

CSS 430

Program 1: System Calls and Shell

Due Date: See the syllabus

0. Attention

This series of programming assignments is a step-by-step implementation of OS simulator in Java. Since all the assignments were comprehensively designed and linked to each other, it is quite difficult to drastically change their questions every quarter. Thus, if you were to contact with the former CSS430 students, you might get the answers, which is nevertheless considered as plagiarism.

Please note that you must independently work on all programming assignments except the final project. The instructor keeps the code of all the former students in his database, compares your code with the database contents, and will never tolerate any academic dishonesty. In fact, some students have been sent to the vice chancellor's office when their plagiarism were found.

1. Purpose

This assignment intends (1) to familiarize you with Linux programming using several system calls such as fork, execp, wait, pipe, dup2, and close, and (2) to help you understand that, from the kernel's view point, the *shell* is simply viewed as an application program that uses system calls to spawn and to terminate other user programs. You will also become familiar with the *ThreadOS* operating system simulator in part 2 of this assignment.

2. Shell

This section explains the behavior and the language syntax of the Unix *shell*.

Command interpretation

The *shell* is a command interpreter that provides Unix users with an interface to the underlying operating system. It interprets user commands and executes them as independent processes. The *shell* also allows users to code an interpretive script using simple programming constructs such as *if*, *while* and *for*, etc. With *shell* scripting, users can create customized automation shell tasks.

The behavior of *shell* simply repeats:

1. Displaying a prompt to indicate that it is ready to accept a next command from its user,
2. Reading a line of keyboard input as a command, and
3. Spawning and having a new process execute the user command.

The prompt symbols frequently used include for example:

```
hostname$
```

or in the case the UWB Linux lab servers, a host name followed by a ':' symbol, and a '~' for the current user as follows:

```
uw1-320-lab:~$
```

How does the *shell* execute a user command? The mechanism follows the steps given below:

1. The *shell* locates an executable file whose name is specified in the first string given from a keyboard input.
2. It creates a child process by duplicating itself.
3. The duplicated shell overloads its process image with the executable file.
4. The overloaded process receives all the remaining strings given from a keyboard input, and starts a command execution.

For instance, assume that your current working directory includes the *a.out* executable file and you have typed the following line input from your keyboard.

```
uw1-320-lab:~$ ./a.out a b c
```

This means that the *shell* duplicates itself and has this duplicated process execute *a.out* that receives a, b, and c as its arguments.

The *shell* has some built-in commands that changes its current status rather than executing a user program. (Note that user programs are distinguished as external commands from the *shell* built-in commands.) For instance,

```
uw1-320-lab:~$ cd public_html
```

changes the *shell*'s current working directory to *public_html*. Thus, *cd* is one of the *shell* built-in commands.

The *shell* can receive two or more commands at a time from a keyboard input. The symbols ';' and '&' are used as a delimiter specifying the end of each single command. If a command is delimited by ';', the *shell* spawns a new process to execute this command, waits for the process to be terminated, and thereafter continues to interpret the next command. If a command is delimited by '&', the *shell* execution continues by interpreting the next command without waiting for the completion of the current command.

```
uw1-320-lab:~$ who & ls & date
```

executes *who*, *ls*, and *date* concurrently. Note that, if the last command does not have an delimiter, the *shell* assumes that it is implicitly delimited by ';'. In the above example, the *shell* waits for the completion of *date*. Taking everything in consideration, the more specific behavior of the *shell* is therefore:

1. Displaying a prompt to show that it is ready to accept a new line input from the keyboard,
2. Reading a keyboard input,
3. Repeating the following interpretation till reaching the end of input line:
 - Changing its current working status if a command is built-in, otherwise
 - Spawning a new process and having it execute this external command.
 - Waiting for the process to be terminated if the command is delimited by ';'.

