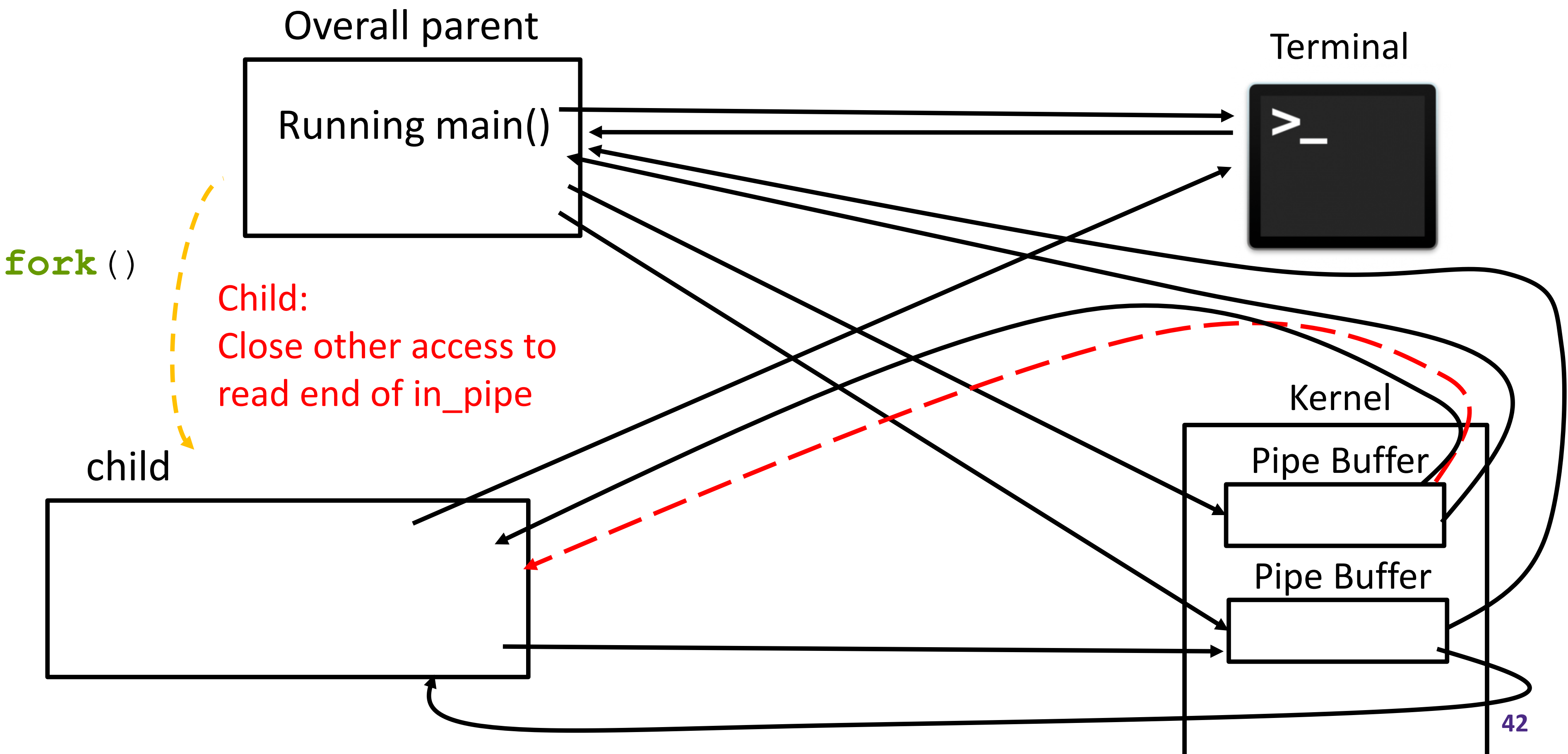

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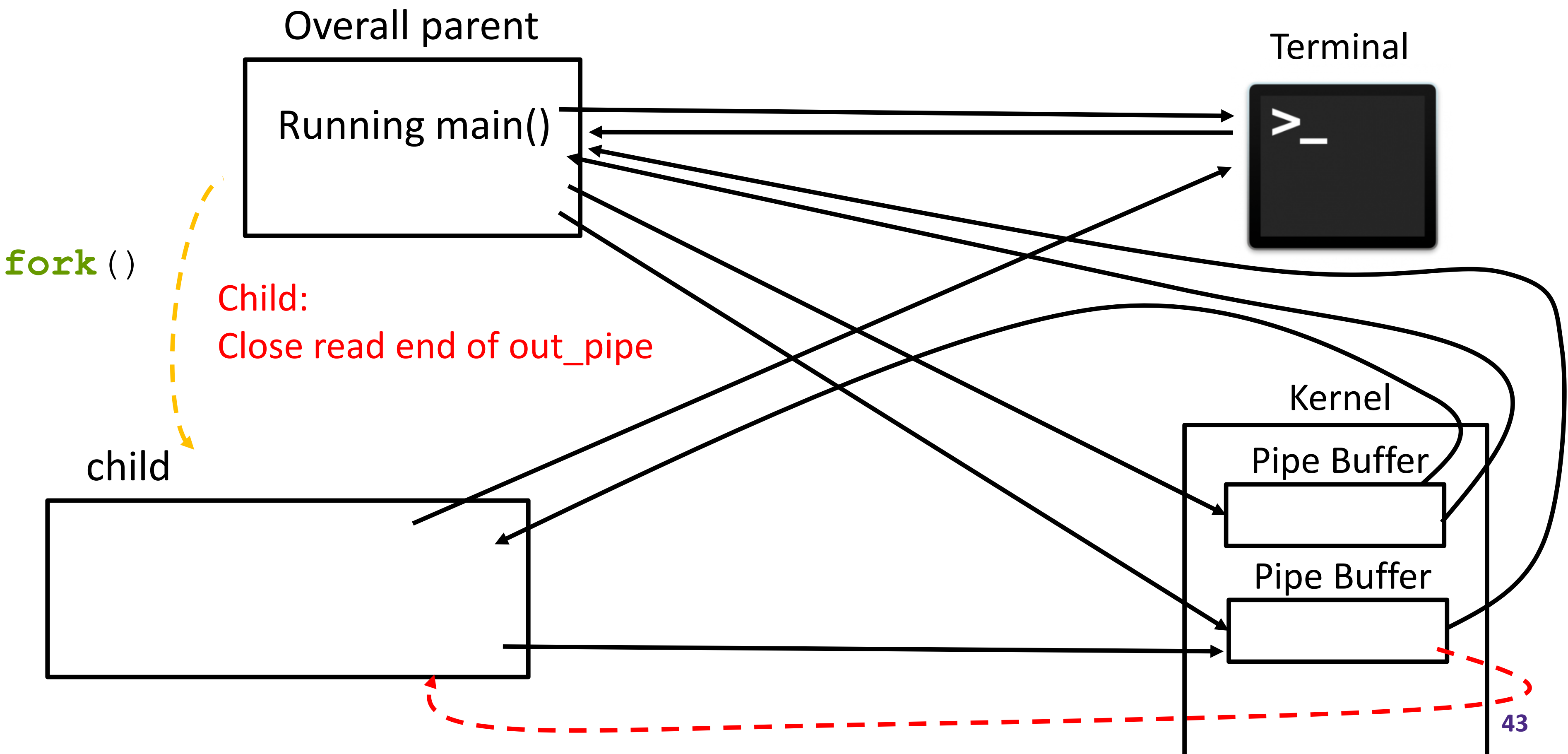

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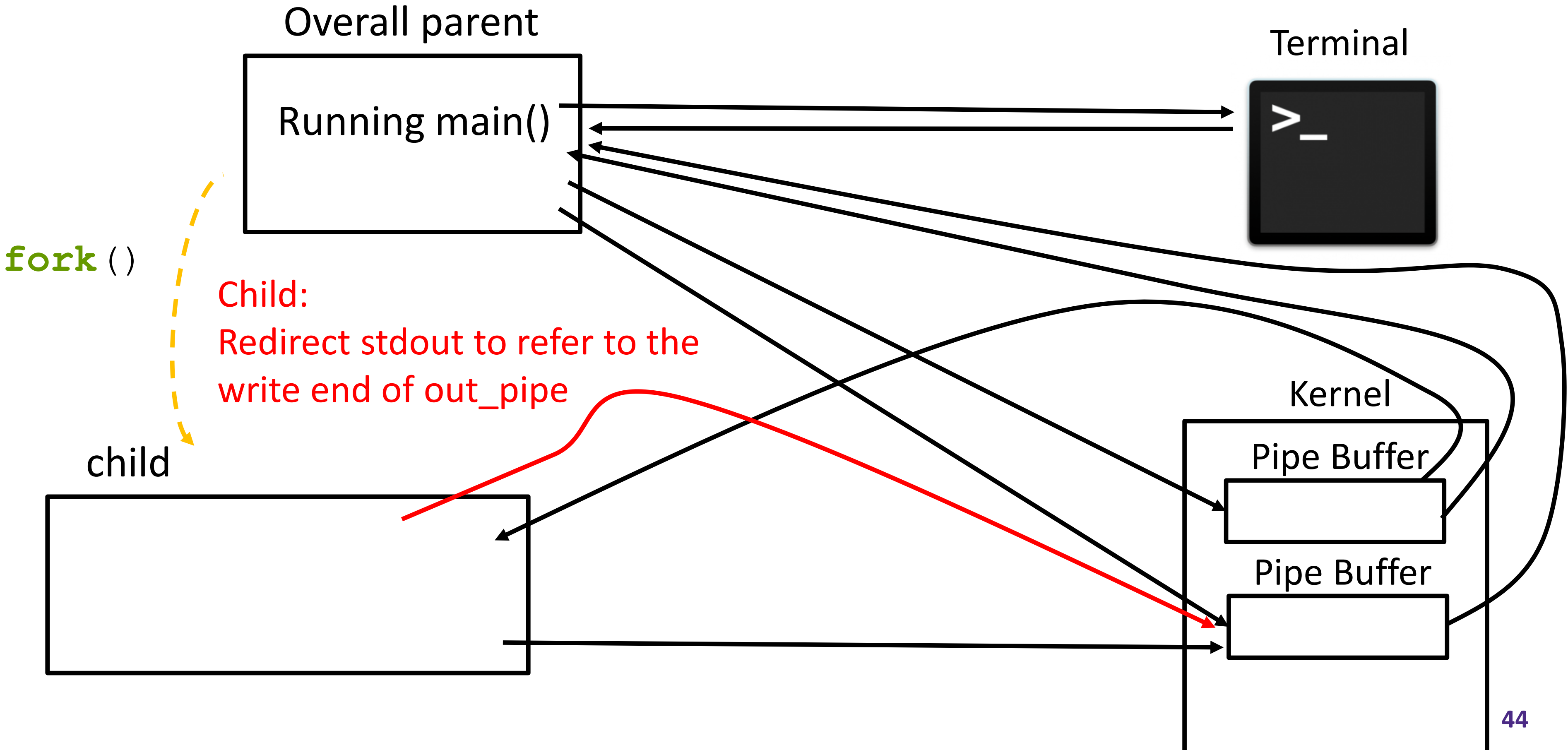
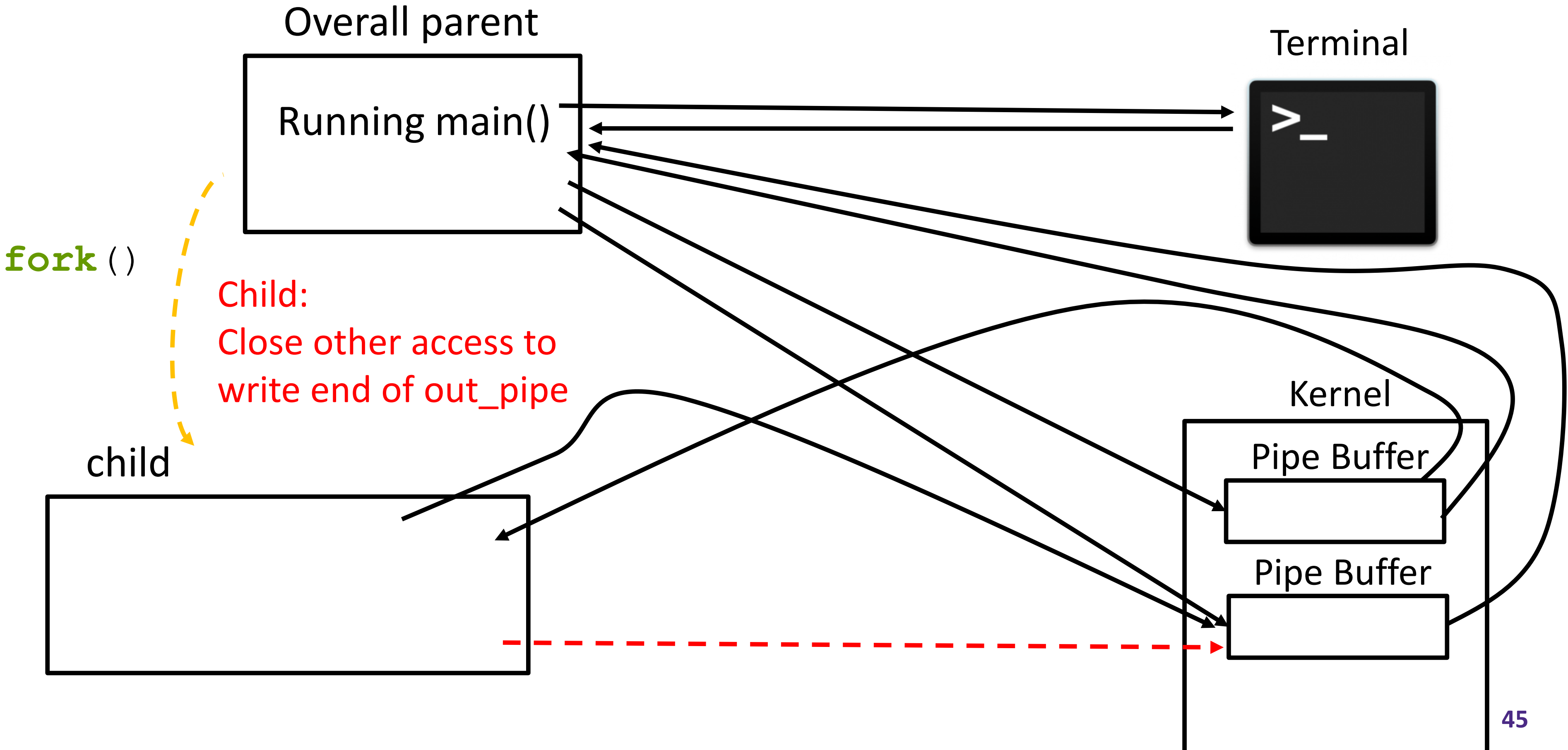


