Operating Systems – Exercise 2

Processes, Threads, Synchronization

General Guidelines:
Submission deadline is **Wednesday, April 15th, 23:55 (Moodle Server Time).**
Pack your files in a ZIP file named Ex2-YourID.zip, for example: Ex2-012345678.zip
Submit the ZIP file in the submission page in the course website

- No late submission will be accepted!
- You should work on your exercise by yourself. Misconducts will be punished harshly.
- Please give concise answers, but make sure to explain any answer.
- Document your code. Place your name and ID at the top of every source file, as well as in the printed theoretical part.
- Do not submit handwritten answers.

Part 1 - Threads (30 points)

A. (20 points)
Write a Multithreaded Program:
In this part you will implement a multithreaded matrix multiplication tool. The program will be able to split the work to multiple threads, to enhance performance.

This program will be able to handle square matrices only.

Write a class named MatrixMultThread implements Runnable, with the following methods:
This class should include the following public static method:
public static float[][] mult(**float**[][] a, **float**[][] b, **int** threadCount)
Parameters:
a – Left hand matrix
b – Right hand matrix
threadCount – Number of threads

Return value:
The result of a*b

Also, you should implement a main method that generates two 1024x1024 matrices filled with random values. Then, it should multiply them using the mult method described above using at least two threads. Also, it should measure the time in milliseconds it took to perform the multiplication and print this time to the screen.

- **Both matrices are of the same size, and square**
- Use System.currentTimeMillis() to retrieve current system time
- See java.lang.Runnable and java.lang.Thread to understand more on threads in Java
- It is your responsibility to manage the workload between threads
- **You may have an upper limit on the number of threads that depends on matrix size. This number should be explicitly stated in the documentation, in a noticeable location.**
- Example for a good implementation: divide the job by rows – each thread handles *number_of_rows* divided by *number_of_threads* rows. Maximal number of threads is *number_of_rows*. Of course, better implementations are possible.
- Only use static variables for constants, not as a synchronization or data exchange tool.

B. (5 points)
Create a line graph of several runs of your implementation of MatrixMultThread on 1024x1024 matrices. Run the program with 1, 2, 3, 4, 5, 6, 7, 8 threads, for each thread count run it 5 times and then use the median result for the graph. The graph X axis will have the number of threads, the Y axis will have the average time it too to execute.

What number of threads gave the best times? _____
How many cores do you have in your computer? _____
(Find it via Task Manager [Windows] / Top [Linux/Mac] / System Monitor [Mac])

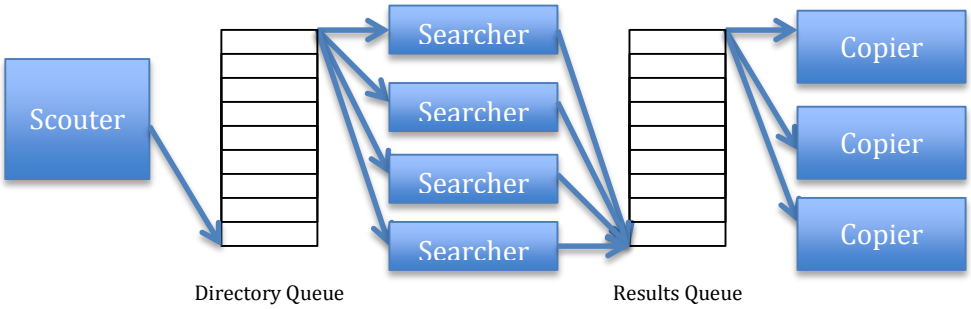
Try to explain the differences / graph trend you got in the experiment: Multithreaded implementation is faster as we utilize more cores on the processor. In this case, if the computer has only one core the multithreaded implementation would have been slower as there is no I/O and context switches would have slowed the process. In case I/O is involved, multithreading can help even on a single core as while one thread is waiting for I/O, the other one runs on CPU.

C. (5 points)
Note: this part is theoretical. No code is required to be written or submitted!
Let's assume you implemented the multiplication as suggested, divide the job by rows – each thread handles *number_of_rows* divided by *number_of_threads* rows. Maximal number of threads is *number_of_rows*.
Now we will change the implementation to multiply each cell of the matrix in its own thread.
How will that affect the performance?
(The hardware does not change, you run the same tests as before)

It will run faster / **slower** because this implementation will use a lot of threads, and as explained, the system will be busy working on creating the threads and joining them -> context switching. Additionally, the logic of splitting the work and then 'adding' the results may also take longer and prove to be an overhead.

<u>Part 2 - Synchronization</u> (40 points)
In this part we will create a multithreaded search utility. The utility will allow searching for files that contain some given file extension, under some given root directory. Files that have this extension will be copied to some specified directory.

Our application consists of two queues and three groups of threads:



The attached JavaDoc contains detailed explanation for each class in the application. Please read it carefully and follow the APIs as defined in it.
(To open the attached JavaDoc open the file <u>index.html</u> inside the directory <u>doc</u>)

A. Write the class `SynchronizedQueue`.
This class should allow multithreaded enqueue/dequeue operations.

The basis for this class is already supplied with this exercise. You have to complete the empty methods according to the documented API and also follow **TODO** comments.
For synchronization you may either use monitors or semaphores, as learned in recitation.
This class uses Java generics. If you are not familiar with this concept you may read the first few pages of this tutorial: http://java.sun.com/j2se/1.5/pdf/generics-tutorial.pdf

B. Write the class `Scouter implements Runnable`.
This class is responsible to list all directories that exist under the given root directory. It enqueues all directories into the directory queue.
There is always only one scouter thread in the system.

