Program 1

Thursday, January 14, 2016 2:55 PM

Program 1: Process Creation and Shell

Due Date: see Canvas

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 their 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

Goals of this assignment
(1) to familiarize you with Linux programming using several system calls such as fork, execlp, 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. The Linux Shell

2.1 Shell Overview

This section explains the behavior and the language syntax of a typical Linux *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 pipes

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. The function dup2 is used to redirect output from one file descriptor to another. Another convenience feature is pipeline.

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

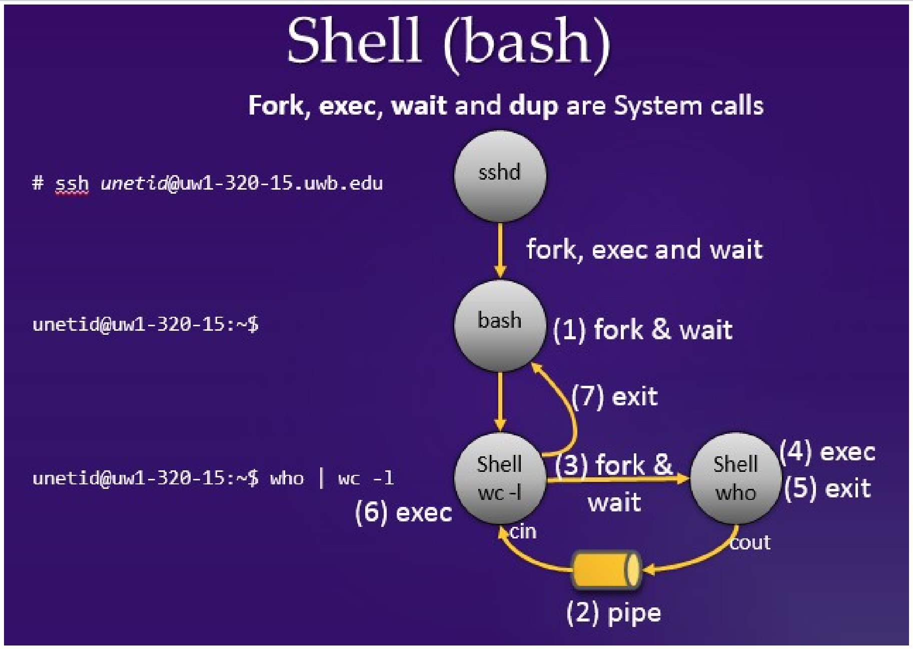
connects *command1*'s standard output to *command2*'s standard input, and also connects *command2*'s standard output to *command3*'s standard input. For instance,

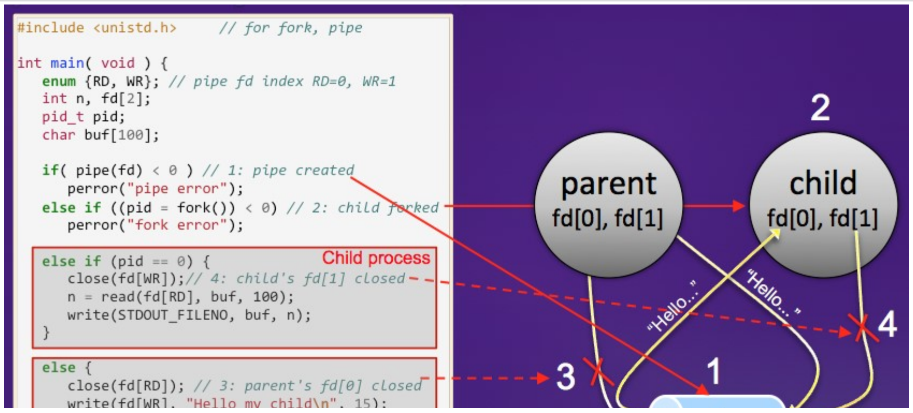
```
uw1-320-lab:~$  who | wc -l
```

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 **execlp** 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.





```
#include <unistd.h>     // for fork, pipe

int main( void ) {
   enum {RD, WR}; // pipe fd index RD=0, WR=1
   int n, fd[2];
   pid_t pid;
   char buf[100];

   if( pipe(fd) < 0 ) // 1: pipe created
      perror("pipe error");
   else if ((pid = fork()) < 0) // 2: child forked
      perror("fork error");

   else if (pid == 0) {
      close(fd[WR]);// 4: child's fd[1] closed
      n = read(fd[RD], buf, 100);
      write(STDOUT_FILENO, buf, n);
   }

   else {
      close(fd[RD]); // 3: parent's fd[0] closed
      write(fd[WR], "Hello my child\n", 15);
```

```
        write(fd[WR], "Hello my child\n", 15);
        wait(NULL);
    }
}
```