Child:
Redirect stdout to refer to the write end of out_pipe

`io_autograder.cpp` Trace

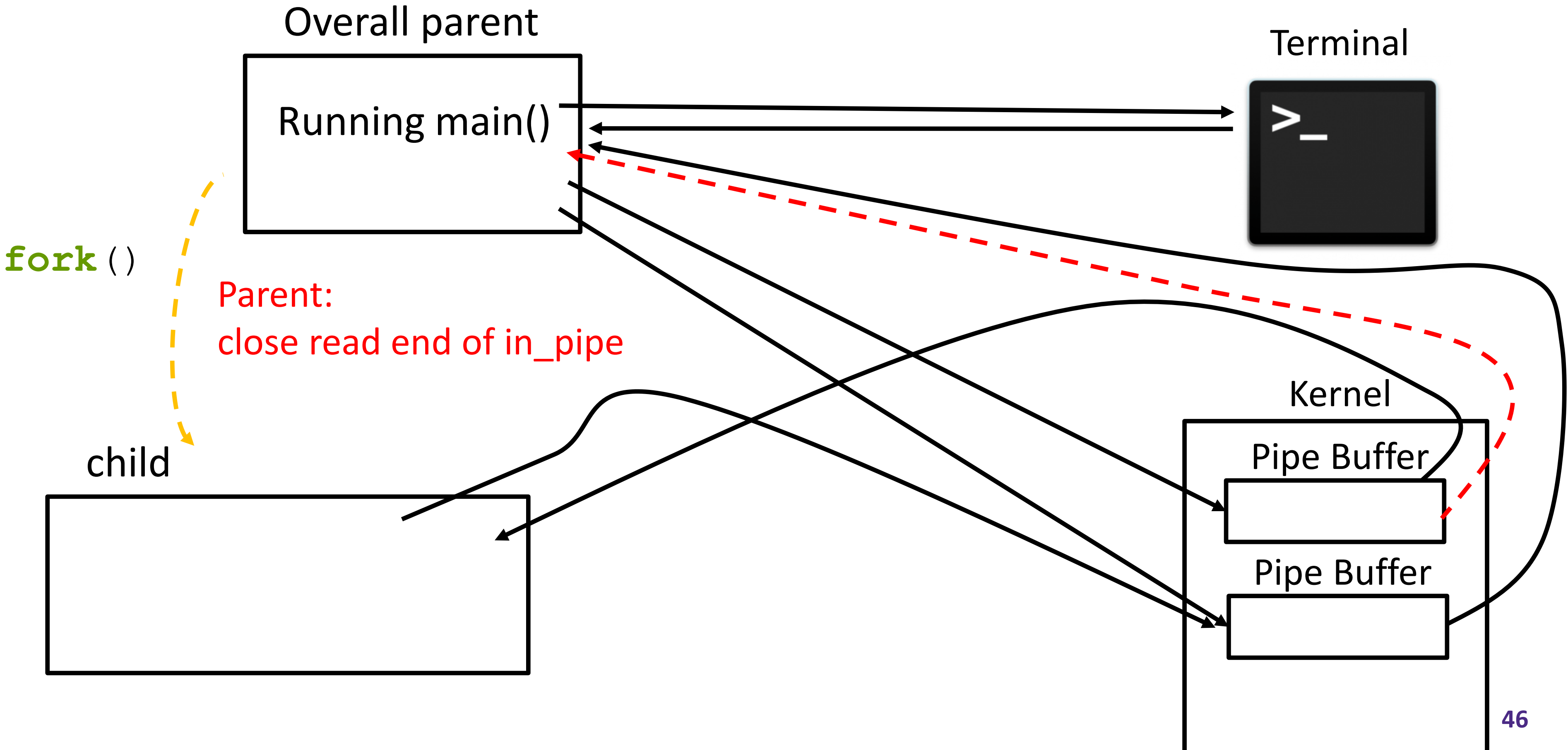
- Compilation done! Run the compiled program… BUT send autograder input and capture output



Child:
Close other access to write end of out_pipe

`io_autograder.cpp` Trace

- Compilation done! Run the compiled program… BUT send autograder input and capture output



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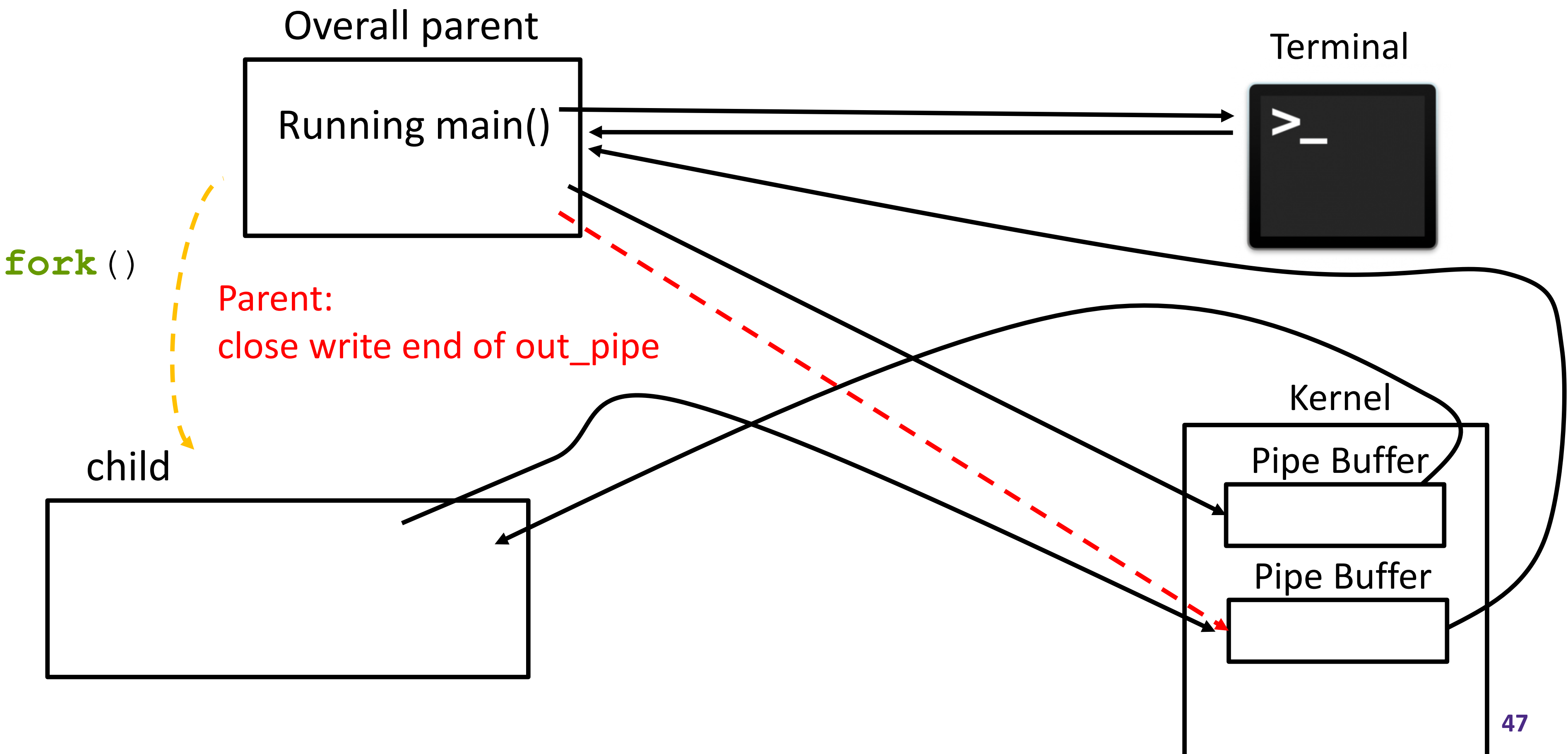