I/O redirection and pipeline

One of the *shell*'s interesting features is I/O redirection.

```
uw1-320-00% a.out < file1 > file2
```

redirects *a.out*'s standard input and output to *file1* and *file2* respectively, so that *a.out* reads from *file1* and writes to *file2* as if it were reading from a keyboard and printing out to a monitor. Another convenience feature is pipeline.

```
uw1-320-lab:~$ command1 | command2 | command3
```

connects *command1*'s standard output to *command2*'s standard input, and also connects *command2*'s standard output to *command3*'s standard input. For instance,

```
uw1-320-lab:~$ who | wc -l
```

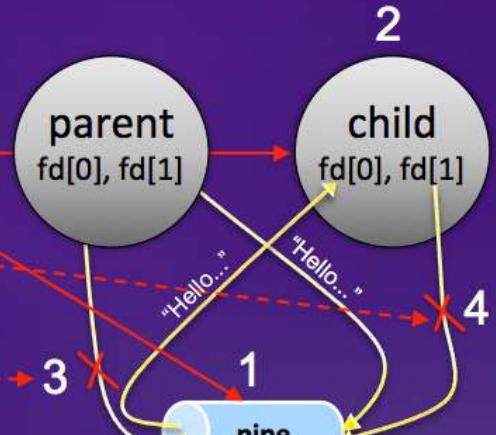
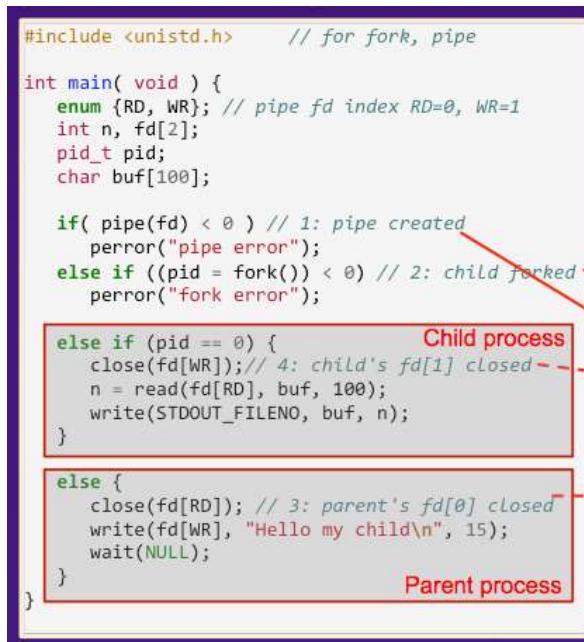
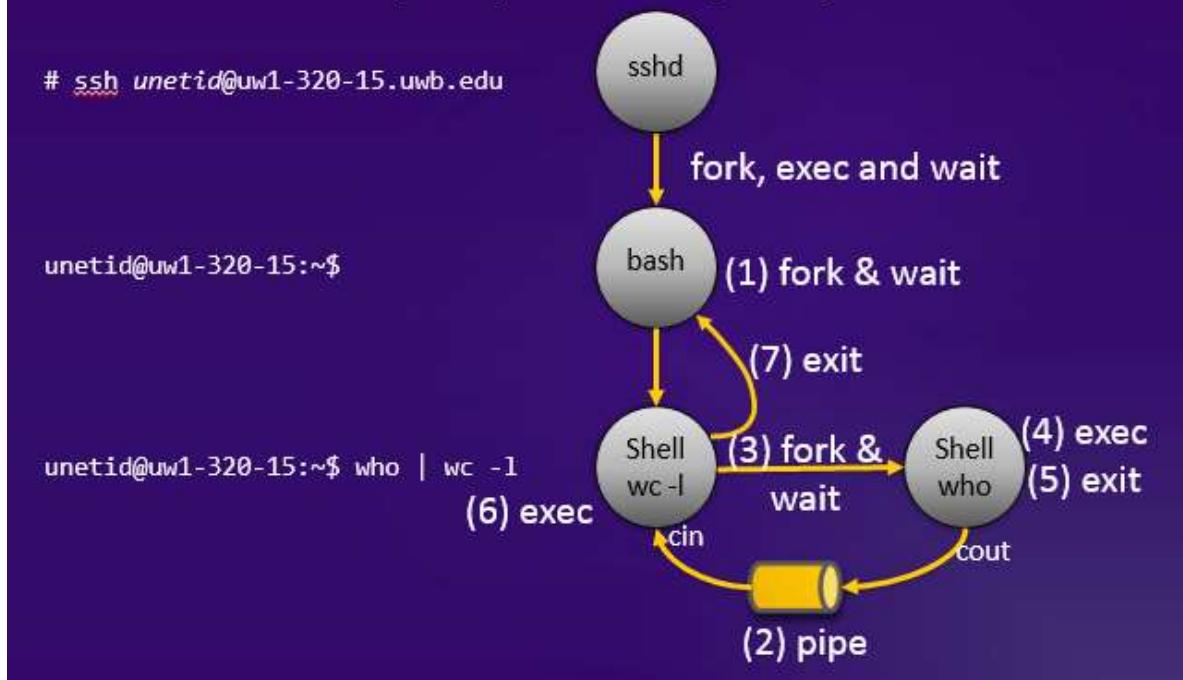
first executes the *who* command that prints out a list of current users. This output is not displayed but is rather passed to *wc*'s standard input. Thereafter, the *wc* is executed with its *-l* option. It reads the list of current users and prints out #lines of this list to the standard output. As a result, you will get the number of the current users.

