Assignment 1

Felix Söderman DD2360 HT23
Github: https://github.com/felixcool200/DD2360HT23

Exercise 1 - Reflection on GPU-accelerated Computing

1. List the main differences between GPUs and CPUs in terms of architecture.

   ANSWER: The main differance between the two is that CPUs are based on Latency oriented processor architecture. This means that it is designed to minimize the time it takes to complete a single task. This results in a few cores that have high clock speed (and high energy usage). A CPU is thus good at solving single threaded tasks fast, such as sorting elements in a list.

   GPUs on the other hand use a throughput-oriented processor architecture. This means it is designed to maximize the amount of problems it can solve rather than making sure they are completed as soon as they are created. GPUs thus have many cores and is good at completling task that are parallelizable, such as AI workloads or processing individual pixels on a screen.

2. Check the latest Top500 list that ranks the top 500 most powerful supercomputers in the world. In the top 10, how many supercomputers use GPUs Report the name of the supercomputers and their GPU vendor (Nvidia, AMD, ...) and model.

   ANSWER: Since the definition of GPU is quite vauge. I will also include computers that run other type of accelerator cards that have similar capabilites.

   1 Frontier - HPE Cray EX235a, **AMD** Instinct MI250X

   3 LUMI - HPE Cray EX235a, **AMD** Instinct MI250X

   4 Leonardo - BullSequana XH2000, **NVIDIA** A100 SXM4 64 GB

   5 Summit - IBM Power System AC922, **NVIDIA** Volta GV100

   6 Sierra - IBM Power System AC922, **NVIDIA** Volta GV100

   8 Perlmutter - HPE Cray EX235n, **NVIDIA** A100 SXM4 40 GB

   9 Selene - NVIDIA DGX A100, **NVIDIA** A100

   10 Tianhe-2A - TH-IVB-FEP Cluster, Intel Xeon E5-2692v2 12C 2.2GHz, **National University of Defense Technology (NUDT)** Matrix-2000 NOTE that this last one is not a GPU per say but an accelerator card.

3. One main advantage of GPU is its power efficiency, which can be quantified by Performance/Power, e.g., throughput as in FLOPS per watt power consumption. Calculate the power efficiency for the top 10 supercomputers. (Hint: use the table in the first lecture)

   ANSWER: One can clearly see that the machines running GPUs are much more power efficient than those who does not.

