Faculty of Engineering
Cairo University

Parallel Computing

#CMP4005

Lab 2 Requirement

Submitted to:

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Matrix Addition

Generic Test Case

Matrix Dimensions : 4x3 (4 rows and 3 columns)
The first testcase we ran each with a matrix of dimensions 10x2 (10 rows and 2 columns)

- *Kernel 1: each thread produces one output matrix element*

  The nvprof command showed the following:

```
==17716== Profiling result:
            Type  Time(%)      Time     Calls       Avg       Min       Max  Name
 GPU activities:   56.28%  3.2960us         1  3.2960us  3.2960us  3.2960us  matrix_addition(float*, float*, float*, int, int)
                   28.42%  1.6640us         1  1.6640us  1.6640us  1.6640us  [CUDA memcpy DtoH]
                   15.30%     896ns         2     448ns     224ns     672ns  [CUDA memcpy HtoD]
      API calls:   83.47%  150.14ms         3  50.046ms  3.9000us  150.12ms  cudaMalloc
                   15.68%  28.206ms         1  28.206ms  28.206ms  28.206ms  cuDevicePrimaryCtxRelease
                    0.25%  454.30us         1  454.30us  454.30us  454.30us  cuLibraryLoadData
                    0.24%  433.80us         3  144.60us  4.6000us  396.10us  cudaFree
                    0.24%  429.70us         3  143.23us  37.500us  323.70us  cudaMemcpy
                    0.06%  103.10us         1  103.10us  103.10us  103.10us  cudaLaunchKernel
                    0.03%  50.400us       114     442ns     100ns  10.700us  cuDeviceGetAttribute
                    0.02%  38.600us         1  38.600us  38.600us  38.600us  cuLibraryUnload
                    0.00%  6.2000us         3  2.0660us     200ns  5.3000us  cuDeviceGetCount
                    0.00%  4.7000us         2  2.3500us     400ns  4.3000us  cuDeviceGet
                    0.00%  4.5000us         1  4.5000us  4.5000us  4.5000us  cuModuleGetLoadingMode
                    0.00%  1.0000us         1  1.0000us  1.0000us  1.0000us  cuDeviceGetName
                    0.00%     600ns         1     600ns     600ns     600ns  cuDeviceTotalMem
                    0.00%     600ns         1     600ns     600ns     600ns  cuDeviceGetLuid
                    0.00%     300ns         1     300ns     300ns     300ns  cuDeviceGetUuid
```

  The kernel (matrix_addition) took approximately 3.3 microseconds to perform the matrix addition on the two matrices. In this kernel each thread is responsible for the output of one element in the output matrix which means that 20 threads were responsible for the addition of the whole matrix.

- *Kernel 2: each thread produces one output matrix row*

  The nvprof command showed the following:

```
==25540== Profiling result:
            Type  Time(%)      Time     Calls       Avg       Min       Max  Name
 GPU activities:   68.90%  5.5990us         1  5.5990us  5.5990us  5.5990us  matrix_addition(float*, float*, float*, int, int)
                   20.47%  1.6630us         1  1.6630us  1.6630us  1.6630us  [CUDA memcpy DtoH]
                   10.63%     864ns         2     432ns     192ns     672ns  [CUDA memcpy HtoD]
      API calls:   85.78%  153.50ms         3  51.166ms  3.4000us  153.48ms  cudaMalloc
                   13.44%  24.051ms         1  24.051ms  24.051ms  24.051ms  cuDevicePrimaryCtxRelease
                    0.27%  488.50us         1  488.50us  488.50us  488.50us  cuLibraryLoadData
                    0.21%  371.10us         3  123.70us  36.700us  275.60us  cudaMemcpy
                    0.20%  354.90us         3  118.30us  4.2000us  333.50us  cudaFree
                    0.04%  76.600us         1  76.600us  76.600us  76.600us  cudaLaunchKernel
                    0.03%  51.700us       114     453ns     200ns  6.0000us  cuDeviceGetAttribute
                    0.02%  38.000us         1  38.000us  38.000us  38.000us  cuLibraryUnload
                    0.00%  7.1000us         3  2.3660us     200ns  6.0000us  cuDeviceGetCount
                    0.00%  5.9000us         2  2.9500us     400ns  5.5000us  cuDeviceGet
                    0.00%  5.0000us         1  5.0000us  5.0000us  5.0000us  cuModuleGetLoadingMode
                    0.00%  1.1000us         1  1.1000us  1.1000us  1.1000us  cuDeviceGetName
                    0.00%     600ns         1     600ns     600ns     600ns  cuDeviceGetLuid
                    0.00%     400ns         1     400ns     400ns     400ns  cuDeviceTotalMem
                    0.00%     300ns         1     300ns     300ns     300ns  cuDeviceGetUuid
```