Shell implementation techniques

Whenever the *shell* executes a new command, it spawns a child *shell* and lets the child execute the command. This behavior is implemented with the **fork** and **execvp** system calls. If the *shell* receives ';' as a command delimiter or receives no delimiter, it must wait for the termination of the spawned child, which is implemented with the **wait** system call. If it receives "&" as a command delimiter, it does not have to wait for the child to be terminated. If the *shell* receives a sequence of commands, each concatenated with "|", it must recursively create children whose number is the same as that of commands. Which child executes which command is a kind of tricky. The farthest offspring will execute the first command, the grand child will execute the 2nd last, and the child will execute the last command. Their standard input and output must be redirected accordingly using the **pipe** and **dup2** system calls. The following diagrams describe how to execute "who | wc -l", and how to use the **pipe** system call.

Shell (bash)

Fork, exec, wait and dup are System calls



3. ThreadOS

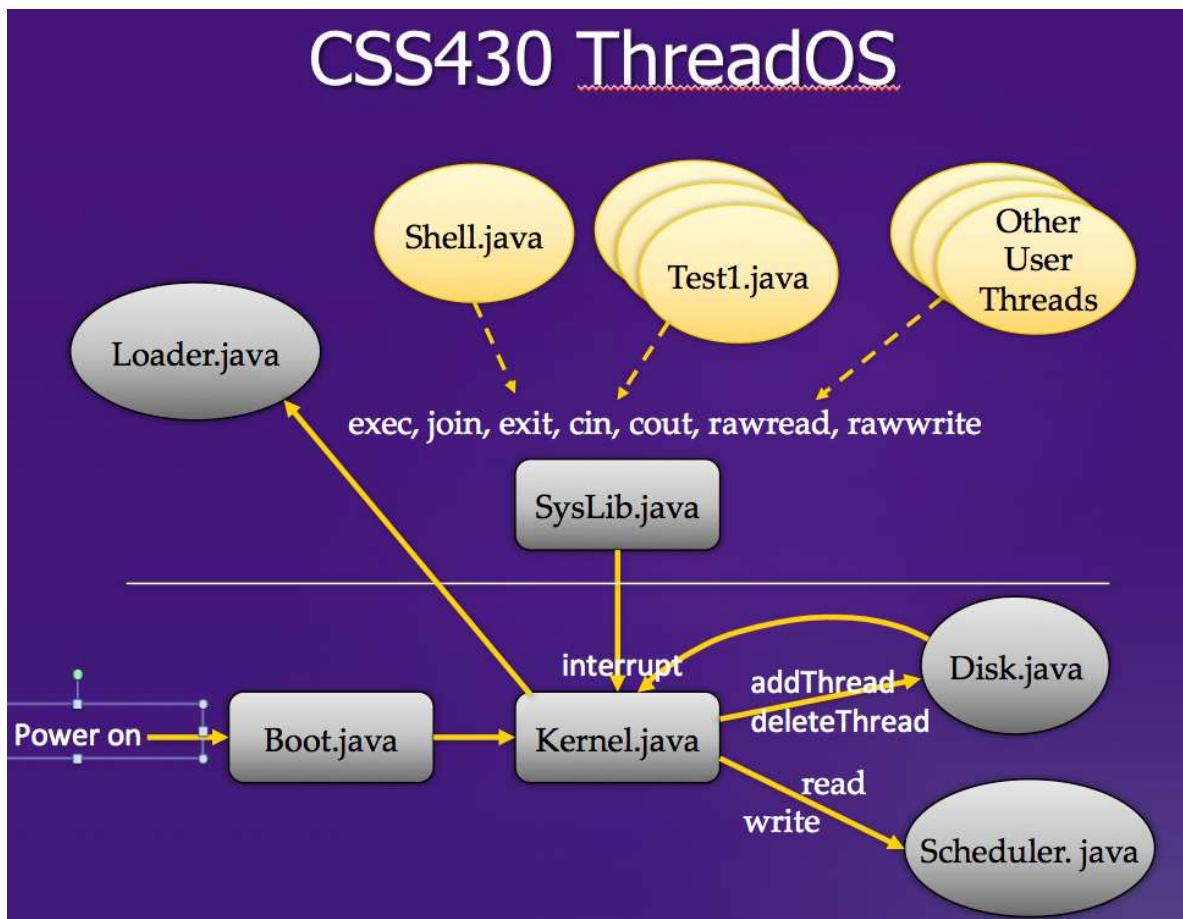
ThreadOS is an operating system simulator that has been designed in Java for our CSS430 course. You need a working knowledge of *ThreadOS* in order to work on the assignment in part 2. The basic features will be explained in the 2nd week's lecture. If you have understood the features discussed in the lecture, you may skip to Section 4, Statement of Work.

