Sri Lanka Institute of Information Technology

BSc (Hons) in Computer Science

Year 3 Semester 1

SE3082 - Parallel Computing

Assignment 3 - Parallelized Matrix Multiplication - Appendices

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Contents

Appendix A - Small Matrix Execution

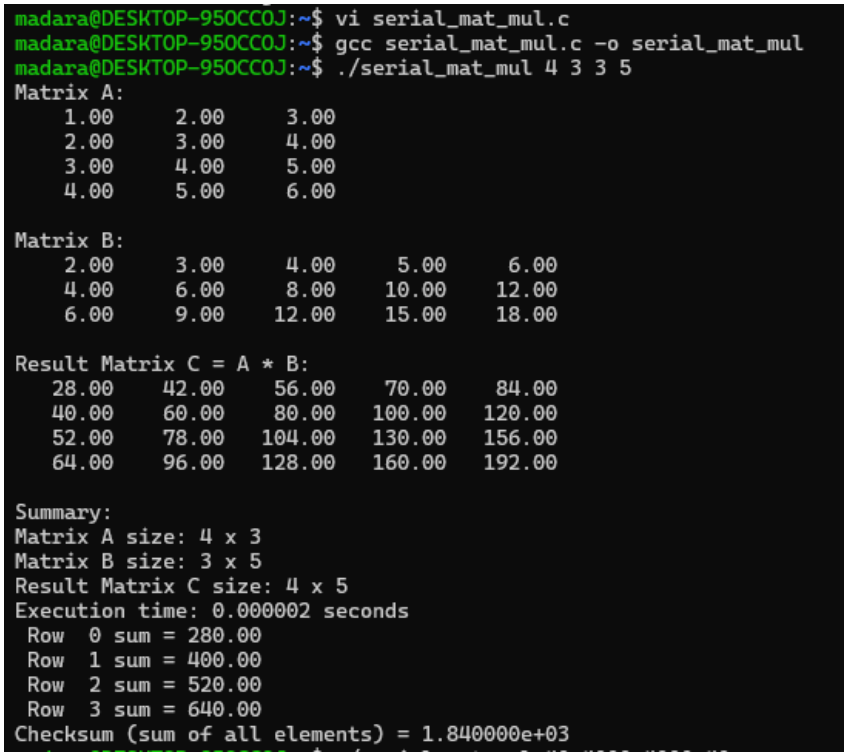
Details

- All dimensions ≤ 10 → program prints full matrices A, B and C
- Useful for verifying correctness manually
- Includes row-wise sums and checksum

Examples

Serial

./serial_mat_mul 4 3 3 5



OpenMP

./openmp_mat_mul 4 3 3 5 4

```
madara@DESKTOP-95OCCOJ:~$ gcc -O3 -fopenmp openmp_mat_mul.c -o o
penmp_mat_mul
madara@DESKTOP-95OCCOJ:~$ ./openmp_mat_mul 4 3 3 5 4
Matrix A:
    1.00     2.00     3.00
    2.00     3.00     4.00
    3.00     4.00     5.00
    4.00     5.00     6.00

Matrix B:
    2.00     3.00     4.00     5.00     6.00
    4.00     6.00     8.00    10.00    12.00
    6.00     9.00    12.00    15.00    18.00

Result Matrix C = A * B:
   28.00    42.00    56.00    70.00    84.00
   40.00    60.00    80.00   100.00   120.00
   52.00    78.00   104.00   130.00   156.00
   64.00    96.00   128.00   160.00   192.00

Summary:
Matrix A size: 4 x 3
Matrix B size: 3 x 5
Result Matrix C size: 4 x 5
Threads used: 4
Execution time: 0.000468 seconds
Row  0 sum = 280.00
Row  1 sum = 400.00
Row  2 sum = 520.00
Row  3 sum = 640.00
Checksum (sum of all elements) = 1.840000e+03
```