The kernel (matrix_addition) took approximately 5.6 microseconds to perform the matrix addition on the two matrices. In this kernel each thread is responsible for the output of one row in the whole matrix which means that 2 threads were responsible for the addition of the whole matrix simultaneously.

- *Kernel 3: each thread produces one output matrix column*

The nvprof command showed the following:

```
==29480== Profiling result:
            Type  Time(%)      Time     Calls       Avg       Min       Max  Name
 GPU activities:   47.84%  2.4640us         1  2.4640us  2.4640us  2.4640us  matrix_addition(float*, float*, float*, int, int)
                   34.79%  1.7920us         1  1.7920us  1.7920us  1.7920us  [CUDA memcpy DtoH]
                   17.38%     895ns         2     447ns     223ns     672ns  [CUDA memcpy HtoD]
      API calls:   79.43%  101.41ms         3  33.804ms  2.8000us  101.40ms  cudaMalloc
                   19.48%  24.866ms         1  24.866ms  24.866ms  24.866ms  cuDevicePrimaryCtxRelease
                    0.35%  445.70us         3  148.57us  3.5000us  409.50us  cudaFree
                    0.32%  412.30us         3  137.43us  47.200us  256.60us  cudaMemcpy
                    0.26%  336.90us         1  336.90us  336.90us  336.90us  cuLibraryLoadData
                    0.09%  112.00us         1  112.00us  112.00us  112.00us  cudaLaunchKernel
                    0.03%  34.500us       114     302ns     100ns  4.6000us  cuDeviceGetAttribute
                    0.02%  24.500us         1  24.500us  24.500us  24.500us  cuLibraryUnload
                    0.01%  15.500us         2  7.7500us     300ns  15.200us  cuDeviceGet
                    0.01%  7.2000us         3  2.4000us     300ns  5.1000us  cuDeviceGetCount
                    0.00%  3.9000us         1  3.9000us  3.9000us  3.9000us  cuModuleGetLoadingMode
                    0.00%  2.9000us         1  2.9000us  2.9000us  2.9000us  cuDeviceGetName
                    0.00%  2.1000us         1  2.1000us  2.1000us  2.1000us  cuDeviceTotalMem
                    0.00%     400ns         1     400ns     400ns     400ns  cuDeviceGetLuid
                    0.00%     200ns         1     200ns     200ns     200ns  cuDeviceGetUuid
```

The kernel (matrix_addition) took approximately 2.5 microseconds to perform the matrix addition on the two matrices. In this kernel each thread is responsible for the output of one column in the output matrix which means that 10 threads were responsible for the addition of the whole matrix.

In the first testcase the since the number of rows was greater than the number of columns the second kernel which applies parallelism in the level of the matrix rows performs the addition in the least amount of time; the third kernel which applies the parallelism on the columns' level performs the addition in almost double the time. Lastly, the first kernel which parallelizes over the whole matrix with each thread performing the addition of one element performs the addition in a time greater than kernel 2 but less than kernel 3.

Testcase 2

Number of Rows >> Number of Columns

The second testcase we ran each with a matrix of dimensions 2x10 (2 rows and 10 columns)