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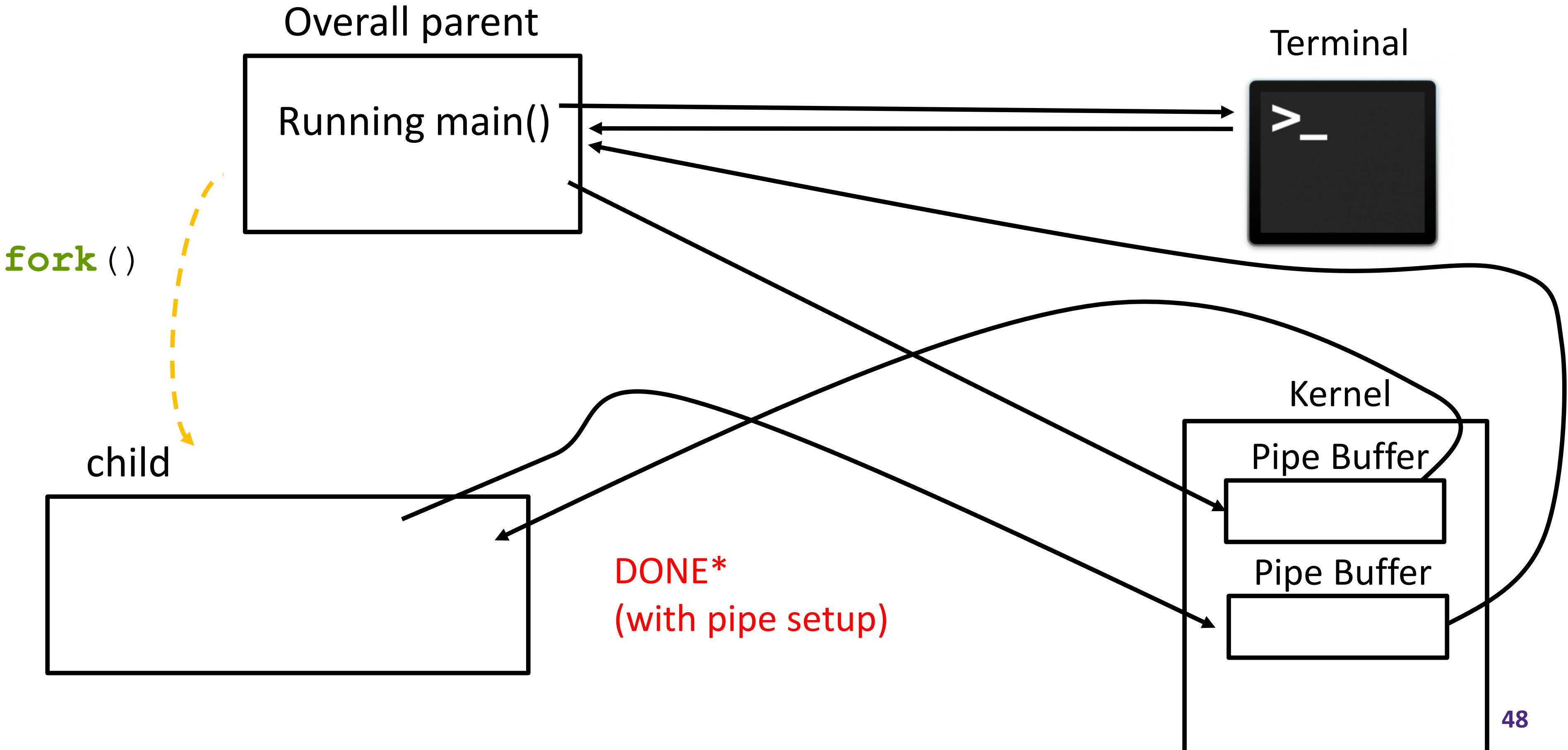

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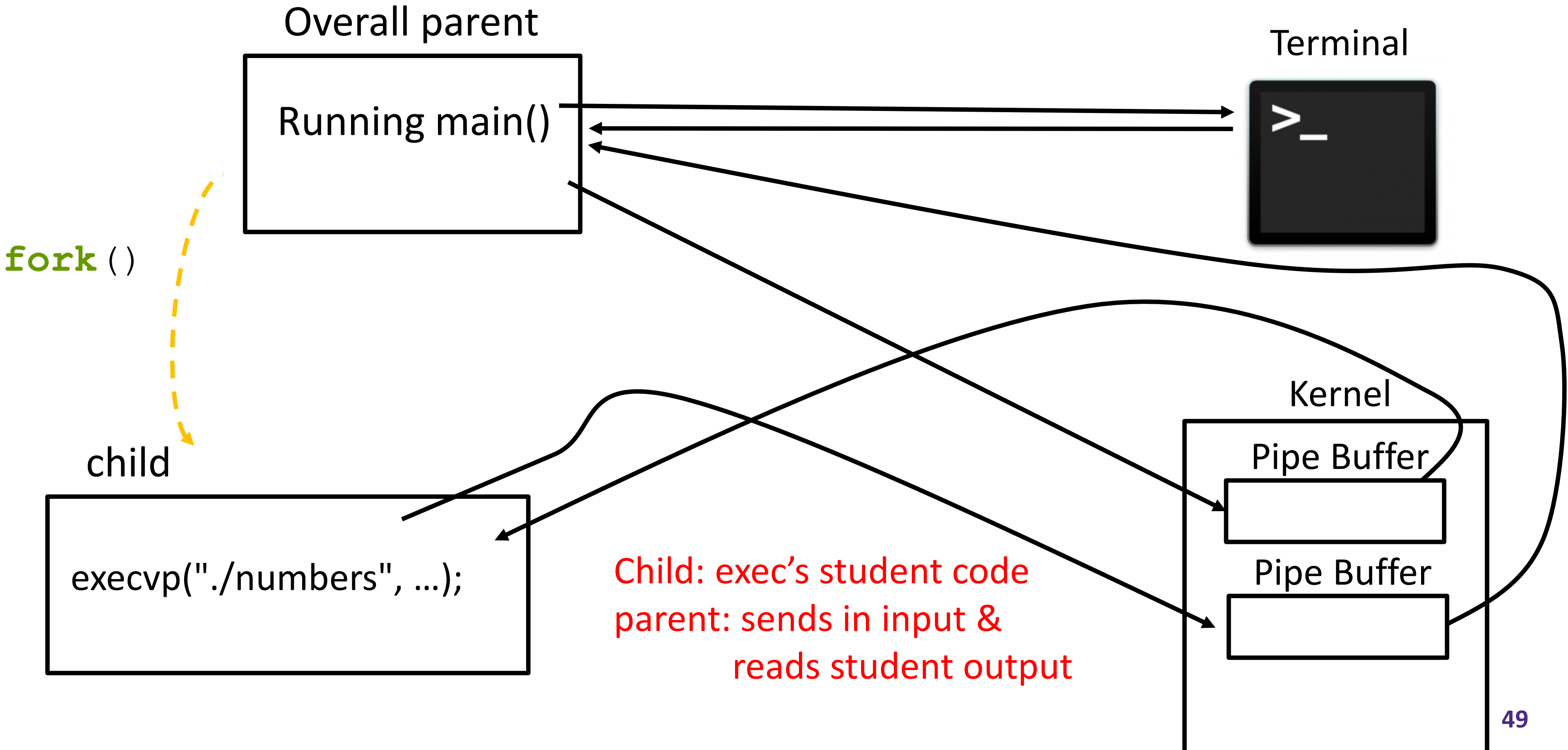

Child: exec's student code
parent: sends in input &
reads student output

Lecture Outline

- Pipe
- **Unix Shell**
- HW4

Unix Shell

- A **user level** process that reads in commands
  - This is the terminal you use to compile, and run your code
- Commands can either specify one of our programs to run or specify one of the already installed programs
  - Other programs can be installed easily.
- There are many commonly used bash programs, we will go over a few and other important bash things.

. / ..

- "/" is used to connect directory and file names together to create a file path.
  - E.g. "**`workspace/595/hello/`**"

- "." is used to specify the current directory.
  - E.g. "**`./test_suite`**" tells to look in the current directory for a file called "**`test_suite`**"

- ".." is like "." but refers to the parent directory.
  - E.g. "**`./solution_binaries/../test_suite`**" would be effectively the same as the previous example.

Common Commands (Pt. 1)

- "**`ls`**" lists out the entries in the specified directory (or current directory if another directory is not specified

- "**`cd`**" changes directory to the specified directory
  - E.g. "**`cd ./solution_binaries`**"

- "**`exit`**" closes the terminal

- "**`mkdir`**" creates a directory of specified name

- "**`touch`**" creates a specified file. If the file already exists, it just updates the file's time stamp

Common Commands (Pt. 2)

- "**`echo`**" takes in command line args and simply prints those args to stdout
  - "**`echo hello!`**" simply prints "**`hello!`**"

- "**`wc`**" reads a file or from stdin some contents. Prints out the line count, word count, and byte count

- "**`cat`**" prints out the contents of a specified file to stdout. If no file is specified, prints out what is read from stdin

- "**`head`**" print the first 10 line of specified file or stdin to stdout

Common Commands (Pt. 3)

- "**`grep`**" given a pattern (regular expression) searches for all occurrences of such a pattern. Can search a file, search a directory recursively or stdin. Results printed to stdout

- "**`history`**" prints out the history of commands used by you on the terminal

- "**`cron`**" a program that regularly checks for and runs any commands that are scheduled via "crontab"

- "**`wget`**" specify a URL, and it will download that file for you

Unix Shell Commands

- Commands can also specify flags
  - E.g. "`ls -l`" lists the files in the specified directory in a more verbose format

- Revisiting the design philosophy:
  - Programs should "Do One Thing And Do It Well."
  - Programs should be written to work together
  - Write programs that handle text streams, since text streams is a universal interface.

- These programs can be easily combined with UNIX Shell operators to solve more interesting problems

Unix Shell Control Operators

- `cmd1 && cmd2`, used to run two commands. The second is only run if cmd1 doesn't fail
  - E.g. "`make && ./test_suite`"

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

- `cmd &`, runs the process in the background, allowing you to immediately input a new command

Unix Shell Control Operators

- `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`"

- Complex example:

```
    cat ./input.txt | ./numbers > out.txt
    && diff out.txt expected.txt
```

Poll Everywhere

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- Which of the following commands will print the number of files in the current directory?

A. ls > wc

B. cd . && ls wc

C. ls | wc

D. ls && wc

E. The correct answer is not listed

F. We're lost…

cd: change directory

ls: list directory contents

wc: reads from stdin, prints the number of words, lines, and characters read.

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- Which of the following commands will print the number of files in the current directory?

A. ls > wc

B. cd . && ls wc

[✓ C. ls | wc]

Correctly gets the number of files, but not ONLY the number of files

D. ls && wc

[✓ E. The correct answer is not listed]

F. We're lost…

`ls | wc -l`
would be preferred.

Lecture Outline

- Pipe
- Unix Shell
- **HW4**

HW4 Demo

- In HW4, you will be writing your own shell that reads from user input
  - Each line is a command that could consist of multiple programs and pipes between them
  - Your shell should fork a process to run each program and setup the pipes in between them

- Some sample programs provided to help with implementation ideas.

Unix Shell Control Operators: Pipe

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

HW4 Demo

- In HW4, you will be writing your own shell that reads from user input
  - Each line is a command that could consist of multiple programs and pipes between them
  - Your shell should fork a process to run each program and setup the pipes in between them

- Some sample programs provided to help with implementation ideas.

