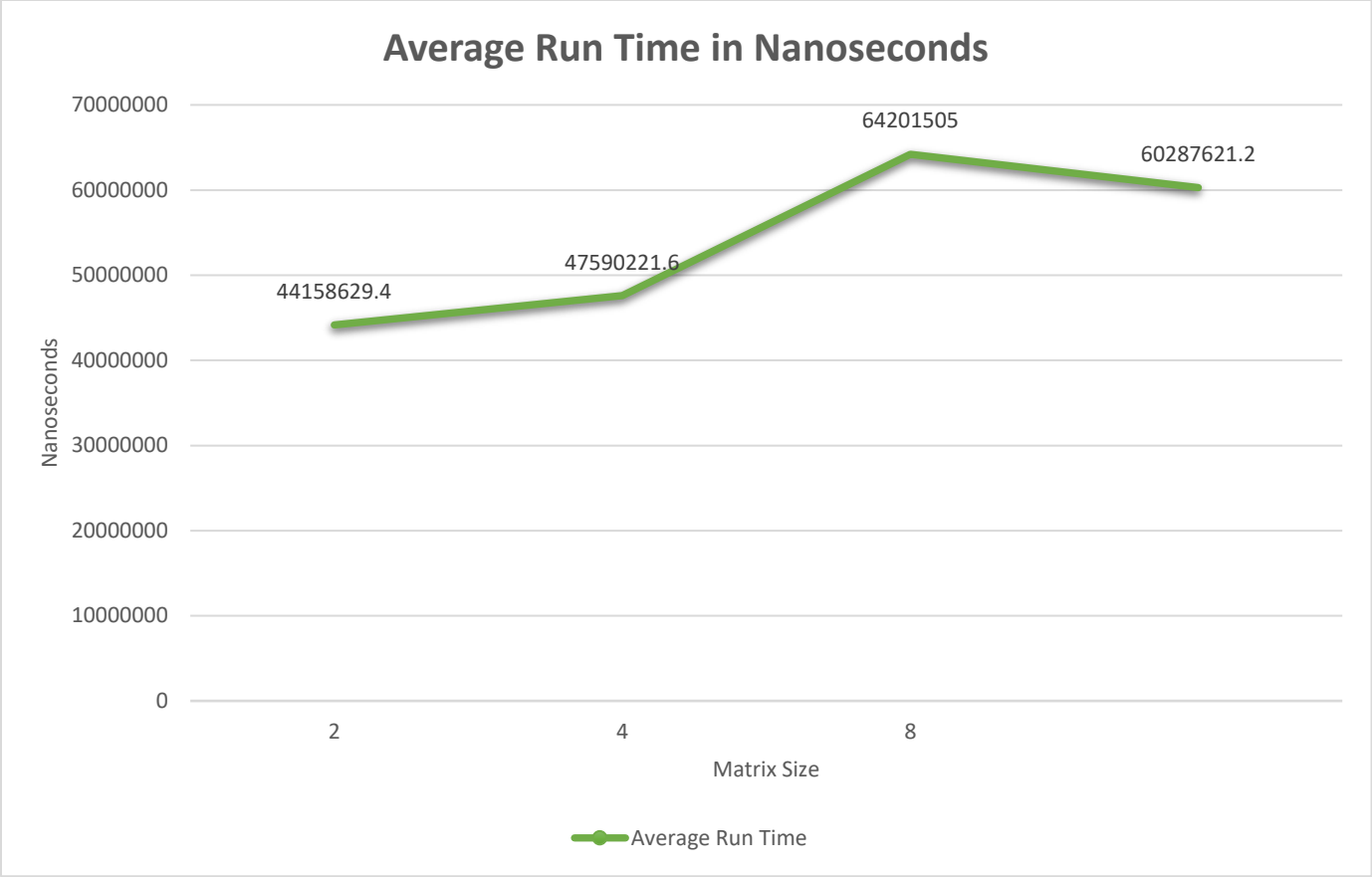
Joseph Camacho-Terrazas
11/14/2020



Matrix Size	Run 1	Run 2	Run 3	Run 4	Run 5	Average Run Time	Standard Deviation
2	45280163ns	42907156ns	44380051ns	44252345ns	43973432ns	44158629.4ns	763692.543
4	43659907ns	46199623ns	49088793ns	48931209ns	50071576ns	47590221.6ns	2348711.154
8	65640643ns	60567908ns	66148423ns	65267696ns	63382855ns	64201505ns	2043114.589
16	60707656ns	63300549ns	56744088ns	60420706ns	60265107ns	60287621.2ns	2089450.126

Given the data, we can see a generally linear increase in runtime as matrix size increases. However, we notice that the run time average actually decreases going from matrix size 8 to 16. I find this odd as there seemed to have been a linear increase in time. I would attribute this to the processor architecture of the lab computers. The processor might handle more threads more efficiently after a certain point. This experiment does show that having a separate thread handle its own row of the matrix is very fast and better than using big loops to fill the matrices and do the calculations.