2.2 Part I: Process Creation Statement of Work

Write a C++ program, named *processes.cpp* that receives one argument, i.e., `argv[1]` and uses system calls (e.g., fork, execlp, pipe, dup2) to implement the same behaviour as the following Linux command line

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

this command gives the number of processes have the string specified by argv[1] (i.e., grep's argument) based on the information provided by ps.

Implement *processes* using the following system calls:

System Call	Description
`pid_t fork( void );`	creates a child process that differs from the parent process only in terms of their process IDs.
`int execlp( 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*
`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.
`int dup2( int oldfd, int newfd );`	creates in newfd a copy of the file descriptor oldfd. This system call redirects the flow of standard input and output to be input and output into the pipe. Oldfd is the file descriptor that points to the pipe, and newfd is the standard input and output fd that you want to redirect to the pipe.
`pid_t wait( int *status );`	waits for process termination.
`int close( int fd );`	closes a file descriptor.

For more details, type the **man** command, followed by the command you're seeking information about, from the *shell* prompt line (e.g. man dup2). 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

3. ThreadOS Shell Design

3.1 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 the next section, 3.2.

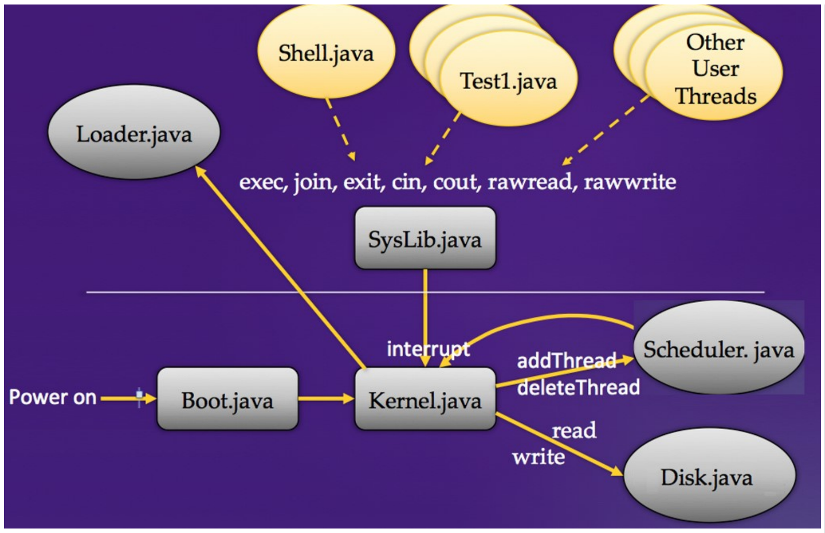
Through this series of assignments, you are to implement and/or to enhance some portions of *ThreadOS*. *ThreadOS* loads Java programs that have been derived from the *Thread* class, manages them as user processes, and provides them with some basic operating system services. Those services include thread 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.

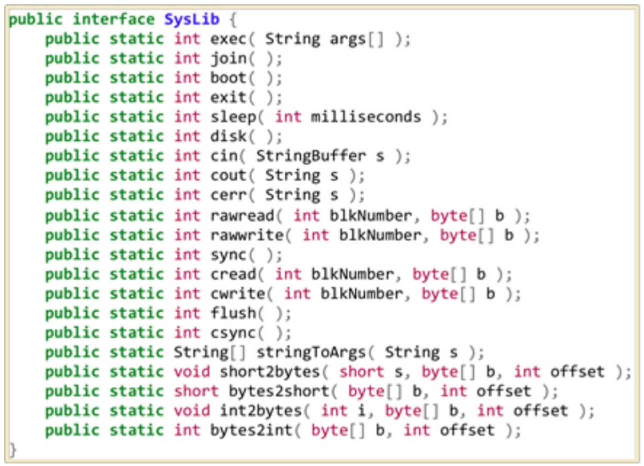
Structure

ThreadOS consists of several components:

