

CS 3110 Project 1:

Matrix Multiplication

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Part 1: Date sets, test strategies and results

(1) Introduction

Problem: Multiply two matrices Matrix1 * Matrix2, each of size $[2^i, 2^i]$ where $i \geq 1$.

Algorithms:

- The classical matrix multiplication: using three for-loop.
- The divided-and-conquer matrix multiplication: divide the problem of multiplying Matrix1 of size $[n \times n]$ and Matrix2 of size $[n \times n]$ into 8 subproblems, each of size $[n/2 \times n/2]$.
- The Strassen's matrix multiplication: using a recursive call to implement this algorithm with 7 multiplications and 18 additions or subtractions.

Input:

- There are three different sets of matrices:
 - A set of 1000 random matrices of size $2 \times 2, 4 \times 4, \dots, 64 \times 64$
 - A set of 100 random matrices of size $2 \times 2, 4 \times 4, \dots, 128 \times 128$
 - A set of 10 random matrices of size $2 \times 2, 4 \times 4, \dots, 512 \times 512$

Test strategies:

- There are 2 test strategies:
 - (1.) Run each matrix of the sets of random matrices of 1000, 100, 10 for 20 times by each algorithm. Record the time taken to multiply a square matrix of each size (2^i , where $i \geq 1$) by each algorithm of trial #20. Record the total time of each algorithm and obtain the total time by calculating the time taken of each algorithm divided by number of times (time taken/ 20).
 - (2.) Take a set of 10 random matrices of size $2 \times 2, 4 \times 4, \dots, 512 \times 512$. Record the time taken to multiply a square matrix of each size (2^i , where $i \geq 1$) by each algorithm of trial #1 to trial #20. Calculate the average time of each algorithm of each matrix (starting from the first matrix to the maximum data set of matrix which is 10) and obtain the average time by computing the sum of time taken of each matrix by each algorithm at trial #1 to trial #20 then divided by number of times (sum of total time trial #1 – trial #20/ 20). Calculate the total time of each algorithm by computing the sum of the average time of each matrix, then divided by total number of matrices (sum of the average time of matrix1 to matrix10/ 10).

Output:

- Indicate the elapsed time to perform matrix multiplication of each algorithm and the total time.
- Example of the program output (showing the elapsed time of multiplying each matrix by each algorithm, the average time of each matrix, and total time of each algorithm:

```
Size: 256*256
Time taken of a data set #1 out of total data sets of 10

Time taken of Classical at trial #1is: 71812200
Time taken of Divide-and-conquer at trial #1is: 8815334000
Time taken of Strassen's at trial #1is: 6457628700
Time taken of Classical at trial #2is: 45630100
Time taken of Divide-and-conquer at trial #2is: 12464529000
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Time taken of Strassen's at trial #5is: 5699090499
Time taken of Classical at trial #6is: 33174000
Time taken of Divide-and-conquer at trial #6is: 9127989700
Time taken of Strassen's at trial #6is: 5809507500
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ime taken of Strassen's at trial #13is: 5412111301
ime taken of Classical at trial #14is: 46369900
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ime taken of Classical at trial #19is: 47600900
ime taken of Divide-and-conquer at trial #19is: 9344135700
ime taken of Strassen's at trial #19is: 6403748800
ime taken of Classical at trial #20is: 50632900
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verage time of Strassen's Multiplication of a matrix #1 out of total data sets of 10 is: 5781299794

ime taken of a data set #2 out of total data sets of 10
ime taken of Classical at trial #1is: 46832199

Time taken of Strassen's at trial #20is: 6883004300
Average time of Classical Matrix Multiplication of a matrix #10 out of total data sets of 10 is: 57448344
Average time of Divide-and-conquer Matrix Multiplication of a matrix #10 out of total data sets of 10 is: 9919406925
Average time of Strassen's Multiplication of a matrix #10 out of total data sets of 10 is: 6678855615

-----The total time of each algorithm-----
Total time of Classical Matrix Multiplication is: 51765073
Total time of Divide-and-conquer Matrix Multiplication is: 8669661134
Total time of Strassen's Multiplication is: 5831838322
```

Please see reference for more details.

Description:

The program will first generate a set of 1000, 100, or 10 random matrices (which is defined as a default value) of given size of 2*2, 4*4, 8*8, 16*16..., n*n. Each matrix will be calculated for 20 times by using 3 different matrix multiplication algorithms.

The program will record the total time of multiplying a given matrix with different algorithms for 20 times. In other words, the program obtains the total time from time taken to multiply matrices for each algorithm divided by number of times.

(2) Main Components

Matrix_Multiplication.java

Contains the following main components of the matrix multiplication program.

2.1 The code component to multiply matrices by using the classical matrix multiplication, the divided-and-conquer matrix multiplication, and the Strassen's matrix multiplication.

2.2 The code component in the main function to test a data set of 1000, 100, or 10 input matrices by using each algorithm.

2.3 The code component in the main function to calculate the total time and the average time of each matrix multiplication

(3) Results

According to the graphs and tables presented in part 3 indicates that classical matrix multiplication always faster than the divided-and-conquer matrix multiplication and the Strassen's matrix multiplication.

I think the reason that the divided-and-conquer matrix multiplication and the Strassen's matrix multiplication take longer time to multiply a set of 1000 matrices of given size of 2^i , where $i \geq 1$, because I implemented divided-and-conquer and Strassen's algorithms by using recursion. It takes time to create multiple stack frames because of the recursive calls, and it takes space and memory to process the matrix multiplication algorithms. However, in term of output quality of matrix multiplication algorithms in this experiment shows that the Strassen's matrix multiplication is faster than the divided-and-conquer matrix multiplication. Moreover, the result also shows that the time increases as the problem size grows.

Part 2: Theoretical Complexity Comparisons

According to the lecture of divide-and-conquer points out the theoretical complexity comparisons of the three algorithms, which are the followings:

