Report Common Assignment 3

Counting sort

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Chapter 1

Problem description

Parallelize and Evaluate Performances of "Counting Sort" Algorithm , by using CUDA.

Counting sort is an algorithm for sorting integer numbers. The computational complexity is equal to $O(n)$.

In this report we analize counting sort algorithm: get execution times, bandwidth and other performances measures when of using:

- Global Memory
- Shared Memory
- Texture Memory

Evaluate performances with different block-grid configurations.

1.1 Experimental setup

All measurements were made using the Google Colab service, with the following setup.

1.1.1 Hardware

CPU

```
processor    : 0
vendor_id    : GenuineIntel
cpu family   : 6
model                : 63
model name   : Intel(R) Xeon(R) CPU @ 2.30GHz
stepping     : 0
microcode    : 0x1
cpu MHz              : 2299.998
cache size   : 46080 KB
physical id  : 0
siblings     : 2
core id              : 0
cpu cores    : 1
apicid               : 0
initial apicid       : 0
fpu          : yes
fpu_exception        : yes
cpuid level  : 13
wp           : yes
flags                :  fpu vme de pse tsc msr pae mce cx8
                   apic sep mtrr pge mca cmov pat pse36
                   clflush mmx fxsr sse sse2 ss ht syscall
                   nx pdpe1gb rdtscp lm constant_tsc rep_good
                   nopl xtopology nonstop_tsc cpuid
                   tsc_known_freq pni pclmulqdq ssse3
                   fma cx16 pcid sse4_1 sse4_2 x2apic
                   movbe popcnt aes xsave avx f16c
                   rdrand hypervisor lahf_lm abm invpcid_single
```

```
                ssbd ibrs ibpb stibp fsgsbase tsc_adjust
                bmi1 avx2 smep bmi2 erms invpcid xsaveopt
                arat md_clear arch_capabilities
bugs                : cpu_meltdown spectre_v1 spectre_v2
              spec_store_bypass l1tf mds swapgs
bogomips    : 4599.99
clflush size        : 64
cache_alignment     : 64
address sizes       : 46 bits physical, 48 bits virtual
power management:

processor   : 1
vendor_id   : GenuineIntel
cpu family  : 6
model               : 63
model name  : Intel(R) Xeon(R) CPU @ 2.30GHz
stepping    : 0
microcode   : 0x1
cpu MHz             : 2299.998
cache size  : 46080 KB
physical id : 0
siblings    : 2
core id             : 0
cpu cores   : 1
apicid              : 1
initial apicid      : 1
fpu         : yes
fpu_exception       : yes
cpuid level : 13
wp          : yes
flags               : fpu vme de pse tsc msr pae mce cx8 apic
```

```
                sep mtrr pge mca cmov pat pse36 clflush
                mmx fxsr sse sse2 ss ht syscall nx pdpe1gb
                rdtscp lm constant_tsc rep_good nopl
                xtopology nonstop_tsc cpuid tsc_known_freq
                pni pclmulqdq ssse3 fma cx16 pcid sse4_1
                sse4_2 x2apic movbe popcnt aes xsave avx
                f16c rdrand hypervisor lahf_lm abm
                invpcid_single ssbd ibrs ibpb stibp fsgsbase
                tsc_adjust bmi1 avx2 smep bmi2 erms invpcid
                xsaveopt arat md_clear arch_capabilities
bugs            : cpu_meltdown spectre_v1 spectre_v2
                spec_store_bypass l1tf mds swapgs
bogomips        : 4599.99
clflush size    : 64
cache_alignment : 64
address sizes   : 46 bits physical, 48 bits virtual
power management:
```

