Technical Report

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August 2018

Summary

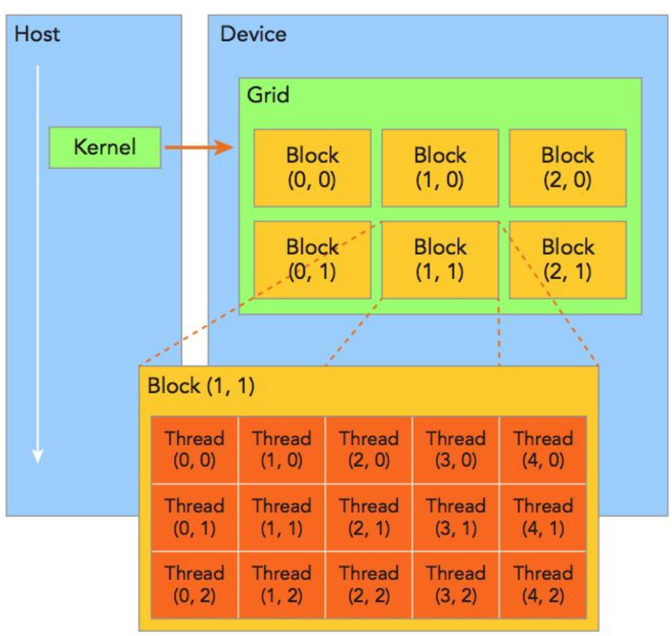
This report explores solving the problem of matrix multiplication using CPU and GPU with different configurations. Using GPU leads to a clear improvement in the performance. The report compares empirical results (execution time) of the different configurations.

1. Introduction

CUDA has an interesting programming model that boosts the performance in problems with lots of data. A simple problem that is data-intensive is high-dimensional matrix multiplication. After a certain point, using CPU, even with threads, is not a viable option to multiply matrices. CUDA gives developers an abstraction of the GPU architecture, making it easy to transfer data from the host (CPU) to the device (GPU), which has an internal memory. The device has a grid of blocks and each block has threads. Changing the setup of the grid and the blocks has a direct impact in the performance. Because of this, we'll explore the results of different-size matrices with the following configurations: CPU, CPU with threads using OpenMP, GPU using a 1D grid, GPU using a 2D grid, and GPU using a 2D grid with 2D blocks.

2. Development and results

As mentioned in the introduction, CUDA gives control to the developers. When a kernel function is called from the host, the device obtains execution and automatically generates the threads and blocks as specified in the host. Having access to the block and grid dimensions gives opportunity for optimization.



To test the configurations, we'll use matrices stored linearly. Doing this allows us to easily map threads to data elements in the matrices. We measure time with 3x3, 1000x1000, 2000x2000 and 4000x4000 matrices with natural numbers using row-major order. Time is measured using chrono *high_resolution_clock*[1].

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 following tables show 5 trials for each configuration. CPU was unable to run 2000x2000 matrix multiplication in an acceptable time. 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			
	3x3	**1000x1000**	**2000x2000**
Trial 1	0.001302	5643.34	81837.3
Trial 2	0.001257	5902.61	74183.4
Trial 3	0.00128	7837.91	74752.7
Trial 4	0.001618	9388.52	75171.9
Trial 5	0.001015	6082.07	75222.4
Average	**0.0012944**	**6970.89**	**76233.54**

CPU with threads			
	3x3	**1000x1000**	**2000x2000**
Trial 1	0.000408	6315.75	72933.7
Trial 2	0.00121	7950.09	74614.7
Trial 3	0.001315	6904.19	73207.2
Trial 4	0.00107	6983.94	75365.1

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

Trial 5	0.000986	5894.8	74223.6
Average	**0.0009978**	**6809.754**	**74068.86**

GPU 1D grid, 1D block, 128 threads per block				
	3x3	**1000x1000** **8 blocks**	**2000x2000** **16 blocks**	**4000x4000** **32 blocks**
Trial 1	0.036468	533.889709	1980.140259	7485.441895
Trial 2	0.029224	489.622406	1933.500244	8741.581055
Trial 3	0.039797	487.324371	1932.235107	7744.794922
Trial 4	0.040914	488.069641	1932.458008	7776.899414
Trial 5	0.041869	536.176270	1933.899658	8756.853516
Average	**0.0376544**	**507.0164794**	**1942.4466552**	**8101.1141604**

GPU 2D grid, 1D block, 128 threads per block				
	3x3 1x3 grid	**1000x1000** 8x1000 grid	**2000x2000** 16x2000 grid	**4000x4000** 32x4000 grid
Trial 1	0.033022	63.710728	498.139618	3831.066650
Trial 2	0.042266	64.600227	468.093292	3799.276367
Trial 3	0.024313	63.881649	468.092377	3807.784424
Trial 4	0.041660	63.774837	467.573517	3802.318359
Trial 5	0.042253	62.991325	466.071503	3815.585449
Average	**0.0367028**	**63.7917532**	**473.5940614**	**3811.2062498**

