PA3: Your Own Linux Shell

TANZIR AHMED
CSCE 313 SPRING 2020

Programming Assignment # 3

Main Challenges (after fork + exec)

- I/O Redirection
- Piping

To solve these challenges, we need the topics:

- File I/O basics
- Inter Process Communication using **pipes**

Main Idea in Pseudocode

A shell's main logic is as follows:

```
while (!endofinput){
    1. get the next command from user
    2. execute the command fully
}
```

However, the we know that **exec()** function (i.e., system call to execute a command) does not return

- Overwrite the main process

Therefore, we need to **fork()** a child process and then **exec()**

- Note that, the parent (i.e., the shell) must **wait()** for the child
- For instance, "sleep 5" should block the shell for 5 seconds

Skeleton Code

```
int main (){
    while (true){
        cout << "My Shell$ "; //print a prompt
        string inputline;
        getline (cin, inputline); //get a line from standard input
        if (inputline == string("exit")){
            cout << "Bye!! End of shell" << endl;
            break;
        }
        int pid = fork ();
        if (pid == 0){ //child process
            // preparing the input command for execution
            char* args [] = {(char *) inputline.c_str(), NULL};
            execvp (args [0], args);
        }else{
            wait (0); //parent waits for child process
        }
    }
}
```

Issues With Skeleton Code

The skeleton is almost a fully functional shell

- Can find commands in the PATH and current directory and execute them properly

However, the following features are missing:

- I/O redirection (e.g., "`ls -l > a.txt`", "`grep pattern < a.txt`")
- Piping (e.g., "`ls - l | grep pattern1|grep pattern2|less -5`")
- Directory handling commands (e.g., "`cd /path/to/dir`")
- Handling background processes (e.g., "`sleep 5 &`")
- Handling commands with arguments (e.g., "`ls -l -a`")
- …

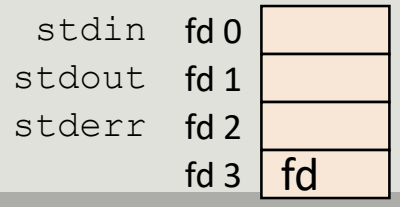
File I/O – File Descriptors

```
int main ()
{
      int fd;  // file descriptor
      char* buf [] = "file content";
      fd = open ("foobar.txt", O_CRAEATE|O_WRONLY);
      write (fd, buf, strlen (buf)); close (fd);
      fd = open("foobar.txt", O_RDONLY, 0);
      read(fd, &c, 1);
      printf("c=%c\n", c);
      close (fd);
      return 0;
}
```

Every process has a file descriptor table, where there are 3 default entries to begin with:

- Standard input, output, and error

Descriptor table
[one table per process]



I/O Redirection

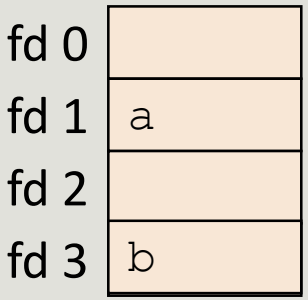
Question: How does a shell implement I/O redirection?

```
unix> ls > foo.txt
```

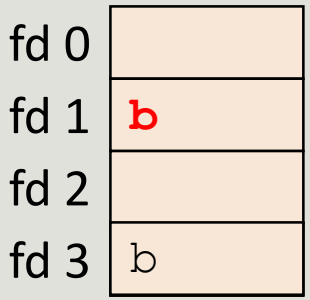
Answer: By calling the **`dup2(source, destination)`** function

- Copies (per-process) descriptor table entry **`source`** to entry **`destination`**

Descriptor table
before `dup2(3,1)`



Descriptor table
after `dup2(3,1)`



Implementing “ls –la>foo.txt”

