IC221: Systems Programming
12-Week Written Exam
[SOLUTIONS]

April 2, 2014

Answer the questions in the spaces provided on the question sheets. If you run out of room for an answer, continue on the back of the page. Show all work, but please be legible. *Microscopic writing will not be graded*.

You are allowed a single crib sheet for this exam on an 8.5"x11" sheet of paper, hand written. You must turn in your crib sheet with your exam.

Name: ______________________________

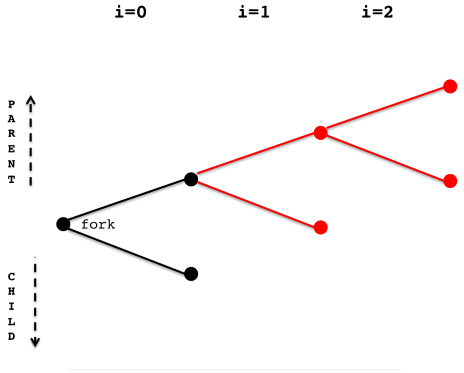
Section: ______________________________

Alpha: ______________________________

Question	Points	Score
1	15	
2	15	
3	15	
4	15	
5	15	
Total:	75	

1. Consider the following program:

```
int main(){
 int i, status;

 for(i=0;i<3;i++){
  if(fork() == 0){
   /*child*/
   printf("Child: %d: Hello World!", i);
   _Exit(0);
  }else{
   /*parent*/
    printf("Parent: %d: Hello World!\n",i);
  }
 }

 wait(&status);
 if(WIFSIGNALED(status)){
   printf("Process signaled\n");
 }
 return 0;
}
```



(a) **[4 points]** To the right of the program, **complete the drawing of the process tree above**, where each dot represents a process and a fork results in a split, up for the parent and down for the child. **Below answer:** How many total processes are created, including the initial parent process? How many total processes are running after the loop? Explain.

> 4 total processes created
> 1 process running after loop
> **[+1 for total process +1 for running after and +2 for process tree]**

(b) **[4 points]** How many times does "`Child: ...`" print and how many times does "`Parent: ...`" print to standard output? Explain.

> `Child: ...` does not print at all because buffer not flushed with `Exit()`
> `Parent: ...` prints 3 times, once for each fork call
> **[+2 for each, partial credit for discussion of buffers but wrong totals]**

(c) **[3 points]** Does the message "`Process signaled`" print? Why or why not based on the value of `status`?

> No because the child exited and was not terminated by a signal. This information is contained within the status and checked with `WIFSIGNALED()`
> **[+2 for No, +1 for No but wrong reason, +1 for mention of status]**

(d) **[4 points]** At the end of the program, are there any zombie processes? If so, why are there zombies and what happens to them when the parent terminates? If not, why aren't there any zombie processes?

> Yes. Three child processes are created but only one is waited on. The other two become zombies. After the parent terminates they will be orphaned and inherited by `init` which will reap them.
> **[+2 for yes, +1 orphaned, +1 for inherited by init; +1 for no with mention of waiting]**

2. (a) **[3 points]** Consider the execution of the following commands, what is the output of jobs?

```
#> sleep 200 &
#> head -c 10 /dev/urandom > rand
#> cat &
#> sleep 10
^Z
#> bg
```

```
[1] Running sleep 200 &
[2] Stopped cat
[3] Running sleep 10 &
```

[+3 for all in right state, +2 for all in running state, +1 for some combination]

(b) **[3 points]** Based on the above commands, what shell command will bring `sleep 200` to the foreground?