- Can run a sample solution with:

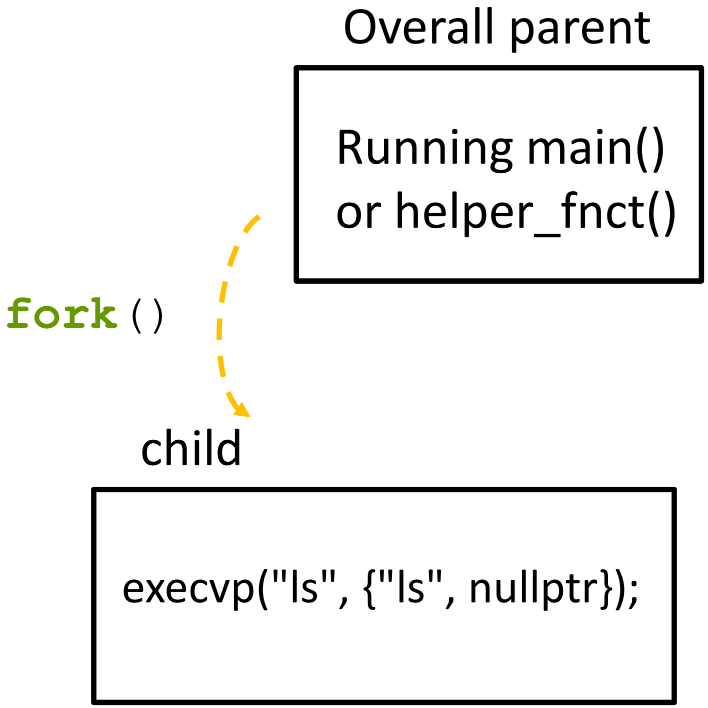
```
./solution_binaries/pipe_shell
```

Suggested Approach

- HIGHLY ENCOURAGED to follow the suggested approach
  - Write a program that acts similarly to stdin_echo.cc
  - Write a program that can handle commands with no pipes
    - `"ls"`
  - Add support for command line arguments
    - `"ls -l"`
  - Add support for commands with ONE pipe
    - `"ls -l | wc"`
  - Generalize to add support for any number of pipes
    - `"ls -l | wc | cat"`

HW4 Example Line

- Consider the case when a user inputs
  - `"ls"`



```
execvp("ls", {"ls", nullptr});
```

HW4 Example Line

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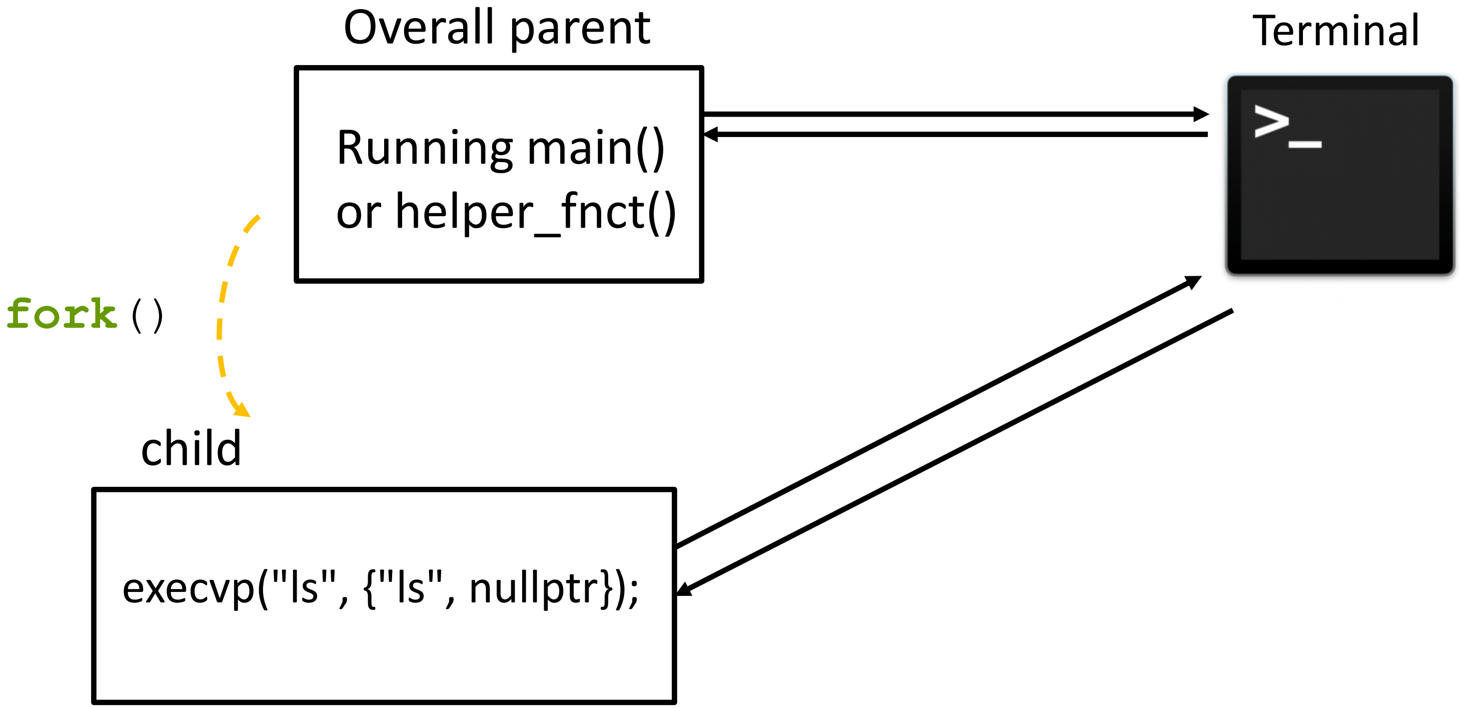


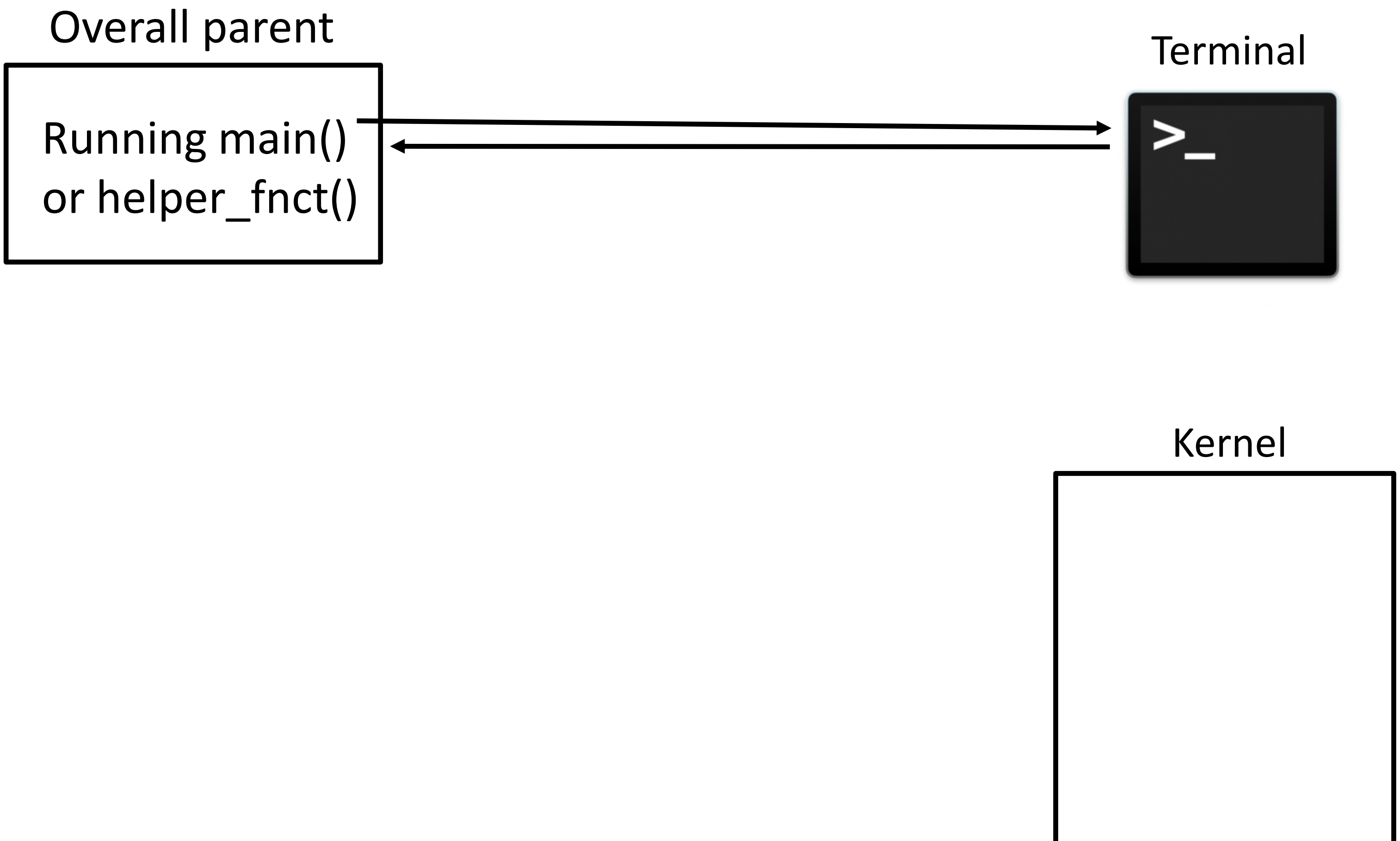
HW4 Hints

- If there are n commands in a line, there should be n-1 pipes
- Each pipe should be written to by exactly one process
- Each pipe should be read by exactly one process
  - Different than the one writing
- There are three cases to consider for commands using pipes
  - The first process, which reads from stdin and writes out to a pipe
  - The last process, which reads from a pipe and writes to stdout
  - Processes in between which read from one pipe and write to another

- More hints when HW is posted

HW4 Example Line 1

- Consider the case when a user inputs
  - `"ls | wc"`



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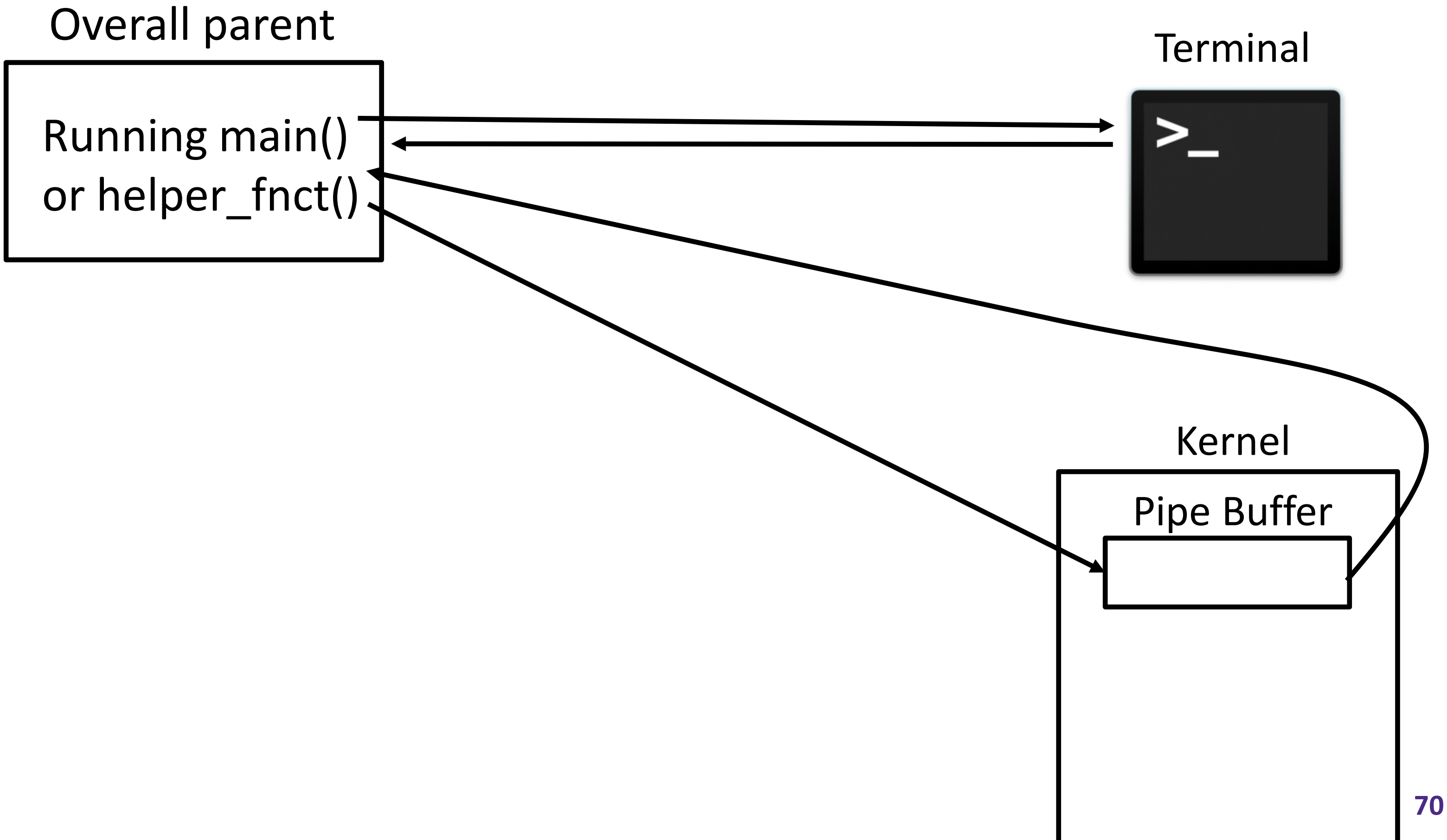