Through this series of assignments, you are to implement and/or to enhance some portions of *ThreadOS*. *ThreadOS* loads Java programs that have been derived from the *Thread* class, manages them as user processes, and provides them with some basic operating system services. Those services include thread spawn, thread termination, disk operations, and even standard input/output. *ThreadOS* receives all service requests as a form of simulated interrupt from each user thread, handles them, and returns a status value to the interrupting thread.

Structure

ThreadOS consists of several components:

Component	Java/Class	Description
Boot	Boot.java	invokes a <i>BOOT</i> system call to have <i>Kernel</i> initialize its internal data, power on <i>Disk</i> , start the <i>Scheduler</i> thread, and finally spawn the <i>Loader</i> thread.
Kernel	Kernel.java	receives an interrupt, services it if possible, otherwise forwards its request to <i>Scheduler</i> or <i>Disk</i> , and returns a completion status.
Disk	Disk.java	simulates a slow disk device composed of 1000 blocks, each containing 512 bytes. Those blocks are divided into 10 tracks, each of which thus includes 100 blocks. The disk has three commands: <i>read</i> , <i>write</i> , and <i>sync</i> detailed in the assignment 3, 4, and 5.
Scheduler	Scheduler.java, TCB.java	receives a <i>Thread</i> object that <i>Kernel</i> instantiated upon receiving an <i>EXEC</i> system call, allocates a new <i>TCB(Thread Control Block)</i> to this thread, enqueues the <i>TCB</i> into its ready queue, and schedules its execution in a round robin fashion.
SysLib	SysLib.java	is a utility that provides user threads with a convenient style of system calls and converts them into corresponding interrupts passed to <i>Kernel</i> .



To start *ThreadOS*, simply type:

```
uw1-320-lab:~$ java Boot
      ThreadOS ver 1.0:
      Type ? for help
      threadOS: a new thread (thread=Thread[Thread-3,2,main] tid=0 pid=-1)
-->
```

Boot initializes *Kernel* data, powers on *Disk* and starts *Scheduler*. It finally launches *Loader* that then carries out one of the following commands:

?	prints out its usage.
I user_program	starts <i>user_program</i> as an independent user thread and waits for its termination.
q	synchronizes disk data and terminates <i>ThreadOS</i>

Note that *Loader* is not a *shell*. It simply launches and waits for the completion of a user program (which may behave as a *shell*). From *ThreadOS*' point of view, there is no distinction between *Loader* and the other user programs.

User Programs

A user program must be a Java thread. Java threads are execution entities concurrently running in a Java application. They maintain their own stacks and program counter but share static variables in their application. At least one thread, (i.e., the *main* thread) is automatically instantiated when an application starts a *main* function. Threads other than the *main* thread can be dynamically created in the similar way to instantiate a new class object using *new*. Once their *start* method is called, they keep executing their own *run* method independently from the calling function such as *main*. Java threads can be defined as a subclass of the *Thread* (<http://docs.oracle.com/javase/7/docs/api/>) class.