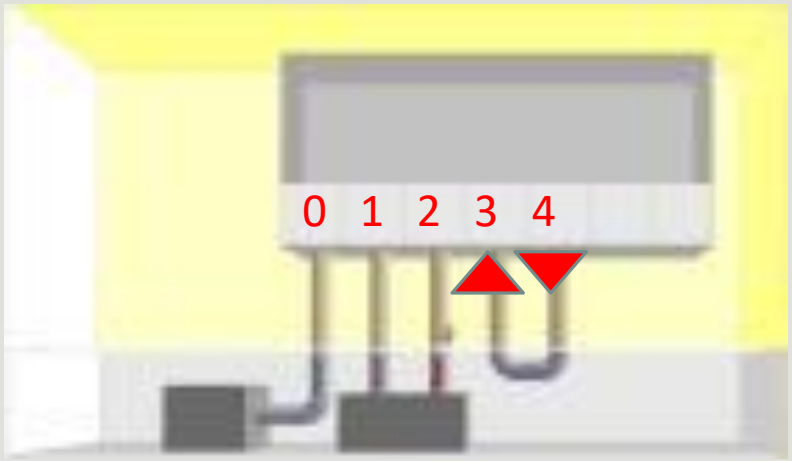
```
#include <stdio.h>
#include <unistd.h>
#include <sys/stat.h>
#include <fcntl.h>
int main ()
{
        int fd = open ("foo.txt", O_CREAT|O_WRONLY|O_TRUNC,
        S_IRUSR | S_IWUSR | S_IRGRP | S_IROTH);
        dup2 (fd, 1); // overwriting stdout with the new file
        execlp ("ls", "ls", "-l", "-a", NULL); // now execute
        return 0;
}
```

IPC Pipe

BEFORE pipe

Process has some usual files open

AFTER pipe



Kernel creates a pipe and sets file descriptors

IPC Pipe - Method

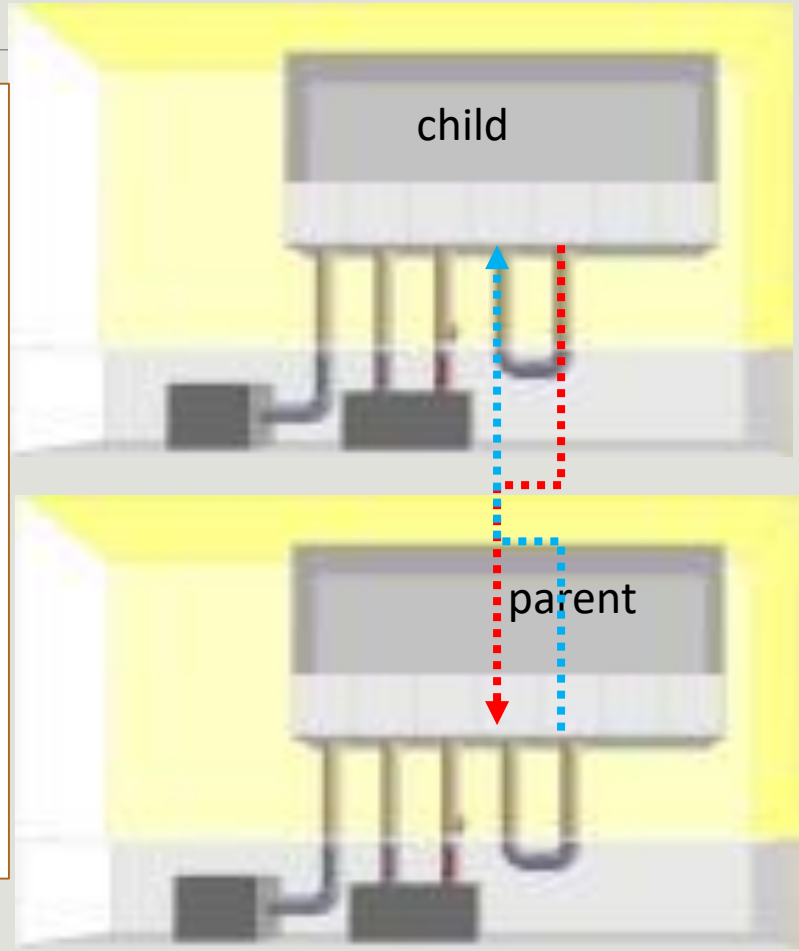
```c
#include <stdio.h>
#include <unistd.h>

void main ()
{
        char buf [10];
        int fds [2];
        pipe (fds);
        printf ("sending msg: Hi\n");
        write (fds[1], "Hi", 3);
        read (fds[0], buf, 3);
        printf ("Received msg: %s\n", buf);
}
```

Connects the two fds as pipe

```
compute-linux1 tanzir/code> ./a.out
sending msg: Hi
Received msg: Hi
```

Pipe Between Two Processes

```
int main ()
{
    int fds [2];
    pipe (fds); // connect the pipe
    if (!fork()){ // on the child side
        char * msg = "a test message";
        printf ("CHILD: Sent %s\n", msg);
        write (fds[1],msg,strlen(msg)+1);
    }else{
        char buf [100];
        read (fds [0], buf, 100);
        printf ("PARENT:Recv %s\n", buf);
    }
    return 0;
}
```



Shell Piping Example: "`ls –l | grep soda`"

Meaning of the command:

- Find all files that has the string "soda" in the filename and show detailed properties of those files

How many processes do we have to run (in addition to our shell process)?