MPI

mpirun -np 4 ./mpi_mat_mul 4 3 3 5

```
madara@DESKTOP-95OCCOJ:~$ vi mpi_mat_mul.c
madara@DESKTOP-95OCCOJ:~$ mpicc -O3 mpi_mat_mul.c -o mpi_mat_mul
madara@DESKTOP-95OCCOJ:~$ mpirun --allow-run-as-root --oversubscribe -np 4 ./mpi_mat_mul 4 3 3 5
Matrix A:
    1.00     2.00     3.00
    2.00     3.00     4.00
    3.00     4.00     5.00
    4.00     5.00     6.00

Matrix B:
    2.00     3.00     4.00     5.00     6.00
    4.00     6.00     8.00    10.00    12.00
    6.00     9.00    12.00    15.00    18.00

Result Matrix C = A*B:
   28.00    42.00    56.00    70.00    84.00
   40.00    60.00    80.00   100.00   120.00
   52.00    78.00   104.00   130.00   156.00
   64.00    96.00   128.00   160.00   192.00

Summary:
Matrix A size: 4 x 3
Matrix B size: 3 x 5
Result Matrix C size: 4 x 5
Execution time(seconds): 0.000000
 Row  0 sum = 280.00
 Row  1 sum = 400.00
 Row  2 sum = 520.00
 Row  3 sum = 640.00
Checksum (sum of all elements)= 1.840000e+03
```

CUDA

./cuda_mat_mul 4 3 3 5 16

```
!./cuda_mat_mul 4 3 3 5 4

Matrix A:
    1.00     2.00     3.00
    2.00     3.00     4.00
    3.00     4.00     5.00
    4.00     5.00     6.00

Matrix B:
    2.00     3.00     4.00     5.00     6.00
    4.00     6.00     8.00    10.00    12.00
    6.00     9.00    12.00    15.00    18.00

Result Matrix C = A * B:
   28.00    42.00    56.00    70.00    84.00
   40.00    60.00    80.00   100.00   120.00
   52.00    78.00   104.00   130.00   156.00
   64.00    96.00   128.00   160.00   192.00

Summary:
Matrix A size: 4 x 3
Matrix B size: 3 x 5
Result Matrix C size: 4 x 5
Execution time(seconds): 0.000154
 Row  0 sum = 280.00
 Row  1 sum = 400.00
 Row  2 sum = 520.00
 Row  3 sum = 640.00
Checksum (sum of all elements) = 1.840000e+03
```