RAM

MemTotal:	13302920	kB
MemFree:	236348	kB
MemAvailable:	12350076	kB
Buffers:	283016	kB
Cached:	11566856	kB
SwapCached:	0	kB
Active:	3457004	kB
Inactive:	8911716	kB
Active(anon):	476972	kB
Inactive(anon):	480	kB
Active(file):	2980032	kB
Inactive(file):	8911236	kB
Unevictable:	0	kB
Mlocked:	0	kB
SwapTotal:	0	kB
SwapFree:	0	kB
Dirty:	200	kB
Writeback:	0	kB
AnonPages:	518888	kB
Mapped:	269548	kB
Shmem:	1228	kB
KReclaimable:	548408	kB
Slab:	600016	kB
SReclaimable:	548408	kB
SUnreclaim:	51608	kB
KernelStack:	5904	kB
PageTables:	7172	kB
NFS_Unstable:	0	kB
Bounce:	0	kB
WritebackTmp:	0	kB

```
CommitLimit:       6651460 kB
Committed_AS:      3798912 kB
VmallocTotal:   34359738367 kB
VmallocUsed:         46004 kB
VmallocChunk:            0 kB
Percpu:               1448 kB
AnonHugePages:           0 kB
ShmemHugePages:          0 kB
ShmemPmdMapped:          0 kB
FileHugePages:           0 kB
FilePmdMapped:           0 kB
CmaTotal:                0 kB
CmaFree:                 0 kB
HugePages_Total:         0
HugePages_Free:          0
HugePages_Rsvd:          0
HugePages_Surp:          0
Hugepagesize:         2048 kB
Hugetlb:                 0 kB
DirectMap4k:        279360 kB
DirectMap2M:       9154560 kB
DirectMap1G:       6291456 kB
```

GPU

```
Device number: 0
Device name: Tesla K80
Compute capability: 3.7

Clock Rate: 823500 kHz
Total SMs: 13
Shared Memory Per SM: 114688 bytes
Registers Per SM: 131072 32-bit
Max threads per SM: 2048
L2 Cache Size: 1572864 bytes
Total Global Memory: 11996954624 bytes
Memory Clock Rate: 2505000 kHz

Max threads per block: 1024
Max threads in X-dimension of block: 1024
Max threads in Y-dimension of block: 1024
Max threads in Z-dimension of block: 64

Max blocks in X-dimension of grid: 2147483647
Max blocks in Y-dimension of grid: 65535
Max blocks in Z-dimension of grid: 65535

Shared Memory Per Block: 49152 bytes
Registers Per Block: 65536 32-bit
Warp size: 32
```

BANDWIDTH

Device 0: Tesla K80

Range Mode

Host to Device Bandwidth, 1 Device(s)

PINNED Memory Transfers

Transfer Size (Bytes)	Bandwidth(MB/s)
1000	278.7
101000	6240.3
201000	6613.4
301000	6923.8
401000	7064.9
501000	7197.9
601000	7046.2
701000	7217.7
801000	7333.4
901000	7454.2

Device to Host Bandwidth, 1 Device(s)

PINNED Memory Transfers

Transfer Size (Bytes)	Bandwidth(MB/s)
1000	419.3
101000	6563.5
201000	7137.2
301000	7351.7
401000	7361.0
501000	7443.2
601000	7505.5
701000	7519.7
801000	7579.2
901000	7571.1

```
Device to Device Bandwidth, 1 Device(s)
PINNED Memory Transfers
```

Transfer Size (Bytes)	Bandwidth(MB/s)
1000	251.6
101000	25527.1
201000	44132.9
301000	57341.3
401000	75400.8
501000	83089.5
601000	89331.3
701000	102785.9
801000	91342.3
901000	80354.0

1.1.2 Software

- NVIDIA-SMI 510.39.01
- Driver Version: 460.32.03
- CUDA Version: 11.2
- Ubuntu 18.04.5 LTS