- Process # 1: To run "ls –l"
- Process # 2: To run "grep soda"

What else do we need so that the process #1 sends its output to process #2

- Idea: If we can connect **stdout of p1** to **stdin of p2**, we are done!!
- Step 1: Redirect stdout of p1 to a file descriptor fd1
- Step 2: Redirect stdin of p2 to a another file descriptor fd2
- Step 3: Now, pipe fd1 and fd2 together so that fd1 is the "write side" and fd2 is the "read side"

Shell Piping: "ls -l | grep soda"

```
void main ()
{
     int fds [2];
     pipe (fds); // connect the pipe
     if (!fork()){ // on the child side
          dup2 (fds[1], 1); // redirect stdout to pipeout
          execlp ("ls", "ls", "-l", NULL);
     }else{
          dup2 (fds[0], 0); // redirect stdin to pipe in
          execlp ("grep", "grep", "soda", NULL);
     }
}
```

Step 3

Step 1

Step 2

How about more than 2 levels of pipe?

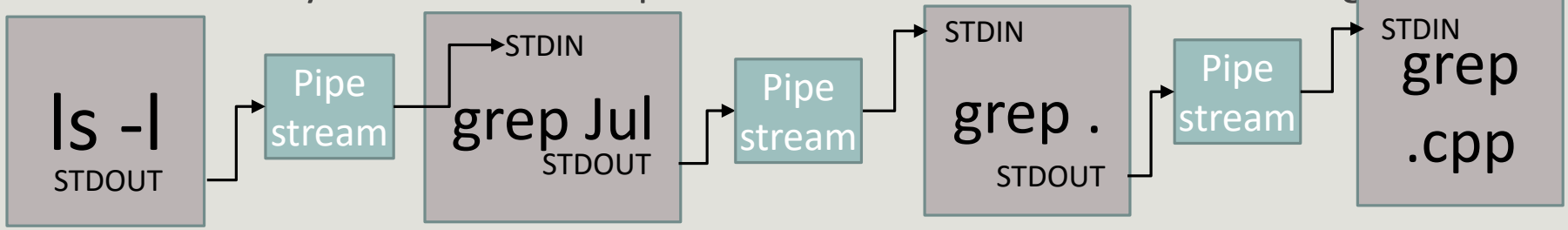
The previous code does not scale to more than 2 levels of "|" symbol

- For instance, how about:

```
ls -la | grep Jul | grep . | grep .cpp
```

We need a loop-structure that goes beyond the previously described hard-coded structure

We really want the above processes connected like the following:



Also, we need a skeletal structure for PA4

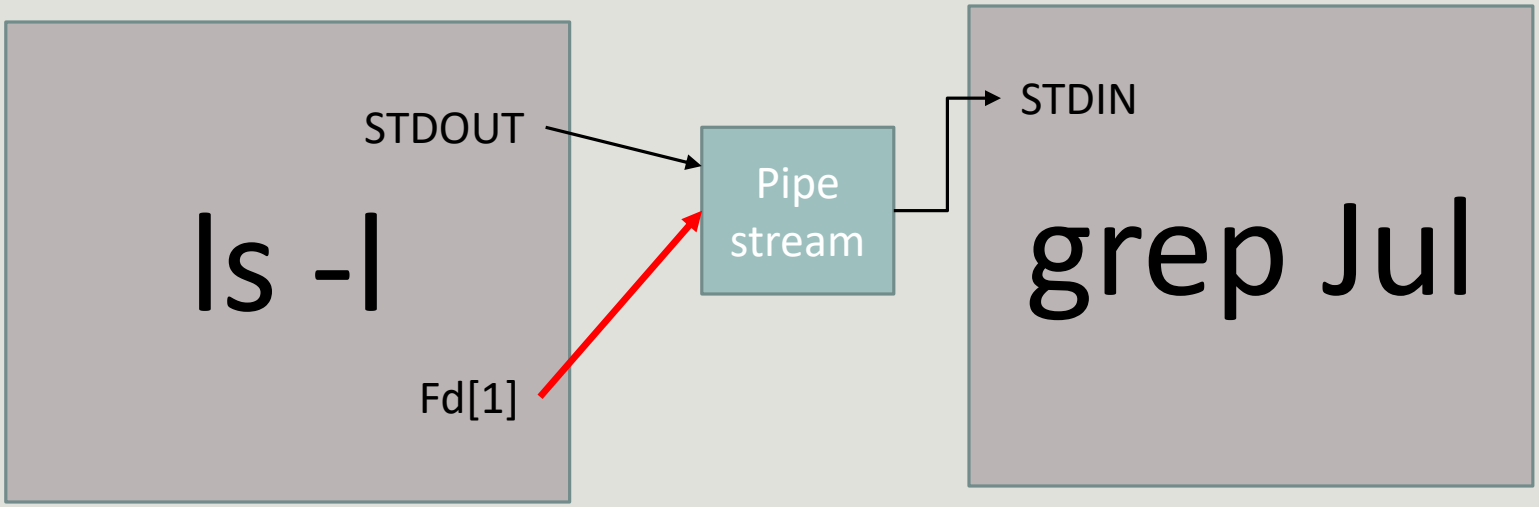
```
while (true){// continue until the user enters a blank like
    string line = read a line from the user;
    // now split the line by | symbol that gives us separate commands
    // You NEED to write this function
    // for instance: ls -la | grep Jul | grep . | grep .cpp
    vector<string> levels = split (line, "|");
    //after the above, levels.size() == 4, because there are
    // 3 pipe symbols making 4 pipe levels

    for (int i=0; i< levels.size(); i++){
        // set up the pipe
        int fd [2];
        pipe ();
        if (!fork()){ // in the child process
            // 1. redirect the output to the next level
            // 2. execute the command at this level
        }else{ // in the parent process
            wait (0); /*1. wait for the child process running
            the current level command */
            //2. redirect input from the child process
        }
    }

}
```