The following Java thread prints out a word given in *args[0]* repeatedly every *loop* number of dummy iterations. The *loop* is given in *args[1]*.

```

1  public class PingPong extends Thread {
2      private String word;
3      private int loop;
4      public PingPong( String[] args ) {
5          word = args[0];
6          loop = Integer.parseInt( args[1] );
7      }
8      public void run( ) {
9          for ( int j = 0; j < 100; j++ ) {
10              SysLib.cout( word + " " );
11              for ( int i = 0; i < loop; i++ );
12          }
13      }
14  }
```

PingPong.java [view raw \(https://gist.github.com/aerodame/508ca4b18bada9500bbf/raw/e1967acb999026a13d37e9cd65a76bd4d3a7f56c/PingPong.java\)](https://gist.github.com/aerodame/508ca4b18bada9500bbf/raw/e1967acb999026a13d37e9cd65a76bd4d3a7f56c/PingPong.java) (<https://gist.github.com/aerodame/508ca4b18bada9500bbf#file-pingpong-java>) hosted with ❤ by GitHub (<https://github.com>)

If you write the following *main* function:

```

1  public class ThreadDriver {
2      public static void main( String[] args ) {
3          String args[2];
4
5          args[0] = "ping"; args[1] = "10000";
6          new PingPong( args ).start( );
7
8          args[0] = "PING"; args[1] = "90000";
9          new PingPong( args ).start( );
10     }
11 }
```

ThreadDriver.java [view raw \(https://gist.github.com/aerodame/5e52f57b6865a95d2fd6/raw/5b9ed5937df3fd14fd75992d5ff43c455cdc70d/ThreadDriver.java\)](https://gist.github.com/aerodame/5e52f57b6865a95d2fd6/raw/5b9ed5937df3fd14fd75992d5ff43c455cdc70d/ThreadDriver.java) (<https://gist.github.com/aerodame/5e52f57b6865a95d2fd6#file-threaddriver-java>) hosted with ❤ by GitHub (<https://github.com>)

it will instantiate two *PingPong* threads, one printing out "ping" every 10000 dummy iterations and the other printing out "PING" every 90000 dummy iterations.

ThreadOS Loader actually takes care of this thread-instantiating part of *main* function. Once you invoke *ThreadOS*, *Loader* waits for a *l* command, say "*I PingPong ping 10000*". Then, it will load your *PingPong* class into the memory, instantiate its object, pass a String array including *ping* and *10000* as arguments to this thread, and wait for its termination. **Note that in general Java threads can receive any type of and any number of arguments, however *ThreadOS* restricts its user programs to receive only a String array as their argument.**

Java itself provides various classes and methods that invoke real OS system calls such as *System.out.println* and *sleep*. Since *ThreadOS* is an operating systems simulator, user programs running on *ThreadOS* are prohibited from using real OS system calls. Prohibited classes include but are not limited to:

- *java.lang.System*
- *java.lang.Thread*
- *java.io.**

Instead, user programs are provided with *ThreadOS*-unique system calls including standard I/O, disk access, and thread control. Therefore, *System.out.print(word + " ")*; should be replaced with one of *ThreadOS*-unique systems calls:

```
SysLib.cout( word + " " );
```

While Java threads can be terminated upon a simple return from their *run* method, *ThreadOS* needs an explicit system call to terminate the current user thread.

```
SysLib.exit( );
```

Thread termination is a part of thread control, thus is one of the *ThreadOS* services. Since the above example of user thread falls into an infinite loop, we need to revise it so that this example code safely terminates the invoked thread and resumes *Loader*.

```

1  public class PingPong extends Thread {
2      private String word;
3      private int loop;
4      public PingPong( String[] args ) {
5          word = args[0];
6          loop = Integer.parseInt( args[1] );
7      }
8      public void run( ) {
9          for ( int j = 0; j < 100; j++ ) {
10              SysLib.cout( word + " " );
11              for (int i = 0; i < loop; i++ );
12          }
13          SysLib.cout( "\n" );
14          SysLib.exit( );
15      }
16  }
```

[PingPong.java](https://gist.github.com/aerodame/b04b3fb8964d43b350e#file-pingpong-java) [view raw](https://gist.github.com/aerodame/b04b3fb8964d43b350e/raw/92a45492e9ad0dda88b8ec4382b6bdaeee12a7b8/PingPong.java) (<https://gist.github.com/aerodame/b04b3fb8964d43b350e>) hosted with ❤ by GitHub (<https://github.com>)