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```java
/*
 * From: http://www.letmeknows.com/2017/04/24/wait-for-threads-to-finish-java/
 *
 * Adopted By: Shaun Cooper
 * Last Updated Nov 2020
 *
 * We need static variable pointers in the main class so that we can share these
 * values with the threads. The threads are address separate from us, so we need
 * to share pointers to the objects that we are sharing and updating.
 */

/*
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*Input: An integer argument that specifies the number of threads
*Output: Thread info, minimum, maximum, and average values, and the run time
*Precondition: User should enter valid integer input
*Postcondition: Results of the thread test will be printed properly
*/

import java.util.*;
import java.math.*;


public class concurrency {

    private static ArrayList<Thread> arrThreads = new ArrayList<Thread>();

    //We use static variable to help us connect the threads to a common block.
    public static int N = 0;
    public static int[][] A;

    //Arrays to store minimum, maximum, and average
    public static float[] Average;
    public static int[] Minimum;
    public static int[] Maximum;

    //Main entry point for the process
    public static void main (String[] args) {
        try {

            //Local tracking variables
            float mainAvg = 0;
            int mainMin = 0;
            int mainMax = 0;
```

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```
            //Size comes from user argument
            int size = Integer.parseInt(args[0]);
            N = size;

            //Create the array from input as well as storage arrays
            A = new int[size][size];
            Average = new float[size];
            Minimum = new int[size];
            Maximum = new int[size];

            //Calculate the maximum exponentional range to help when filling the
array
            int minRange = (int) (Math.pow(2, (31-N)));
            int maxRange = (int) (Math.pow(2, (32-N)));
            int range = maxRange - minRange;

            //Fill the array with random values
            for (int x = 0; x < A.length; x++) {
                for (int y = 0; y < A.length; y++) {
                    A[x][y] = (int)(range * Math.random() + 1);
                }
            }

            //Take the start time in nanoseconds
            long startTime = System.nanoTime();

            //Create N threads to work on each row
            for (int x = 0; x < size; x++){
                Thread T1 = new Thread(new ThreadTest(x));
                T1.start(); //Standard thread start
                arrThreads.add(T1);
            }

            // Wait for each thread to complete
            for (int x = 0; x < arrThreads.size(); x++)
                {arrThreads.get(x).join();}

            //Take the finish time in nanoseconds
            long finishTime = System.nanoTime();

            //Set mainMin as the first index of Minimum
            mainMin = Minimum[0];
            //Retrieve minimum, maximum, and average values
            for(int x = 0; x < N; x++){
                if (Minimum[x] < mainMin) {
```

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```
                    mainMin = Minimum[x];
                }
                if (Maximum[x] > mainMax) {
                    mainMax = Maximum[x];
                }
                mainAvg = mainAvg + Average[x];
            }

            //Final results printouts
            System.out.println("Main Thread has N as value " + N);
            System.out.println("Time: " + (finishTime - startTime) + " nanosecond
s");
            System.out.println("Maximum: " + mainMax + " Minimum: " + mainMin + "
 Average: " + mainAvg);

            //This for loop will not stop execution of any thread, only it will c
ome out
            //when all threads are executed.
            System.out.println("Main thread exiting.");

        } catch(Exception e) {
            System.out.println(e.getMessage());
        }
    }
} // End Main

class ThreadTest implements Runnable {
    private int i;

    //Local minimum, maximum, and average values for ThreadTest
    private float TTavg = 0;
    private int TTmin = 0;
    private int TTmax = 0;

    ThreadTest(int ind) {
        i = ind;
    }

    public void run() {
        try {
            TTmin = concurrency.A[i][0];
            System.out.println("Thread is started " + i + " Array is " + concurre
ncy.A[i][0]);