- *Kernel 1: each thread produces one output matrix element*

The nvprof command showed the following:

```
==24880== Profiling result:
            Type  Time(%)      Time     Calls       Avg       Min       Max  Name
 GPU activities:   54.94%  3.0410us         1  3.0410us  3.0410us  3.0410us  matrix_addition(float*, float*, float*, int, int)
                   28.89%  1.5990us         1  1.5990us  1.5990us  1.5990us  [CUDA memcpy DtoH]
                   16.17%     895ns         2     447ns     223ns     672ns  [CUDA memcpy HtoD]
      API calls:   81.51%  154.41ms         3  51.470ms  2.9000us  154.39ms  cudaMalloc
                   17.71%  33.555ms         1  33.555ms  33.555ms  33.555ms  cuDevicePrimaryCtxRelease
                    0.26%  490.50us         3  163.50us  4.8000us  434.20us  cudaFree
                    0.24%  445.90us         1  445.90us  445.90us  445.90us  cuLibraryLoadData
                    0.20%  382.60us         3  127.53us  27.500us  298.70us  cudaMemcpy
                    0.04%  81.500us         1  81.500us  81.500us  81.500us  cudaLaunchKernel
                    0.02%  41.300us         1  41.300us  41.300us  41.300us  cuLibraryUnload
                    0.01%  22.700us       114     199ns     100ns  1.9000us  cuDeviceGetAttribute
                    0.00%  5.6000us         3  1.8660us     200ns  4.9000us  cuDeviceGetCount
                    0.00%  3.7000us         2  1.8500us     100ns  3.6000us  cuDeviceGet
                    0.00%  2.2000us         1  2.2000us  2.2000us  2.2000us  cuModuleGetLoadingMode
                    0.00%     700ns         1     700ns     700ns     700ns  cuDeviceGetName
                    0.00%     500ns         1     500ns     500ns     500ns  cuDeviceTotalMem
                    0.00%     500ns         1     500ns     500ns     500ns  cuDeviceGetLuid
                    0.00%     200ns         1     200ns     200ns     200ns  cuDeviceGetUuid
```

The kernel (matrix_addition) took approximately 3.0 microseconds to perform the matrix addition on the two matrices. In this kernel each thread is responsible for the output of one element in the output matrix which means that 20 threads were responsible for the addition of the whole matrix.

- *Kernel 2: each thread produces one output matrix row*
- *The nvprof command showed the following:*

```
==22576== Profiling result:
            Type  Time(%)      Time     Calls       Avg       Min       Max  Name
 GPU activities:   57.95%  3.6160us         1  3.6160us  3.6160us  3.6160us  matrix_addition(float*, float*, float*, int, int)
                   26.67%  1.6640us         1  1.6640us  1.6640us  1.6640us  [CUDA memcpy DtoH]
                   15.38%     960ns         2     480ns     192ns     768ns  [CUDA memcpy HtoD]
      API calls:   86.23%  157.81ms         3  52.603ms  5.3000us  157.77ms  cudaMalloc
                   12.85%  23.514ms         1  23.514ms  23.514ms  23.514ms  cuDevicePrimaryCtxRelease
                    0.33%  609.40us         1  609.40us  609.40us  609.40us  cuLibraryLoadData
                    0.30%  548.50us         3  182.83us  5.9000us  470.60us  cudaFree
                    0.18%  326.40us         3  108.80us  55.300us  194.90us  cudaMemcpy
                    0.06%  101.90us         1  101.90us  101.90us  101.90us  cudaLaunchKernel
                    0.02%  45.000us         1  45.000us  45.000us  45.000us  cuLibraryUnload
                    0.02%  38.900us       114     341ns     100ns  3.4000us  cuDeviceGetAttribute
                    0.00%  8.4000us         2  4.2000us     300ns  8.1000us  cuDeviceGet
                    0.00%  5.1000us         3  1.7000us     200ns  4.2000us  cuDeviceGetCount
                    0.00%  3.5000us         1  3.5000us  3.5000us  3.5000us  cuModuleGetLoadingMode
                    0.00%  1.1000us         1  1.1000us  1.1000us  1.1000us  cuDeviceGetName
                    0.00%     600ns         1     600ns     600ns     600ns  cuDeviceTotalMem
                    0.00%     600ns         1     600ns     600ns     600ns  cuDeviceGetLuid
                    0.00%     300ns         1     300ns     300ns     300ns  cuDeviceGetUuid
```

The kernel (matrix_addition) took approximately 3.0 microseconds to perform the matrix addition on the two matrices. In this kernel each thread is responsible for the output of one element in the output matrix which means that 10 threads were responsible for the addition of the whole matrix.

