

# NWEN303 - Assignment 1

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## 1. Synchronisation

### A)

A race condition is when the result of an operation is dependent on sequence of execution of two or more threads. Race conditions can come in many types and may break the correctness of the operation. The given algorithm to concurrently find where  $f(x)$  equals 0 has a few race conditions.

One race condition results from the algorithm shares the variable  $k$  between all threads which is set to be the starting point for the thread to find the answer. The race condition comes from the series of values actually checked is dependent on which is the last thread to start and set  $k$  to be its starting point and every other thread is then set to be this value as well. This will cause the algorithm to only check  $1/N$  of the search space it was suppose to.

There is another race condition that results from having  $k$  shared between all the threads. This could occur when one thread finds a value of  $k$  and in the time between starting the execution of the check of  $f(k) == 0$  and printing the  $k$  another thread could modify  $k$  due to that thread failed its check for  $f(k) == 0$  because another thread updating  $k$  in between these checks. This race condition is a combination of check-then-act and read-modify-write races. This would cause incorrect results from the algorithm.

A result of having the `found` boolean being shared a race condition is introduced. This race condition is cause when a thread has just found a correct value of  $k$  and is about to update the `found` variable but another thread could start another loop in between the time of find the result. This would cause an extra loop to be executed, which in this context is not expensive and is a reasonable cost. However if in that extra loop the thread finds another solution it will result in more than 1 result for the algorithm which is not desired.

## B)

There are a few modifications I would make to the given algorithm to avoid the race conditions currently present.

The most major modification would be to make `k` a thread local variable. This will prevent each thread from over writing each others starting values or current values between checking `f(k) == 0` and printing `k`. This would greatly increase the correctness of the algorithm.

Depending on the acceptability of the algorithm finding more than 1 solution the `found` might need to be locked. Given that only 1 solution is acceptable the `found` variable will need to synchronise in the success branch of `f(k) == 0` and preform an extra check for if `found` is true before printing the result to prevent a check-then-act race condition. This will result in a chance of an extra loop to be executed if the loop starts just before the `found` variable is updated but to prevent this it would require locking `found` as it is being read which would hurt the performance of the algorithm.

## C)

Fairness in concurrency is when each threads is an even share of the available resources such as CPU time, memory or CPU cache. The correctness of my algorithm in part B) relies on each thread being given CPU time to progress. In an unfair situation on thread could be given CPU time sparingly and end up being behind the other threads as they progress further in their allocated work. This could cause the correctness of the algorithm to suffer if one thread that would eventually find the solution is not run.

## D)

In the absence of fairness the algorithm from B) could be modified to remove this assumption. One possible way of doing this is by having a shared queue of available values to be checked. Instead of being given a starting value to increment each thread would just dequeue a value to check from the shared work queue. This would result in some loss of performance as threads might have to wait on a lock on the queue when getting values from it, depending on the implementation of the queue.

## 2. Measuring Array Sum

Each experiment was preformed on three systems: an 8 core desktop computer which has a clock speed of 4Ghz, a 4 core laptop with a clock speed of around

2.1Ghz and Lighthouse with 64 cores with a clock speed of 1.1Ghz. The Java versions were consistent expect for Lighthouse being only Java 7 while all other machines were the latest Java 8. All measurements of time are recorded in milliseconds. Each data point is an average of 10 runs of the experiment.

## Sequential Summing

The first experiments is a base line of summing elements on a single thread. The range of sizes uses where 100 to 10 million incrementing by a multiple of 10 each step. The results for each of the array sizes were very similar so only Figure 1 showing the time spent on summing 10 million elements is included. There are many factored that would of contributed to these consistent sub-millisecond results could be the absence of having to switch between threads with other threads or processes. Another possible reason could be that the Java virtual machine identified the tight loop and applied just-in-time compiling to increase the performance of the loop to near native speeds coupled with the benefits of the temporal cache locality of summing arrays with such a simple operation as addition.

## Global Variable

The next part of the experiment is to show the affect of concurrently summing the array with different methods using different numbers of threads and array sizes. For this part the concurrent method used is to sum from each thread into a shared synchronised global variable and yield the thread after each addition.