            //Loop finds minimum, maximum, and average values
```

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```
            for (int x = 0; x < concurrency.N; x++) {
                if (concurrency.A[i][x] < TTmin){
                    TTmin = concurrency.A[i][x];
                }
                if (concurrency.A[i][x] > TTmax){
                    TTmax = concurrency.A[i][x];
                }
                TTavg = TTavg + (concurrency.A[i][x]/ (concurrency.N * concurrenc
y.N));
            }

            //Store value in global Minimum, Maximum, and Average
            concurrency.Average[i] = TTavg;
            concurrency.Minimum[i] = TTmin;
            concurrency.Maximum[i] = TTmax;
            System.out.println("Thread is exiting " + i);

        } catch(Exception e){
            System.out.println(e.getMessage());
        }
    }
}
```

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```
jterrazas@babbage:~/Documents/programs/CS 471/Concurrency> ./runcon.sh
Thread is started 1 Array is 189647587
Thread is started 0 Array is 42823511
Thread is exiting 0
Thread is exiting 1
Main Thread has N as value 2
Time: 44280661 nanoseconds
Maximum: 520063731 Minimum: 42823511 Average: 2.49082624E8
Main thread exiting.
Thread is started 0 Array is 86042096
Thread is started 1 Array is 527675062
Thread is exiting 0
Thread is exiting 1
Main Thread has N as value 2
Time: 42807378 nanoseconds
Maximum: 527675062 Minimum: 86042096 Average: 3.29974816E8
Main thread exiting.
Thread is started 0 Array is 280365936
Thread is started 1 Array is 352552085
Thread is exiting 0
Thread is exiting 1
Main Thread has N as value 2
Time: 44048299 nanoseconds
Maximum: 352552085 Minimum: 64048982 Average: 2.38716064E8
Main thread exiting.
Thread is started 1 Array is 498797209
Thread is started 0 Array is 13697155
Thread is exiting 1
Thread is exiting 0
Main Thread has N as value 2
Time: 42232402 nanoseconds
Maximum: 533759719 Minimum: 13697155 Average: 3.74167136E8
Main thread exiting.
Thread is started 0 Array is 27240518
Thread is started 1 Array is 105970146
Thread is exiting 1
Thread is exiting 0
Main Thread has N as value 2
Time: 43780054 nanoseconds
Maximum: 498801434 Minimum: 27240518 Average: 2.72927072E8
Main thread exiting.
Thread is started 0 Array is 37224311
Thread is started 3 Array is 121799533
Thread is started 1 Array is 71269301
Thread is started 2 Array is 124205492
Thread is exiting 3
Thread is exiting 0
Thread is exiting 2
Thread is exiting 1
Main Thread has N as value 4
Time: 47579861 nanoseconds
Maximum: 133183249 Minimum: 8723817 Average: 7.0853904E7
Main thread exiting.
```

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```
Thread is started 0 Array is 122094857
Thread is started 2 Array is 47457469
Thread is started 1 Array is 110199792
Thread is started 3 Array is 85680611
Thread is exiting 2
Thread is exiting 0
Thread is exiting 3
Thread is exiting 1
Main Thread has N as value 4
Time: 46867203 nanoseconds
Maximum: 122094857 Minimum: 28315593 Average: 7.9327776E7
Main thread exiting.
Thread is started 2 Array is 26973016
Thread is started 3 Array is 122648876
Thread is started 1 Array is 129298258
Thread is started 0 Array is 80491003
Thread is exiting 2
Thread is exiting 1
Thread is exiting 3
Thread is exiting 0
Main Thread has N as value 4
Time: 43917137 nanoseconds
Maximum: 129298258 Minimum: 12021395 Average: 9.8773616E7
Main thread exiting.
Thread is started 3 Array is 133413657
Thread is started 1 Array is 68944789
Thread is started 2 Array is 2034524
Thread is started 0 Array is 122215494
Thread is exiting 3
Thread is exiting 2
Thread is exiting 1
Thread is exiting 0
Main Thread has N as value 4
Time: 45297467 nanoseconds
Maximum: 134110758 Minimum: 2034524 Average: 8.5754704E7
Main thread exiting.
Thread is started 3 Array is 93578496
Thread is started 2 Array is 51086103
Thread is started 1 Array is 42081356
Thread is started 0 Array is 44310045
Thread is exiting 3
Thread is exiting 0
Thread is exiting 1
Thread is exiting 2
Main Thread has N as value 4
Time: 44394777 nanoseconds
Maximum: 130785168 Minimum: 633900 Average: 6.850436E7
Main thread exiting.
Thread is started 1 Array is 2457052
Thread is started 4 Array is 8134340
Thread is started 6 Array is 39714
Thread is started 5 Array is 323059
Thread is started 7 Array is 5484978
```