- *Kernel 3: each thread produces one output matrix column*

The nvprof command showed the following:

```
==10820== Profiling result:
            Type  Time(%)      Time     Calls       Avg       Min       Max  Name
 GPU activities:   68.38%  5.5360us         1  5.5360us  5.5360us  5.5360us  matrix_addition(float*, float*, float*, int, int)
                   20.55%  1.6640us         1  1.6640us  1.6640us  1.6640us  [CUDA memcpy DtoH]
                   11.07%     896ns         2     448ns     224ns     672ns  [CUDA memcpy HtoD]
      API calls:   86.04%  113.32ms         3  37.772ms  2.3000us  113.30ms  cudaMalloc
                   13.03%  17.160ms         1  17.160ms  17.160ms  17.160ms  cuDevicePrimaryCtxRelease
                    0.48%  637.30us         1  637.30us  637.30us  637.30us  cuLibraryLoadData
                    0.19%  247.50us         3  82.500us  27.300us  175.20us  cudaMemcpy
                    0.15%  200.30us         3  66.766us  3.7000us  182.00us  cudaFree
                    0.04%  55.400us         1  55.400us  55.400us  55.400us  cudaLaunchKernel
                    0.03%  36.700us         1  36.700us  36.700us  36.700us  cuLibraryUnload
                    0.02%  32.000us       114     280ns     100ns  2.6000us  cuDeviceGetAttribute
                    0.00%  6.5000us         3  2.1660us     300ns  5.0000us  cuDeviceGetCount
                    0.00%  4.9000us         2  2.4500us     400ns  4.5000us  cuDeviceGet
                    0.00%  3.1000us         1  3.1000us  3.1000us  3.1000us  cuModuleGetLoadingMode
                    0.00%  1.0000us         1  1.0000us  1.0000us  1.0000us  cuDeviceGetName
                    0.00%     600ns         1     600ns     600ns     600ns  cuDeviceGetLuid
                    0.00%     500ns         1     500ns     500ns     500ns  cuDeviceTotalMem
                    0.00%     300ns         1     300ns     300ns     300ns  cuDeviceGetUuid
```

The kernel (matrix_addition) took approximately 5.5 microseconds to perform the matrix addition on the two matrices. In this kernel each thread is responsible for the output of one row in the whole matrix which means that 2 threads were responsible for the addition of the whole matrix simultaneously.

In the second testcase the since the number of columns was greater than the number of rows the second kernel which applies parallelism in the level of the matrix rows performs the addition in the greatest amount of time; the third kernel which applies the parallelism on the columns' level performs the addition in almost half the time. Lastly, the first kernel which parallelizes over the whole matrix with each thread performing the addition of one element performs the addition in a time approximately equal to the time of the first testcase.

Testcase 3

Number of Rows == Number of Columns

The third testcase we ran each with a matrix of dimensions 3x3 (3 rows and 3 columns)

- *Kernel 1: each thread produces one output matrix element*

The nvprof command showed the following:

```
==2492== Profiling result:
            Type  Time(%)      Time     Calls       Avg       Min       Max  Name
 GPU activities:   57.29%  3.5200us         1  3.5200us  3.5200us  3.5200us  [CUDA memcpy DtoH]
                   29.17%  1.7920us         1  1.7920us  1.7920us  1.7920us  matrix_addition(float*, float*, float*, int, int)
                   13.54%     832ns         2     416ns     192ns     640ns  [CUDA memcpy HtoD]
      API calls:   84.90%  150.10ms         3  50.034ms  4.5000us  150.08ms  cudaMalloc
                   14.42%  25.496ms         1  25.496ms  25.496ms  25.496ms  cuDevicePrimaryCtxRelease
                    0.27%  482.60us         1  482.60us  482.60us  482.60us  cuLibraryLoadData
                    0.17%  292.70us         3  97.566us  39.200us  189.80us  cudaMemcpy
                    0.15%  258.40us         3  86.133us  5.8000us  233.30us  cudaFree
                    0.04%  66.100us         1  66.100us  66.100us  66.100us  cudaLaunchKernel
                    0.03%  48.400us         1  48.400us  48.400us  48.400us  cuLibraryUnload
                    0.02%  35.500us       114     311ns     100ns  2.3000us  cuDeviceGetAttribute
                    0.00%  5.4000us         3  1.8000us     300ns  4.6000us  cuDeviceGetCount
                    0.00%  4.6000us         2  2.3000us     300ns  4.3000us  cuDeviceGet
                    0.00%  3.5000us         1  3.5000us  3.5000us  3.5000us  cuModuleGetLoadingMode
                    0.00%     900ns         1     900ns     900ns     900ns  cuDeviceGetName
                    0.00%     600ns         1     600ns     600ns     600ns  cuDeviceGetLuid
                    0.00%     500ns         1     500ns     500ns     500ns  cuDeviceTotalMem
                    0.00%     300ns         1     300ns     300ns     300ns  cuDeviceGetUuid
```

