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Assignment 1 - GPU programming
Dr. Cherif Salama

GPU used:

- Device name: NVIDIA GeForce RTX 3090
- max number of threads: 1024

Wed Sep 28 14:43:47 2022											
NVIDIA-SMI 515.65.01			Driver Version: 515.65.01		CUDA Version: 11.7						
GPU	Name	Persistence-M	Fan	Temp	Perf	Pwr:Usage/Cap	Bus-Id	Disp.A	Volatile	Uncorr.	ECC
									GPU-Util	Compute M.	MIG M.
0	NVIDIA GeForce ...	On	30%	35C	P8	27W / 350W	00000000:02:00.0	On	438MiB / 24576MiB	0%	N/A
										Default	N/A

Q1. For vector addition, assume that each vector length is 4000, each thread calculates one output element, and the thread block size is 512 threads. How many threads will be in the grid?

Ans:

- Since each thread computes 1 output element, we need 4000 threads in total.
- For 512 threads per block, we need the ceiling of $4000/512$ blocks as we cannot have partial blocks.
- Thus, we would have 8 blocks in the grid, which means $8 \text{ blocks} * 512 \text{ threads per block} = 4096 \text{ threads}$.

Task 1:

```
● cse-p07-g07f@csep07g07f:~/Documents/GPU/mina_assignment1$ ./small_task1
Size of the vector: 18
Device Number: 0
    Device name: NVIDIA GeForce RTX 3090
    max number of theads: 1024
Number of blocks: 1
The vectors are equal
Input vector 1:
128.61 99.59 101.02 630.30 398.86 544.16 473.52 545.85 924.96 791.52 651.04 736.
47 260.51 626.99 336.89 407.94 29.48 182.73
Input vector 2:
297.90 717.23 234.38 28.60 910.05 659.04 761.54 14.03 320.54 598.54 566.19 770.4
0 595.58 837.21 731.58 465.49 507.54 130.50
GPU output vector:
426.50 816.83 335.40 658.90 1308.92 1203.20 1235.07 559.88 1245.50 1390.05 1217.
23 1506.87 856.10 1464.20 1068.47 873.44 537.02 313.22
○ cse-p07-g07f@csep07g07f:~/Documents/GPU/mina_assignment1$
```

```
● cse-p07-g07f@csep07g07f:~/Documents/GPU/mina_assignment1$ cat small_out.txt
Size of the vector: 7
Device Number: 0
    Device name: NVIDIA GeForce RTX 3090
    max number of theads: 1024
Number of blocks: 1
The vectors are equal
Input vector 1:
611.56 109.44 164.42 260.39 751.68 189.78 861.71
Input vector 2:
497.72 272.13 812.92 442.79 624.15 260.36 136.43
GPU output vector:
1109.28 381.57 977.34 703.18 1375.82 450.13 998.15
○ cse-p07-g07f@csep07g07f:~/Documents/GPU/mina_assignment1$
```

The small task1 is a binary that generates smaller vectors in random also by using the modulus operator. This allows the screenshots to be a little bit more beautiful as the huge vectors prevent you from seeing the input and output on the same screen.

What is the maximum size of the vectors that can be used if the kernel is launched with a single block?

Ans:

A single block can have at most 1024 threads as per the compute capabilities for our GPU and its CUDA version. Thus, given that each thread adds 4 elements together, we can have at most $1024 * 4 = 4096$ elements per vector.

Task 2:

Write a full program to randomly generate a grayscale picture by generating a 2D array of integers of size 1000x800 randomly initialized to values ranging between 0 and 255. Your program should then use a CUDA kernel with a 2D grid and 2D blocks to multiply each pixel of the picture by 3 (trimming the resulting value to 255 if it exceeds that value). Each block should have 16x16 threads and each thread should be responsible for a single pixel.

How many blocks in each dimension will we have? How many threads in total will be in the grid?

Since our image has 1000 rows, and 800 columns.

We would have $\text{Ceil}(\frac{1000}{16}) = 63 \text{ blocks in the } x_{\text{dim}}$

and we would have $\text{Ceil}(\frac{800}{16}) = 50 \text{ blocks in the } y_{\text{dim}}$

Therefore, the total number of blocks is:

$$\text{blocks}_{\text{total}} = 63 * 50 = 3150 \text{ blocks}$$

And we have $\text{ThreadsPerBlock} = 16 * 16 = 256 \text{ threads per block}$

Therefore, $\text{Total threads in the Grid} = 3150 \text{ blocks} \times 256 \frac{\text{threads}}{\text{block}} = 806400 \text{ threads}$