Each machine that ran this experiment had large variations between each others in their results expect for the relatively low cost of initialising the threads at the start of each run. Lighthouse and the 4 Core laptop both showed plateauing after around 4 threads were used. For the laptop this would make sense as this is the point where the number of threads for the program will be greater than the number of physical cores to compute the operations. Expect for Lighthouse with its 64 threads this does not make much sense and I presume it is a *feature* of the operation system's scheduler to fairly distribute cpu time. A interesting point in the 4 core laptop is the amount of time taken is a magnitude greater than the other machines and while running the tests I recorded 80% of cpu time was spent on kernel tasks, I presume this to be resulting from page faults as the process was making an excess number of context switches between threads and the system resulted over a million page faults by the process by the end of the experiment. This is most likely caused by the OS of the laptop stored the large array to page file for an unknown reason, even though it had enough RAM storage for the array.

The affect of the yield as a part of the method to calculate this causes the thread to stop and go to the back of the queue for CPU time and is platform dependent

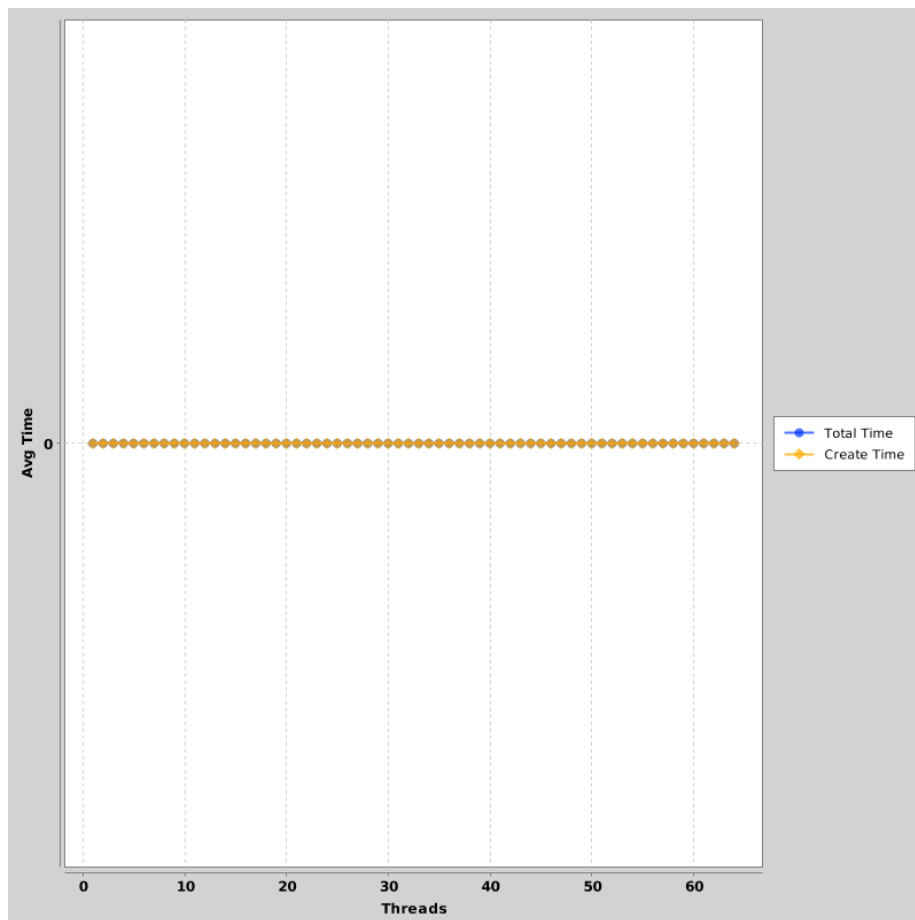


Figure 1: Single Threaded Sumation with 10 million elements

on how this will affect results. The amount of time to create the threads had an upwards trend with the number of threads needed to be created as expected but it was relatively very small. A side-affect of using a synchronised shared global variable to be summed to is each thread must wait till the last thread to start updating it has completed so a considerable amount of time is waiting for another thread to finish as well as then yielding its spot to be currently executed and moved to the back of the cpu time queue hurts and the associated context switching between threads is costly.