The kernel (matrix_addition) took approximately 3.5 microseconds to perform the matrix addition on the two matrices. In this kernel each thread is responsible for the output of one element in the output matrix which means that 9 threads were responsible for the addition of the whole matrix simultaneously.

- *Kernel 2: each thread produces one output matrix row*

The nvprof command showed the following:

```
==27896== Profiling result:
            Type  Time(%)      Time     Calls       Avg       Min       Max  Name
 GPU activities:   60.20%  3.8720us         1  3.8720us  3.8720us  3.8720us  matrix_addition(float*, float*, float*, int, int)
                   24.88%  1.6000us         1  1.6000us  1.6000us  1.6000us  [CUDA memcpy DtoH]
                   14.93%     960ns         2     480ns     224ns     736ns  [CUDA memcpy HtoD]
      API calls:   81.79%  117.52ms         3  39.173ms  2.5000us  117.48ms  cudaMalloc
                   17.24%  24.767ms         1  24.767ms  24.767ms  24.767ms  cuDevicePrimaryCtxRelease
                    0.33%  468.60us         3  156.20us  29.900us  344.80us  cudaMemcpy
                    0.26%  369.00us         1  369.00us  369.00us  369.00us  cuLibraryLoadData
                    0.24%  343.80us         3  114.60us  3.2000us  328.80us  cudaFree
                    0.08%  114.10us         1  114.10us  114.10us  114.10us  cudaLaunchKernel
                    0.04%  51.300us       114     450ns     100ns  32.000us  cuDeviceGetAttribute
                    0.03%  36.000us         1  36.000us  36.000us  36.000us  cuLibraryUnload
                    0.00%  4.9000us         3  1.6330us     200ns  4.3000us  cuDeviceGetCount
                    0.00%  3.5000us         2  1.7500us     200ns  3.3000us  cuDeviceGet
                    0.00%  1.7000us         1  1.7000us  1.7000us  1.7000us  cuModuleGetLoadingMode
                    0.00%     800ns         1     800ns     800ns     800ns  cuDeviceGetName
                    0.00%     400ns         1     400ns     400ns     400ns  cuDeviceTotalMem
                    0.00%     300ns         1     300ns     300ns     300ns  cuDeviceGetLuid
                    0.00%     200ns         1     200ns     200ns     200ns  cuDeviceGetUuid
```

The kernel (matrix_addition) took approximately 3.9 microseconds to perform the matrix addition on the two matrices. In this kernel each thread is responsible for the output of one element in the output matrix which means that 9 threads were responsible for the addition of the whole matrix.

- *Kernel 3: each thread produces one output matrix column*

The nvprof command showed the following:

```
==26872== Profiling result:
            Type  Time(%)      Time     Calls       Avg       Min       Max  Name
 GPU activities:   62.00%  3.9680us         1  3.9680us  3.9680us  3.9680us  matrix_addition(float*, float*, float*, int, int)
                   24.50%  1.5680us         1  1.5680us  1.5680us  1.5680us  [CUDA memcpy DtoH]
                   13.50%     864ns         2     432ns     192ns     672ns  [CUDA memcpy HtoD]
      API calls:   82.68%  116.39ms         3  38.796ms  2.1000us  116.38ms  cudaMalloc
                   16.11%  22.672ms         1  22.672ms  22.672ms  22.672ms  cuDevicePrimaryCtxRelease
                    0.47%  665.80us         3  221.93us  2.7000us  629.00us  cudaFree
                    0.33%  469.30us         3  156.43us  23.500us  347.90us  cudaMemcpy
                    0.26%  369.80us         1  369.80us  369.80us  369.80us  cuLibraryLoadData
                    0.08%  110.90us         1  110.90us  110.90us  110.90us  cudaLaunchKernel
                    0.04%  61.800us         1  61.800us  61.800us  61.800us  cuLibraryUnload
                    0.01%  19.700us       114     172ns     100ns  2.0000us  cuDeviceGetAttribute
                    0.00%  3.8000us         3  1.2660us     200ns  3.4000us  cuDeviceGetCount
                    0.00%  3.6000us         2  1.8000us     200ns  3.4000us  cuDeviceGet
                    0.00%  1.9000us         1  1.9000us  1.9000us  1.9000us  cuModuleGetLoadingMode
                    0.00%     800ns         1     800ns     800ns     800ns  cuDeviceGetName
                    0.00%     400ns         1     400ns     400ns     400ns  cuDeviceTotalMem
                    0.00%     300ns         1     300ns     300ns     300ns  cuDeviceGetLuid
                    0.00%     100ns         1     100ns     100ns     100ns  cuDeviceGetUuid
```