1 Frontier - RMax = 1194 [PFLOPS], Power = 22703 [kW] => Power efficiency = 52.59 [GFLOPS/watts]

2 Supercomputer Fugaku - RMax = 442.01 [PFLOPS], Power = 29,899.23 kW [kW] => Power efficiency = 14.78 [GFLOPS/watts]

3 LUMI - RMax = 309.10 [PFLOPS], Power = 6015.77 [kW] => Power efficiency = 51.38 [GFLOPS/watts]

4 Leonardo - RMax = 238.70 [PFLOPS], Power = 7404.40 [kW] => Power efficiency = 32.24 [GFLOPS/watts]

5 Summit - RMax = 148.60 [PFLOPS], Power = 10096.00 [kW] => Power efficiency = 14.72 [GFLOPS/watts]

6 Sierra - RMax = 94.64 [PFLOPS], Power = 7438.28 [kW] => Power efficiency = 12.72 [GFLOPS/watts]

7 Sunway TaihuLight - RMax = 93.01 [PFLOPS], Power = 15371 [kW] => Power efficiency = 6.05 [GFLOPS/watts]

8 Perlmutter - RMax = 70.87 [PFLOPS], Power = 2589 [kW] => Power efficiency = 27.37 [GFLOPS/watts]

9 Selene - RMax = 63.46 [PFLOPS], Power = 2646 [kW] => Power efficiency = 23.98 [GFLOPS/watts]

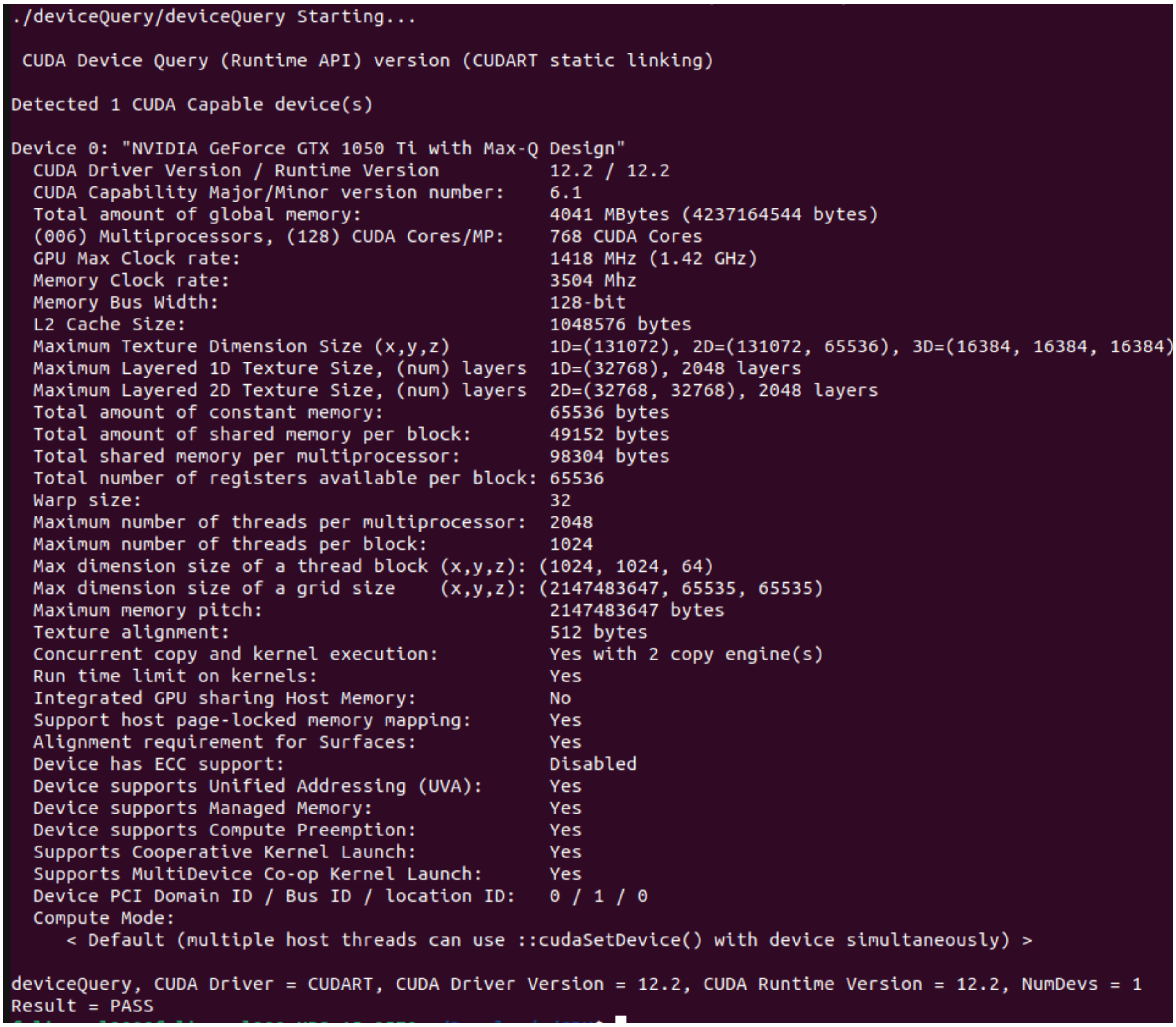
10 Tianhe-2A - RMax = 61.44 [PFLOPS], Power = 18482 [kW] => Power efficiency = 3.32 [GFLOPS/watts]