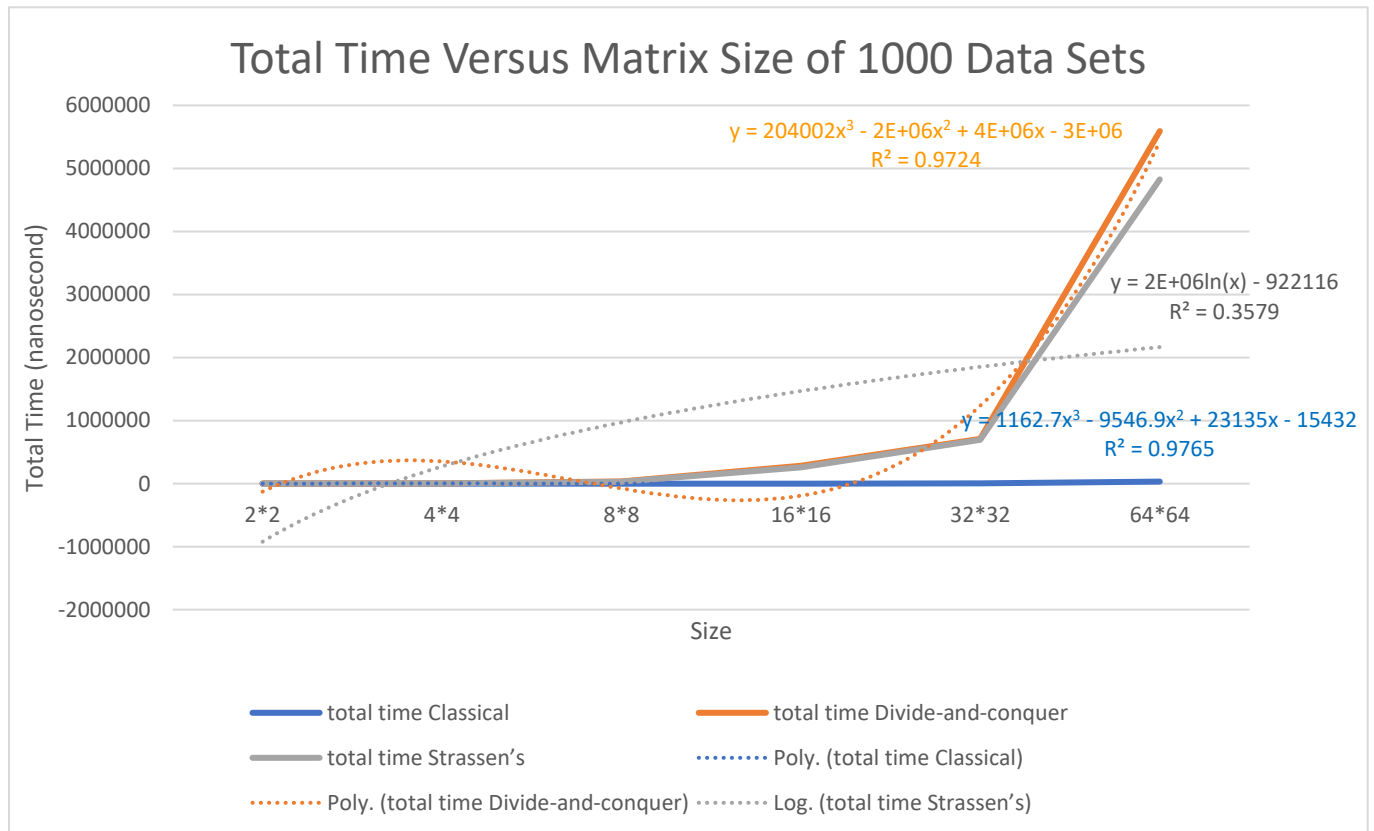
Algorithm	Recurrence Relation	Complexity
Classical matrix multiplication	$T(n) = O(n^3)$	$O(n^3)$
Divided-and-conquer matrix multiplication	$T(n) = 8 * T(n/2) + an^2$	$O(n^3)$
Strassen's matrix multiplication	$T(n) = 7 * T(n/2) + an^2, n > 2$ $T(n) = b, n \leq 2$	$O(n^{\lg 7}) = (n^{2.81})$

The Strassen's algorithm is indeed asymptotically faster than the classical algorithm and divide-and-conquer algorithm.

Part3: Classical Matrix Multiplication Vs Divide-and-Conquer Matrix Multiplication Vs Strassen's Matrix Multiplication

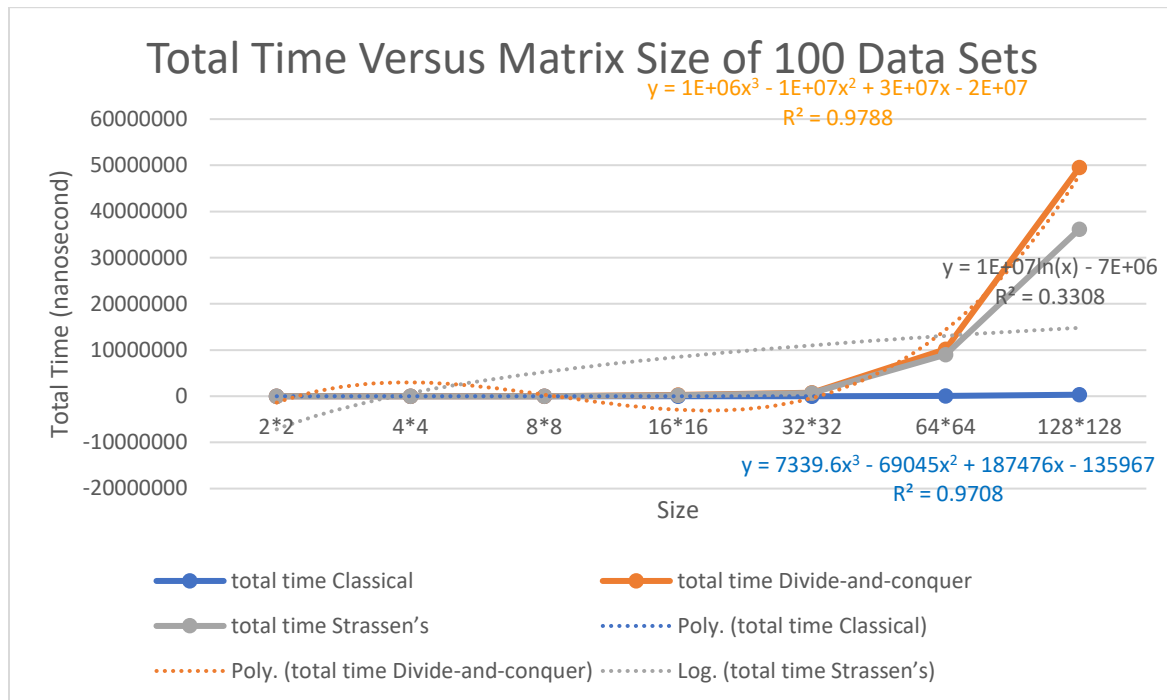
The first test strategies:

The graph shows the total time taken to run a set of 1000 random matrices by each different 3 algorithms for 20 times per each matrix versus the size of i^2 , where $i \geq 1$.



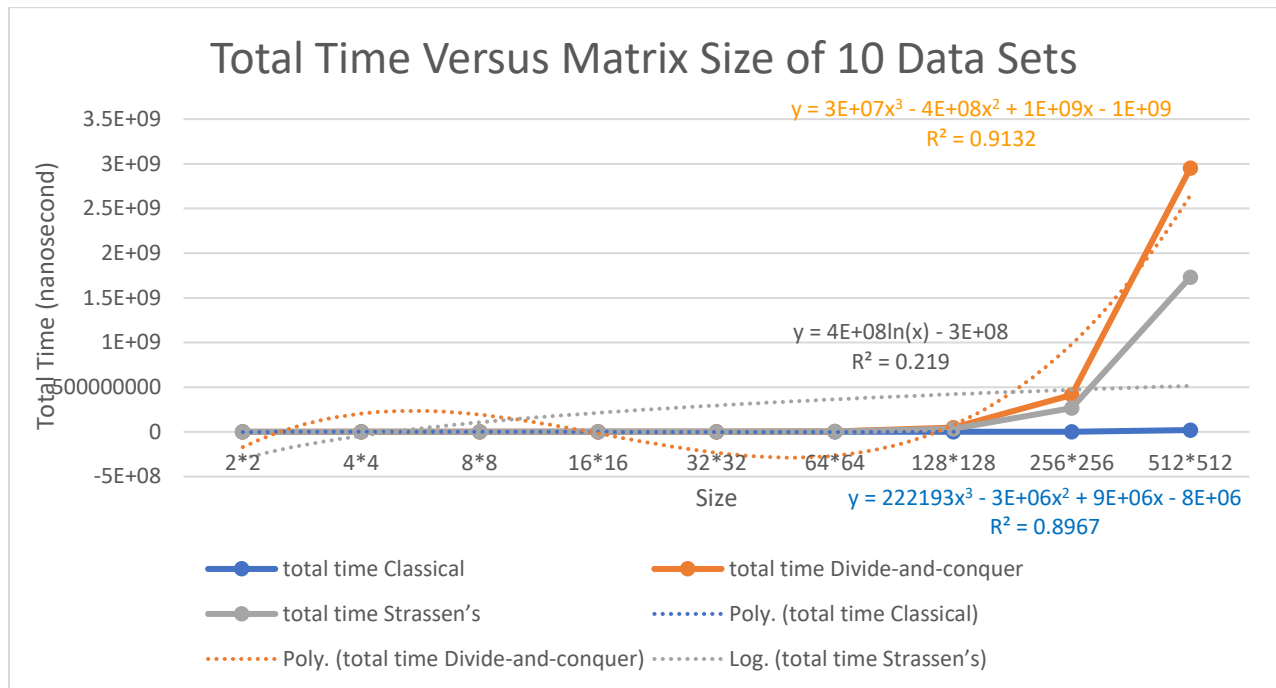
The orange line shows the line of total time of divide-and-conquer which its function is growing faster than the line of total time of Strassen's method (the gray line). The divide-and-conquer function has the time complexity of $O(n^3)$, and the Strassen's method which has the time complexity of $O(n^{2.81})$ which equals to $O(n^{\lg 7})$. For this reason, the function of divide-and-conquer is growing slightly faster than the function of Strassen's method. Also, the logarithmic function has higher order of time complexity than the polynomial function; in other words, logarithmic function is more efficient than polynomial function.