Chapter 2

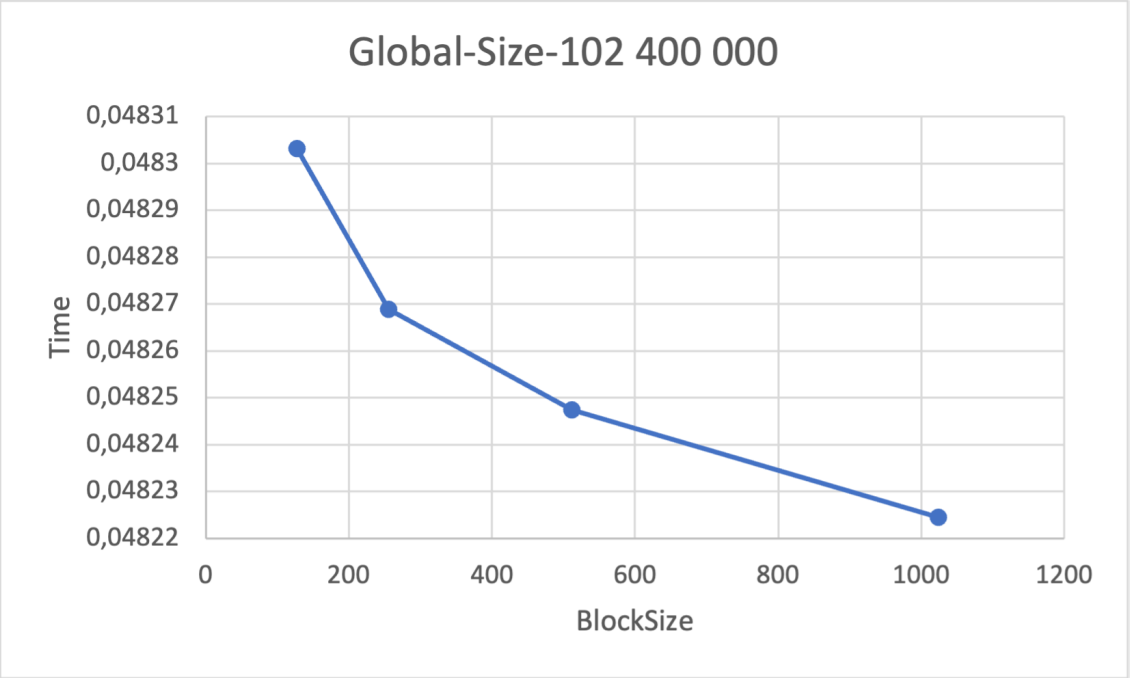
Performance

2.1 Case study n°1 - Global Memory

In this case study, we have analyzed the counting sort algorithm using global memory. The size of the problem is 102 400 000 and than we evaluate the performances with block size of:

- 128: with this choice we have that 2048/128 = 16 blocks. The occupancy is 100%.
- 256: with this choice we have that 2048/256 = 8 blocks. The occupancy is 100%.
- 512: with this choice we have that 2048/512 = 4 blocks. The occupancy is 100%.
- 1024: with this choice we have that 2048/1024 = 2 blocks. The occupancy is 100%.

N	BlockSize	GridSize	mips	time_sec
102 400 000	128	800 000	1 945 600 655	0,04830324
102 400 000	256	400 000	1 945 601 167	0,04826894
102 400 000	512	200 000	1 945 602 191	0,04824748
102 400 000	1024	100 000	1 945 604 239	0,04822454