Exercise 2 - Query Nvidia GPU Compute Capability

1. The screenshot of the output from running deviceQuery test in /1_Utilities.

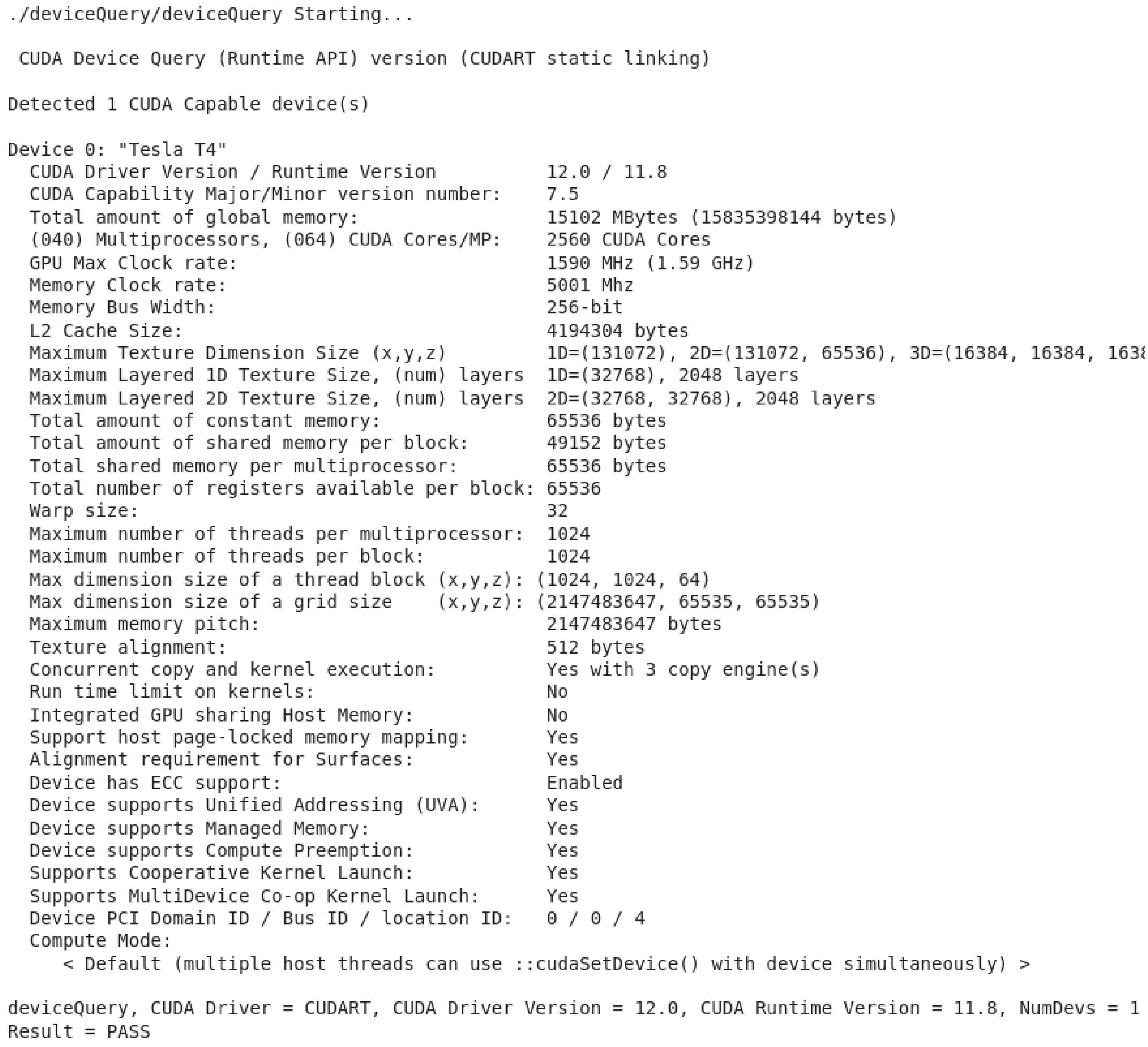
   ANSWER: The screenshot of the output from you running deviceQuery test.