`fg 1 or fg %1`
[+2 for `fg`; +1 for indicating job number]

(c) **[3 points]** For how many seconds does the following pipeline run for? Explain.

```
sleep 1000 | cat /proc/cpuinfo | grep processor | sleep 10
```

1000 seconds because all run in parallel
[+2 for 1000 seconds, +1 for parralel, +1 for 1010 seconds with some explanation]

(d) **[3 points]** Using the following pipeline of commands and their `pid` (indicated in italics above each command), what is the `pgid` of each process in the pipeline? Will all processes terminate after a `Ctrl-C`? Why or why not?

```
   1994       1995       1996       1997
sleep 20 | sleep 30 | sleep 40 | sleep 50
```

The pgid is 1994, the pid of the first process in the pipeline. Yes, all terminate after `Ctrl-C` because sent to the foreground process group
[+2 for 1994, +1 for yes sent to foreground process group]

(e) **[3 points]** At the mark, what process state would the parent process be in, Ready and Waiting, Ready and Running, Blocked and Waiting? Explain.

```
int main(){
 if(fork() == 0){
   while(1);
 }else{
   wait(NULL); //MARK
 }
}
```

Blocked and Waiting: Blocking on the system call `wait` until the child completes, which it wont. **[+2 for Blocked and Waiting, +1 for explanation]**

3.

```
int main(int argc, char * argv[]){

  char str1[] = "Go Navy! ";
  char str2[] = "Beat Army! ";
  char buffer[1024];
  int pfd1[2], pfd2[2], n;


  pipe(pfd1);  pipe(pfd2);

  if( fork() == 0){ /* Child */

    //MARK 1
    close(pfd1[0]);
    close(pfd2[1]);

    //MARK 2
    write(pfd1[1], str1, strlen(str1));

    //MARK 3
    n = read(pfd2[0], buffer, 1024);
    write(1, buffer, n);

  }else{  /* Parent */

    //MARK 4
    close(pfd1[1]);
    close(pfd2[0]);

    //MARK 5
    n = read(pfd1[0], buffer, 1024);
    write(1, buffer, n);

    //MARK 6
    write(pfd2[1], str2, strlen(str2));

    wait(NULL);
  }

  return 0;
}
```

(a) [**3 points**] In the program to the right, two pipes are opened before `fork()` how is it that the child also has access to them to communicate with the parent?

Open files, including pipes, are duplicated on a fork, and they are communicate via the kernel buffers. **[+2 for duplication on fork, +1 for kernel buffers]**

(b) [**4 points**] In the program to the right, which system call will complete first, `MARK 2` in the child or `MARK 5` in the parent? Explain.

`MARK 2` will complete before `MARK 5` because the parent will block on the `read()` until data is written to the pipe. Expected output is:
Go Navy! Beat Army
[+2 for Mark 2 over Mark 5, +1 mention blocking, +1 for right output]

(c) [**4 points**] In the above program, what is `MARK 1` and `MARK 4` doing to the pipe? Why are the operations mirrored in parent and child?

The pipes are being widowed, and the procedure is mirrored because the parent and child read/write from different ends of each pipe.
[+3 for widowing, +1 for using different ends in parent/child]

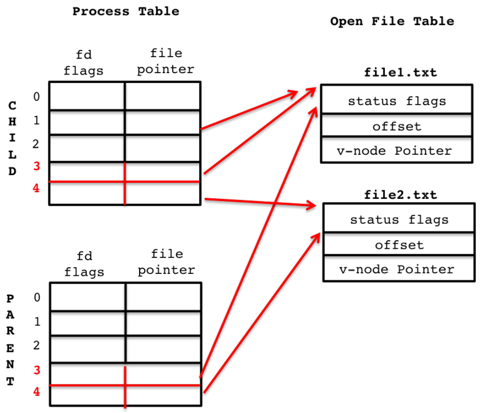
(d) [**4 points**] Consider the following change in the program at `MARK 2` where `str1` is written continually to the pipe in a loop. Will the child ever reach `MARK 3`? If yes, why, and if no, why not?

```
//MARK 2
while(1){
 write(pfd[1], str1, strlen(str1));
}
```

The child will never reach `MARK 3` because the pipe will fill up and subsequent writes will block until the pipe is read again, which it is not.
[+3 Never reach MARK 3, +1 for explanation]

