# Technical Report

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September 2018

**Summary**

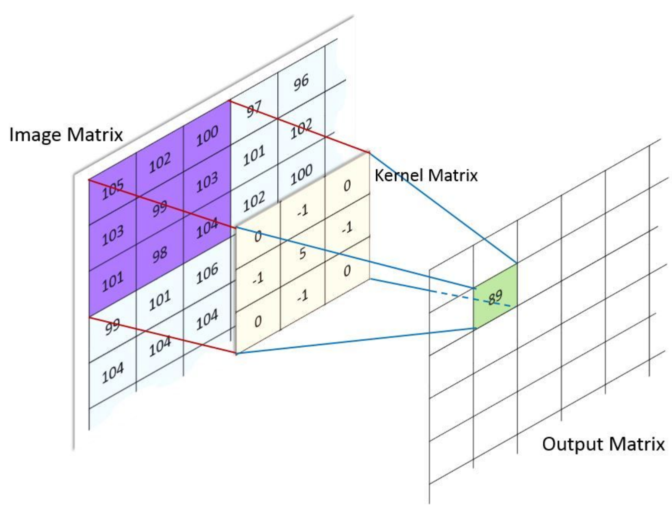
*This report explores implementing a box blur algorithm using CPU and GPU and comparing the running times. Using GPU shows a huge advantage for images of all sizes when comparing against CPU implementations. The report compares empirical results (execution time) of the different configurations and different image sizes.*

## 1. Introduction

Images are stored as matrices, and, as such, allow us to use the boost of using parallel computing with GPU. A computing intensive operation with images is applying convolutional filters to change them, like using a blur algorithms or edge detection. A simple blur algorithm is box linear filter, in which the result of each pixel is the average of its neighboring pixels. This report compares the computing times of applying a blur filter to images of different sizes with CPU and GPU.

## 2. Development and results

To implement the box blur, we use a simple O(n*m) algorithm, where n is the size of the image and m is the size of the filter. For every pixel in the image, the neighboring pixel values are averaged. For this experiment, we'll be using a 5x5 filter. Something to consider when using convolutions is how to work with the borders. There are different ways of achieving this. In this case, we use the 'same padding' strategy so the output image size is the same than the input image size. For border pixels, we only use the number of pixels used to calculate the average. For example, in a corner, the sum of the pixel values is divided by 9 instead of 25.



OpenCV is a library that allows to easily do image manipulation. We'll use it to load and display the images. We measure time with 400x640, 1224x1840, 1836x3264 images. Time is measured using chrono *high_resolution_clock*[1]. We'll use the direct mat classes for the CPU implementations, and convert the matrix to a linear array for the GPU implementations, which might have a direct impact in the performance.

The programs are being run using GeForce GTX 670. It has 1344 CUDA cores and 7 multiprocessors. The GPU max clock rate is 0.98 GHz. The memory clock rate is 3004 Mhz. For CPU the programs are being run in an Intel i7-4770 Processor, which has 4 cores. The clock speed is 3.4 GHz. The CPU threading is implemented using OpenMP.

The following tables show 5 trials for each configuration. All times in the tables are measured in milliseconds. Changing the number of threads in the GPU implementations did not have any representative impact in performance.

| **CPU** | | | |
|---|---|---|---|
| | **400x640** | **1224x1840** | **1836x3264** |
| **Trial 1** | 111.862617 | 1007.567810 | 2664.621826 |
| **Trial 2** | 112.598030 | 1010.070374 | 2689.509277 |
| **Trial 3** | 112.987930 | 1008.305115 | 2656.525391 |
| **Trial 4** | 111.837479 | 1001.849731 | 2683.803223 |
| **Trial 5** | 112.779030 | 1014.352783 | 2667.580078 |
| **Average** | **112.4130172** | **1008.4291626** | **2672.407959** |

| **CPU with 8 threads** | | | |
|---|---|---|---|
| | **400x640** | **1224x1840** | **1836x3264** |
| **Trial 1** | 9.224474 | 30.667297 | 89.275299 |
| **Trial 2** | 9.794754 | 31.029327 | 86.606384 |
| **Trial 3** | 8.636539 | 30.695984 | 80.479889 |
| **Trial 4** | 8.265758 | 37.294201 | 77.396820 |