Screenshot from running Device Query on Felix laptop



```
./deviceQuery/deviceQuery Starting...

 CUDA Device Query (Runtime API) version (CUDART static linking)

Detected 1 CUDA Capable device(s)

Device 0: "NVIDIA GeForce GTX 1050 Ti with Max-Q Design"
  CUDA Driver Version / Runtime Version          12.2 / 12.2
  CUDA Capability Major/Minor version number:    6.1
  Total amount of global memory:                 4041 MBytes (4237164544 bytes)
  (006) Multiprocessors, (128) CUDA Cores/MP:    768 CUDA Cores
  GPU Max Clock rate:                            1418 MHz (1.42 GHz)
  Memory Clock rate:                             3504 Mhz
  Memory Bus Width:                              128-bit
  L2 Cache Size:                                 1048576 bytes
  Maximum Texture Dimension Size (x,y,z)         1D=(131072), 2D=(131072, 65536), 3D=(16384, 16384, 16384)
  Maximum Layered 1D Texture Size, (num) layers  1D=(32768), 2048 layers
  Maximum Layered 2D Texture Size, (num) layers  2D=(32768, 32768), 2048 layers
  Total amount of constant memory:               65536 bytes
  Total amount of shared memory per block:       49152 bytes
  Total shared memory per multiprocessor:        98304 bytes
  Total number of registers available per block: 65536
  Warp size:                                     32
  Maximum number of threads per multiprocessor:  2048
  Maximum number of threads per block:           1024
  Max dimension size of a thread block (x,y,z): (1024, 1024, 64)
  Max dimension size of a grid size    (x,y,z): (2147483647, 65535, 65535)
  Maximum memory pitch:                          2147483647 bytes
  Texture alignment:                             512 bytes
  Concurrent copy and kernel execution:          Yes with 2 copy engine(s)
  Run time limit on kernels:                     Yes
  Integrated GPU sharing Host Memory:            No
  Support host page-locked memory mapping:       Yes
  Alignment requirement for Surfaces:            Yes
  Device has ECC support:                        Disabled
  Device supports Unified Addressing (UVA):      Yes
  Device supports Managed Memory:                Yes
  Device supports Compute Preemption:            Yes
  Supports Cooperative Kernel Launch:            Yes
  Supports MultiDevice Co-op Kernel Launch:      Yes
  Device PCI Domain ID / Bus ID / location ID:   0 / 1 / 0
  Compute Mode:
     < Default (multiple host threads can use ::cudaSetDevice() with device simultaneously) >

deviceQuery, CUDA Driver = CUDART, CUDA Driver Version = 12.2, CUDA Runtime Version = 12.2, NumDevs = 1
Result = PASS
```