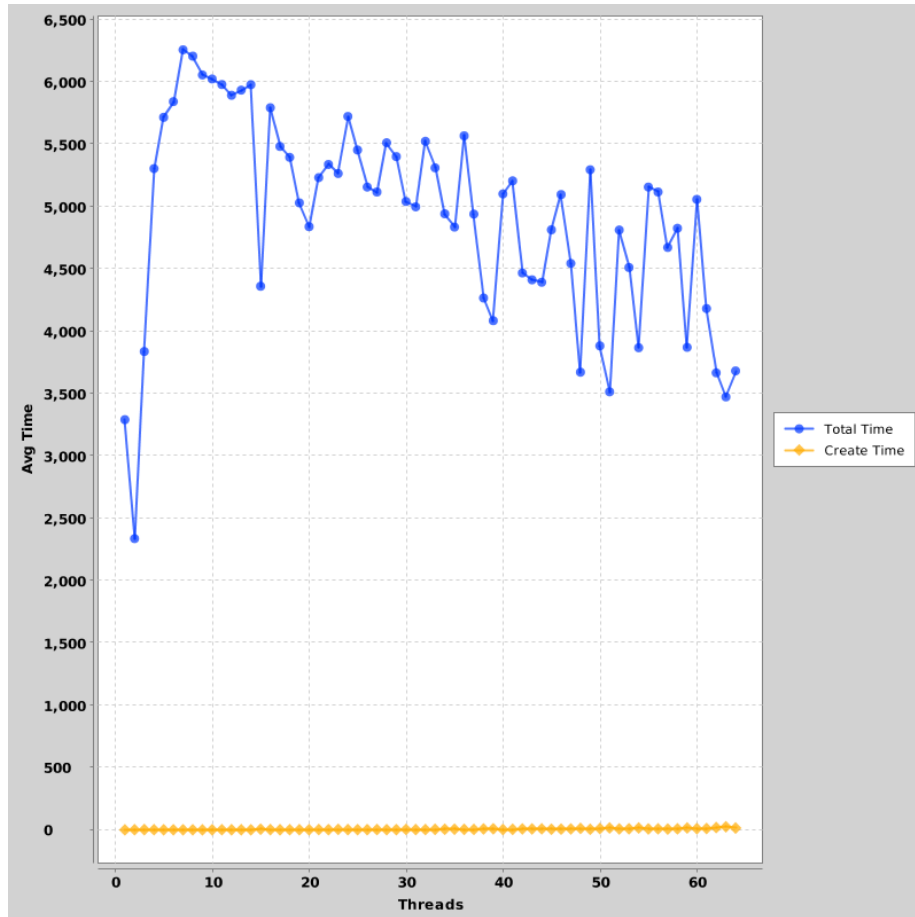


Figure 2: Global Variable Sum 10 million elements on 8 cores

## Local Variable

The other method used to test summing large arrays concurrently was to use a local variable instead of a shared variable. So this makes the method be give