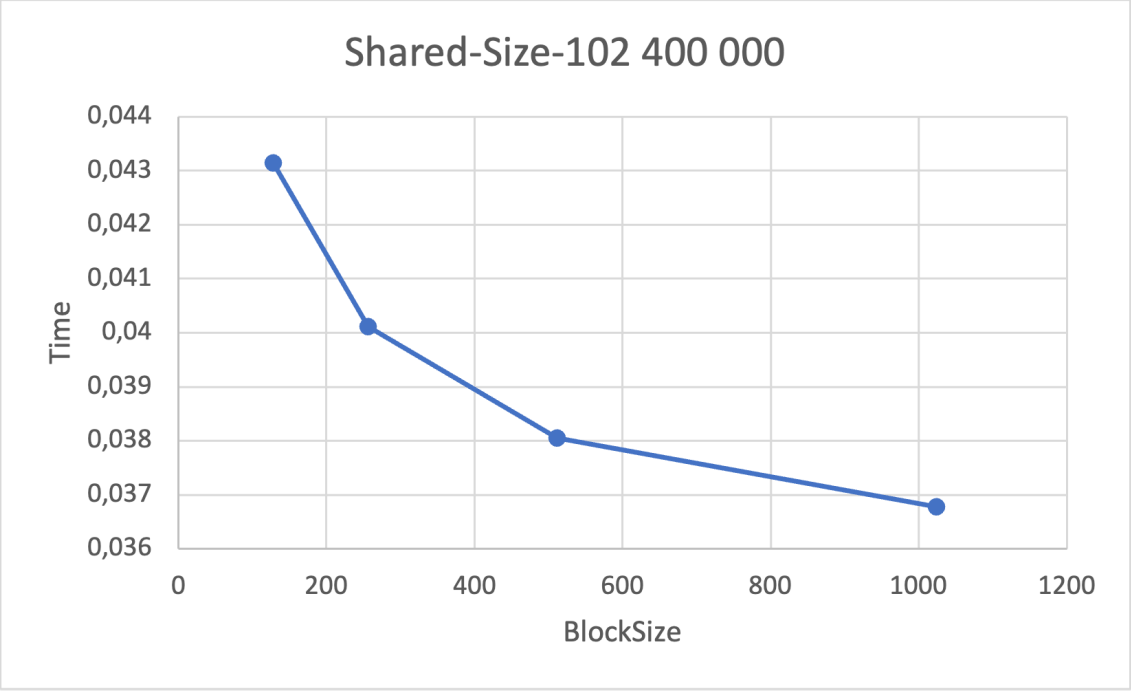


2.2 Case study n°2 - Shared Memory

In this case study, we have analyzed the counting sort algorithm using shared memory. The size of the problem is 102 400 000 and than we evaluate the performances with block size of:

- 128: with this choice we have that 2048/128 = 16 blocks. The occupancy is 100%.
- 256: with this choice we have that 2048/256 = 8 blocks. The occupancy is 100%.
- 512: with this choice we have that 2048/512 = 4 blocks. The occupancy is 100%.
- 1024: with this choice we have that 2048/1024 = 2 blocks. The occupancy is 100%.

N	BlockSize	GridSize	mips	time_sec
102 400 000	128	800 000	2 272 804 239	0,04314758
102 400 000	256	400 000	2 292 802 191	0,04011825
102 400 000	512	200 000	2 332 801 167	0,03805279
102 400 000	1024	100 000	2 412 800 655	0,03677322