4. Consider the following program

```
int main(){
  int fd1 = open("file1.txt", O_RDONLY);
  int fd2 = open("file2.txt", O_WRONLY | O_CREAT, 0640);
  pid_t cpid;
  char c;

  while(1){
    if( (cpid = fork()) == 0){
      /*Child*/

      close(1);
      dup2(fd2,1);

      if(read(fd1, &c, 1) > 0){ //read 1 byte from file
        write(1, &c, 1); //write 1 byte to stdout
      }
      _exit(0); //exit hard
    }else{
      /*Parent*/
      wait(NULL); //wait for child to exit

      if( read(fd1, &c, 1) <= 0){//read 1 byte from file
        break; //exit on EOF or read fail
      }else{
        write(1, &c, 1);//otherwise write 1 byte to stdout
      }
    }
  }

  return 0;
}
```



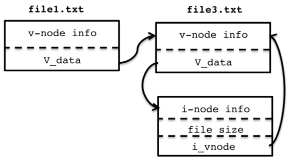
[+1 for new file descriptor table entries; +3 for dup in child and shared files; +2 for dup without shared or shared without dup]

(a) **[4 points]** Complete the figure of the Process Table and Open File Table entries for the above program, drawing arrows for references and including new file descriptor table entries. You only need to complete one of the children since they are all the same.

(b) **[4 points]** If `file1.txt` contained the phrase "Go_Navy!_Beat_Army!", where "_" indicates a space, what is written to standard output and what is written to `file2.txt`? Explain.

> `file2.txt`: G_ay_etAm! (every other char starting with 'G')
> `stdout`: oNv!Ba_ry (every other char starting with 'o')
> Child writes everything to `file2.txt` because that is duped onto its standard output.
> **[+3 for write outputs or +1 for all to stdout; +1 for explanation]**

(c) **[4 points]** If `file1.txt` was linked in the v-node/i-node structure like below, would the functionality of the program change if `file1.txt` were replaced by `file3.txt`? Explain, and what kind of link is this?



> Functionality is the same because O.S. follows the links. This is a symbolic link.
> **[+2 for same with explanation; +2 for symbolic]**

(d) **[3 points]** In which node, v-node or i-node, is device specific information stored for reading and writing the file from/to the device?

> i-node
> **[All or nothing]**

5. Consider the following program

```
int ticks=0;
void handler(int signum){
  ticks++;
  printf("tick tock: %d\n", ticks);


  if(ticks < 10){
    alarm(1);
  }else{
    raise(9); //<-- MARK 1
  }
}

int main(){

  signal(SIGALRM, handler); //<-- MARK 2
  alarm(1);

  //MARK 3
  while(1){
    pause(); //<-- MARK 3
  }
}
```

(a) [**3 points**] At `MARK 2`, what is the purpose of the call to `signal()` with respect to future deliveries of `SIGALRM` from the O.S.?

> Registers a signal handler with the O.S., `handler` is called whenever a `SIGALRM` is delivered.
> **[+2 Handler is called when SIGALRM is delivered, +1 register with OS]**

(b) [**4 points**] What is the result of the system call at `MARK 1`? What is the *name* of the signal being raised?

> Sends the current process the designated signal, SIGKILL whose number value is 9 **[+2 raise description, +2 SIGKILL]**

(c) [**4 points**] How many `SIGALRM` signals are delivered to the program? Explain.

> 10 `SIGALRM`s are delivered. First alarm scheduled in main, then every time the handler is invoked, another alarm is schedule, stopping at 10.
> **[+3 10 `SIGALRM`s, +1 for explanation]**

(d) [**4 points**] What is the purpose of `pause()` at `MARK 3`? Is it better or worse then replacing it with the following code without `pause()`?

```
//MARK 3
while(1);
```

> `pause()` will suspend the process a signal is handled, and it better than the busy loop because it does not waist process resources. **[+2 for explanation, +2 for betteer than busy loop, +1 for better without explanation]**