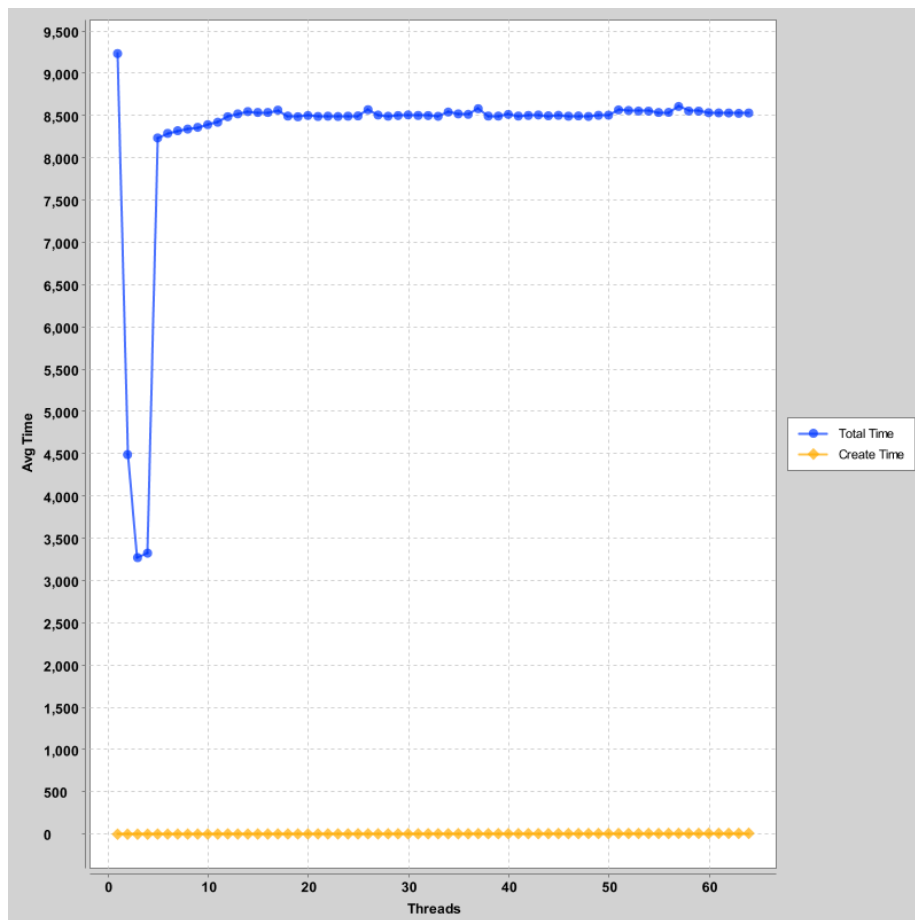


Figure 3: Global Variable Sum 10 million elements on 64 cores

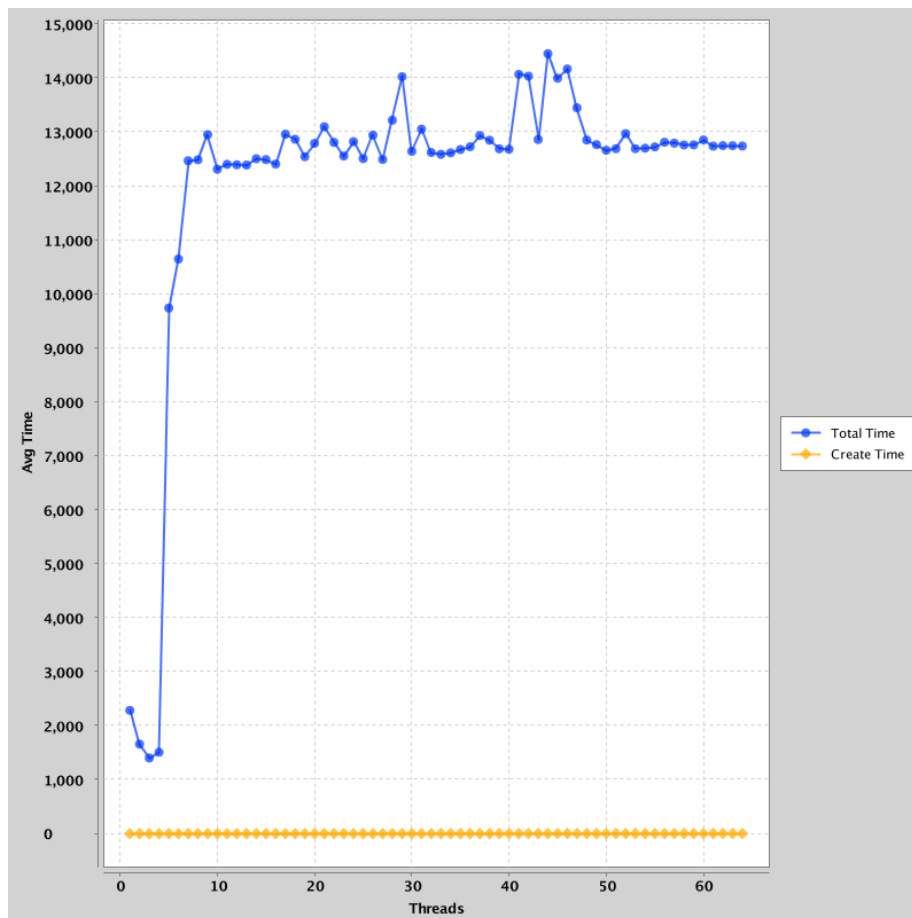


Figure 4: Global Variable Sum 10 million elements on 4 cores

each thread a range in the array and make a local sum of its elements and the main thread then summing up the results of the threads after they join back into the main thread, to be consistent after each element is summed the thread is yielded as well.

In this experiment each of the machines behaved differently to each other. However the 4 core laptop behaved similarly to how it was in the global variable experiment and the same page fault issue was observed again which explains the same shape of the graph. Expect the average time was a tenth of the global variable variant which can be attributed to not having to be locked waiting for the global variable to sum a value. The results observed from Lighthouse and its 64 threads shows a speed up with every thread added. This is likely caused by each thread getting one physical CPU to compute and no interdependence between threads on who has the lock on the global sum variable. A similar trend can be seen in the 8 core PC but quickly loses it after the number of threads exceeds the number of CPU cores in the machine. In laptop and Lighthouse runs the cost of starting the threads were relatively negligible, while the cost of making threads on the 8 core PC shows an increasing trend past 8 threads. This could be caused by the lower overall time to sum the array is lower due to clock speed differences so the change in time to create threads becomes more significant with the number of threads used.

Overall the usage of the local variable significantly increases the performance of the summation when compared to the use of global variable. This generally comes down to not needing to synchronise between all the threads to access the shared global variable. The amount of time overall to sum the array has a large range of factors from, number of cores and thus the number of threads that can be run at one, usage of page file and repeated page faults on large data structures and the usage of different concurrent methods.