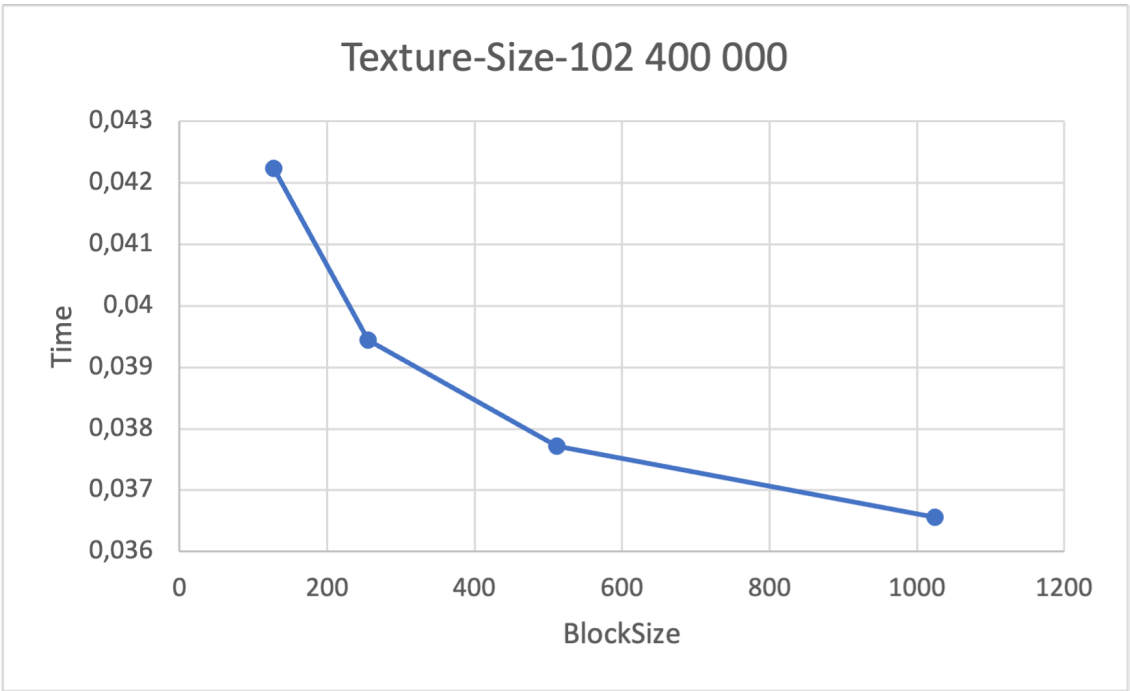


2.3 Case study n°3 - Texture Memory

In this case study, we have analyzed the counting sort algorithm using texture memory. The size of the problem is 102 400 000 and than we evaluate the performances with block size of:

- 128: with this choice we have that 2048/128 = 16 blocks. The occupancy is 100%.
- 256: with this choice we have that 2048/256 = 8 blocks. The occupancy is 100%.
- 512: with this choice we have that 2048/512 = 4 blocks. The occupancy is 100%.
- 1024: with this choice we have that 2048/1024 = 2 blocks. The occupancy is 100%.

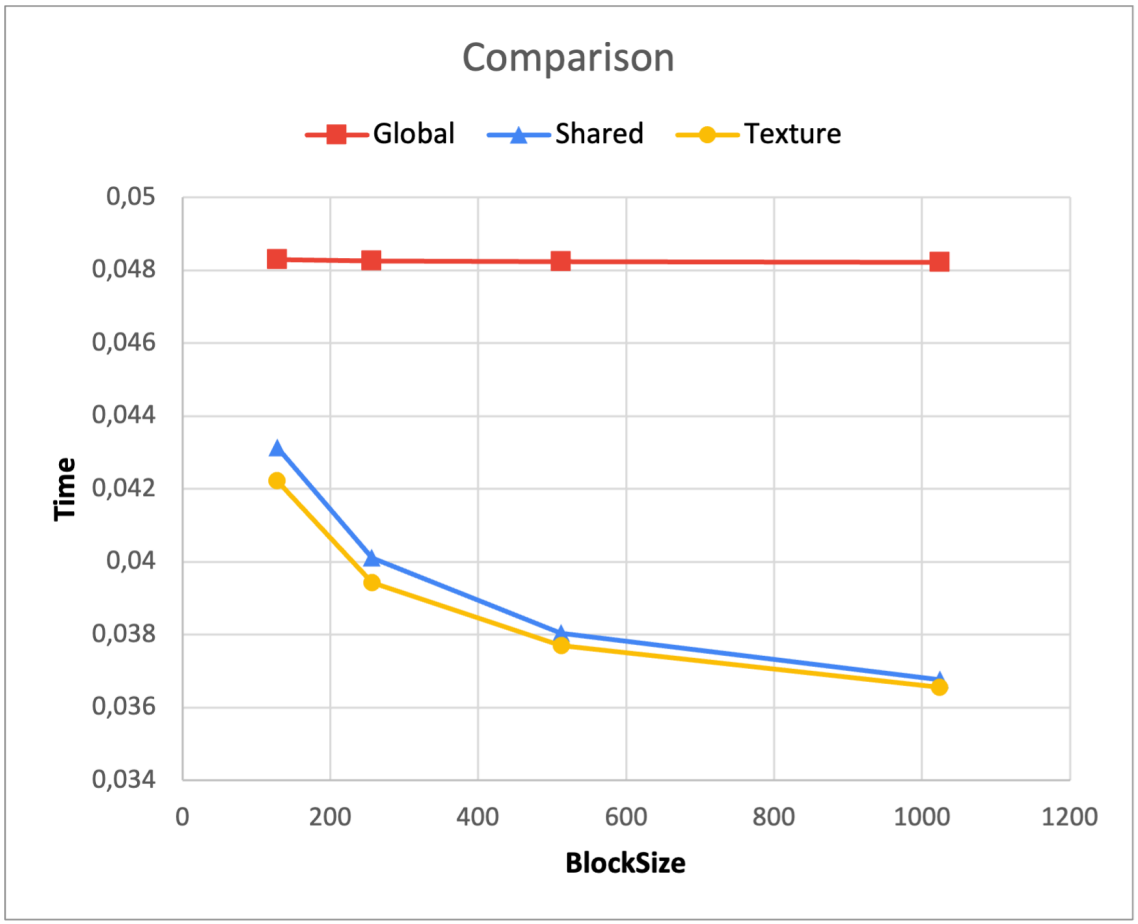
N	BlockSize	GridSize	mips	time_sec
102 400 000	128	800 000	2 272 804 239	0,04223858
102 400 000	256	400 000	2 292 802 191	0,03944138
102 400 000	512	200 000	2 332 801 167	0,03771372
102 400 000	1024	100 000	2 412 800 655	0,03656407