The kernel (matrix_addition) took approximately 4.0 microseconds to perform the matrix addition on the two matrices. In this kernel each thread is responsible for the output of one element in the output matrix which means that 9 threads were responsible for the addition of the whole matrix.

In the third testcase since the number of columns and the number of rows are equal all the kernels performed the matrix addition in approximately the same time since kernel 2 and kernel 3 apply the same level of parallelism and kernel 1 is consistent with all the other testcases.

Testcase 4

Number of Rows == Number of Columns

The fourth testcase we ran each with a matrix of dimensions 10x10 to see the effect on kernel1

- *Kernel 1: each thread produces one output matrix element*

The nvprof command showed the following:

```
==22572== Profiling result:
            Type  Time(%)      Time     Calls       Avg       Min       Max  Name
 GPU activities:   54.24%  3.0720us         1  3.0720us  3.0720us  3.0720us  matrix_addition(float*, float*, float*, int, int)
                   29.38%  1.6640us         1  1.6640us  1.6640us  1.6640us  [CUDA memcpy DtoH]
                   16.38%     928ns         2     464ns     256ns     672ns  [CUDA memcpy HtoD]
      API calls:   80.16%  111.33ms         3  37.110ms  2.3000us  111.32ms  cudaMalloc
                   18.15%  25.208ms         1  25.208ms  25.208ms  25.208ms  cuDevicePrimaryCtxRelease
                    1.03%  1.4308ms         1  1.4308ms  1.4308ms  1.4308ms  cuLibraryLoadData
                    0.28%  394.60us         3  131.53us  23.000us  289.80us  cudaMemcpy
                    0.23%  314.00us         3  104.67us  3.6000us  281.10us  cudaFree
                    0.05%  72.200us         1  72.200us  72.200us  72.200us  cudaLaunchKernel
                    0.05%  70.800us       114     621ns     100ns  8.7000us  cuDeviceGetAttribute
                    0.03%  42.600us         1  42.600us  42.600us  42.600us  cuLibraryUnload
                    0.00%  6.5000us         3  2.1660us     300ns  4.4000us  cuDeviceGetCount
                    0.00%  5.4000us         2  2.7000us     300ns  5.1000us  cuDeviceGet
                    0.00%  5.4000us         1  5.4000us  5.4000us  5.4000us  cuDeviceGetName
                    0.00%  3.4000us         1  3.4000us  3.4000us  3.4000us  cuModuleGetLoadingMode
                    0.00%  3.1000us         1  3.1000us  3.1000us  3.1000us  cuDeviceGetLuid
                    0.00%  2.4000us         1  2.4000us  2.4000us  2.4000us  cuDeviceTotalMem
                    0.00%     200ns         1     200ns     200ns     200ns  cuDeviceGetUuid
```

The kernel (matrix_addition) took approximately 3.0 microseconds to perform the matrix addition on the two matrices. In this kernel each thread is responsible for the output of one element in the output matrix which means that 100 threads were responsible for the addition of the whole matrix.