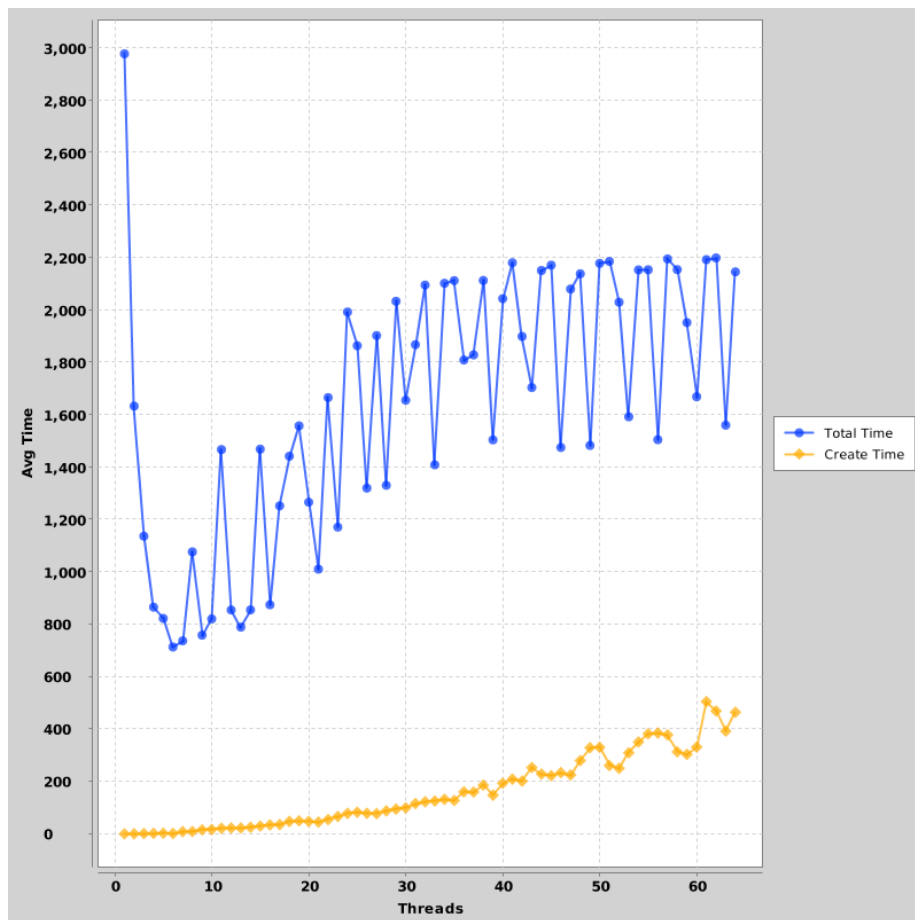


Figure 5: Local Variable Sum 10 million elements on 8 cores

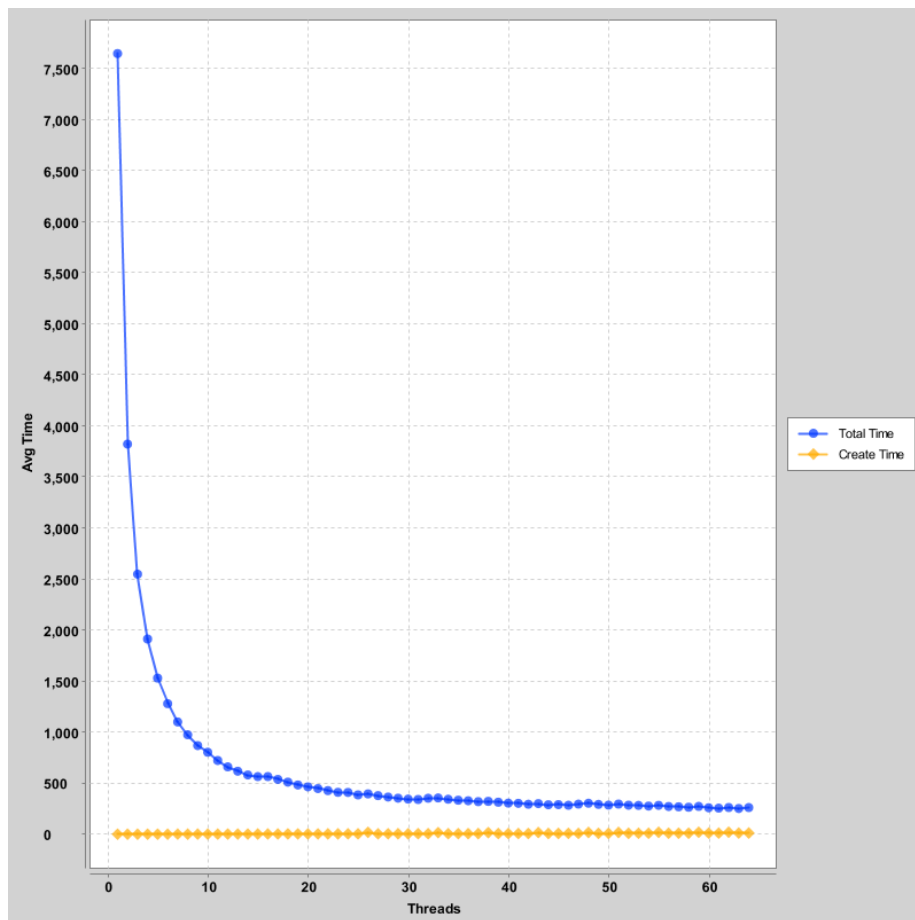


Figure 6: Local Variable Sum 10 million elements on 64 cores

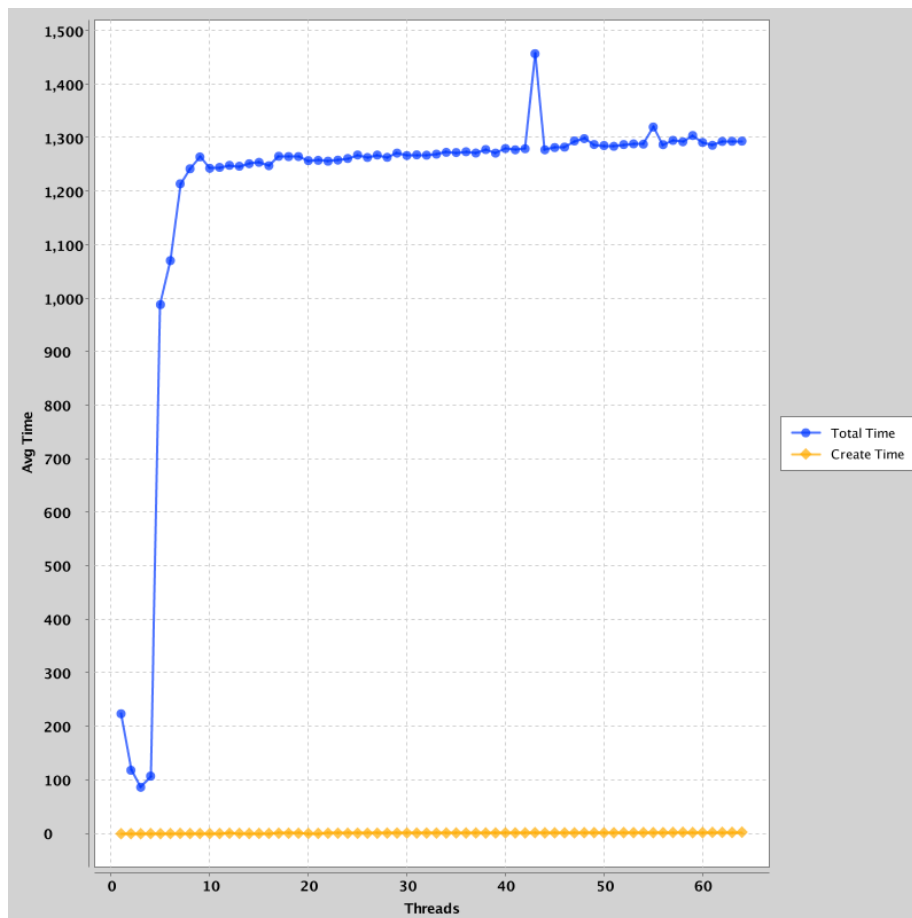


Figure 7: Local Variable Sum 10 million elements on 4 cores

### 3. Recursive Array Sum

The next experiment is to try another method to concurrently sum the array. This method splits the array in half and passes it to two threads to compute if the size of the array is over a threshold, if it is lower the thread will sum the array iteratively and yield after each calculation. The parent thread waits for the join from its two child threads and sums their results.