The graph shows the total time taken to run a set of 100 random matrices by each different 3 algorithms for 20 times per each matrix versus the size of i^2 , where $i \geq 1$.



According to the observations, running a set of 100 matrices of smaller size, i.e., 2×2 , 4×4 , 8×8 , and 16×16 gives the result of time taken to multiply matrices. It shows that the first couple times of running the program; the total time of divide-and-conquer is faster than Strassen's method which I did not encounter this kind of problem when running with a set of 1000 matrices. However, when I run the program multiple times, I started to obtain an accurate result where Strassen's method takes shorter amount of time to multiply matrices than divide-and-conquer. The functions of divide-and-conquer and Strassen's algorithm starts to increase rapidly in a higher size of matrix, i.e., these functions of a set of 100 matrices grows increasingly at size of (64×64) ; however, these functions of a set of 1000 matrices starts to grow increasingly at size of (32×32) .

The graph shows the total time taken to run a set of 10 random matrices by each different 3 algorithms for 20 times per each matrix versus the size of i^2 , where $i \geq 1$.



According to this graph shows that the functions of divide-and-conquer and Strassen's method grow rapidly at size of 256*256. It took about 1.5 hour to compile a set of 10 random matrices of size 256*256, and it took about 5 hours to compile a set of 10 random matrices of size 512*512. As a result, I notice that the functions of divide-and-conquer and Strassen's method start to grow rapidly when the runtime of matrix multiplication is more than or equal to one hour.

The functions of these graphs of the total time taken to run a set of 1000, 100, and 10 random matrices by each different 3 algorithms for 20 times have the same pattern. The lines of total time classical, total time Divide-and-conquer, and total time Strassen's are in the same format regardless of the matrix size.

The table shows the average time at trial #20 of each algorithm by obtaining the total time of each size, then divided by the maximum size that each data set can go.

data set	classical matrix multiplication algorithm	divided-and-conquer matrix multiplication algorithm	Strassen's matrix multiplication algorithm
10	2511233	379743606.1	226822955.6
100	55070.71	8688921.429	6585959.286
1000	6204.167	1103315.667	967730.5

According to the average time at trail #20, I find that a smaller data set of matrices takes longer amount of time than a higher data set of matrices. For example, the average runtime of classical, divide-and-conquer, and Strassen's of 10 matrices is slower than 100 and 1000 matrices; 10 matrices takes longer to multiply matrices by each algorithm. I think the reason is because if the number of data sets is smaller, we could extend the maximum size of a matrix.

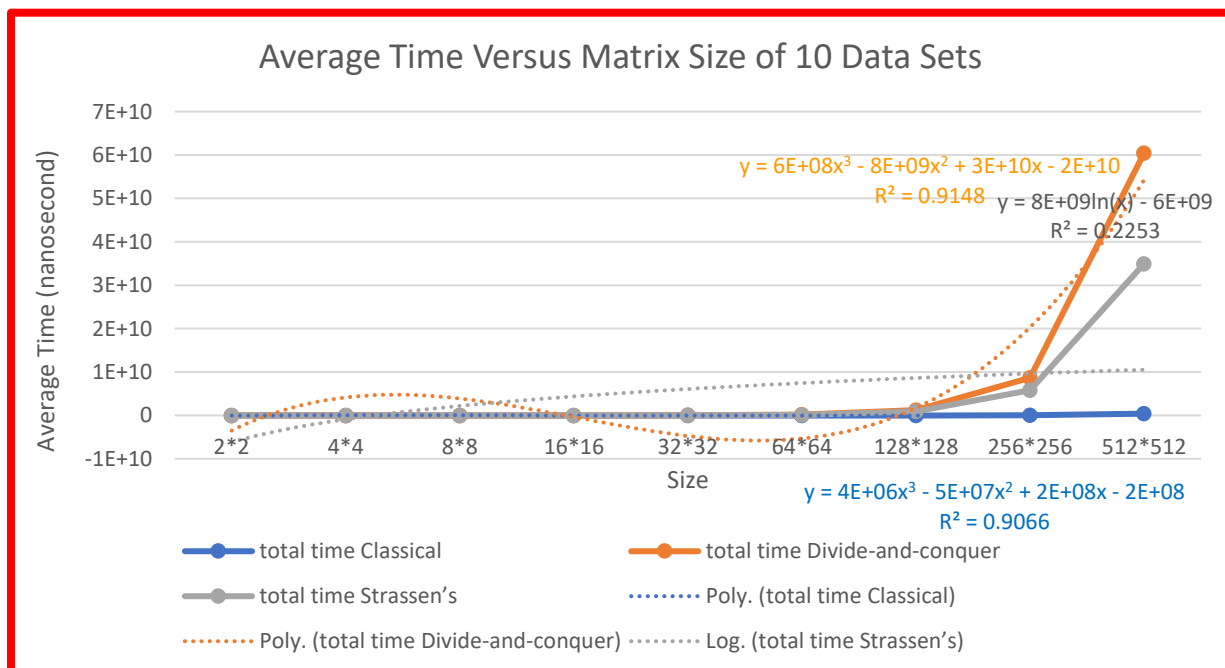
The second test strategies:

The table shows the average time obtained by the formula (total average time = time taken at trial #1 + time taken at trial #2 + time taken at trial #3 + ... + time taken at trial #n, where n is the number of times to run each matrix) / (the number of data set * the number of times).

size(2^i ; $i \geq 1$)	total time Classical	total time Divide-and-conquer	total time Strassen's
2*2	588	99712	11051
4*4	2048	100153	95965
8*8	30942	811929	567578
16*16	115803	4685661	3955379
32*32	190238	25927585	25581665
64*64	977931	170558445	149864209
128*128	6332368	1214213973	927664935
256*256	51765073	8669661134	5831838322
512*512	413060358	60440891615	34944643126

We can plot the graph by using the table above.