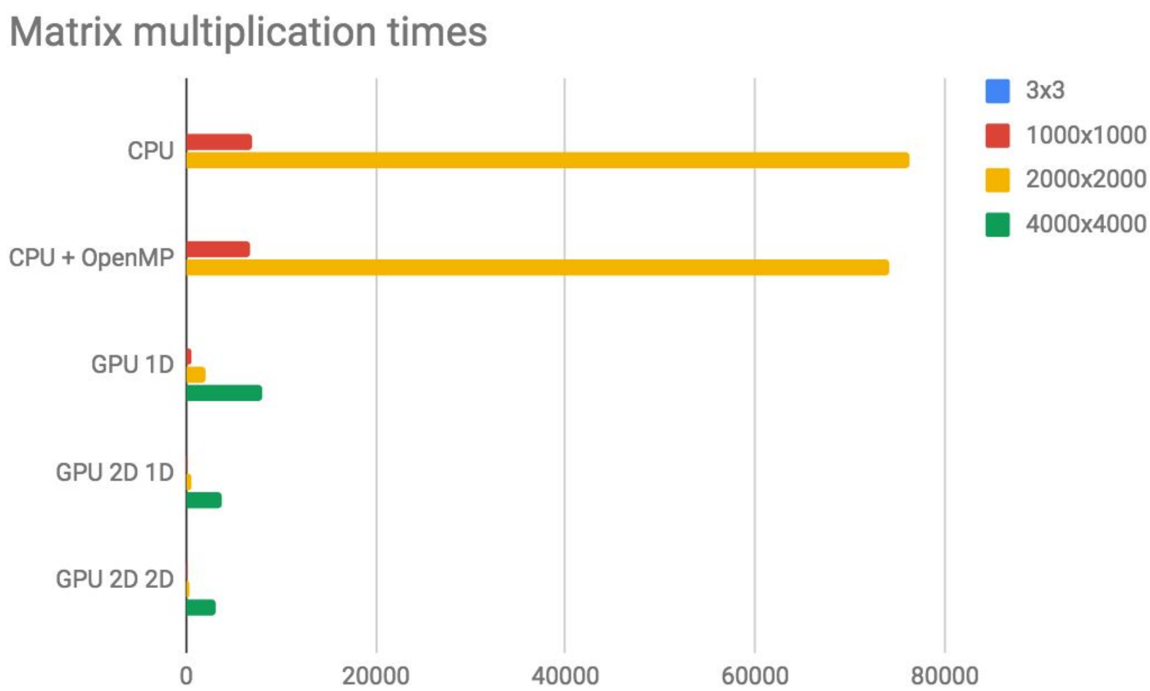
GPU 2D grid, 2D block, 32x32 block size				
	3x3 1x1 grid	**1000x1000** 32x32 grid	**2000x2000** 63x63 grid	**4000x4000** 125x125 grid

Trial 1	0.030596	58.653423	449.625061	3166.145996
Trial 2	0.040654	62.907055	413.866425	3147.636963
Trial 3	0.037539	61.644348	399.948914	3155.324951
Trial 4	0.035190	62.770149	405.283752	3163.276855
Trial 5	0.020625	61.128883	403.779327	3165.669434
Average	**0.0329208**	**61.4207716**	**414.5006958**	**3159.6108398**

3. Analysis

The following table summarizes the results from the previous section.

	3x3	**1000x1000**	**2000x2000**	**4000x4000**
CPU	0.0012944	6970.89	76233.54	
CPU + OpenMP	0.0009978	6809.754	74068.86	
GPU 1D	0.0376544	507.0164794	1942.4466552	8101.1141604
GPU 2D 1D	0.0367028	63.7917532	473.5940614	3811.2062498
GPU 2D 2D	0.0329208	61.4207716	414.5006958	3159.6108398



We obtain the best results using 2D grid with 2D array of threads per block. The difference between 2D 1D and 2D 2D is small, but still significant. The difference between CPU and CPU with threads is really small and not necessarily significant.

Speedup from CPU			
	3x3	**1000x1000**	**2000x2000**
CPU + OpenMP	1.2975	1.024	1.0292
GPU 1D	0.0348	13.7488	39.2461
GPU 2D 1D	0.0353	109.2757	160.9681
GPU 2D 2D	0.0393	113.4940	183.9165

As the data gets larger, the GPU speedup increases. We can also compare the speed between GPU configurations.

Speedup from GPU for 4000x4000 configurations		
	GPU 1D	**GPU 2D 1D**
GPU 2D 1D	2.1256	1
GPU 2D 2D	2.56394	1.2062

While the difference between 2D 1D and 2D 1D configurations isn’t too big, it’s still a 20% of difference. The speedup from using 2D configurations is clear and consistent across all matrix sizes.

4. Conclusions

Using GPU takes longer to configure than CPU, as can be noted in small matrices (eg 3x3), but presents a huge boost in running time. There’s a lot of variation in the time. This can be due to many factors, causing the results not to be consistent and have smaller statistical significance.

Changing the number of threads per block in the 3 experiments with GPU showed no direct impact in running time. This is because, at the end, we are always using the same number of threads: N. If a matrix is 1000x1000, the program checks that the thread is smaller than 1000 (ix < n). Because of this, even if we have more threads, the algorithm makes no use of them. I expected a better performance of CPU with threads in comparison to the CPU, but the results were pretty much the same when comparing to the GPU.