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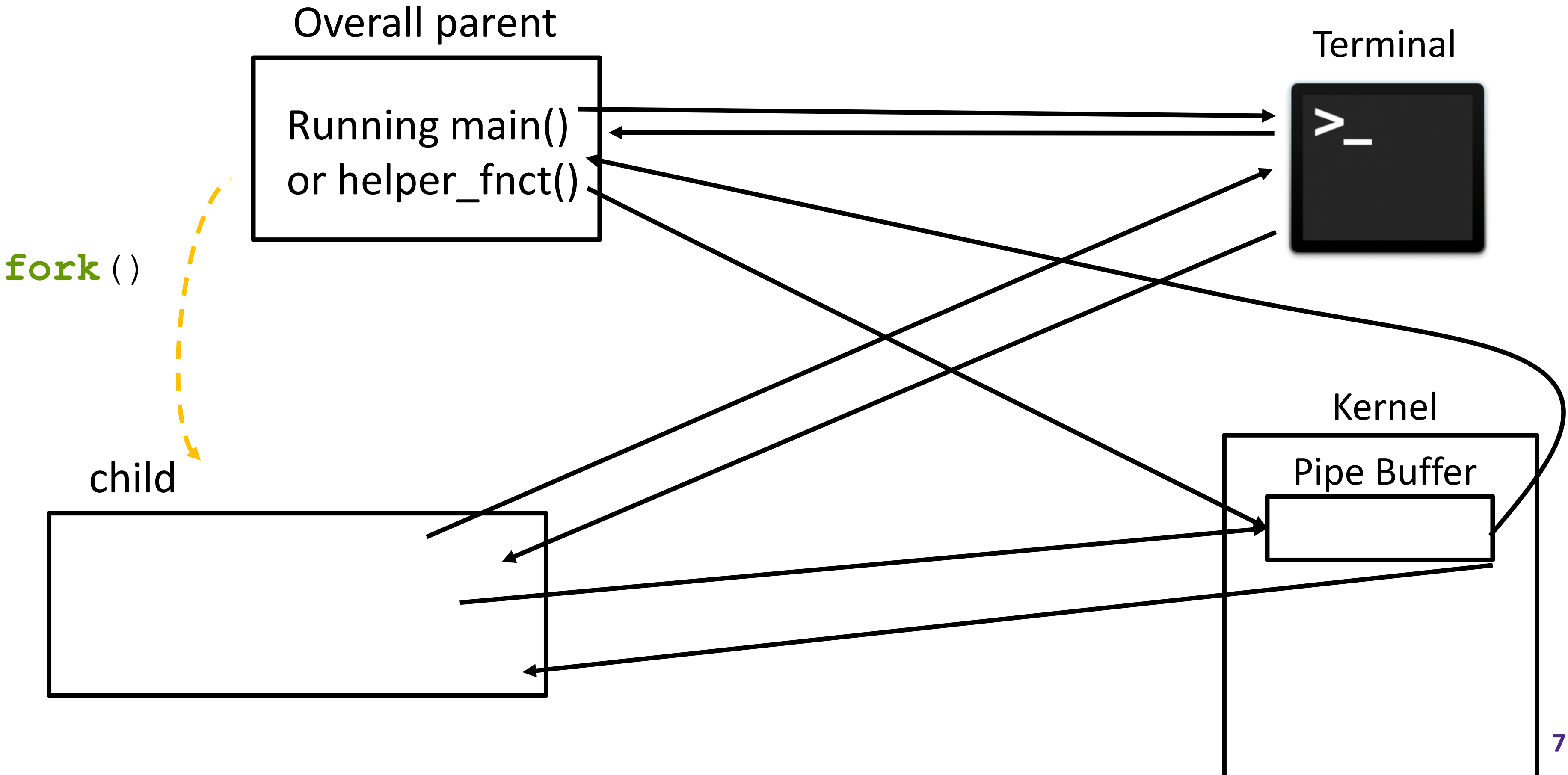

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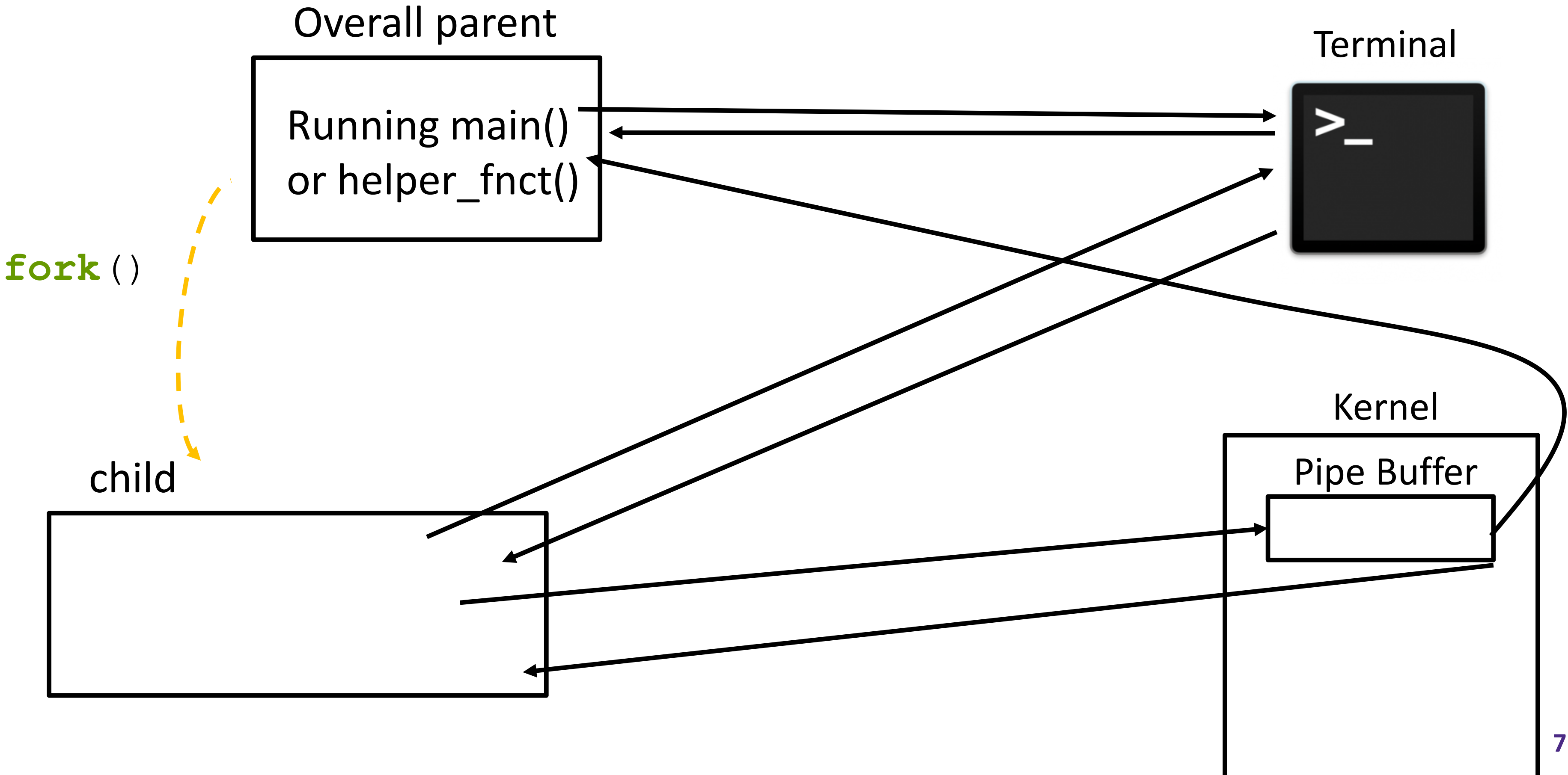

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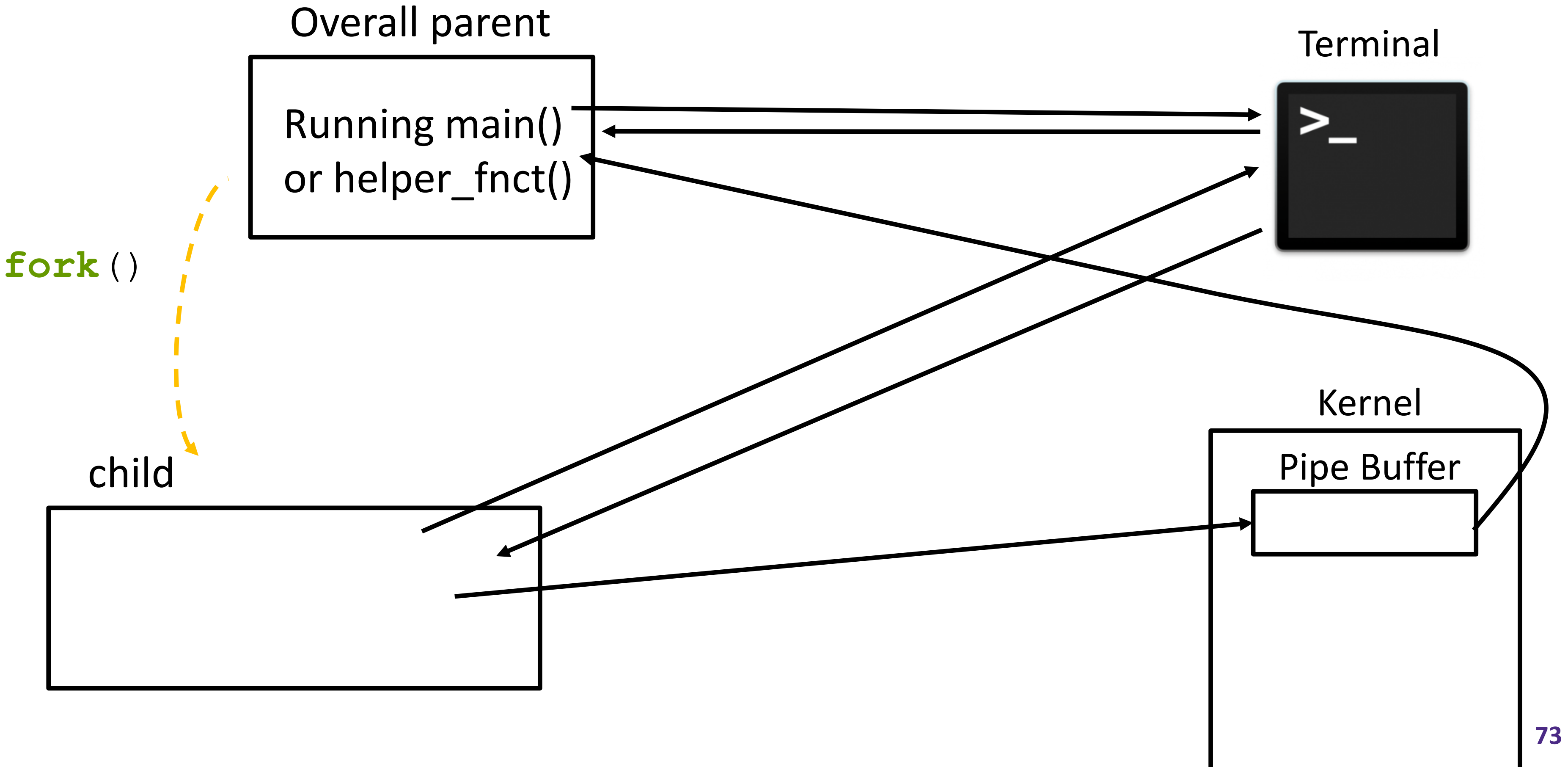