The graph shows the average time to run a set of 10 random matrices by each different 3 algorithms for 20 times per each matrix versus the size of i^2 , where $i \geq 1$.



According to the graph of average time for each 3 different algorithms, it still shows that total time Classical is a linear line, and the divide-and-conquer is slower than the Strassen's. In term of a comparison of each algorithm, we can rank 3 algorithms according to the graph of the average time in the following order, from fastest to slowest:

classical algorithm < Strassen's algorithm < divide-and-conquer algorithm

Part 4: Strength and Constraints

Strength:

- The classical matrix multiplication is always faster than the divide-and-conquer matrix multiplication. This result does not really follow theoretical way as they both have the same level of time complexity which is $O(n^3)$.
- The Strassen's matrix multiplication is always faster than the divide-and-conquer matrix multiplication only if a larger set amount of data is tested. In other word, at trial #20, running matrix multiplication of a set of 1000 matrices of size 2^i , where $i \geq 1$ indicates that the Strassen's matrix multiplication is always faster than the divide-and-conquer matrix multiplication. However, running matrix multiplication of a set of 100 matrices of size 2^i , where $1 \leq i < 4$ gives the different result. At the first couple times when running the program, the divide-and-conquer matrix multiplication takes less time than the Strassen's matrix multiplication. The more times we run the program; I was able to obtain the correct result where the Strassen's matrix multiplication will become faster. Therefore, I think the larger set amount of data helps to obtain more accurate result.

Constraints:

- When testing a set of 1000 matrices of size 128×128 , I could not wait for more than 5 hours even though I attempted to run it 3 times because I did not understand at the beginning; at what size should I stop running the program.
- When testing a set of 100 matrices of size 256×256 , I left it run overnight, and I had received an error. Therefore, I think the size 256×256 of 100 matrices is the maximum size as I could go.
- When testing a set of 10 matrices of size 512×512 took about 5 hours, so I acknowledge that at size 512×512 should be the maximum size that I can go.
- I had to rest the computer after it was generating a lot of heat while running matrices multiplication of a large size.
- I had a slower CPU to run, and my CPU has a low memory.

(5) Evaluation

Everything was done on time and in the quality, I strived for when I first started working on the first project of matrix multiplication algorithms. I have also been spending multiple weeks to test the program with the different number of input matrices to obtain the accurate result and to get the deep understanding of the data for better analysis. Even though I found out that I did not calculated the total time correctly 3 days before the due date, I still did my best to obtain the correct average time and present the data with accurate results as much as possible.

Reference

The table shows the elapsed time and the total time to multiply a set of 1000 random matrices of size $(2^i * i^2)$, where $i \geq 1$ by each different 3 algorithms for 20 times per each matrix.

size ($2^i; i \geq 1$)	elapsed time Classical	elapsed time Divide-and- conquer	elapsed time S	total time Classical	total time Divide-and- conquer	total time Strassen's
2*2	300	5900	5500	15	295	275
4*4	600	85300	44300	30	4265	2215
8*8	3600	659400	557200	180	32970	27860
16*16	22900	5643599	5150799	1145	282179	257539
32*32	83300	14167000	13845000	4165	708350	692250
64*64	633800	111836700	96524899	31690	5591835	4826244
Average Time				6204.167	1103316	967730.5

Note: total = elapsed time/ number of times \rightarrow elapsed time/ 20

The table shows the elapsed time and the total time to multiply a set of 100 random matrices of size $(2^i * i^2)$, where $i \geq 1$ by each different 3 algorithms for 20 times per each matrix.

size ($2^i; i \geq 1$)	elapsed time Classical	elapsed time Divide-and- conquer	elapsed time Strassen's	total time Classical	total time Divide-and- conquer	total time Strassen's
2*2	400	5900	5500	20	295	275
4*4	1400	121100	111900	70	6055	5595
8*8	1800	323000	301600	90	16150	15080
16*16	33200	5823300	3926500	1660	291165	196325
32*32	93400	15597500	14409500	4670	779875	720475
64*64	1102300	204213600	179595000	55115	10210680	8979750
128*128	6477400	990364600	723684300	323870	49518230	36184215
Average Time:				55070.71	8688921	6585959

The table shows the elapsed time and the total time to multiply a set of 10 random matrices of size $(2^i * i^2)$, where $i \geq 1$ by each different 3 algorithms for 20 times per each matrix.

size(2^i ; $i \geq 1$)	elapsed C	elapsed D	elapsed S	total C	total D	total S
2*2	400	6000	5700	20	300	285
4*4	1700	122600	85700	85	6130	4285
8*8	5300	585600	370600	265	29280	18530
16*16	68700	11060700	8121000	3435	553035	406050
32*32	149000	23866700	23441700	7450	1193335	1172085
64*64	822800	126322000	117835800	41140	6316100	5891790
128*128	5300600	945727400	710042200	265030	47286370	35502110
256*256	42119600	8234331800	5328632700	2105980	411716590	266431635
512*512	403553900	59011826300	34639596600	20177695	2950591315	1731979830
Average Time:				2511233	379743606	226822956