Appendix B - Medium Matrix Execution

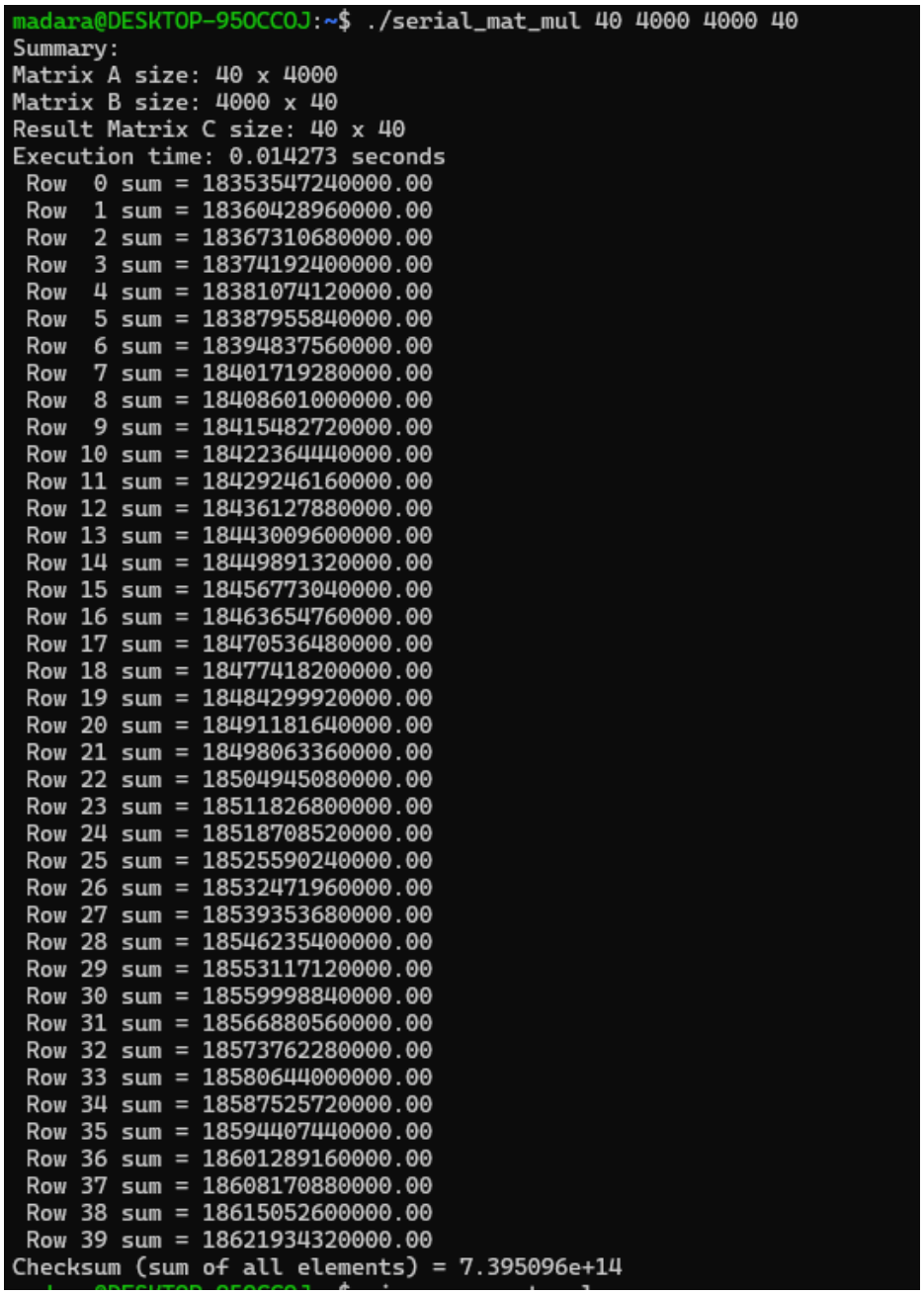
Details

- Dimensions > 10 → Matrices are not printed
- Dimensions ≤ 50 → Row sums are printed
- Suitable for verifying correctness without printing massive outputs
- Shows execution time and checksum

Examples

Serial

./serial_mat_mul 40 4000 4000 40



OpenMP

./openmp_mat_mul 40 4000 4000 40 **2**

```
madara@DESKTOP-95OCCOJ:~$ gcc -O3 -fopenmp openmp_mat_mul.c -o openmp_mat_mul
madara@DESKTOP-95OCCOJ:~$ ./openmp_mat_mul 40 4000 4000 40 2
Summary:
Matrix A size: 40 x 4000
Matrix B size: 4000 x 40
Result Matrix C size: 40 x 40
Threads used: 2
Execution time: 0.002370 seconds
Row  0 sum = 18353547240000.00
Row  1 sum = 18360428960000.00
Row  2 sum = 18367310680000.00
Row  3 sum = 18374192400000.00
Row  4 sum = 18381074120000.00
Row  5 sum = 18387955840000.00
Row  6 sum = 18394837560000.00
Row  7 sum = 18401719280000.00
Row  8 sum = 18408601000000.00
Row  9 sum = 18415482720000.00
Row 10 sum = 18422364440000.00
Row 11 sum = 18429246160000.00
Row 12 sum = 18436127880000.00
Row 13 sum = 18443009600000.00
Row 14 sum = 18449891320000.00
Row 15 sum = 18456773040000.00
Row 16 sum = 18463654760000.00
Row 17 sum = 18470536480000.00
Row 18 sum = 18477418200000.00
Row 19 sum = 18484299920000.00
Row 20 sum = 18491181640000.00
Row 21 sum = 18498063360000.00
Row 22 sum = 18504945080000.00
Row 23 sum = 18511826800000.00
Row 24 sum = 18518708520000.00
Row 25 sum = 18525590240000.00
Row 26 sum = 18532471960000.00
Row 27 sum = 18539353680000.00
Row 28 sum = 18546235400000.00
Row 29 sum = 18553117120000.00
Row 30 sum = 18559998840000.00
Row 31 sum = 18566880560000.00
Row 32 sum = 18573762280000.00
Row 33 sum = 18580644000000.00
Row 34 sum = 18587525720000.00
Row 35 sum = 18594407440000.00
Row 36 sum = 18601289160000.00
Row 37 sum = 18608170880000.00
Row 38 sum = 18615052600000.00
Row 39 sum = 18621934320000.00
Checksum (sum of all elements) = 7.395096e+14
```