- *Kernel 2: each thread produces one output matrix row*

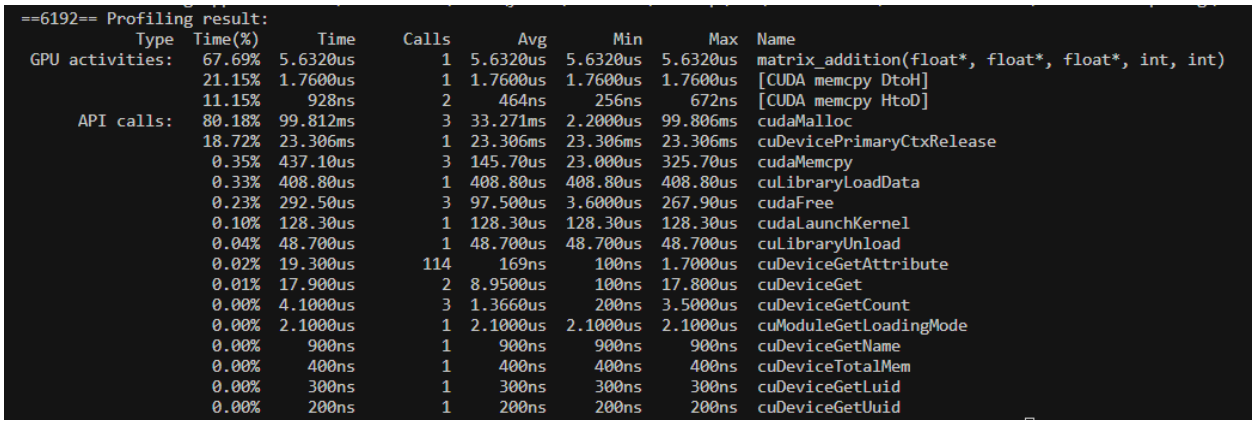
The nvprof command showed the following:

```
==28652== Profiling result:
            Type  Time(%)      Time     Calls       Avg       Min       Max  Name
 GPU activities:   69.65%  5.7280us         1  5.7280us  5.7280us  5.7280us  matrix_addition(float*, float*, float*, int, int)
                   19.47%  1.6010us         1  1.6010us  1.6010us  1.6010us  [CUDA memcpy DtoH]
                   10.88%     895ns         2     447ns     223ns     672ns  [CUDA memcpy HtoD]
      API calls:   83.37%  139.39ms         3  46.464ms  2.3000us  139.39ms  cudaMalloc
                   15.81%  26.427ms         1  26.427ms  26.427ms  26.427ms  cuDevicePrimaryCtxRelease
                    0.28%  474.50us         3  158.17us  44.900us  296.30us  cudaMemcpy
                    0.23%  387.80us         3  129.27us  5.8000us  346.40us  cudaFree
                    0.20%  335.10us         1  335.10us  335.10us  335.10us  cuLibraryLoadData
                    0.05%  82.600us         1  82.600us  82.600us  82.600us  cudaLaunchKernel
                    0.03%  51.900us         1  51.900us  51.900us  51.900us  cuLibraryUnload
                    0.01%  24.800us       114     217ns     100ns  2.3000us  cuDeviceGetAttribute
                    0.00%  3.8000us         2  1.9000us     200ns  3.6000us  cuDeviceGet
                    0.00%  3.7000us         3  1.2330us     200ns  3.1000us  cuDeviceGetCount
                    0.00%  3.2000us         1  3.2000us  3.2000us  3.2000us  cuModuleGetLoadingMode
                    0.00%  1.0000us         1  1.0000us  1.0000us  1.0000us  cuDeviceGetName
                    0.00%     400ns         1     400ns     400ns     400ns  cuDeviceGetLuid
                    0.00%     300ns         1     300ns     300ns     300ns  cuDeviceGetUuid
                    0.00%     200ns         1     200ns     200ns     200ns  cuDeviceTotalMem
```

The kernel (matrix_addition) took approximately 5.7 microseconds to perform the matrix addition on the two matrices. In this kernel each thread is responsible for the output of one row in the output matrix which means that 10 threads were responsible for the addition of the whole matrix.