Full Sample Output:

```
Size: 256*256
Time taken of a data set #1 out of total data sets of 10

Time taken of Classical at trial #1is: 71812200
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Time taken of Classical at trial #17is: 47436300
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Time taken of Classical at trial #18is: 47132100
Time taken of Divide-and-conquer at trial #18is: 8439474900
Time taken of Strassen's at trial #18is: 5496904300
Time taken of Classical at trial #19is: 52989100
Time taken of Divide-and-conquer at trial #19is: 8404389401
Time taken of Strassen's at trial #19is: 5574791400
Time taken of Classical at trial #20is: 45517901
Time taken of Divide-and-conquer at trial #20is: 8351157300
Time taken of Strassen's at trial #20is: 5426886999
Average time of Classical Matrix Multiplication of a matrix #2 out of total data sets of 10 is: 51481319

Average time of Divide-and-conquer Matrix Multiplication of a matrix #2 out of total data sets of 10 is: 8624953204

Average time of Strassen's Multiplication of a matrix #2 out of total data sets of 10 is: 5889244945

Time taken of a data set #3 out of total data sets of 10

Time taken of Classical at trial #1is: 42820100
Time taken of Divide-and-conquer at trial #1is: 8413589900
Time taken of Strassen's at trial #1is: 5684298999
Time taken of Classical at trial #2is: 48961600
Time taken of Divide-and-conquer at trial #2is: 8751079501
Time taken of Strassen's at trial #2is: 5521109900
Time taken of Classical at trial #3is: 50774000
Time taken of Divide-and-conquer at trial #3is: 8537898100
Time taken of Strassen's at trial #3is: 5577864100
Time taken of Classical at trial #4is: 45303200
Time taken of Divide-and-conquer at trial #4is: 8035961700
Time taken of Strassen's at trial #4is: 5178639900
Time taken of Classical at trial #5is: 54164899
Time taken of Divide-and-conquer at trial #5is: 7821571499
Time taken of Strassen's at trial #5is: 5383150000
Time taken of Classical at trial #6is: 46041600
Time taken of Divide-and-conquer at trial #6is: 8083815900
Time taken of Strassen's at trial #6is: 5961440500
Time taken of Classical at trial #7is: 52469299
Time taken of Divide-and-conquer at trial #7is: 8645974700
Time taken of Strassen's at trial #7is: 5356375699
Time taken of Classical at trial #8is: 54443300
Time taken of Divide-and-conquer at trial #8is: 8545694000
Time taken of Strassen's at trial #8is: 5511080101
Time taken of Classical at trial #9is: 46491900
Time taken of Divide-and-conquer at trial #9is: 8567182600
Time taken of Strassen's at trial #9is: 5722143101
Time taken of Classical at trial #10is: 50631300
Time taken of Divide-and-conquer at trial #10is: 8196647301
Time taken of Strassen's at trial #10is: 5830343000
Time taken of Classical at trial #11is: 50214300
Time taken of Divide-and-conquer at trial #11is: 8436453200
Time taken of Strassen's at trial #11is: 5659473700
Time taken of Classical at trial #12is: 48968300
Time taken of Divide-and-conquer at trial #12is: 8236483800
Time taken of Strassen's at trial #12is: 6293573400
Time taken of Classical at trial #13is: 60724101
Time taken of Divide-and-conquer at trial #13is: 8414360300
Time taken of Strassen's at trial #13is: 5392698901
Time taken of Classical at trial #14is: 49388299
Time taken of Divide-and-conquer at trial #14is: 8298650799
Time taken of Strassen's at trial #14is: 5563668100
Time taken of Classical at trial #15is: 50548301
Time taken of Divide-and-conquer at trial #15is: 7874562700
Time taken of Strassen's at trial #15is: 5269362000
Time taken of Classical at trial #16is: 46637100
Time taken of Divide-and-conquer at trial #16is: 7759490399
Time taken of Strassen's at trial #16is: 5165614700
Time taken of Classical at trial #17is: 52109299
Time taken of Divide-and-conquer at trial #17is: 7749303000

Time taken of Strassen's at trial #17is: 5175697800
Time taken of Classical at trial #18is: 50624600
Time taken of Divide-and-conquer at trial #18is: 7717030900
Time taken of Strassen's at trial #18is: 5218287100
Time taken of Classical at trial #19is: 50273800
Time taken of Divide-and-conquer at trial #19is: 7828668700
Time taken of Strassen's at trial #19is: 5256924000
Time taken of Classical at trial #20is: 48834201
Time taken of Divide-and-conquer at trial #20is: 8196776400
Time taken of Strassen's at trial #20is: 5596012400
Average time of Classical Matrix Multiplication of a matrix #3 out of total data sets of 10 is: 50021174

Average time of Divide-and-conquer Matrix Multiplication of a matrix #3 out of total data sets of 10 is: 8205559769

Average time of Strassen's Multiplication of a matrix #3 out of total data sets of 10 is: 5515887870

Time taken of a data set #4 out of total data sets of 10

Time taken of Classical at trial #1is: 43587400
Time taken of Divide-and-conquer at trial #1is: 8431237000
Time taken of Strassen's at trial #1is: 5541866899
Time taken of Classical at trial #2is: 50031400
Time taken of Divide-and-conquer at trial #2is: 8424186600
Time taken of Strassen's at trial #2is: 5573973800
Time taken of Classical at trial #3is: 49587800
Time taken of Divide-and-conquer at trial #3is: 8474187701
Time taken of Strassen's at trial #3is: 5520347100
Time taken of Classical at trial #4is: 46245000
Time taken of Divide-and-conquer at trial #4is: 8212303301
Time taken of Strassen's at trial #4is: 5602714700
Time taken of Classical at trial #5is: 50389601
Time taken of Divide-and-conquer at trial #5is: 8356440799
Time taken of Strassen's at trial #5is: 6081089100
Time taken of Classical at trial #6is: 68443501
Time taken of Divide-and-conquer at trial #6is: 8852906000
Time taken of Strassen's at trial #6is: 5667127000
Time taken of Classical at trial #7is: 51419401
Time taken of Divide-and-conquer at trial #7is: 8084501500
Time taken of Strassen's at trial #7is: 5763814800
Time taken of Classical at trial #8is: 49722399
Time taken of Divide-and-conquer at trial #8is: 8591131000
Time taken of Strassen's at trial #8is: 6632471801
Time taken of Classical at trial #9is: 113331501
Time taken of Divide-and-conquer at trial #9is: 12592648000
Time taken of Strassen's at trial #9is: 7468369299
Time taken of Classical at trial #10is: 94805300
Time taken of Divide-and-conquer at trial #10is: 9232256300
Time taken of Strassen's at trial #10is: 6089710699
Time taken of Classical at trial #11is: 46263800
Time taken of Divide-and-conquer at trial #11is: 9399621200
Time taken of Strassen's at trial #11is: 5762522500
Time taken of Classical at trial #12is: 55026800
Time taken of Divide-and-conquer at trial #12is: 8690729601
Time taken of Strassen's at trial #12is: 5503681899
Time taken of Classical at trial #13is: 49529000
Time taken of Divide-and-conquer at trial #13is: 8293594001
Time taken of Strassen's at trial #13is: 5606156100
Time taken of Classical at trial #14is: 48108700
Time taken of Divide-and-conquer at trial #14is: 8520868400
Time taken of Strassen's at trial #14is: 5576792800
Time taken of Classical at trial #15is: 53269399
Time taken of Divide-and-conquer at trial #15is: 8635555201
Time taken of Strassen's at trial #15is: 5658760400
Time taken of Classical at trial #16is: 48074400
Time taken of Divide-and-conquer at trial #16is: 8592093900
Time taken of Strassen's at trial #16is: 5672749799
Time taken of Classical at trial #17is: 52279400
Time taken of Divide-and-conquer at trial #17is: 8310319601
Time taken of Strassen's at trial #17is: 5912839300
Time taken of Classical at trial #18is: 47635601