./openmp_mat_mul 40 4000 4000 40 **4**

```
madara@DESKTOP-95OCCOJ:~$ gcc -O3 -fopenmp openmp_mat_mul.c -o openmp_mat_mul
madara@DESKTOP-95OCCOJ:~$ ./openmp_mat_mul 40 4000 4000 40 4
Summary:
Matrix A size: 40 x 4000
Matrix B size: 4000 x 40
Result Matrix C size: 40 x 40
Threads used: 4
Execution time: 0.001142 seconds
Row  0 sum = 18353547240000.00
Row  1 sum = 18360428960000.00
Row  2 sum = 18367310680000.00
Row  3 sum = 18374192400000.00
Row  4 sum = 18381074120000.00
Row  5 sum = 18387955840000.00
Row  6 sum = 18394837560000.00
Row  7 sum = 18401719280000.00
Row  8 sum = 18408601000000.00
Row  9 sum = 18415482720000.00
Row 10 sum = 18422364440000.00
Row 11 sum = 18429246160000.00
Row 12 sum = 18436127880000.00
Row 13 sum = 18443009600000.00
Row 14 sum = 18449891320000.00
Row 15 sum = 18456773040000.00
Row 16 sum = 18463654760000.00
Row 17 sum = 18470536480000.00
Row 18 sum = 18477418200000.00
Row 19 sum = 18484299920000.00
Row 20 sum = 18491181640000.00
Row 21 sum = 18498063360000.00
Row 22 sum = 18504945080000.00
Row 23 sum = 18511826800000.00
Row 24 sum = 18518708520000.00
Row 25 sum = 18525590240000.00
Row 26 sum = 18532471960000.00
Row 27 sum = 18539353680000.00
Row 28 sum = 18546235400000.00
Row 29 sum = 18553117120000.00
Row 30 sum = 18559998840000.00
Row 31 sum = 18566880560000.00
Row 32 sum = 18573762280000.00
Row 33 sum = 18580644000000.00
Row 34 sum = 18587525720000.00
Row 35 sum = 18594407440000.00
Row 36 sum = 18601289160000.00
Row 37 sum = 18608170880000.00
Row 38 sum = 18615052600000.00
Row 39 sum = 18621934320000.00
Checksum (sum of all elements) = 7.395096e+14
```

MPI

mpirun -np **2** ./mpi_mat_mul 40 4000 4000 40

```
madara@DESKTOP-95OCCOJ:~$ vi mpi_mat_mul.c
madara@DESKTOP-95OCCOJ:~$ mpicc -O3 mpi_mat_mul.c -o mpi_mat_mul
madara@DESKTOP-95OCCOJ:~$ mpirun --allow-run-as-root --oversubscribe -np 2 ./mpi_mat_mul 40 4000 4000 40
Summary:
Matrix A size: 40 x 4000
Matrix B size: 4000 x 40
Result Matrix C size: 40 x 40
Execution time(seconds): 0.003465
 Row  0 sum = 18353547240000.00
 Row  1 sum = 18360428960000.00
 Row  2 sum = 18367310680000.00
 Row  3 sum = 18374192400000.00
 Row  4 sum = 18381074120000.00
 Row  5 sum = 18387955840000.00
 Row  6 sum = 18394837560000.00
 Row  7 sum = 18401719280000.00
 Row  8 sum = 18408601000000.00
 Row  9 sum = 18415482720000.00
 Row 10 sum = 18422364440000.00
 Row 11 sum = 18429246160000.00
 Row 12 sum = 18436127880000.00
 Row 13 sum = 18443009600000.00
 Row 14 sum = 18449891320000.00
 Row 15 sum = 18456773040000.00
 Row 16 sum = 18463654760000.00
 Row 17 sum = 18470536480000.00
 Row 18 sum = 18477418200000.00
 Row 19 sum = 18484299920000.00
 Row 20 sum = 18491181640000.00
 Row 21 sum = 18498063360000.00
 Row 22 sum = 18504945080000.00
 Row 23 sum = 18511826800000.00
 Row 24 sum = 18518708520000.00
 Row 25 sum = 18525590240000.00
 Row 26 sum = 18532471960000.00
 Row 27 sum = 18539353680000.00
 Row 28 sum = 18546235400000.00
 Row 29 sum = 18553117120000.00
 Row 30 sum = 18559998840000.00
 Row 31 sum = 18566880560000.00
 Row 32 sum = 18573762280000.00
 Row 33 sum = 18580644000000.00
 Row 34 sum = 18587525720000.00
 Row 35 sum = 18594407440000.00
 Row 36 sum = 18601289160000.00
 Row 37 sum = 18608170880000.00
 Row 38 sum = 18615052600000.00
 Row 39 sum = 18621934320000.00
Checksum (sum of all elements)= 7.395096e+14
```