Component	Java/Class	Description
Boot	Boot.java	invokes a *BOOT* system call to have *Kernel* initialize its internal data, power on *Disk*, start the *Scheduler* thread, and finally spawn the *Loader* thread.
Kernel	Kernel.java	receives an interrupt, services it if possible, otherwise forwards its request to *Scheduler* or *Disk*, 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: *read*, *write*, and *sync* detailed in the assignment 3, 4, and 5.
Scheduler	Scheduler.java, TCB.java	receives a Thread object that *Kernel* instantiated upon receiving an *EXEC* system call, allocates a new *TCB(Thread Control Block)* to this thread, enqueues the *TCB* 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 *Kernel*.

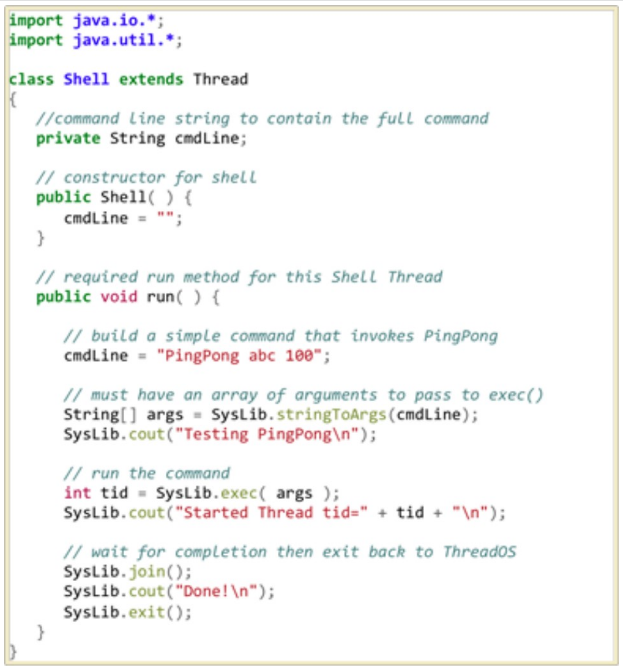
CSS430 ThreadOS





```java
public interface SysLib {
    public static int exec( String args[] );
    public static int join( );
    public static int boot( );
    public static int exit( );
    public static int sleep( int milliseconds );
    public static int disk( );
    public static int cin( StringBuffer s );
    public static int cout( String s );
    public static int cerr( String s );
    public static int rawread( int blkNumber, byte[] b );
    public static int rawwrite( int blkNumber, byte[] b );
    public static int sync( );
    public static int cread( int blkNumber, byte[] b );
    public static int cwrite( int blkNumber, byte[] b );
    public static int flush( );
    public static int csync( );
    public static String[] stringToArgs( String s );
    public static void short2bytes( short s, byte[] b, int offset );
    public static short bytes2short( byte[] b, int offset );
    public static void int2bytes( int i, byte[] b, int offset );
    public static int bytes2int( byte[] b, int offset );
}
```

ThreadOS Syslib



```java
import java.io.*;
import java.util.*;

class Shell extends Thread
{
   //command line string to contain the full command
   private String cmdLine;

   // constructor for shell
   public Shell( ) {
      cmdLine = "";
   }

   // required run method for this Shell Thread
   public void run( ) {

      // build a simple command that invokes PingPong
      cmdLine = "PingPong abc 100";

      // must have an array of arguments to pass to exec()
      String[] args = SysLib.stringToArgs(cmdLine);
      SysLib.cout("Testing PingPong\n");

      // run the command
      int tid = SysLib.exec( args );
      SysLib.cout("Started Thread tid=" + tid + "\n");

      // wait for completion then exit back to ThreadOS
      SysLib.join();
      SysLib.cout("Done!\n");
      SysLib.exit();
   }
}
```

Shell.java (starter example)

Running ThreadOS

After you get hold of the code, 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)
         -->
```

Scroll down to the "Code Availability" section for instructions on how to get the ThreadOS code.)

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.
l user_program	starts *user_program* as an independent user thread and waits for its termination.
q	synchronizes disk data and terminates *ThreadOS*

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* 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]*.