The image itself has 800000 pixels, so we are launching 6400 threads without really needing to, but that's minimal compared to the 800,000.

```
PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL JUPYTER COMMENTS
● cse-p07-g07f@csep07g07f:~/Documents/GPU$ cd mina_assignment1/
● cse-p07-g07f@csep07g07f:~/Documents/GPU/mina_assignment1$ ./task2
Images are equal
The original image:
103 198 105 115 81 255 74 236 41 205 186 171 242 251 227 70 124 194 84 248 27 232 231 141 118 90 46 99 51 159 201 154 102 5
0 13 183 49 88 163 90 37 93 5 23 88 233 94 212 171 178 205 198 155 180 84 17 14 130 116 65 33 61 220 135 112 233 62 161 65
225 252 103 62 1 126 151 234 220 107 150 143 56 92 42 236 176 59 251 50 175 60 84 236 24 219 92 2 26 254 67 251 250 170 58
251 41 209 230 5 60 124 148 117 216 190 97 137 249 92 187 168 153 15 149 177 235 241 179 5 239 247 0 233 161 58 229 202 11
203 208 72 71 100 189 31 35 30 168 28 123 100 197 20 115 90 197 94 75 121 99 59 112 100 36 17 158 9 220 170 212 172 242 27
16 175 59 51 205 227 80 72 71 21 92 187 111 34 25 186 155 125 245 11 225 26 28 127 35 248 41 248 164 27 19 181 202 78 232 1
52 50 56 224 121 77 61 52 188 95 78 119 250 203 108 5 172 134 33 43 170 26 85 162 190 112 181 115 59 4 92 211 54 148 179 17
5 226 240 228 158 79 50 21 73 253 130 78 169 8 112 212 178 138 41 84 72 154 10 188 213 14 24 168 68 172 91 243 142 76 215 4
5 155 9 66 229 6 196 51 175 205 163 132 127 45 173 212 118 71 222 50 28 236 74 196 48 246 32 35 133 108 251 178 7 4 244 236
11 185 32 186 134 195 62 5 241 236 217 103 51 183 153 80 163 227 20 211 217 52 247 94 160 242 16 168 246 5 148 1 190 180 1
88 68 120 250 73 105 230 35 208 26 218 105 106 126 76 126 81 37 179 72 132 83 58 148 251 49 153 144 50 87 68 238 155 188 23
3 229 37 207 8 245 233 226 94 83 96 170 210 178 208 133 250 84 216 53 232 212 102 130 100 152 217 168 135 117 101 112 90 13
8 63 98 128 41 68 222 124 165 137 78 87 89 211 81 173 172 134 149 128 236 23 228 133 241 140 12 102 241 124 192 124 187 34
252 228 102 218 97 11 99 175 98 188 131 180 105 47 58 255 175 39 22 147 172 7 31 184 109 17 52 45 141 239 79 137 212 182 99
53 193 199 228 36 131 103 216 237 150 18 236 69 57 2 216 229 10 248 157 119 9 209 165 150 193 244 31 149 170 130 202 108 7
```

```

cse-p07-g07f@csep07g07f:~/Documents/GPU/mina_assignment1$ ./task2 > task2_out.txt
cse-p07-g07f@csep07g07f:~/Documents/GPU/mina_assignment1$ head -1 task2_out.txt
Images are equal
cse-p07-g07f@csep07g07f:~/Documents/GPU/mina_assignment1$ 

```

Task 3:

Write a full CUDA program to perform matrix addition on square matrices **such that each thread is responsible for computing one column of the output (sum) matrix**. The size of the matrices and their values should be randomly selected.

```

cse-p07-g07f@csep07g07f:~/Documents/GPU/mina_assignment1$ nvidia-smi > specs.txt
cse-p07-g07f@csep07g07f:~/Documents/GPU/mina_assignment1$ ls
mina_task1_out.txt small_out.txt specs.txt task1_out.txt task2_out.txt task3 task3.cu task3_out.txt tatsuask1_out.txt
cse-p07-g07f@csep07g07f:~/Documents/GPU/mina_assignment1$ head -1 task3_out.txt
dimension matrix A: 11213 x 11213
cse-p07-g07f@csep07g07f:~/Documents/GPU/mina_assignment1$ head -1 task3_out_2.txt
dimension matrix A: 11213 x 11213
cse-p07-g07f@csep07g07f:~/Documents/GPU/mina_assignment1$ ./task3 > task3_out_2.txt

```

Output size was huge since I printed the two matrices in the input and the output. It was around 8 GBs for a 30k by 30k matrix addition.

Thus, for this problem, I would only show the output, and I will not attach it.

I generated another binary that generates much smaller matrices and used it.