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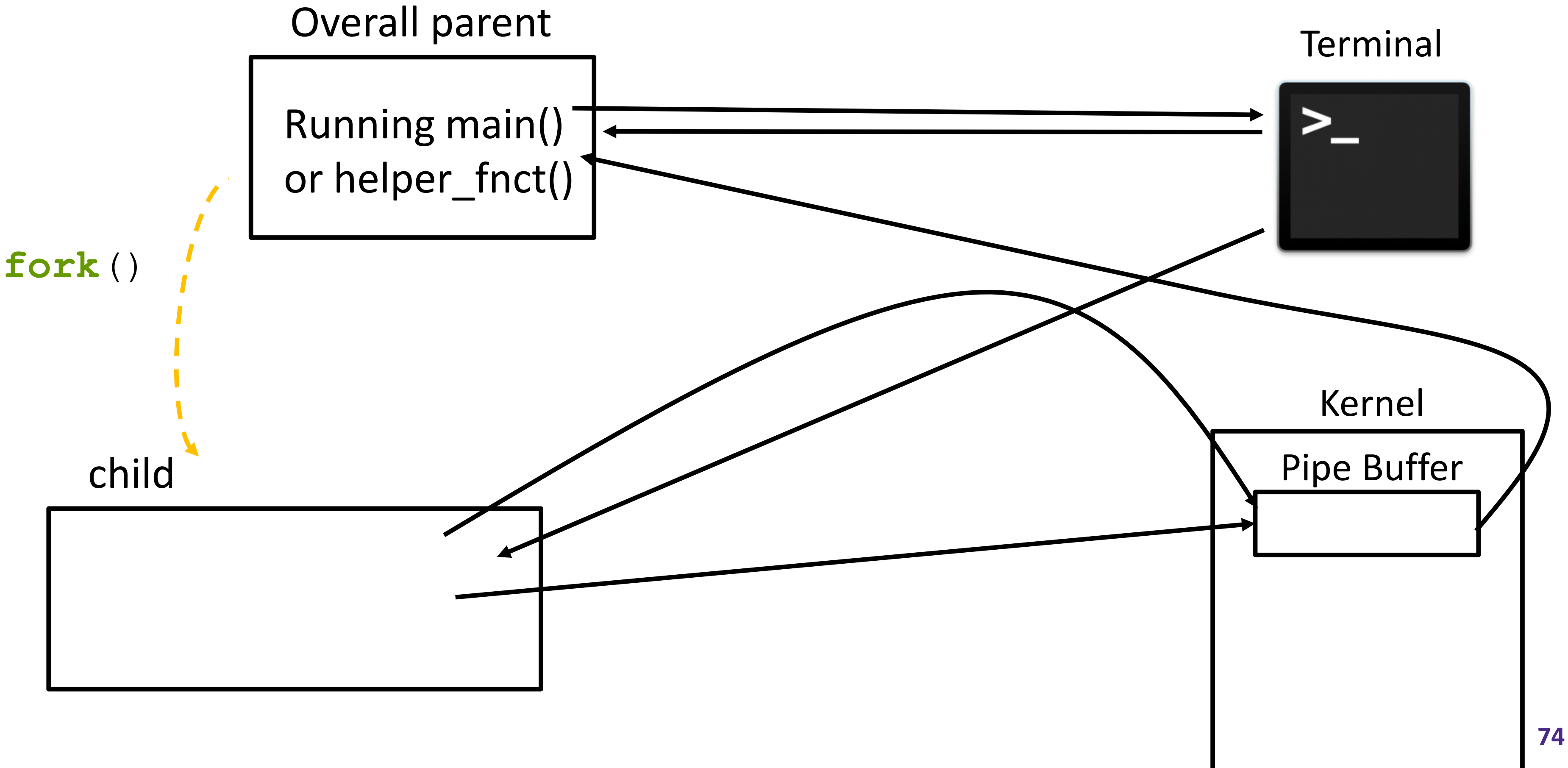

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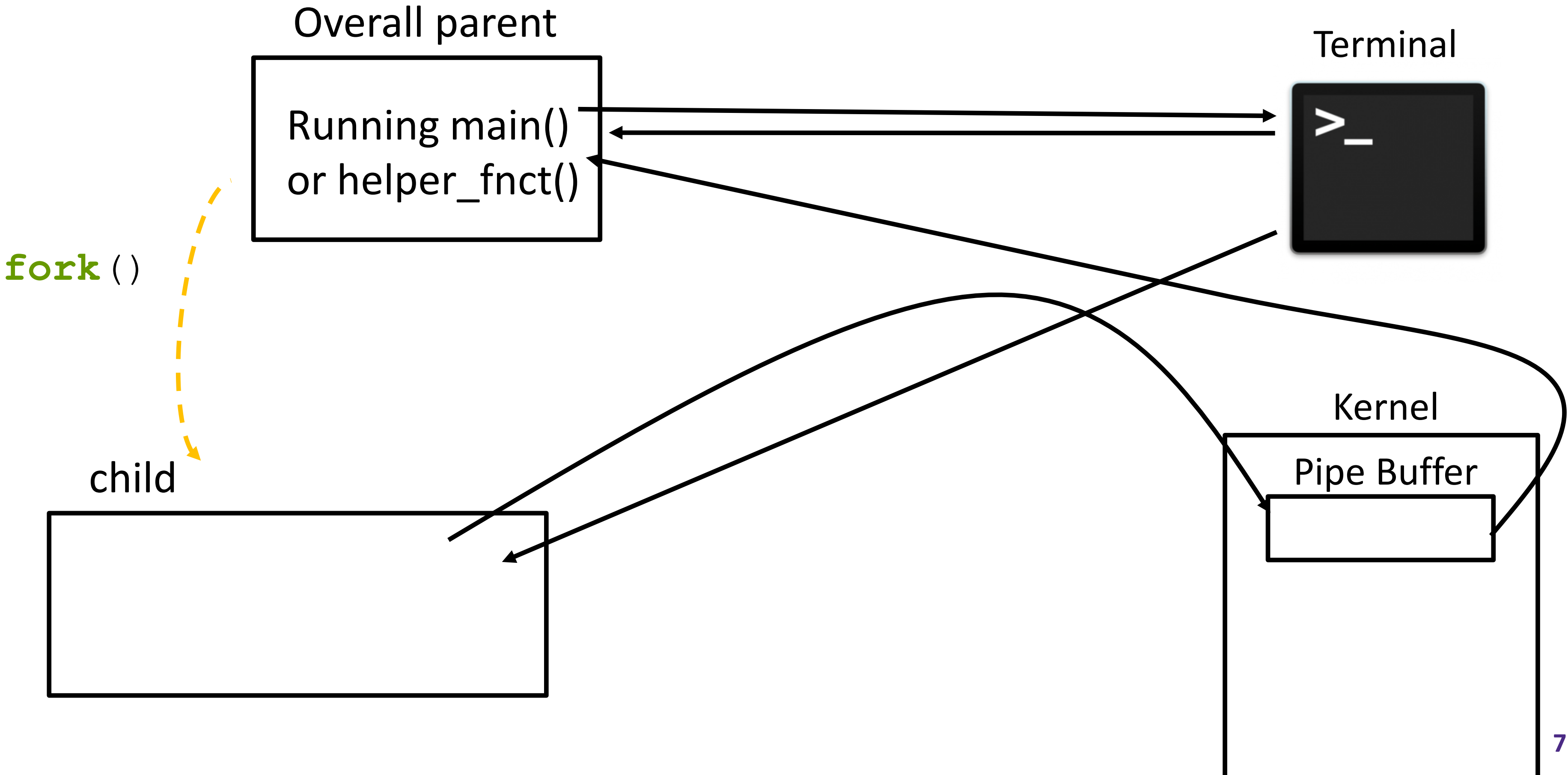

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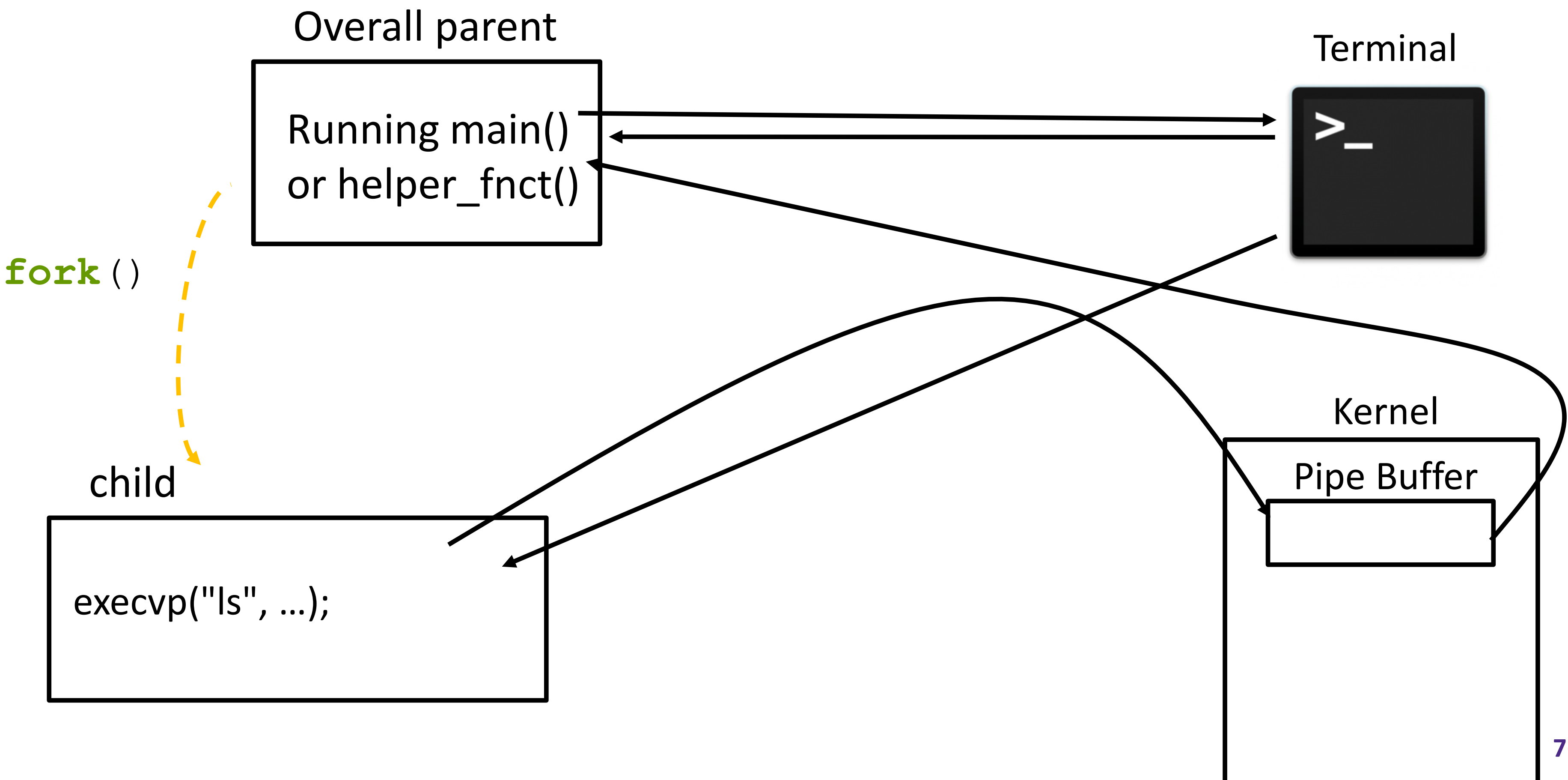