Time taken of Divide-and-conquer at trial #18is: 8317645800
Time taken of Strassen's at trial #18is: 5678019000

Time taken of Classical at trial #19is: 45521400
Time taken of Divide-and-conquer at trial #19is: 8349069700
Time taken of Strassen's at trial #19is: 5641872200
Time taken of Classical at trial #20is: 49735099
Time taken of Divide-and-conquer at trial #20is: 8591562799
Time taken of Strassen's at trial #20is: 5688719201
Average time of Classical Matrix Multiplication of a matrix #4 out of total data sets of 10 is: 55650345

Average time of Divide-and-conquer Matrix Multiplication of a matrix #4 out of total data sets of 10 is: 8747642920

Average time of Strassen's Multiplication of a matrix #4 out of total data sets of 10 is: 5832179919

Time taken of a data set #5 out of total data sets of 10

Time taken of Classical at trial #1is: 54928399
Time taken of Divide-and-conquer at trial #1is: 8424569100
Time taken of Strassen's at trial #1is: 5452759300
Time taken of Classical at trial #2is: 55579599
Time taken of Divide-and-conquer at trial #2is: 8138002700
Time taken of Strassen's at trial #2is: 5387724500
Time taken of Classical at trial #3is: 51250701
Time taken of Divide-and-conquer at trial #3is: 8103030500
Time taken of Strassen's at trial #3is: 5628304600
Time taken of Classical at trial #4is: 48171301
Time taken of Divide-and-conquer at trial #4is: 8370258899
Time taken of Strassen's at trial #4is: 6067365799
Time taken of Classical at trial #5is: 58615200
Time taken of Divide-and-conquer at trial #5is: 8438023200
Time taken of Strassen's at trial #5is: 5453137900
Time taken of Classical at trial #6is: 53968600
Time taken of Divide-and-conquer at trial #6is: 8930380000
Time taken of Strassen's at trial #6is: 5708531900
Time taken of Classical at trial #7is: 46077301
Time taken of Divide-and-conquer at trial #7is: 8459682500
Time taken of Strassen's at trial #7is: 5514491101
Time taken of Classical at trial #8is: 46233499
Time taken of Divide-and-conquer at trial #8is: 8315492500
Time taken of Strassen's at trial #8is: 5961295801
Time taken of Classical at trial #9is: 47801400
Time taken of Divide-and-conquer at trial #9is: 8075470300
Time taken of Strassen's at trial #9is: 5416681900
Time taken of Classical at trial #10is: 49031300
Time taken of Divide-and-conquer at trial #10is: 8221217600
Time taken of Strassen's at trial #10is: 5725997000
Time taken of Classical at trial #11is: 45208200
Time taken of Divide-and-conquer at trial #11is: 8358952501
Time taken of Strassen's at trial #11is: 5575914200
Time taken of Classical at trial #12is: 47010901
Time taken of Divide-and-conquer at trial #12is: 8344308900
Time taken of Strassen's at trial #12is: 5455257099
Time taken of Classical at trial #13is: 46003700
Time taken of Divide-and-conquer at trial #13is: 8017862400
Time taken of Strassen's at trial #13is: 5486266600
Time taken of Classical at trial #14is: 50385000
Time taken of Divide-and-conquer at trial #14is: 8442873100
Time taken of Strassen's at trial #14is: 5362412301
Time taken of Classical at trial #15is: 64924700
Time taken of Divide-and-conquer at trial #15is: 7981433300
Time taken of Strassen's at trial #15is: 5738375200
Time taken of Classical at trial #16is: 47981099
Time taken of Divide-and-conquer at trial #16is: 8234044501
Time taken of Strassen's at trial #16is: 6001706599
Time taken of Classical at trial #17is: 47446600
Time taken of Divide-and-conquer at trial #17is: 8068233000
Time taken of Strassen's at trial #17is: 5487711800
Time taken of Classical at trial #18is: 46256400
Time taken of Divide-and-conquer at trial #18is: 8499342700
Time taken of Strassen's at trial #18is: 5678741799
Time taken of Classical at trial #19is: 49124601
Time taken of Divide-and-conquer at trial #19is: 8354596600
Time taken of Strassen's at trial #19is: 6132806400
Time taken of Classical at trial #20is: 55251599

Time taken of Divide-and-conquer at trial #20is: 8181481499
Time taken of Strassen's at trial #20is: 5346342399
Average time of Classical Matrix Multiplication of a matrix #5 out of total data sets of 10 is: 50562505

Average time of Divide-and-conquer Matrix Multiplication of a matrix #5 out of total data sets of 10 is: 8297962790

Average time of Strassen's Multiplication of a matrix #5 out of total data sets of 10 is: 5629091209

Time taken of a data set #6 out of total data sets of 10

Time taken of Classical at trial #1is: 46842800
Time taken of Divide-and-conquer at trial #1is: 8259726800
Time taken of Strassen's at trial #1is: 5621041499
Time taken of Classical at trial #2is: 48389400
Time taken of Divide-and-conquer at trial #2is: 8315057799
Time taken of Strassen's at trial #2is: 5600144600
Time taken of Classical at trial #3is: 47454499
Time taken of Divide-and-conquer at trial #3is: 8214882300
Time taken of Strassen's at trial #3is: 5743433400
Time taken of Classical at trial #4is: 50938999
Time taken of Divide-and-conquer at trial #4is: 8772184200
Time taken of Strassen's at trial #4is: 5522462099
Time taken of Classical at trial #5is: 64550400
Time taken of Divide-and-conquer at trial #5is: 8500343400
Time taken of Strassen's at trial #5is: 5502527799
Time taken of Classical at trial #6is: 47158300
Time taken of Divide-and-conquer at trial #6is: 7975120500
Time taken of Strassen's at trial #6is: 5444750800
Time taken of Classical at trial #7is: 48122199
Time taken of Divide-and-conquer at trial #7is: 8997946799
Time taken of Strassen's at trial #7is: 6596021600
Time taken of Classical at trial #8is: 69524600
Time taken of Divide-and-conquer at trial #8is: 8350114500
Time taken of Strassen's at trial #8is: 5130516300
Time taken of Classical at trial #9is: 45900401
Time taken of Divide-and-conquer at trial #9is: 7995492401
Time taken of Strassen's at trial #9is: 5498894999
Time taken of Classical at trial #10is: 55962700
Time taken of Divide-and-conquer at trial #10is: 8207615100
Time taken of Strassen's at trial #10is: 5467414301
Time taken of Classical at trial #11is: 47318200
Time taken of Divide-and-conquer at trial #11is: 8403672900
Time taken of Strassen's at trial #11is: 5280353499
Time taken of Classical at trial #12is: 47577000
Time taken of Divide-and-conquer at trial #12is: 8411874999
Time taken of Strassen's at trial #12is: 555287601
Time taken of Classical at trial #13is: 47404799
Time taken of Divide-and-conquer at trial #13is: 8316299200
Time taken of Strassen's at trial #13is: 5351397600
Time taken of Classical at trial #14is: 45894500
Time taken of Divide-and-conquer at trial #14is: 8162559599
Time taken of Strassen's at trial #14is: 5635370701
Time taken of Classical at trial #15is: 51593099
Time taken of Divide-and-conquer at trial #15is: 8252375799
Time taken of Strassen's at trial #15is: 5489538800
Time taken of Classical at trial #16is: 47530701
Time taken of Divide-and-conquer at trial #16is: 7988359300
Time taken of Strassen's at trial #16is: 5404510499
Time taken of Classical at trial #17is: 48334500
Time taken of Divide-and-conquer at trial #17is: 8757214199
Time taken of Strassen's at trial #17is: 6529103200
Time taken of Classical at trial #18is: 48938100
Time taken of Divide-and-conquer at trial #18is: 8891080400
Time taken of Strassen's at trial #18is: 5763425100
Time taken of Classical at trial #19is: 47966099
Time taken of Divide-and-conquer at trial #19is: 8115771699
Time taken of Strassen's at trial #19is: 5609508200
Time taken of Classical at trial #20is: 46428000
Time taken of Divide-and-conquer at trial #20is: 8567294500