mpirun -np 4 ./mpi_mat_mul 40 4000 4000 40

```
madara@DESKTOP-95OCCOJ:~$ mpirun --allow-run-as-root --oversubscribe -np 4 ./mpi_mat_mul 40 4000 4000 40
Summary:
Matrix A size: 40 x 4000
Matrix B size: 4000 x 40
Result Matrix C size: 40 x 40
Execution time(seconds): 0.001987
 Row  0 sum = 18353547240000.00
 Row  1 sum = 18360428960000.00
 Row  2 sum = 18367310680000.00
 Row  3 sum = 18374192400000.00
 Row  4 sum = 18381074120000.00
 Row  5 sum = 18387955840000.00
 Row  6 sum = 18394837560000.00
 Row  7 sum = 18401719280000.00
 Row  8 sum = 18408601000000.00
 Row  9 sum = 18415482720000.00
 Row 10 sum = 18422364440000.00
 Row 11 sum = 18429246160000.00
 Row 12 sum = 18436127880000.00
 Row 13 sum = 18443009600000.00
 Row 14 sum = 18449891320000.00
 Row 15 sum = 18456773040000.00
 Row 16 sum = 18463654760000.00
 Row 17 sum = 18470536480000.00
 Row 18 sum = 18477418200000.00
 Row 19 sum = 18484299920000.00
 Row 20 sum = 18491181640000.00
 Row 21 sum = 18498063360000.00
 Row 22 sum = 18504945080000.00
 Row 23 sum = 18511826800000.00
 Row 24 sum = 18518708520000.00
 Row 25 sum = 18525590240000.00
 Row 26 sum = 18532471960000.00
 Row 27 sum = 18539353680000.00
 Row 28 sum = 18546235400000.00
 Row 29 sum = 18553117120000.00
 Row 30 sum = 18559998840000.00
 Row 31 sum = 18566880560000.00
 Row 32 sum = 18573762280000.00
 Row 33 sum = 18580644000000.00
 Row 34 sum = 18587525720000.00
 Row 35 sum = 18594407440000.00
 Row 36 sum = 18601289160000.00
 Row 37 sum = 18608170880000.00
 Row 38 sum = 18615052600000.00
 Row 39 sum = 18621934320000.00
Checksum (sum of all elements)= 7.395096e+14
madara@DESKTOP-95OCCOJ:~$
```