- *Kernel 3: each thread produces one output matrix column*

  The nvprof command showed the following:



```
==6192== Profiling result:
            Type  Time(%)      Time     Calls       Avg       Min       Max  Name
 GPU activities:   67.69%  5.6320us         1  5.6320us  5.6320us  5.6320us  matrix_addition(float*, float*, float*, int, int)
                   21.15%  1.7600us         1  1.7600us  1.7600us  1.7600us  [CUDA memcpy DtoH]
                   11.15%     928ns         2     464ns     256ns     672ns  [CUDA memcpy HtoD]
      API calls:   80.18%  99.812ms         3  33.271ms  2.2000us  99.806ms  cudaMalloc
                   18.72%  23.306ms         1  23.306ms  23.306ms  23.306ms  cuDevicePrimaryCtxRelease
                    0.35%  437.10us         3  145.70us  23.000us  325.70us  cudaMemcpy
                    0.33%  408.80us         1  408.80us  408.80us  408.80us  cuLibraryLoadData
                    0.23%  292.50us         3  97.500us  3.6000us  267.90us  cudaFree
                    0.10%  128.30us         1  128.30us  128.30us  128.30us  cudaLaunchKernel
                    0.04%  48.700us         1  48.700us  48.700us  48.700us  cuLibraryUnload
                    0.02%  19.300us       114     169ns     100ns  1.7000us  cuDeviceGetAttribute
                    0.01%  17.900us         2  8.9500us     100ns  17.800us  cuDeviceGet
                    0.00%  4.1000us         3  1.3660us     200ns  3.5000us  cuDeviceGetCount
                    0.00%  2.1000us         1  2.1000us  2.1000us  2.1000us  cuModuleGetLoadingMode
                    0.00%     900ns         1     900ns     900ns     900ns  cuDeviceGetName
                    0.00%     400ns         1     400ns     400ns     400ns  cuDeviceTotalMem
                    0.00%     300ns         1     300ns     300ns     300ns  cuDeviceGetLuid
                    0.00%     200ns         1     200ns     200ns     200ns  cuDeviceGetUuid
```

  The kernel (matrix_addition) took approximately 5.6 microseconds to perform the matrix addition on the two matrices. In this kernel each thread is responsible for the output of one column in the output matrix which means that 10 threads were responsible for the addition of the whole matrix.

In the third testcase since the number of columns and the number of rows are equal all the kernels performed the matrix addition in approximately the same time since kernel 2 and kernel 3 apply the same level of parallelism and kernel 1 is consistent with all the other testcases.

Large Matrices

Matrix Dimensions *(RxC)*	Kernel#1 (element)	Kernel#2 (rows)	Kernel#3 (columns)
200x200	208.90 us	212.32 us	212.67 us
10x200	3.8400 us	37.664 us	6.2720 us
200x10	3.8080 us	6.6560 us	37.888 us
1000x1000	5.1472 ms	5.1412 ms	5.1083 ms
50x1000	272.51 us	259.01 us	275.52 us
1000x50	270.33 us	260.45 us	270.11us

1x10000	29.472 us	1.4430 ms	29.408 us
10000x1	30.304 us	30.560 us	1.4428 ms
1x50000	259.55 us	7.4926 ms	290.11 us
50000x1	271.04 us	259.01 us	7.4820ms

Conclusion

In conclusion, based on the testcases applied and the nvprof command the best performance is achieved depending on the nature of the matrix; if the matrices consists of number of rows >> the number of columns then kernel 2 is the best choice (each thread is responsible for the output of one row in the output matrix). If the matrix consists of the number of columns >> number of rows then the best approach is to apply the parallelism over the columns like kernel 3 (each thread is responsible for the output of one column in the output matrix). Executing kernel 1 where each thread is responsible for one element in the output matrix gives an average and close time with all the testcases we tried which is closer to the least time achieved each time so it doesn't give the best performance but doesn't give the worst performance either. However, when we increased the number of rows and columns significantly with the rows == columns the difference in time was conveyed between kernel 1 and kernel 2 and 3; where kernel 1 performed the addition in the least amount of time with approximately half the time it took kernels 2 and 3. Therefore, when the matrix is large with approximately equal number of rows and columns it is best to use kernel 1 or to parallelise each element in the matrix.

When the matrix dimensions are small the difference between the times of the 3 kernels is not significant but as the dimensions of the matrix increase the time for kernel 1 increases depending on the total amount of elements in the matrix, while kernels 2 and 3 their times vary according to the rows on columns of the matrix even if they have the same number of elements. So choosing the second kernel when the number of rows is larger than the number of columns would be better and choosing the third kernel when the columns are much larger than the rows is the best way to go.