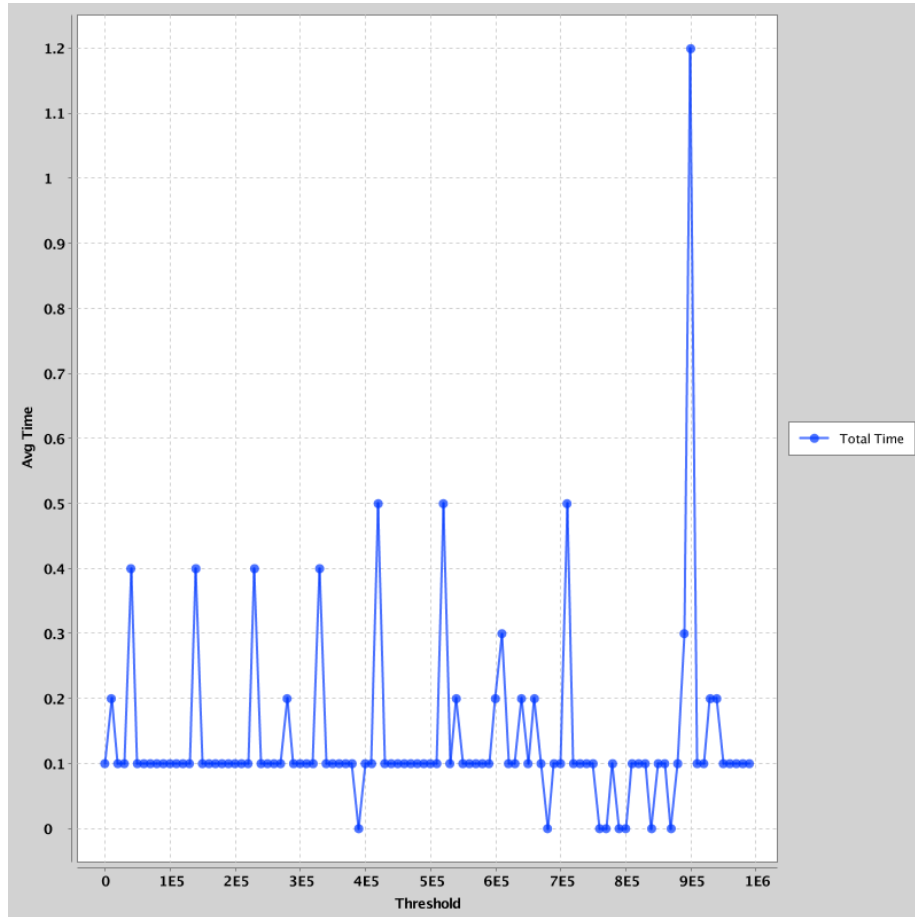


Figure 8: Recursive Sum 1 million elements on 4 cores

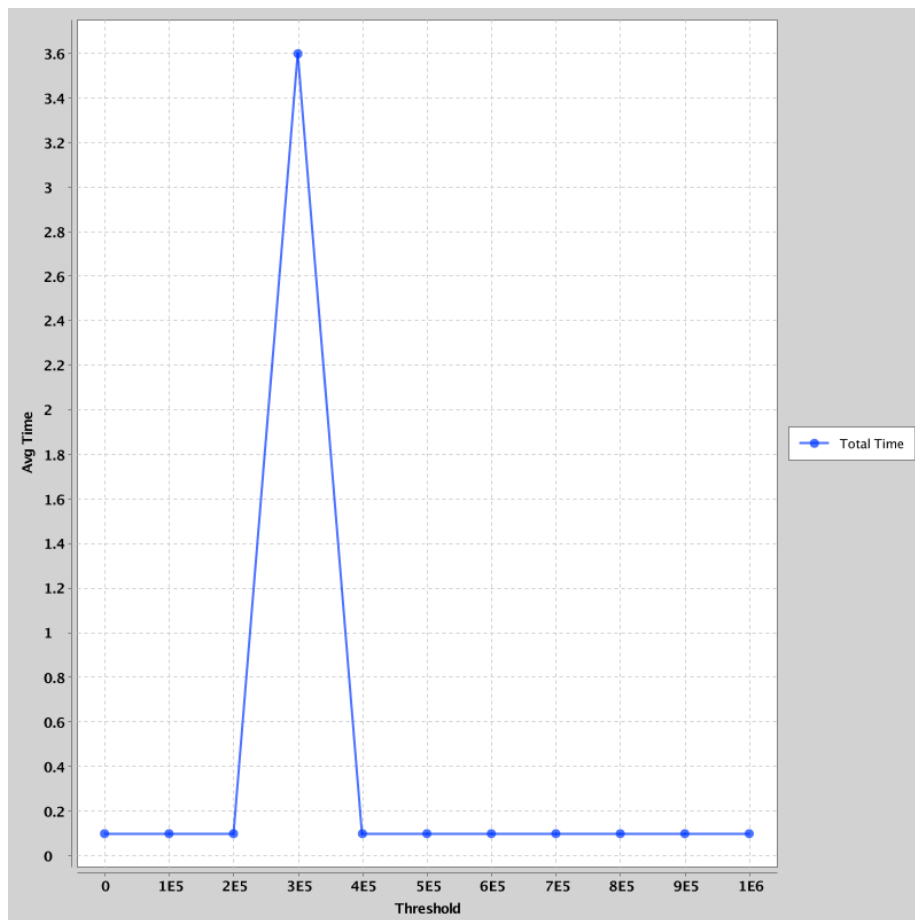


Figure 9: Recursive Sum 10 million elements on 4 cores