System Calls

ThreadOS Kernel receives requests from each user thread as interrupts to it. Such an interrupt is performed by calling:

```
Kernel.interrupt( int interruptRequestVector,
                  int trapNumber,
                  int parameter,
                  Object args );
```

where *interruptRequestVector* may be

- 1: INTERRUPT_SOFTWARE,
- 2: INTERRUPT_DISK, and
- 3: INTERRUPT_IO

trapNumber specifies a request type of software interrupt such as

- 0: BOOT
- 1: EXEC
- 2: WAIT
- 3: KILL, etc.

parameter is a device-specific value to control each device; and

args are arguments of each interrupt request.

Since this interrupt method is not an elegant form to a user program, *ThreadOS* provides a user program with its system library, called *SysLib* that includes several important system-call functions as shown below. (Unless otherwise mentioned, each of these functions returns 0 on success or -1 on error.)

1. **SysLib.exec(String args[])** loads the class specified in args[0], instantiates its object, simply passes the following elements of String array, (i.e., args[1], args[2], ...), and starts it as a child thread. It returns a child thread ID on success, otherwise -1.
2. **SysLib.join()** waits for the termination of one of child threads. It returns the ID of the child thread that has woken up the calling thread. If it fails, it returns -1.
3. **SysLib.exit()** terminates the calling thread and wakes up its parent thread if this parent is waiting on join().
4. **SysLib.cin(StringBuffer s)** reads keyboard input to the StringBuffer s.
5. **SysLib.cout(String s)** prints out the String s to the standard output. Like C's *printf*, it recognizes '\n' as a new-line character.
6. **SysLib.cerr(String s)** prints out the String s to the standard error. Like C's *printf*, it recognizes '\n' as a new-line character.
7. **SysLib.rawread(int blkNumber, byte[] b)** reads one block data to the byte array b from the block specified by blkNumber.
8. **SysLib.rawwrite(int blkNumber, byte[] b)** writes one block data from the byte array b to the block specified by blkNumber.
9. **SysLib.sync()** writes back all on-memory data into a disk.

In addition to those system calls, the system library includes several utility functions. One of them is:

1. **public static String[] SysLib.stringToArgs(String s)** converts a space-delimited string into a String array in that each space-delimited word is stored into a different array element. This call returns such a String array.

Other components

These components include *Scheduler* and *Disk*. They will be explained in details as you will need to hack them in the assignments 2 - 5. What you need to know for the assignment 1 is only how to get started and finished with *ThreadOS*, all of which have been introduced above.

4. Statement of Work

Part 1: Linux System Programming

Code a C++ program, named *processes.cpp* that receives one argument, (i.e., *argv[1]*) upon its invocation and searches how many processes whose name is given in *argv[1]* are running on the system where your program has been invoked. To be specific, your program should demonstrate the same behavior as:

```
$ ps -A | grep argv[1] | wc -l
```

Implement *processes* using the following system calls:

1. **pid_t fork(void);** creates a child process that differs from the parent process only in terms of their process IDs.
2. **int execvp(const char *file, const char *arg, ..., (char *)0);** replaces the current process image with a new process image that will be loaded from *file*. The first argument *arg* must be the same as *file*.
3. **int pipe(int filedes[2]);** creates a pair of file descriptors (which point to a pipe structure), and places them in the array pointed to by *filedes*. *filedes[0]* is for reading data from the pipe, *filedes[1]* is for writing data to the pipe.

4. **int dup2(int oldfd, int newfd);** creates in newfd a copy of the file descriptor oldfd.
5. **pid_t wait(int *status);** waits for process termination
6. **int close(int fd);** closes a file descriptor.