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```
Thread is started 2 Array is 404763
Thread is started 3 Array is 1125614
Thread is started 0 Array is 8267331
Thread is exiting 5
Thread is exiting 3
Thread is exiting 0
Thread is exiting 6
Thread is exiting 4
Thread is exiting 2
Thread is exiting 1
Thread is exiting 7
Main Thread has N as value 8
Time: 59190166 nanoseconds
Maximum: 8330841 Minimum: 39714 Average: 4239917.0
Main thread exiting.
Thread is started 0 Array is 1706089
Thread is started 2 Array is 1636462
Thread is started 3 Array is 4380654
Thread is started 4 Array is 3183475
Thread is started 5 Array is 220477
Thread is started 7 Array is 288881
Thread is started 1 Array is 6629054
Thread is started 6 Array is 8347098
Thread is exiting 4
Thread is exiting 5
Thread is exiting 3
Thread is exiting 7
Thread is exiting 0
Thread is exiting 2
Thread is exiting 1
Thread is exiting 6
Main Thread has N as value 8
Time: 59809188 nanoseconds
Maximum: 8347098 Minimum: 193123 Average: 4287848.0
Main thread exiting.
Thread is started 0 Array is 1691402
Thread is started 6 Array is 3206126
Thread is started 4 Array is 5232303
Thread is started 7 Array is 3474015
Thread is started 2 Array is 2640373
Thread is started 1 Array is 307140
Thread is started 3 Array is 1898650
Thread is started 5 Array is 3618131
Thread is exiting 4
Thread is exiting 0
Thread is exiting 6
Thread is exiting 5
Thread is exiting 7
Thread is exiting 1
Thread is exiting 3
Thread is exiting 2
Main Thread has N as value 8
Time: 58396341 nanoseconds
```

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```
Maximum: 8316651 Minimum: 307140 Average: 4232052.0
Main thread exiting.
Thread is started 4 Array is 3649636
Thread is started 6 Array is 3680132
Thread is started 7 Array is 5966685
Thread is started 1 Array is 2342922
Thread is started 2 Array is 3449084
Thread is started 0 Array is 6705624
Thread is started 5 Array is 526644
Thread is started 3 Array is 7624967
Thread is exiting 5
Thread is exiting 1
Thread is exiting 2
Thread is exiting 7
Thread is exiting 3
Thread is exiting 0
Thread is exiting 4
Thread is exiting 6
Main Thread has N as value 8
Time: 64170086 nanoseconds
Maximum: 8175993 Minimum: 12473 Average: 4363404.0
Main thread exiting.
Thread is started 1 Array is 8129353
Thread is started 0 Array is 8070703
Thread is started 7 Array is 5350244
Thread is started 2 Array is 3658210
Thread is started 4 Array is 5609785
Thread is started 3 Array is 7558079
Thread is started 5 Array is 4268834
Thread is started 6 Array is 3374769
Thread is exiting 2
Thread is exiting 4
Thread is exiting 6
Thread is exiting 0
Thread is exiting 1
Thread is exiting 7
Thread is exiting 3
Thread is exiting 5
Main Thread has N as value 8
Time: 61808752 nanoseconds
Maximum: 8129353 Minimum: 18631 Average: 4337813.0
Main thread exiting.
Thread is started 7 Array is 11404
Thread is started 2 Array is 2340
Thread is started 1 Array is 14749
Thread is started 15 Array is 10089
Thread is started 11 Array is 29084
Thread is started 4 Array is 7023
Thread is started 12 Array is 13377
Thread is started 8 Array is 3357
Thread is exiting 4
Thread is started 3 Array is 6655
Thread is started 10 Array is 31264
```