```java
public class PingPong extends Thread {
   private String word;
   private int loop;
   public PingPong( String[] args ) {
      word = args[0];
      loop = Integer.parseInt( args[1] );
   }
   public void run( ) {
      for ( int j = 0; j < 100; j++ ) {
         SysLib.cout( word + " " );
         for (int i = 0; i < loop; i++ );
      }
   }
}
```

PingPong.java hosted with ❤ by GitHub view raw

If you write the following main function

```java
public class ThreadDriver {
   public static void main( String[] args ) {
      String args[2];

      args[0] = "ping"; args[1] = "10000";
      new PingPong( args ).start( );

      args[0] = "PING"; args[1] = "90000";
      new PingPong( args ).start( );
   }
}
```

ThreadDriver.java hosted with ❤ by GitHub view raw

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 *"l 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*.

```java
public class PingPong extends Thread {
   private String word;
   private int loop;
   public PingPong( String[] args ) {
      word = args[0];
      loop = Integer.parseInt( args[1] );
   }
   public void run( ) {
      for ( int j = 0; j < 100; j++ ) {
         SysLib.cout( word + " " );
         for (int i = 0; i < loop; i++ );
      }
      SysLib.cout( "\n" );
      SysLib.exit( );
   }
}
```

PingPong.java hosted with ❤ by GitHub view raw

System Calls and Interface

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.

3.2 ThreadOS Shell Design Statement of Work

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
         -->l Shell
         l 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. **Each delimiter corresponds to its argument to the left.** 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.

```
Shell[1]% PingPong abc 10 & PingPong xyz 10 ; PingPong 123 10 &
```

In the example above, the abc thread would run, then xyz would also run (it doesn't need to wait for abc since it's delimited by &). Thread 123 would have to wait until thread xyz completed (since it is delimited by ;). Thread 123 would then run and the shell prompt would also print before 123 finishes.

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 (between 1 to n).

To test your Shell.java, use *PingPong.java* that is found in the same directory as *ThreadOS*. Your test should be

```
Shell[1]% PingPong abc 10000 & PingPong xyz 10000 & PingPong 123 10000 &
Shell[2]% PingPong abc 10000 ; PingPong xyz 10000 ; PingPong 123 10000 ;
```

*Note: the above 2 lines of output was adjusted on 7/5/2015 so that the first line reads **Shell[1]** and the second line reads **Shell[2]***

Code availability

Option 1 Linux Lab: (Preferred option)

The complete ThreadOS source code can be found in the UW1-320 Linux machines
`/usr/apps/CSS430/ThreadOS/`

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.)

Option 2 Right here (not recommended, only in emergency)

In case you have issues accessing the lab, the code needed for the second part (ThreadOS) of this assignment here:

P1	Inside this zip: • The ThreadOS folder contains all the .class files you need to run ThreadOS • The src folder contains the .java source files you need to edit • Note: IntelliJ will need this folder structure and you need to create a project from scratch

Note on Tools:

You are welcome to use your favourite tools for compiling/running java, like command-line from the linux lab or Eclipse.   I would like to recommend IntelliJ IDEA, for portability and debugging tools.

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 s. Parsing and splitting the line into words can be performed with the StringTokenizer 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.

4. What to Turn In

Part 1 must include:

Your processes.cpp source code

An output when running: (this should go in the report)

```
processes tty
ps -A | grep tty | wc -l

processes Sys
ps -A | grep Sys | wc -l

processes user
ps -A | grep user | wc - l
```

Part 2 must include:

Shell.java

An output when testing your Shell.java with PingPong.java (this goes in the report)

Part 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 other figures.
- Output: Include ***screenshots*** of the output from running your processes program with various commands, also take a comparative screenshot of running the same commands directly on the command line (as specified in Part1 above)
- Output: Include ***screenshots*** of the output from testing your Shell.java as stated in Part 2.

How to submit

Submit on Canvas two files:

1. A .zip file with all your *source* code, do not submit executables or binaries: naming yourinetid_P1.zip pparsons_P1.zip
2. Separately submit a docx or pdf file with your report, include your output screenshots in here: yourinetid_P1report.docx example pparsons_P1report.pdf

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

5. Note

Visit **the Canvas page about general assignment information** in order to double-check your working environment and turn-in procedure.

6. FAQ

This website could answer your questions. Please click here before emailing the professor :-)