For more details, type the **man** command from the *shell* prompt line. Use only the system calls listed above. Do not use the **system** system call. Imitate how the *shell* performs "ps -A | grep argv[1] | wc -l". In other words, your parent process spawns a child that spawns a grand-child that spawns a great-grand-child. Each process should execute a different command as follows:

Process	Command	Stdin	Stdout
Parent	wait for a child	no change	no change
Child	wc -l	redirected from a grand-child's stdout	no change
Grand-child	grep argv[1]	redirected from a great-grand-child's stdout	redirected to a child's stdin
Great-grand-child	ps -A	no change	redirected to a grand-child's stdin

Part 2: ThreadOS Shell Design

Code *Shell.java*, a Java thread that will be invoked from *ThreadOS Loader* and behave as a shell command interpreter.

```
uw1-320-lab:~$ java Boot
    ThreadOS ver 1.0:
    Type ? for help
-->1 Shell
1 Shell
threadOS: a new thread (thread=Thread[Thread-6,2,main] tid=1 pid=0)
shell[1]% TestProg1 & TestProg2
... A concurrent execution of TestProg1 and TestProg2
...
shell[2]% TestProg1 ; TestProg2
... A sequential execution of TestProg1 and TestProg2
...
shell[3]% exit
-->q
uw1-320-lab:~$
```

Once your *Shell.java* is invoked, it should print out a command prompt:

```
shell[1]%
```

When a user types multiple commands, each delimited by '&' or ';', your *Shell.java* executes each of them as an independent child thread with a *SysLib.exec()* system call. Note that the symbol '&' means a concurrent execution, while the symbol ';' means a sequential execution. Thus, when encountering a delimiter ';', your *Shell.java* needs to call *SysLib.join()* system call(s) in order to wait for **this** child thread to be terminated. Since *SysLib.join()* may return the ID of any child thread that has been previously terminated, you have to repeat calling *SysLib.join()* until it returns the exact ID of the child thread that you wants to wait for.

You do not need to implement standard I/O redirection or pipes. You do not need to provide shell variables and programming constructs, either. Only the required functionality of your *Shell.java* is handling an arbitrary number of commands in a line. You may assume that commands, arguments, and even delimiters are separated by arbitrary amounts of spaces or tabs.

To test your *Shell.java*, you can utilize *PingPong.java* that is found in the same directory as *ThreadOS*.

Some possible **test cases** are shown below. Your Shell should handle at least these cases as others you utilize to test.

```
Shell[1]% PingPong abc 100 ; PingPong xyz 50 ; PingPong 123 100
Shell[2]% PingPong abc 50 ; PingPong xyz 100 & PingPong 123 100
Shell[3]% PingPong abc 100 & PingPong xyz 100 ; PingPong 123 50
Shell[4]% PingPong abc 50 & PingPong xyz 50 & PingPong 123 100
```

The general complete ThreadOS source code can be found in

- UW1-320 Linux machines: /usr/apps/CSS430/ThreadOS/

However, some professors prefer to organize their program assignments in subsets of the source code so that only the Java and Class files necessary for that particular assignment are grouped under the assignment folder. Please refer to Canvas for your particular session and professor for the authoritative guidance.

Copy all compiled class files into your directory and thereafter compile your shell.java. Do not try to compile the ThreadOS source code, some portion of which cannot be accessed. (Those are your future assignments.)

Hints: In order to read a command line, you should use `SysLib.cin(StringBuffer s)` that returns a line of keyboard input to the `StringBuffer` (<http://docs.oracle.com/javase/7/docs/api/>) `s`. Parsing and splitting the line into words can be performed with the `StringTokenizer` (<http://docs.oracle.com/javase/7/docs/api/>) class found in `java.util`. For the same purpose, you can also use the `SysLib.stringToArgs(String s)` utility function which is much easier to use.

5. What to Turn In

1. Part 1 must include:

```
Your processes.cpp source code
An output when running your program vs. the actual system calls:
$ processes kworker
$ ps -A | grep kworker | wc -l

$ processes sshd
$ ps -A | grep sshd | wc -l

$ processes scsi
$ ps -A | grep scsi | wc -l
```

2. Part 2 must include:

```
Shell.java
An outputs when testing your Shell.java with PingPong.java for the test cases above.
```

3. Report:

Document how to test your Shell.java. Explain the algorithm of your processes.cpp and Shell.java in some statements, using some flowcharts, or whatever.

4. Softcopy:

processes.cpp and Shell.java

gradeguide1.txt (gradeguide1.txt) is the grade guide for the assignment 1.

6. Note

Visit **CSS430 Operating Systems Assignments Home Page** ([assignment_s14.html](#)) in order to reassure your working environment and turn-in procedure.

7. FAQ

This website could answer your questions. Please click here ([prog1_faq.html](#)) before emailing the professor :-).