C. Write the class `Searcher implements Runnable`.
This class reads a directory from the directory queue and lists all files in this directory. Then, it checks each file to see if the extension matches the one given. Files that has the right extension are enqueued to the results queue (to be copied).

D. Write the class `Copier implements Runnable`.
This class reads a file from the results queue (the queue of files that has the right extension), and copies it into the specified destination directory.

E. Write the class `DiskSearcher`.
This is the main class of the application. This class contains a `main` method that starts the search process according to the given command lines.
Usage of the main method from command line goes as follows:

```
> java DiskSearcher <extension> <root directory> <destination directory>
                    <# of searchers> <# of copiers>
```

For example:

```
> java DiskSearcher txt C:\OS_Exercises C:\temp 10 5
```

This will run the search application to look for files with the extension 'txt', in the directory C:\OS_Exercises and all of its subdirectories. Any matched file will be copied to C:\temp. The application will use 10 searcher threads and 5 copier threads.
Specifically, it should:

- Start a single scouter thread
- Start a group of searcher threads (number of searchers as specified in arguments)
- Start a group of copier threads (number of copiers as specified in arguments)
- Wait for scouter to finish
- Wait for searcher and copier threads to finish

Specific guidelines:

1. Read the attached JavaDoc. It contains a lot of information and tips.
   You must follow the public APIs as defined in the attached JavaDoc!
2. Use the attached code as a basis for your exercise. Do not change already-written code. Just add your code.
3. To list files or directories under a given directory, use the `File` class and its methods `listFiles()` and `listfiles(FilenameFilter)`.
   Note that if for some reason these methods fail, they return null. You may ignore such failures and skip them (they usually occur because insufficient privileges).
4. If you have a problem reading the content of a file, skip it.

Part 3 - Theoretical (30 points)

A. (10 Points)
Two threads execute the following code:

```
for i = 6 to 22
    x += 2
```

(x is a shared variable, initially set to zero. `i` is a local (unshared) variable)

What is/are the possible value(s) for x at the end? Prove formally!
Upper bound is 68: contrary assume that `x` > 68. Then `x` was incremented more than 17 times per thread (began at 0, incremented by 2 each time). But each thread performs exactly 17 add instructions on `x`, so there are total of 34 add instructions performed, and each instruction increments x by 2 so the total is 68 → contradiction!
Lower bound is 4: contrary assume that `x` < 4 (must be 0 or 2). So the last `store` instruction wrote 0 or 2. It means that the preceding `load` instruction read -2 or 0. -2 is impossible, so it can be only 0. But this means that no `store` instruction was performed so far, so it cannot be the last `store` instruction → Contradiction.
For any number n of form 2*n, between 4 and 68, by induction: We know x can be 4. We assume that if x can be n-2, x can also be n (for n <= 68). If x can be n-2 and n-2 < 68, then we know that at least one store instruction was overridden by another store instruction (otherwise x was 68). But we know that there could be an order that would avoid this override. So x can be n.
Side claim: x must be modulus 2: if x was not then at least one add instruction should have added 1 to it → contradiction.
(If you think that the result is a single possible value, write it and prove. If you think that it's a set of distinct values, prove how to get each one of them. If you think it's a range, prove how to reach the bounds, why they are the bounds, what values between them are possible and why).

B. (10 points)
Suppose two threads execute the following C code concurrently, accessing shared variables a, b, and c:

Initialization:

```
int a = 5;
int b = 0;
int c = 0;
```

Thread 1:

```
1.  if (a < 0) {
2.          c = b - a;
3.  } else {
4.          c = b + a;
5.  }
```

Thread 2:

```
1.  b = 10;
2.  a = -4;
```

* the numbers to the left are the line numbers

What are the possible values for **c** after both threads complete? Explain!
You can assume that reads and writes of the variables are atomic, and that the order of statements within each thread is preserved in the code generated by the C compiler.

Possible values are: -4, 5, 6, 14, 15
Since both threads run concurrently, the operating system will decide which thread gets CPU time. In each operation, either thread 1 **or** thread 2 can run (we assumed the reads and write are atomic).
-4: Thread 1 executed the if at line 1, then it read the value of the variable b for the addition at line 4, then thread 2 got prioritized and finished execution, then thread 1 finished.
5: Thread 1 finished running before thread 2 started
6: Thread 1 executed the if at line 1, got false and is now waiting, then thread 2 finished executing, then thread 1 resumed at line 4
14: Thread 2 finished running before thread 1 started
15: Thread 1 executed the if at line 1, got false and is now waiting, then thread 2 executed line 1, then thread 1 finished executing [then thread 2]

C. (10 points)
What would be the output of the following pseudo C/UNIX code? Explain!

Notes:
Be careful not to explain what the code does! Do not tell a story about x, that it will be multiplied by 2 and then something else will happen. Give a concise answer about what the output to the screen will be.

i.

```
int x; // x is a global variable
int main() {
      int i;
      x = 1;
      for (i = 0; i < 75; i++) {
            x = i;
            fork();
            printf("X=%d\n", x);
      }
      return 0;
}
```

$\sum_1^{75} 2^i$ rows will be printed. The row "X=2^i" will be printed 2^i times. Rows order can vary. It does not matter whether x is local or global here as anyway, different processes do not share variables.

ii.

```
int k; // global variable
void main() {
      k = 1;
      createThread(,,printSomething, ...);
}

void *printSomething() {
      if (k < 7) {
            atomic_add(&k, 2); // atomically adds 1 to k
            createThread(,,printSomething, ...);
            printf("%d", k);
      }
}
```

Four new threads are created. Possible outputs are 357, 377, 557, 577, 777 (first thread prints 3, 5 or 7, second prints 5 or 7, third prints 7, and fourth prints nothing.