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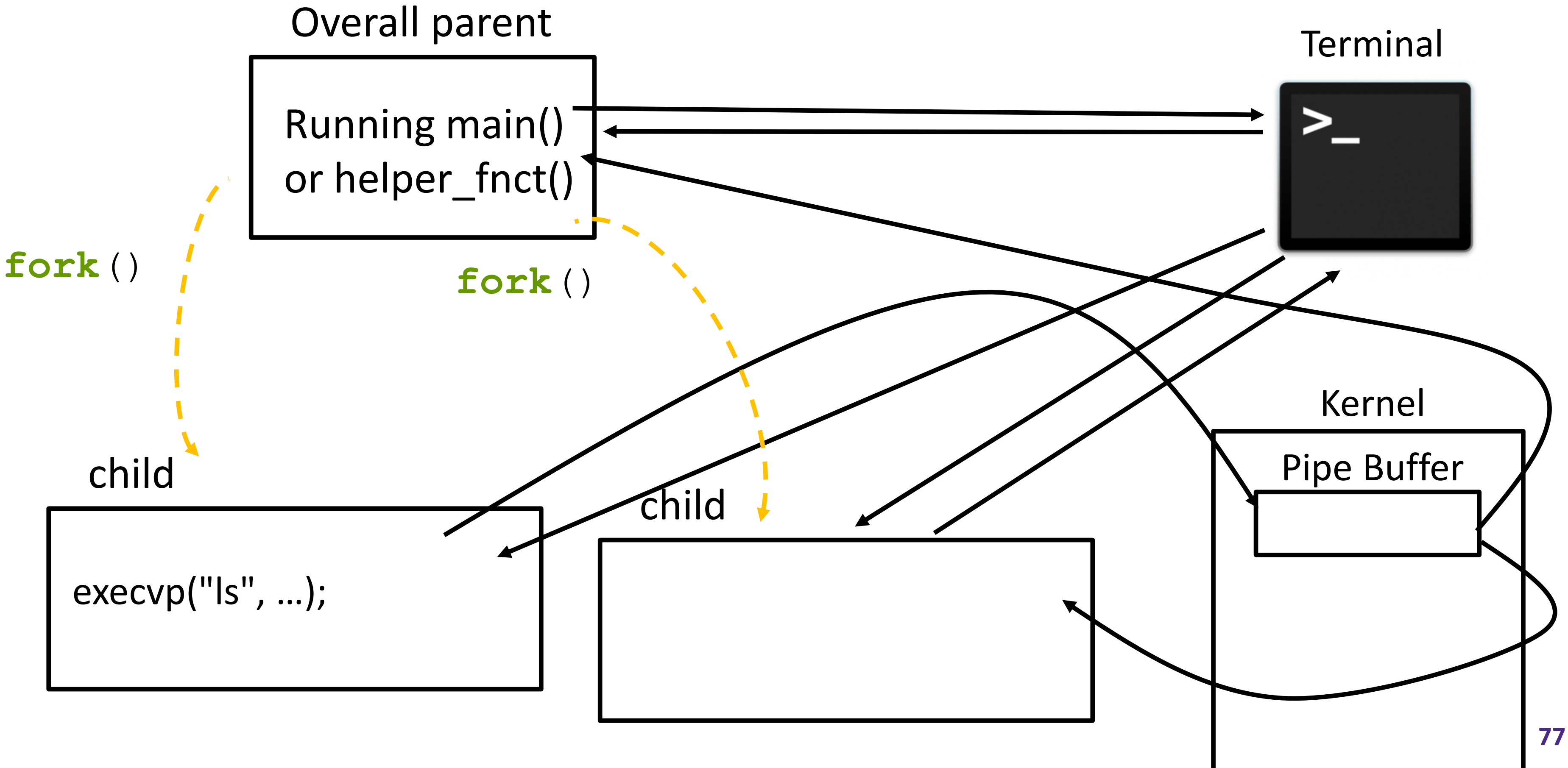

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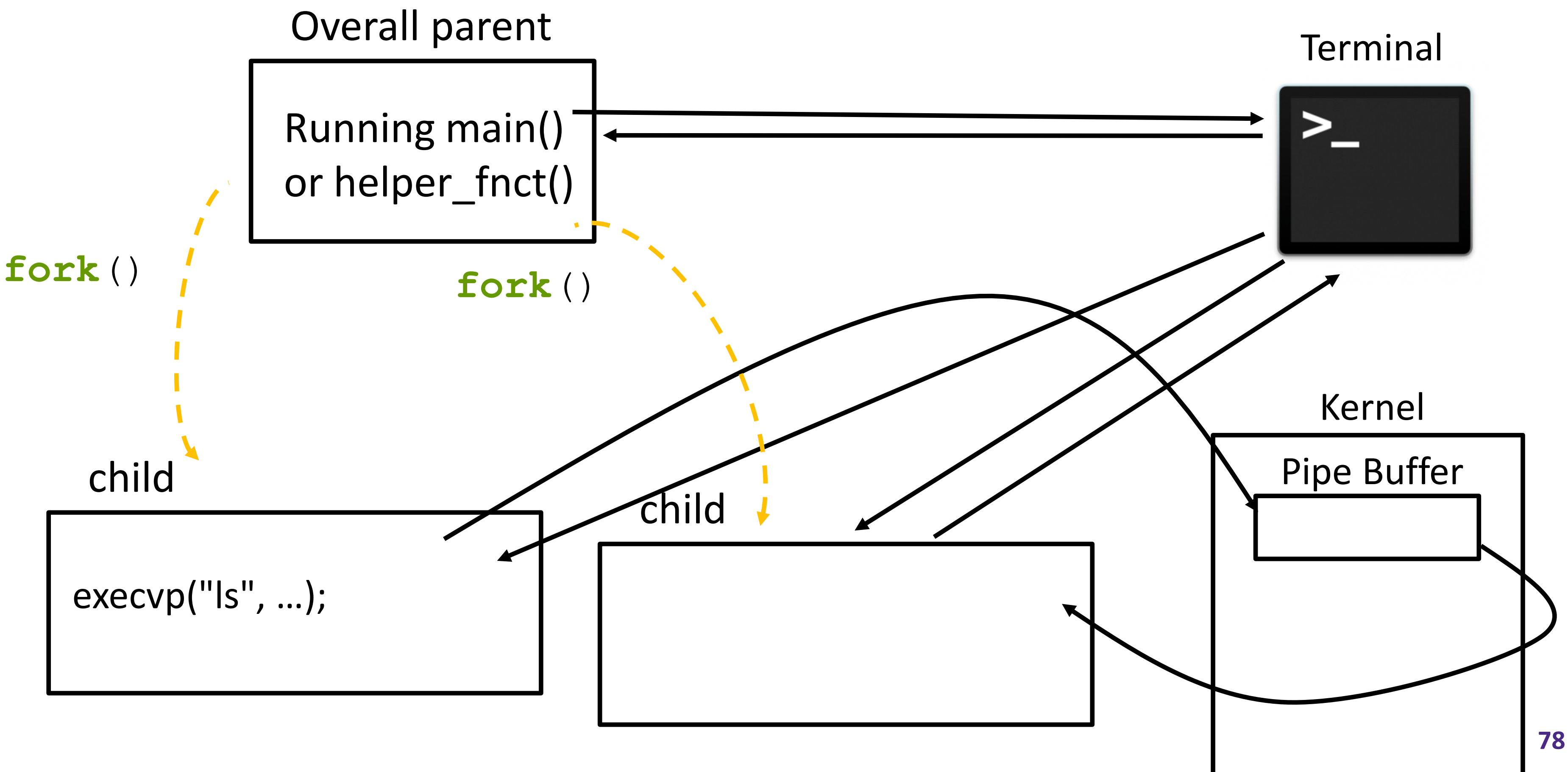

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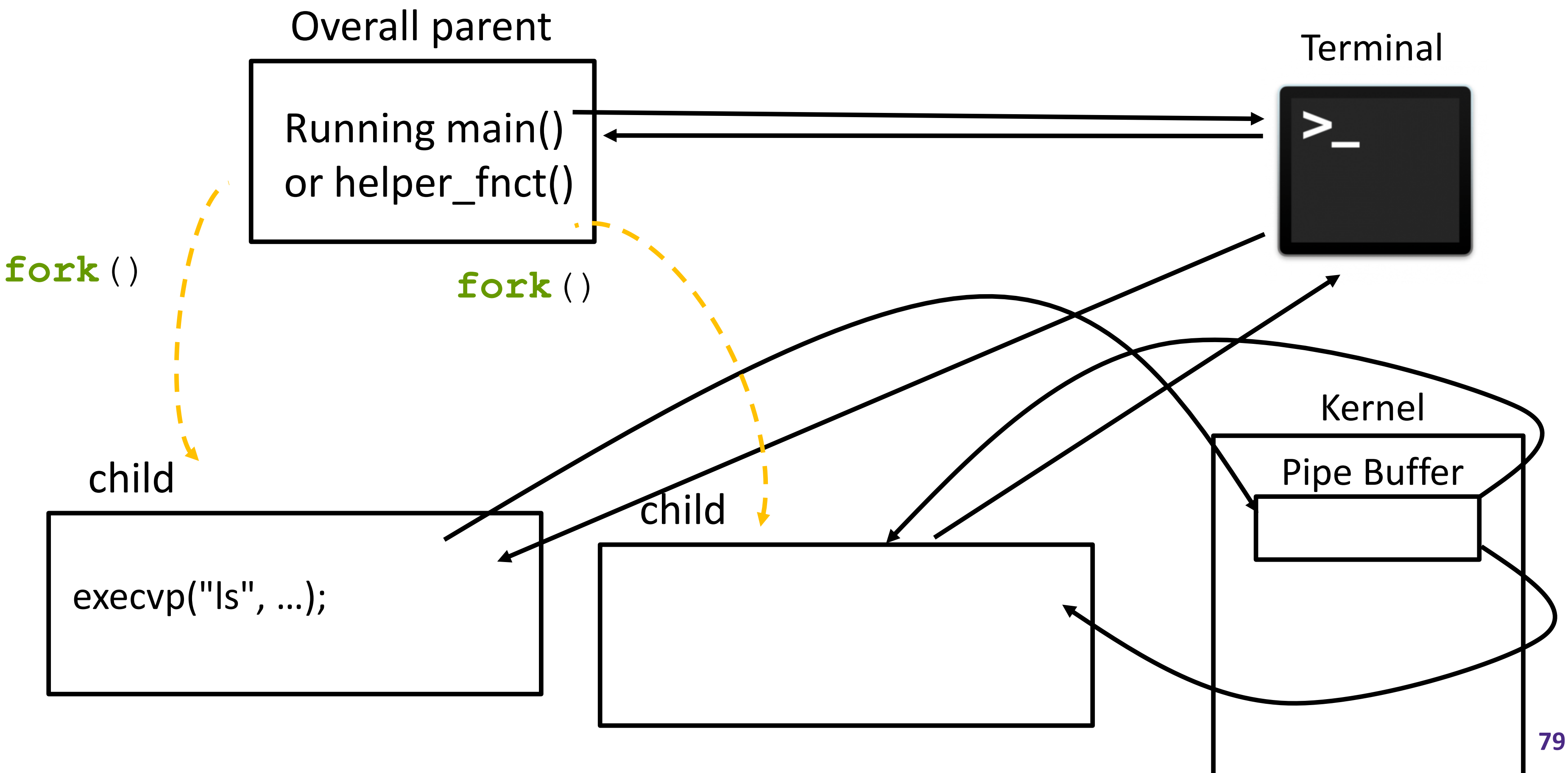