[1] https://en.cppreference.com/w/cpp/chrono/high_resolution_clock

| | | | |
|---|---|---|---|
| **Trial 5** | 8.225322 | 30.547173 | 85.598801 |
| **Average** | **8.8293694** | **32.0467964** | **83.8714386** |

| **GPU 2D grid, 1D block, 128 threads per block** | | | |
|---|---|---|---|
| | **400x640**<br>20x1 | **1224x1840**<br>58x1 | **1836x3264**<br>102x1 |
| **Trial 1** | 0.014175 | 0.016186 | 0.022186 |
| **Trial 2** | 0.013603 | 0.015078 | 0.018780 |
| **Trial 3** | 0.013326 | 0.017702 | 0.020118 |
| **Trial 4** | 0.013399 | 0.015522 | 0.019190 |
| **Trial 5** | 0.013344 | 0.016399 | 0.019396 |
| **Average** | **0.0135694** | **0.0161774** | **0.019934** |

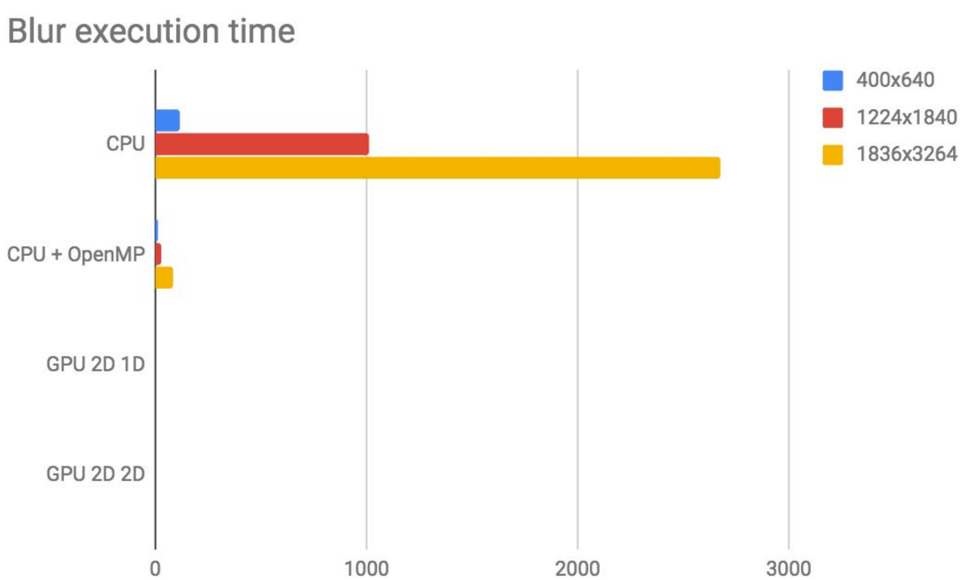
| **GPU 2D grid, 2D block, 32x32 block size** | | | |
|---|---|---|---|
| | **400x640**<br>20x13 | **1224x1840**<br>58x39 | **1836x3264**<br>102x58 |
| **Trial 1** | 0.012744 | 0.016832 | 0.023640 |
| **Trial 2** | 0.013426 | 0.014364 | 0.024043 |
| **Trial 3** | 0.013465 | 0.014684 | 0.035690 |
| **Trial 4** | 0.013953 | 0.014020 | 0.023371 |
| **Trial 5** | 0.015167 | 0.013761 | 0.022503 |
| **Average** | **0.013751** | **0.0147322** | **0.0258494** |