Time taken of Strassen's at trial #20is: 5566406800
Average time of Classical Matrix Multiplication of a matrix #6 out of total data sets of 10 is: 50191464

Average time of Divide-and-conquer Matrix Multiplication of a matrix #6 out of total data sets of 10 is: 8372749319

Average time of Strassen's Multiplication of a matrix #6 out of total data sets of 10 is: 5615605469

Time taken of a data set #7 out of total data sets of 10

Time taken of Classical at trial #1is: 46687600
Time taken of Divide-and-conquer at trial #1is: 8631003799
Time taken of Strassen's at trial #1is: 5932292901
Time taken of Classical at trial #2is: 52232301
Time taken of Divide-and-conquer at trial #2is: 8785809099
Time taken of Strassen's at trial #2is: 5764720501
Time taken of Classical at trial #3is: 48586200
Time taken of Divide-and-conquer at trial #3is: 8499349099
Time taken of Strassen's at trial #3is: 5742516200
Time taken of Classical at trial #4is: 53005000
Time taken of Divide-and-conquer at trial #4is: 8630329000
Time taken of Strassen's at trial #4is: 5548733400
Time taken of Classical at trial #5is: 47189100
Time taken of Divide-and-conquer at trial #5is: 8840390200
Time taken of Strassen's at trial #5is: 5775832200
Time taken of Classical at trial #6is: 46476500
Time taken of Divide-and-conquer at trial #6is: 8962378601
Time taken of Strassen's at trial #6is: 5776178100
Time taken of Classical at trial #7is: 49013501
Time taken of Divide-and-conquer at trial #7is: 8319129000
Time taken of Strassen's at trial #7is: 5799999500
Time taken of Classical at trial #8is: 52977601
Time taken of Divide-and-conquer at trial #8is: 8489800501
Time taken of Strassen's at trial #8is: 5597718701
Time taken of Classical at trial #9is: 50541399
Time taken of Divide-and-conquer at trial #9is: 8689376800
Time taken of Strassen's at trial #9is: 5964651800
Time taken of Classical at trial #10is: 52400601
Time taken of Divide-and-conquer at trial #10is: 8950053700
Time taken of Strassen's at trial #10is: 5816813201
Time taken of Classical at trial #11is: 50197501
Time taken of Divide-and-conquer at trial #11is: 8629356199
Time taken of Strassen's at trial #11is: 5764793499
Time taken of Classical at trial #12is: 59096700
Time taken of Divide-and-conquer at trial #12is: 8548439100
Time taken of Strassen's at trial #12is: 5864086400
Time taken of Classical at trial #13is: 71586000
Time taken of Divide-and-conquer at trial #13is: 8826625800
Time taken of Strassen's at trial #13is: 5772269401
Time taken of Classical at trial #14is: 48905300
Time taken of Divide-and-conquer at trial #14is: 8445129200
Time taken of Strassen's at trial #14is: 5534656099
Time taken of Classical at trial #15is: 48646599
Time taken of Divide-and-conquer at trial #15is: 8818470800
Time taken of Strassen's at trial #15is: 5540523200
Time taken of Classical at trial #16is: 45773400
Time taken of Divide-and-conquer at trial #16is: 8639557601
Time taken of Strassen's at trial #16is: 5639830301
Time taken of Classical at trial #17is: 51012700
Time taken of Divide-and-conquer at trial #17is: 9030553900
Time taken of Strassen's at trial #17is: 5792473000
Time taken of Classical at trial #18is: 47551000
Time taken of Divide-and-conquer at trial #18is: 8395613400
Time taken of Strassen's at trial #18is: 5590440500
Time taken of Classical at trial #19is: 46408500
Time taken of Divide-and-conquer at trial #19is: 8498791000
Time taken of Strassen's at trial #19is: 5674296499
Time taken of Classical at trial #20is: 48840100
Time taken of Divide-and-conquer at trial #20is: 8658764100
Time taken of Strassen's at trial #20is: 5765225300

Average time of Classical Matrix Multiplication of a matrix #7 out of total data sets of 10 is: 50856380

Average time of Divide-and-conquer Matrix Multiplication of a matrix #7 out of total data sets of 10 is: 8664446044

Average time of Strassen's Multiplication of a matrix #7 out of total data sets of 10 is: 5732902535

Time taken of a data set #8 out of total data sets of 10

Time taken of Classical at trial #1is: 47625800
Time taken of Divide-and-conquer at trial #1is: 8423753000
Time taken of Strassen's at trial #1is: 5829467700
Time taken of Classical at trial #2is: 63566800
Time taken of Divide-and-conquer at trial #2is: 8280533700
Time taken of Strassen's at trial #2is: 5282542201
Time taken of Classical at trial #3is: 47686800
Time taken of Divide-and-conquer at trial #3is: 7871945999
Time taken of Strassen's at trial #3is: 5155653700
Time taken of Classical at trial #4is: 49247499
Time taken of Divide-and-conquer at trial #4is: 7864629000
Time taken of Strassen's at trial #4is: 5141064401
Time taken of Classical at trial #5is: 47144599
Time taken of Divide-and-conquer at trial #5is: 7841583600
Time taken of Strassen's at trial #5is: 5158990500
Time taken of Classical at trial #6is: 47722500
Time taken of Divide-and-conquer at trial #6is: 8494779301
Time taken of Strassen's at trial #6is: 5381907500
Time taken of Classical at trial #7is: 49597601
Time taken of Divide-and-conquer at trial #7is: 8310318700
Time taken of Strassen's at trial #7is: 5828986501
Time taken of Classical at trial #8is: 48023200
Time taken of Divide-and-conquer at trial #8is: 8762166499
Time taken of Strassen's at trial #8is: 7527562000
Time taken of Classical at trial #9is: 48079201
Time taken of Divide-and-conquer at trial #9is: 10835362299
Time taken of Strassen's at trial #9is: 5742003900
Time taken of Classical at trial #10is: 49884000
Time taken of Divide-and-conquer at trial #10is: 8909641399
Time taken of Strassen's at trial #10is: 6225473100
Time taken of Classical at trial #11is: 79004600
Time taken of Divide-and-conquer at trial #11is: 8290817299
Time taken of Strassen's at trial #11is: 5950339701
Time taken of Classical at trial #12is: 53772800
Time taken of Divide-and-conquer at trial #12is: 8848694300
Time taken of Strassen's at trial #12is: 5714475300
Time taken of Classical at trial #13is: 52171900
Time taken of Divide-and-conquer at trial #13is: 8615465299
Time taken of Strassen's at trial #13is: 5678980799
Time taken of Classical at trial #14is: 57042400
Time taken of Divide-and-conquer at trial #14is: 8531501100
Time taken of Strassen's at trial #14is: 5321206100
Time taken of Classical at trial #15is: 50423700
Time taken of Divide-and-conquer at trial #15is: 7977948199
Time taken of Strassen's at trial #15is: 5296590501
Time taken of Classical at trial #16is: 48415201
Time taken of Divide-and-conquer at trial #16is: 7936383100
Time taken of Strassen's at trial #16is: 5167510200
Time taken of Classical at trial #17is: 48630899
Time taken of Divide-and-conquer at trial #17is: 7797990501
Time taken of Strassen's at trial #17is: 6556902301
Time taken of Classical at trial #18is: 86431600
Time taken of Divide-and-conquer at trial #18is: 9833435400
Time taken of Strassen's at trial #18is: 6824628999
Time taken of Classical at trial #19is: 55722301
Time taken of Divide-and-conquer at trial #19is: 8832017500
Time taken of Strassen's at trial #19is: 6813440601
Time taken of Classical at trial #20is: 80876600
Time taken of Divide-and-conquer at trial #20is: 9295071099
Time taken of Strassen's at trial #20is: 5726171699
Average time of Classical Matrix Multiplication of a matrix #8 out of total data sets of 10 is: 55553500

Average time of Divide-and-conquer Matrix Multiplication of a matrix #8 out of total data sets of 10 is: 8577701864

Average time of Strassen's Multiplication of a matrix #8 out of total data sets of 10 is: 5816194885