CUDA

./cuda_mat_mul 40 4000 4000 40 **4**

```
!./cuda_mat_mul 40 4000 4000 40 4
```

```
Summary:
Matrix A size: 40 x 4000
Matrix B size: 4000 x 40
Result Matrix C size: 40 x 40
Execution time(seconds): 0.000330
 Row  0 sum = 18353544495104.00
 Row  1 sum = 18360423153664.00
 Row  2 sum = 18367306006528.00
 Row  3 sum = 18374188859392.00
 Row  4 sum = 18381069615104.00
 Row  5 sum = 18387950370816.00
 Row  6 sum = 18394833223680.00
 Row  7 sum = 18401713979392.00
 Row  8 sum = 18408594735104.00
 Row  9 sum = 18415479685120.00
 Row 10 sum = 18422360440832.00
 Row 11 sum = 18429243293696.00
 Row 12 sum = 18436124049408.00
 Row 13 sum = 18443004805120.00
 Row 14 sum = 18449891852288.00
 Row 15 sum = 18456770510848.00
 Row 16 sum = 18463655460864.00
 Row 17 sum = 18470529925120.00
 Row 18 sum = 18477416972288.00
 Row 19 sum = 18484295630848.00
 Row 20 sum = 18491182678016.00
 Row 21 sum = 18498061336576.00
 Row 22 sum = 18504946286592.00
 Row 23 sum = 18511824945152.00
 Row 24 sum = 18518711992320.00
 Row 25 sum = 18525586456576.00
 Row 26 sum = 18532473503744.00
 Row 27 sum = 18539352162304.00
 Row 28 sum = 18546237112320.00
 Row 29 sum = 18553117868032.00
 Row 30 sum = 18560000720896.00
 Row 31 sum = 18566879379456.00
 Row 32 sum = 18573760135168.00
 Row 33 sum = 18580645085184.00
 Row 34 sum = 18587523743744.00
 Row 35 sum = 18594408693760.00
 Row 36 sum = 18601287352320.00
 Row 37 sum = 18608168108032.00
 Row 38 sum = 18615053058048.00
 Row 39 sum = 18621931716608.00
Checksum (sum of all elements) = 7.395095e+14
```

./cuda_mat_mul 40 4000 4000 40 **8**

```
!./cuda_mat_mul 40 4000 4000 40 8
```

```
Summary:
Matrix A size: 40 x 4000
Matrix B size: 4000 x 40
Result Matrix C size: 40 x 40
Execution time(seconds): 0.000234
 Row  0 sum = 18353544495104.00
 Row  1 sum = 18360423153664.00
 Row  2 sum = 18367306006528.00
 Row  3 sum = 18374188859392.00
 Row  4 sum = 18381069615104.00
 Row  5 sum = 18387950370816.00
 Row  6 sum = 18394833223680.00
 Row  7 sum = 18401713979392.00
 Row  8 sum = 18408594735104.00
 Row  9 sum = 18415479685120.00
 Row 10 sum = 18422360440832.00
 Row 11 sum = 18429243293696.00
 Row 12 sum = 18436124049408.00
 Row 13 sum = 18443004805120.00
 Row 14 sum = 18449891852288.00
 Row 15 sum = 18456770510848.00
 Row 16 sum = 18463655460864.00
 Row 17 sum = 18470529925120.00
 Row 18 sum = 18477416972288.00
 Row 19 sum = 18484295630848.00
 Row 20 sum = 18491182678016.00
 Row 21 sum = 18498061336576.00
 Row 22 sum = 18504946286592.00
 Row 23 sum = 18511824945152.00
 Row 24 sum = 18518711992320.00
 Row 25 sum = 18525586456576.00
 Row 26 sum = 18532473503744.00
 Row 27 sum = 18539352162304.00
 Row 28 sum = 18546237112320.00
 Row 29 sum = 18553117868032.00
 Row 30 sum = 18560000720896.00
 Row 31 sum = 18566879379456.00
 Row 32 sum = 18573760135168.00
 Row 33 sum = 18580645085184.00
 Row 34 sum = 18587523743744.00
 Row 35 sum = 18594408693760.00
 Row 36 sum = 18601287352320.00
 Row 37 sum = 18608168108032.00
 Row 38 sum = 18615053058048.00
 Row 39 sum = 18621931716608.00
Checksum (sum of all elements) = 7.395095e+14
```

Appendix C - Large Matrix Execution (Performance Evaluation Only)

Details

- Dimensions > 50 → no row sums or full matrices printed
- Only summary, execution time and checksum shown
- Used for performance graphs and analysis

Examples

Serial

./serial_mat_mul 400 4000 4000 400

```
madara@DESKTOP-95OCCOJ:~$ ./serial_mat_mul 4000 400 400 4000
Summary:
Matrix A size: 4000 x 400
Matrix B size: 400 x 4000
Result Matrix C size: 4000 x 4000
Execution time: 20.005880 seconds
Checksum (sum of all elements) = 5.821108e+18
```