Here I am generating 484x484 matrices, which were randomly generated and the same for the size. Even for this small matrix, the output was around 80 megabytes.

```
● cse-p07-g07f@csep07g07f:~/Documents/GPU$ cd mina_assignment1/
● cse-p07-g07f@csep07g07f:~/Documents/GPU/mina_assignment1$ ./task3_small
dimension matrix A: 484 x 484
dimension matrix B: 484 x 484
Matrix A:
1587893632.00 2052004608.00 1280059008.00 127101808.00 432461600.00 1062400384.00 1507827712.00 1688504192.00 289997408.00
1450323072.00 676691328.00 745716224.00 1047395840.00 1224835712.00 1850632320.00 1729107584.00 1933792640.00 1440341248.00
1381556352.00 1742517248.00 1690145664.00 591028032.00 829540160.00 1840228352.00 645337984.00 363584864.00 1096198400.00
125930984.00 1705160717.00 510565696.00 342243648.00 551724032.00 1725818112.00 1194920704.00 1412024832.00 626425152.00 14
47388416.00 2005176576.00 1349501824.00 1248982528.00 693505600.00 1169385344.00 577984768.00 1785814656.00 498599488.00 15
43683200.00 241086240.00 969395840.00 1939988992.00 779311616.00 806787328.00 11733331.00 475706336.00 236137024.00 1567347
712.00 1672564224.00 952003264.00 1903073536.00 1989782400.00 1665505792.00 1690301184.00 1181741312.00 1009628928.00 17508
08192.00 20486522.00 2006664320.00 1788372864.00 933965952.00 1887824000.00 1941803648.00 507738848.00 1421057536.00 138665
37.00 842426528.00 570568320.00 197063408.00 1421974144.00 2044773248.00 1382458368.00 1086253696.00 2030733952.00 82735056
.00 816348416.00 1788218752.00 39320332.00 1864376704.00 901939392.00 2006801280.00 167114400.00 771791136.00 1061832960.00
851068544.00 200355680.00 620442816.00 248972240.00 838275200.00 504647200.00 1803845632.00 1937711232.00 1877684352.00 87
9635968.00 376607136.00 585044352.00 549897600.00 937489024.00 1489841408.00 143419712.00 188161728.00 941784512.00 1926589
440.00 367817408.00 1322979200.00 1538391168.00 45976600.00 276438368.00 1158166784.00 1370754688.00 790166016.00 177069862
4.00 560474112.00 514484800.00 412542304.00 96258256.00 10016143904.00 1409308672.00 81315824.00 1398130560.00 502107008.00
236152624.00 211765696.00 324260896.00 1668665344.00 515630240.00 1503330944.00 1651411328.00 699549248.00 1966636928.00 6
76244928.00 1712795648.00 953454336.00 311154880.00 604262912.00 291581536.00 350839968.00 1654453564.00 1040325184.00 1449
353344.00 1526246400.00 872854464.00 2103828736.00 798415168.00 395158592.00 176798592.00 532980064.00 601808768.00 160434

61824.00 1225143848.00 673778688.00 299151266.00 342415872.00 259369264.00 2393635584.00 2505835008.00 677978176.00 2311727368.00 2441588224.00 2011231488.00 801272512.00
699518208.00 180827376.00 1229642114.00 2856567712.00 1396462880.00 2102477360.00 279793176.00 1978534144.00 646557376.00 2806979709.00 15167798976.00 2393241736.00 14834848
.00 69988265.00 1655846400.00 2296727296.00 2602975232.00 198834560.00 2510259200.00 1992875392.00 1893497984.00 1852244736.00 2244418816.00 1496123136.00 1760497920.00 1
48401152.00 1345600864.00 1648404736.00 2426304688.00 2028675840.00 2101430848.00 994794974.00 359706784.00 2979792096.00 3457164800.00 281720320.00 1741239296.00 145395635
.00 172229292.00 258167072.00 2958214400.00 810152960.00 1975265650.00 699378176.00 2860447232.00 2040731648.00 681998280.00 1081748224.00 1686188800.00 3831761296.00 297654
4128.00 190481408.00 285724176.00 118003176.00 2013149284.00 82028504592.00 2726771200.00 2823728320.00 1941281536.00 513484608.00 1947177344.00 1176371456.00 344217972.00
1363397120.00 11141929448.00 1681786624.00 771841408.00 2386681568.00 2648938496.00 1312120624.00 3041851136.00 31910160.00 2615989248.00 1879925765.00 291654
608.00 2799882848.00 1158279888.00 2856872448.00 2780595200.00 3421777928.00 876646848.00 3753282560.00 2726315088.00 1459405568.00 326891328.00 3877823744.00 3825828352.00
51688448.00 2441149184.00 1656633216.00 2665170432.00 302817168.00 210884392.00 2050159616.00

Matrices are equal
minaashraf@Mina-MacBook-Pro:~
```

You can see at the end it says the output is correct as per the CPU algorithm comparison.

```
● cse-p07-g07f@csep07g07f:~$ cd Documents/GPU/mina_assignment1/
● cse-p07-g07f@csep07g07f:~/Documents/GPU/mina_assignment1$ nvcc task3.cu -o task3
● cse-p07-g07f@csep07g07f:~/Documents/GPU/mina_assignment1$ ./task3
dimension matrix A: 1353 x 1353
dimension matrix B: 1353 x 1353
Matrix A size: 1353 x 1353
Matrix B size: 1353 x 1353
Matrices are equal
● cse-p07-g07f@csep07g07f:~/Documents/GPU/mina_assignment1$ ./task3
dimension matrix A: 18799 x 18799
dimension matrix B: 18799 x 18799

Matrix A size: 18799 x 18799
Matrix B size: 18799 x 18799
Matrices are equal
○ cse-p07-g07f@csep07g07f:~/Documents/GPU/mina_assignment1$ 
○ cse-p07-g07f@csep07g07f:~/Documents/GPU/mina_assignment1$ █
```