Time taken of a data set #9 out of total data sets of 10

Time taken of Classical at trial #1is: 61523600

Time taken of Divide-and-conquer at trial #1is: 8903132800
Time taken of Strassen's at trial #1is: 6333841900
Time taken of Classical at trial #2is: 51246400
Time taken of Divide-and-conquer at trial #2is: 8926022601
Time taken of Strassen's at trial #2is: 6157892400
Time taken of Classical at trial #3is: 47809299
Time taken of Divide-and-conquer at trial #3is: 9241442401
Time taken of Strassen's at trial #3is: 6242135000
Time taken of Classical at trial #4is: 60790001
Time taken of Divide-and-conquer at trial #4is: 8978065100
Time taken of Strassen's at trial #4is: 6239470099
Time taken of Classical at trial #5is: 56427300
Time taken of Divide-and-conquer at trial #5is: 9570190000
Time taken of Strassen's at trial #5is: 6347914900
Time taken of Classical at trial #6is: 48331500
Time taken of Divide-and-conquer at trial #6is: 9076115500
Time taken of Strassen's at trial #6is: 6327317801
Time taken of Classical at trial #7is: 51033300
Time taken of Divide-and-conquer at trial #7is: 9422072900
Time taken of Strassen's at trial #7is: 6510699601
Time taken of Classical at trial #8is: 51529800
Time taken of Divide-and-conquer at trial #8is: 8873313800
Time taken of Strassen's at trial #8is: 5669665400
Time taken of Classical at trial #9is: 52341299
Time taken of Divide-and-conquer at trial #9is: 8509819599
Time taken of Strassen's at trial #9is: 5771143599
Time taken of Classical at trial #10is: 50575901
Time taken of Divide-and-conquer at trial #10is: 8197821500
Time taken of Strassen's at trial #10is: 5647053300
Time taken of Classical at trial #11is: 47176900
Time taken of Divide-and-conquer at trial #11is: 8409985600
Time taken of Strassen's at trial #11is: 5893767201
Time taken of Classical at trial #12is: 50863000
Time taken of Divide-and-conquer at trial #12is: 8072806699
Time taken of Strassen's at trial #12is: 5488715001
Time taken of Classical at trial #13is: 48895901
Time taken of Divide-and-conquer at trial #13is: 8274611100
Time taken of Strassen's at trial #13is: 5732788301
Time taken of Classical at trial #14is: 46950700
Time taken of Divide-and-conquer at trial #14is: 7885120000
Time taken of Strassen's at trial #14is: 5398715100
Time taken of Classical at trial #15is: 50015101
Time taken of Divide-and-conquer at trial #15is: 8256762301
Time taken of Strassen's at trial #15is: 5643003000
Time taken of Classical at trial #16is: 49854400
Time taken of Divide-and-conquer at trial #16is: 8225033800
Time taken of Strassen's at trial #16is: 5239231399
Time taken of Classical at trial #17is: 47861200
Time taken of Divide-and-conquer at trial #17is: 7986802499
Time taken of Strassen's at trial #17is: 5241974900
Time taken of Classical at trial #18is: 49166300
Time taken of Divide-and-conquer at trial #18is: 8041346601
Time taken of Strassen's at trial #18is: 5531332200
Time taken of Classical at trial #19is: 47770699
Time taken of Divide-and-conquer at trial #19is: 8409179199
Time taken of Strassen's at trial #19is: 5786405500
Time taken of Classical at trial #20is: 46438200
Time taken of Divide-and-conquer at trial #20is: 7902325800
Time taken of Strassen's at trial #20is: 5339353100
Average time of Classical Matrix Multiplication of a matrix #9 out of total data sets of 10 is: 50830040

Average time of Divide-and-conquer Matrix Multiplication of a matrix #9 out of total data sets of 10 is: 8558098490

Average time of Strassen's Multiplication of a matrix #9 out of total data sets of 10 is: 5827120985

Time taken of a data set #10 out of total data sets of 10

Time taken of Classical at trial #1is: 43569400
Time taken of Divide-and-conquer at trial #1is: 8027275600
Time taken of Strassen's at trial #1is: 5326486101
Time taken of Classical at trial #2is: 48403700
Time taken of Divide-and-conquer at trial #2is: 7920961301

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Time taken of Strassen's at trial #2is: 5630752501
Time taken of Classical at trial #3is: 54074901
Time taken of Divide-and-conquer at trial #3is: 10352023200
Time taken of Strassen's at trial #3is: 8011734000
Time taken of Classical at trial #4is: 48086400
Time taken of Divide-and-conquer at trial #4is: 7728679600
Time taken of Strassen's at trial #4is: 5181416501
Time taken of Classical at trial #5is: 45475100
Time taken of Divide-and-conquer at trial #5is: 7716295400
Time taken of Strassen's at trial #5is: 5095380800
Time taken of Classical at trial #6is: 44838800
Time taken of Divide-and-conquer at trial #6is: 7472704501
Time taken of Strassen's at trial #6is: 4873557099
Time taken of Classical at trial #7is: 54285699
Time taken of Divide-and-conquer at trial #7is: 7478846400
Time taken of Strassen's at trial #7is: 4992229600
Time taken of Classical at trial #8is: 45430400
Time taken of Divide-and-conquer at trial #8is: 7543414799
Time taken of Strassen's at trial #8is: 4964787500
Time taken of Classical at trial #9is: 48929700
Time taken of Divide-and-conquer at trial #9is: 13202185201
Time taken of Strassen's at trial #9is: 6653002200
Time taken of Classical at trial #10is: 47203500
Time taken of Divide-and-conquer at trial #10is: 10500658801
Time taken of Strassen's at trial #10is: 6985897001
Time taken of Classical at trial #11is: 64140100
Time taken of Divide-and-conquer at trial #11is: 10425273100
Time taken of Strassen's at trial #11is: 7687646801
Time taken of Classical at trial #12is: 62341800
Time taken of Divide-and-conquer at trial #12is: 10635922300
Time taken of Strassen's at trial #12is: 7357940301
Time taken of Classical at trial #13is: 65318400
Time taken of Divide-and-conquer at trial #13is: 10664083700
Time taken of Strassen's at trial #13is: 8602663700
Time taken of Classical at trial #14is: 66186700
Time taken of Divide-and-conquer at trial #14is: 11450148500
Time taken of Strassen's at trial #14is: 6830301300
Time taken of Classical at trial #15is: 79337100
Time taken of Divide-and-conquer at trial #15is: 10575840800
Time taken of Strassen's at trial #15is: 7897884000
Time taken of Classical at trial #16is: 63895500
Time taken of Divide-and-conquer at trial #16is: 10610610801
Time taken of Strassen's at trial #16is: 7441709399
Time taken of Classical at trial #17is: 77796000
Time taken of Divide-and-conquer at trial #17is: 13124098000
Time taken of Strassen's at trial #17is: 9246056700
Time taken of Classical at trial #18is: 62354700
Time taken of Divide-and-conquer at trial #18is: 11058085700
Time taken of Strassen's at trial #18is: 6924438901
Time taken of Classical at trial #19is: 62629099
Time taken of Divide-and-conquer at trial #19is: 11335994800
Time taken of Strassen's at trial #19is: 6990223600
Time taken of Classical at trial #20is: 64669900
Time taken of Divide-and-conquer at trial #20is: 10565036000
Time taken of Strassen's at trial #20is: 6883004300
Average time of Classical Matrix Multiplication of a matrix #10 out of total data sets of 10 is: 57448344

Average time of Divide-and-conquer Matrix Multiplication of a matrix #10 out of total data sets of 10 is:
9919406925

Average time of Strassen's Multiplication of a matrix #10 out of total data sets of 10 is: 6678855615

-----The total time of each algorithm-----
Total time of Classical Matrix Multiplication is: 51765073
Total time of Divide-and-conquer Matrix Multiplication is: 8669661134
Total time of Strassen's Multiplication is: 5831838322

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