OpenMP (N=number of threads)

./openmp_mat_mul 400 400 400 400 **N**

```
madara@DESKTOP-95OCCOJ:~$ gcc -O3 -fopenmp openmp_mat_mul.c -o o
penmp_mat_mul
madara@DESKTOP-95OCCOJ:~$ ./openmp_mat_mul 4000 400 400 4000 1
Summary:
Matrix A size: 4000 x 400
Matrix B size: 400 x 4000
Result Matrix C size: 4000 x 4000
Threads used: 1
Execution time: 3.139375 seconds
Checksum (sum of all elements) = 5.821108e+18
madara@DESKTOP-95OCCOJ:~$ ./openmp_mat_mul 4000 400 400 4000 2
Summary:
Matrix A size: 4000 x 400
Matrix B size: 400 x 4000
Result Matrix C size: 4000 x 4000
Threads used: 2
Execution time: 1.770128 seconds
Checksum (sum of all elements) = 5.821108e+18
madara@DESKTOP-95OCCOJ:~$ ./openmp_mat_mul 4000 400 400 4000 4
Summary:
Matrix A size: 4000 x 400
Matrix B size: 400 x 4000
Result Matrix C size: 4000 x 4000
Threads used: 4
Execution time: 0.954210 seconds
Checksum (sum of all elements) = 5.821108e+18
```

MPI (P=number of processors)

mpirun -np **P** ./mpi_mat_mul 400 400 400 400

```
madara@DESKTOP-95OCCOJ:~$ mpirun --allow-run-as-root --oversubsc
ribe -np 1 ./mpi_mat_mul 4000 400 400 4000
Summary:
Matrix A size: 4000 x 400
Matrix B size: 400 x 4000
Result Matrix C size: 4000 x 4000
Execution time(seconds): 7.910358
Checksum (sum of all elements)= 5.821108e+18
madara@DESKTOP-95OCCOJ:~$ mpirun --allow-run-as-root --oversubsc
ribe -np 2 ./mpi_mat_mul 4000 400 400 4000
Summary:
Matrix A size: 4000 x 400
Matrix B size: 400 x 4000
Result Matrix C size: 4000 x 4000
Execution time(seconds): 4.940714
Checksum (sum of all elements)= 5.821108e+18
madara@DESKTOP-95OCCOJ:~$ mpirun --allow-run-as-root --oversubsc
ribe -np 4 ./mpi_mat_mul 4000 400 400 4000
Summary:
Matrix A size: 4000 x 400
Matrix B size: 400 x 4000
Result Matrix C size: 4000 x 4000
Execution time(seconds): 3.685876
Checksum (sum of all elements)= 5.821108e+18
```

CUDA (B=block size)

./cuda_mat_mul 1024 1024 1024 1024 **B**

[6] ✓ 1s

```
!./cuda_mat_mul 4000 400 400 4000 1
```

```
Summary:
Matrix A size: 4000 x 400
Matrix B size: 400 x 4000
Result Matrix C size: 4000 x 4000
Execution time(seconds): 0.767903
Checksum (sum of all elements) = 5.821111e+18
```

[7] ✓ 0s

```
!./cuda_mat_mul 4000 400 400 4000 2
```

```
Summary:
Matrix A size: 4000 x 400
Matrix B size: 400 x 4000
Result Matrix C size: 4000 x 4000
Execution time(seconds): 0.305794
Checksum (sum of all elements) = 5.821111e+18
```

[8] ✓ 0s

```
!./cuda_mat_mul 4000 400 400 4000 4
```

```
Summary:
Matrix A size: 4000 x 400
Matrix B size: 400 x 4000
Result Matrix C size: 4000 x 4000
Execution time(seconds): 0.139503
Checksum (sum of all elements) = 5.821111e+18
```

[9] ✓ 0s

```
!./cuda_mat_mul 4000 400 400 4000 8
```

```
Summary:
Matrix A size: 4000 x 400
Matrix B size: 400 x 4000
Result Matrix C size: 4000 x 4000
Execution time(seconds): 0.071058
Checksum (sum of all elements) = 5.821111e+18
```