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```
Thread is started 14 Array is 19483
Thread is started 5 Array is 11920
Thread is started 9 Array is 25969
Thread is exiting 5
Thread is exiting 14
Thread is exiting 10
Thread is exiting 3
Thread is exiting 8
Thread is exiting 2
Thread is exiting 15
Thread is exiting 7
Thread is exiting 11
Thread is exiting 12
Thread is exiting 9
Thread is started 6 Array is 28522
Thread is started 13 Array is 31470
Thread is started 0 Array is 21361
Thread is exiting 1
Thread is exiting 13
Thread is exiting 6
Thread is exiting 0
Main Thread has N as value 16
Time: 57314248 nanoseconds
Maximum: 32765 Minimum: 209 Average: 17135.0
Main thread exiting.
Thread is started 7 Array is 1807
Thread is started 4 Array is 24549
Thread is started 12 Array is 30535
Thread is started 13 Array is 9829
Thread is started 8 Array is 22775
Thread is started 5 Array is 29779
Thread is started 1 Array is 21192
Thread is started 2 Array is 11425
Thread is started 0 Array is 16286
Thread is started 3 Array is 7257
Thread is started 15 Array is 2943
Thread is started 11 Array is 14832
Thread is started 9 Array is 10528
Thread is started 14 Array is 13234
Thread is exiting 0
Thread is exiting 15
Thread is exiting 5
Thread is exiting 2
Thread is exiting 8
Thread is exiting 14
Thread is started 10 Array is 24722
Thread is exiting 10
Thread is exiting 1
Thread is exiting 13
Thread is exiting 7
Thread is exiting 4
Thread is exiting 12
Thread is exiting 11
```

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```
Thread is started 6 Array is 13473
Thread is exiting 6
Thread is exiting 9
Thread is exiting 3
Main Thread has N as value 16
Time: 56683201 nanoseconds
Maximum: 32596 Minimum: 301 Average: 16330.0
Main thread exiting.
Thread is started 15 Array is 3740
Thread is started 3 Array is 21132
Thread is started 14 Array is 13100
Thread is started 5 Array is 11762
Thread is started 6 Array is 2443
Thread is started 13 Array is 14610
Thread is started 7 Array is 8788
Thread is started 0 Array is 4773
Thread is started 11 Array is 4215
Thread is exiting 6
Thread is exiting 15
Thread is exiting 13
Thread is started 10 Array is 30502
Thread is started 9 Array is 20697
Thread is started 1 Array is 31142
Thread is exiting 9
Thread is started 4 Array is 9854
Thread is exiting 10
Thread is started 12 Array is 615
Thread is started 8 Array is 29407
Thread is started 2 Array is 20811
Thread is exiting 5
Thread is exiting 2
Thread is exiting 3
Thread is exiting 8
Thread is exiting 14
Thread is exiting 12
Thread is exiting 11
Thread is exiting 0
Thread is exiting 4
Thread is exiting 1
Thread is exiting 7
Main Thread has N as value 16
Time: 57041707 nanoseconds
Maximum: 32753 Minimum: 27 Average: 16552.0
Main thread exiting.
Thread is started 8 Array is 15032
Thread is started 13 Array is 15106
Thread is started 10 Array is 2954
Thread is started 5 Array is 15339
Thread is started 14 Array is 27571
Thread is started 6 Array is 9290
Thread is started 0 Array is 978
Thread is started 3 Array is 23757
Thread is exiting 6
```

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```
Thread is exiting 8
Thread is started 1 Array is 21469
Thread is started 7 Array is 2907
Thread is exiting 3
Thread is exiting 13
Thread is exiting 0
Thread is exiting 1
Thread is started 11 Array is 9337
Thread is exiting 11
Thread is exiting 10
Thread is exiting 5
Thread is started 12 Array is 3287
Thread is exiting 12
Thread is started 15 Array is 24786
Thread is started 9 Array is 8621
Thread is exiting 14
Thread is started 4 Array is 1662
Thread is exiting 4
Thread is exiting 7
Thread is exiting 9
Thread is exiting 15
Thread is started 2 Array is 29008
Thread is exiting 2
Main Thread has N as value 16
Time: 60223945 nanoseconds
Maximum: 32711 Minimum: 117 Average: 15802.0
Main thread exiting.
Thread is started 3 Array is 20537
Thread is started 1 Array is 17168
Thread is started 4 Array is 23414
Thread is started 0 Array is 375
Thread is started 14 Array is 5457
Thread is started 15 Array is 8183
Thread is started 9 Array is 8308
Thread is started 12 Array is 27001
Thread is started 13 Array is 27037
Thread is started 5 Array is 8729
Thread is started 6 Array is 5815
Thread is started 10 Array is 1225
Thread is started 2 Array is 21603
Thread is started 7 Array is 13435
Thread is started 8 Array is 929
Thread is started 11 Array is 21503
Thread is exiting 8
Thread is exiting 6
Thread is exiting 9
Thread is exiting 7
Thread is exiting 12
Thread is exiting 13
Thread is exiting 11
Thread is exiting 10
Thread is exiting 14
Thread is exiting 15
```

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```
Thread is exiting 1
Thread is exiting 4
Thread is exiting 5
Thread is exiting 2
Thread is exiting 0
Thread is exiting 3
Main Thread has N as value 16
Time: 59015263 nanoseconds
Maximum: 32759 Minimum: 14 Average: 15950.0
Main thread exiting.
jterrazas@babbage:~/Documents/programs/CS 471/Concurrency>
```