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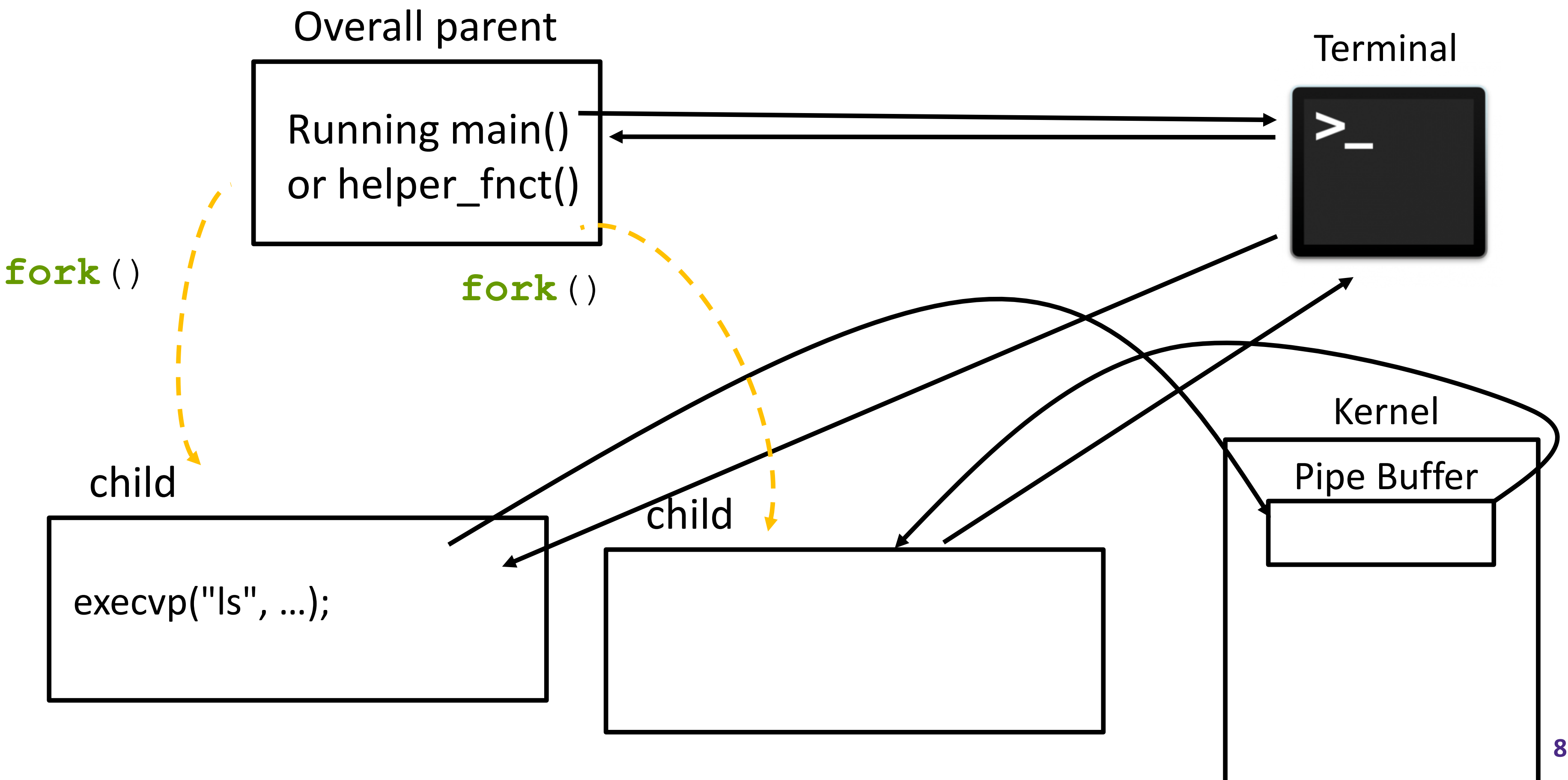

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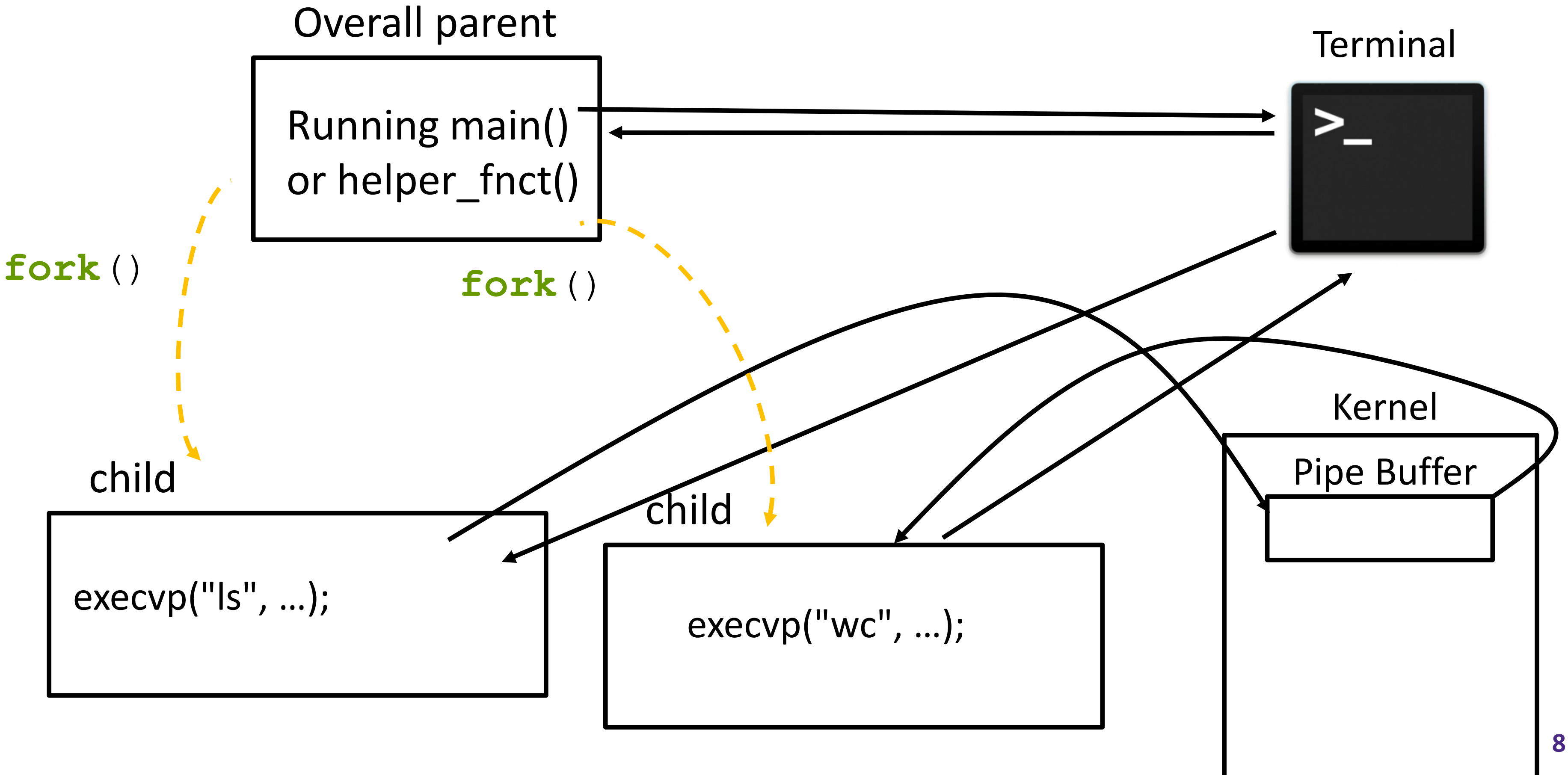
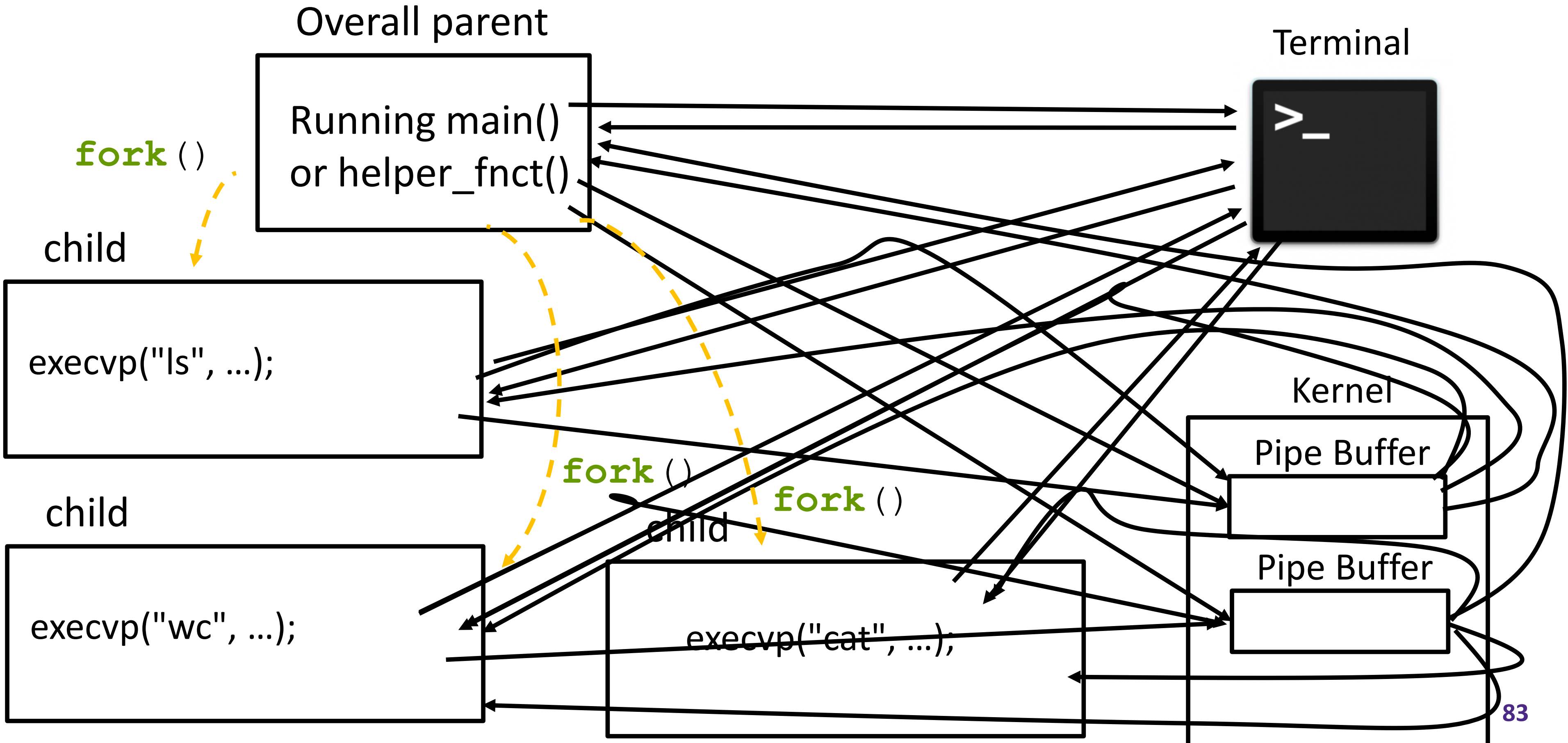


HW4 Example Line 2

- Consider the case when a user inputs
  - `"ls | wc | cat"`


Overall parent
Running main()
or helper_fnct()
Terminal
>_
fork()
child
execvp("ls", ...);
child
execvp("wc", ...);
fork()
fork()
child
execvp("cat", ...);
Kernel
Pipe Buffer
Pipe Buffer