Assignment 2: The N-Body Problem

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Description of how parallelization was applied and rationale for the parallelization method used

Following the pattern of the previous assignment, this assignment focused a lot on a trial-and-error methodology, in which I've tried different parallelization methods to achieve the goal, which was to parallelize `NBodySystem.advance()` method.

Before even trying to parallelize it, there was a couple of things that I thought I could do to this method. On the assignment description we can find that this method has a $o(n^2)$ complexity. However, after analyzing carefully this method, we can conclude that it has, in fact, $o(n^2) + o(n)$. This happens because there's a second for-loop to update x, y, z coordinates. To simplify this, I've extracted this logic to new method `void moveBody(NBody body, double dt)` and moved this inside the first for-loop.

I've also extracted velocity (vx, vz, vy) and mass calculations to a new method `void makeCalculations(NBody iBody, NBody body, double dt)`. As you can imagine, this minor refactor wasn't made to increase performance. Just to make things easier when trying different parallelization methods.

Regarding the parallelization itself, I will now describe the methods used the obtained results. (Whilst testing these different methods I've always compared them to the results achieved with the sequential version.)

1) Using bare-bone Threads: Since we were dealing with lists, I thought that we could do a somewhat similar approach to "Matrix Multiplication" exercise. However, I couldn't just split the for-loop into N different parts and hope this would work. Every iteration has to have a reference to its past elements, so as I should have expected, this led to inaccurate `energy` results.

2) Using ExecutorService: ExecutorService abstracts away many of the complexities associated with the lower-level abstractions like raw Thread. This seemed like a good choice. Basically, I've created a `newFixedThreadPool` with 8 number of threads (to match my CPU specs) and instead of calling `makeCalculations` directly, I called it with `executor.submit`. This was terrible performance wise, even to the point of stop running the simulation because it was running for too long with my CPU at 100% on all cores.

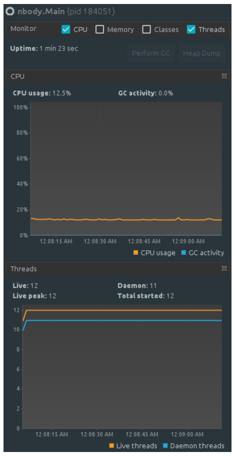
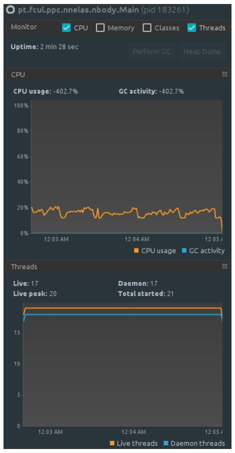
3) Using Streams: With Streams I found that it was somewhat simple to parallelize the `advance` method. In practice, I would only need to 1) call `.parallel()` to iterate the for-loop in parallel; 2) call `.forEachOrdered()` to ensure that the items were executed orderly.

Measurements showing whether parallelization was advantageous in each case

For this assignment I have used a machine with the following configurations:

CPU	CPU Cores	CPU Threads	RAM	Operating System
Intel i7-8550U (8) @ 4.000GHz	4	8	24 GB	Linux Mint 20 x86_64

As the above screenshots from VisualVM show, although using Streams API simplifies all that "hard-work" of managing tasks, it does not resolve all synchronization issues nor makes the solution faster. A parallel stream should not be used when we have a massive amount of items to process, that only increases the thread coordination problem. To sum up, using Streams led to an increase of more than 1 minute between sequential and parallelized version.

Sequential	Using Streams
 nbody.Main (pid 184051) Monitor ☑ CPU □ Memory □ Classes ☑ Threads Uptime: 1 min 23 sec CPU usage: 12.5% GC activity: 0.0% Live: 12 Daemon: 11 Live peak: 12 Total started: 12 Perform GC Heap Dump CPU 100% 80% 60% 40% 20% 0% 12:08:15 AM 12:08:30 AM 12:08:45 AM 12:09:00 AM CPU usage GC activity Threads 12 10 8 6 4 2 0 12:08:15 AM 12:08:30 AM 12:08:45 AM 12:09:00 AM Live threads Daemon threads	 pt.fcul.ppc.nnelas.nbody.Main (pid 183261) Monitor ☑ CPU □ Memory □ Classes ☑ Threads Uptime: 2 min 28 sec CPU usage: -402.7% GC activity: -402.7% Live: 17 Daemon: 17 Live peak: 20 Total started: 21 Perform GC Heap Dump CPU 100% 80% 60% 40% 20% 0% 12:03 AM 12:04 AM 12:05 A CPU usage GC activity Threads 15 10 5 0 12:03 AM 12:04 AM 12:05 A Live threads Daemon threads