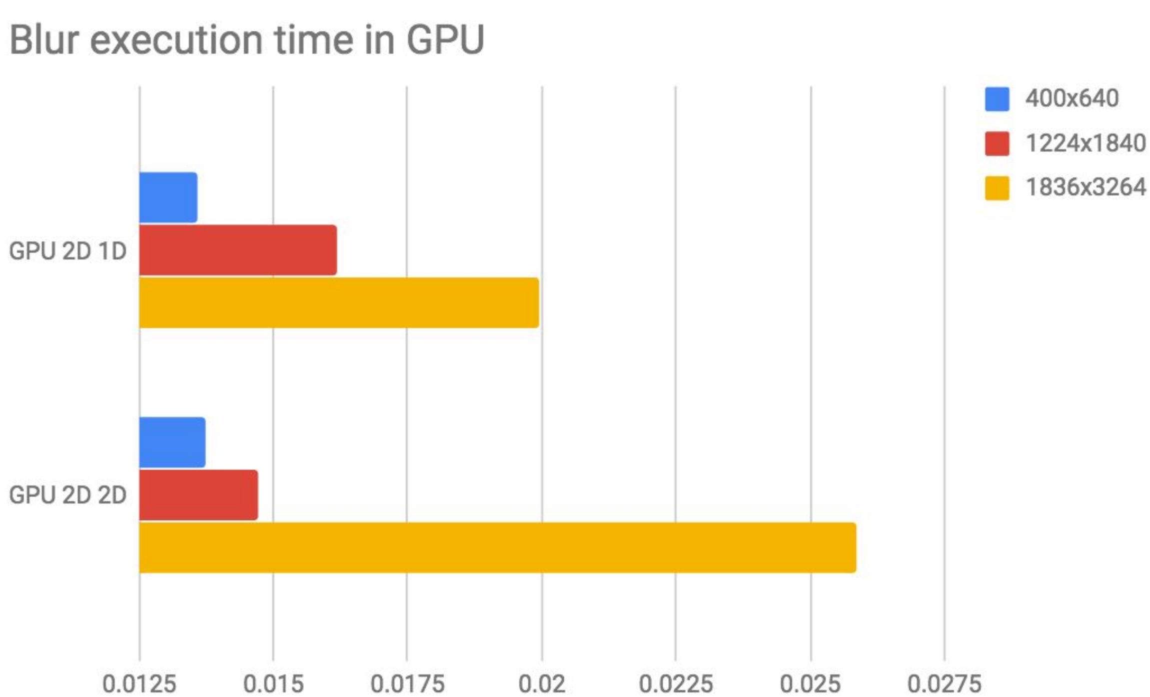
# 3. Analysis

The following table summarizes the results from the previous section.

| | **400x640** | **1224x1840** | **1836x3264** |
|---|---|---|---|

| | | | |
|---|---|---|---|
| **CPU** | 112.4130172 | 1008.4291626 | 2672.407959 |
| **CPU + OpenMP** | 8.8293694 | 32.0467964 | 83.8714386 |
| **GPU 2D 1D** | 0.0135694 | 0.0161774 | 0.019934 |
| **GPU 2D 2D** | 0.013751 | 0.0147322 | 0.0258494 |



In general, we obtain the best results using 2D grid with 1D array of threads per block. Using threads in CPU shows a improvement in the performance time, but GPU performs even better. The GPU configurations perform differently depending on the image size. The 2D 2D configuration was better for medium-sized images (1224x1840). The 2D 1D configuration did better in the small and larger images.

| Speedup from CPU | | | |
|---|---|---|---|
| | **400x640** | **1224x1840** | **1836x3264** |
| **CPU + OpenMP** | 12.73 | 31.4673938079 | 31.8631467828 |
| **GPU 2D 1D** | 8284.30271051 | 62335.6758564 | 134062.805207 |
| **GPU 2D 2D** | 8174.89762199 | 68450.6837132 | 103383.752002 |

# 4. Conclusions

Using GPU shows clear advantage for images of all sizes. Changing the block size in the 2D 2D configuration had a no visible impact in the results. The 2D 1D configuration showed a better speedup in small and large images, but the difference isn't too significant.

A thing that is important to consider is that in the CPU implementations, the solutions are using the OpenCV Mat class. In the GPU implementations, a linear array is used, which offers additional advantages.