Each Iteration of the Loop

```
if (!fork()){// child process
    /* redirect output to the next level
     unless this is the last level */
    if (i < levels.size() - 1){
        dup2 (fd[1], 1); // redirect STDOUT to fd[1], so that it
        can write to the other side
        close (fd[1]); // STDOUT already points fd[1], which MUST
        be closed
    }
    //execute function that can split the command by spaces to
    // find out all the arguments, see the definition
    execute (levels [i]); // this is where you execute the
    command, you NEED to write this function
} else{
    wait(0); // wait for the child process
    dup2 (fd [0], 0); // now redirect the input for the next loop
    iteration
    close (fd [1]); // fd [1] MUST be closed, otherwise the next
    level will wait
}
```

Why close fd[1]?

Because with pipe() and redirection, we obtain a picture like the following:



If we do not close fd[1], the next level process grep thinks that there is more data coming and thus keeps waiting

Therefore, closing the fd[1] side finally provides the EOF (end of file) symbol to the input to grep, which then finishes

Zombie Processes

Idea

- When process terminates, still consumes system resources
  - Various tables maintained by OS (to store exit status)
- Called a “zombie”
  - Living corpse, half alive and half dead

Reaping

- Performed by parent on terminated child by calling **wait()** function
- Parent is given exit status (i.e., **wait (&status)**)
- Kernel discards process

Zombie Example

```c
void main ()
{
  if (fork() == 0){    // child process
   // exiting the child process right away
   printf ("Child PID: %d\n", getpid ());
  }
  else{// parent process
    printf ("Parent PID: %d\n", getpid ());
    // do nothing
    while (1);
  }
}
```

```
[tanzir@compute forkdemos]$ ./a.out
Parent PID: 4902
Child PID: 4903
^Z
Suspended
[tanzir@compute forkdemos]$ ps -l
F S   UID   PID  PPID  C PRI  NI ADDR SZ WCHAN  TTY          TIME CMD
0 S 21956  3476  3475  0  80   0 - 31643 sigsus pts/2    00:00:00 tcsh
0 T 21956  4902  3476 28  80   0 -  1040 signal pts/2    00:00:02 a.out
1 Z 21956  4903  4902  0  80   0 -     0 exit   pts/2    00:00:00 a.out <defunct>
0 R 21956  4904  3476  0  80   0 - 37233 -      pts/2    00:00:00 ps
[tanzir@compute forkdemos]$
```

- `ps` shows child process as "defunct"
- Terminated child continue to take resources in Zombie state
- This state is over when
  - Parent is killed, or
  - Parent performs wait ()
- Killing parent allows child to be reaped

Handling Background Processes

First things is, we cannot issue wait()

- That will get your shell stuck on the bg process
- Example: “sleep 5” should take 5 seconds to run and give shell back
- On the other hand, “sleep 5 &” should take just 0 seconds, because it is running in the bg

However, not using wait() would lead to Zombie processes

How to get around this problem?

Solution:

1. Collect the pid of each background process in a list
2. Periodically (e.g., before each command) call waitpid () function in a non-blocking manner on each pid in the above
   - Blocking waitpid() will get the shell process stuck
3. Remove the pids that are done from the list