Chapter 3

Considerations

3.1 Comparison



As can be seen from the graph above, shared and textured versions are influenced by the BlockSize: as the size increases, the time decreases.

Comparing the various versions, a clear improvement can be seen in the use of shared com-

pared to global as the shared has a very low latency. In the texture, there is an improvement over the global and shared versions, but only a small improvement in terms of time compared to the shared.

3.2 Premises

- Global memory is L1/L2-cache and texture memory is a separate texture cache.
- L2 is global so each access to global memory goes through L2 first, L1 is local to the multiprocessor.
- Texture memory is read-only, our program cannot dictate what is in the texture cache, so it is transparent to the program. (Behaves much like a CPU cache).
- We used atomic functions because the counting sort algorithm required that several threads access the same locations but above all it avoids data inconsistency due to the race condition.

  Referring to the documentation, we realized that the atomic function was useful for our purpose because:

  an atomic function performs a read-modify-write atomic operation on one 32-bit or 64-bit word residing in global or shared memory.

  The operation is atomic in the sense that it is guaranteed to be performed without interference from other threads. In other words, no other thread can access this address until the operation is complete.

  Atomic functions do not act as memory fences and do not imply synchronization or ordering constraints for memory operations.

  In particular, we used atomicAdd and atomicSub function, the following URLs are referred to the specified functions documentation:

  https://docs.nvidia.com/cuda/cuda-c-programming-guide/index.html#atomicadd

  https://docs.nvidia.com/cuda/cuda-c-programming-guide/index.html#atomicsub

Chapter 4

How to run

Use the colab notebook in the folder or go to this URL:

https://drive.google.com/drive/u/1/folders/10ZMNoKnH-foAqqGiVjpBPBVHRx-Z5TAw

You can find the complete project on GitHub: https://github.com/scov8/CommonAssignment3

The starting point for the global and shared counting sort was taken here:

https://github.com/avtrunov/CUDA/blob/500bf0f1ca9af066f8dba6572d7b11121046d3a6/CountingSort.cu

https://github.com/jtruong27/ECEC413/blob/9713c61a9c5dc10c77b5d79def7ea83abc21fcb0/Homework_5/CountingSort_CUDA/counting_sort_kernel.cu

The previous year's group 02 files proposed by the professor during the course were used for file generation and extraction.