Screenshot from running Device Query on Google Colab

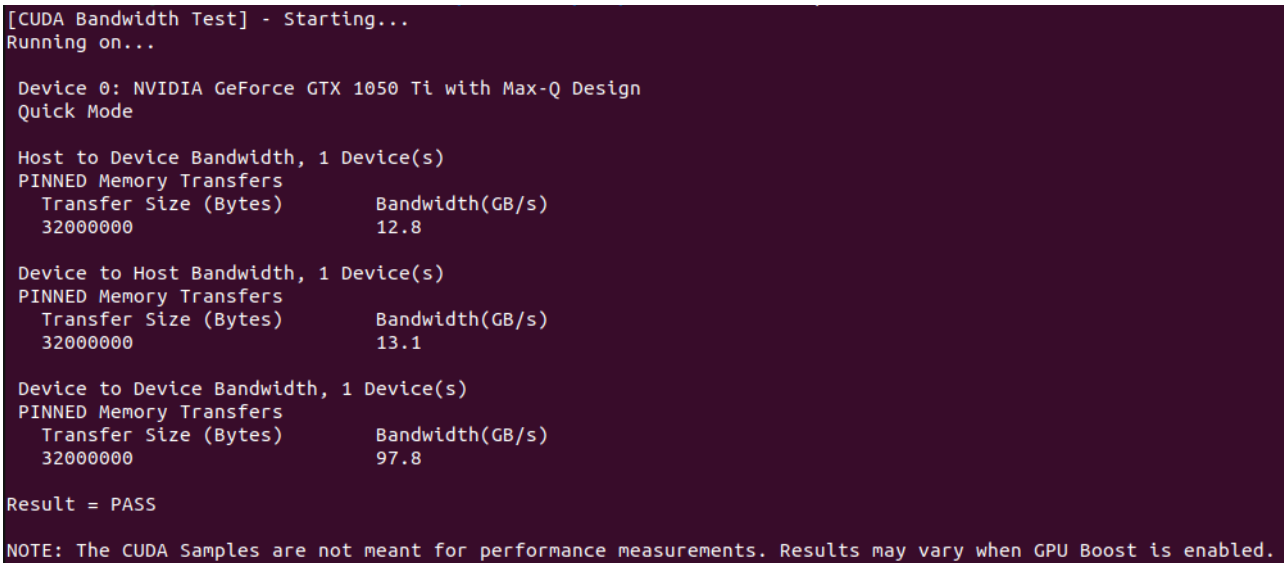


```
./deviceQuery/deviceQuery Starting...

 CUDA Device Query (Runtime API) version (CUDART static linking)

Detected 1 CUDA Capable device(s)

Device 0: "Tesla T4"
  CUDA Driver Version / Runtime Version          12.0 / 11.8
  CUDA Capability Major/Minor version number:    7.5
  Total amount of global memory:                 15102 MBytes (15835398144 bytes)
  (040) Multiprocessors, (064) CUDA Cores/MP:    2560 CUDA Cores
  GPU Max Clock rate:                            1590 MHz (1.59 GHz)
  Memory Clock rate:                             5001 Mhz
  Memory Bus Width:                              256-bit
  L2 Cache Size:                                 4194304 bytes
  Maximum Texture Dimension Size (x,y,z)         1D=(131072), 2D=(131072, 65536), 3D=(16384, 16384, 1638
  Maximum Layered 1D Texture Size, (num) layers  1D=(32768), 2048 layers
  Maximum Layered 2D Texture Size, (num) layers  2D=(32768, 32768), 2048 layers
  Total amount of constant memory:               65536 bytes
  Total amount of shared memory per block:       49152 bytes
  Total shared memory per multiprocessor:        65536 bytes
  Total number of registers available per block: 65536
  Warp size:                                     32
  Maximum number of threads per multiprocessor:  1024
  Maximum number of threads per block:           1024
  Max dimension size of a thread block (x,y,z): (1024, 1024, 64)
  Max dimension size of a grid size    (x,y,z): (2147483647, 65535, 65535)
  Maximum memory pitch:                          2147483647 bytes
  Texture alignment:                             512 bytes
  Concurrent copy and kernel execution:          Yes with 3 copy engine(s)
  Run time limit on kernels:                     No
  Integrated GPU sharing Host Memory:            No
  Support host page-locked memory mapping:       Yes
  Alignment requirement for Surfaces:            Yes
  Device has ECC support:                        Enabled
  Device supports Unified Addressing (UVA):      Yes
  Device supports Managed Memory:                Yes
  Device supports Compute Preemption:            Yes
  Supports Cooperative Kernel Launch:            Yes
  Supports MultiDevice Co-op Kernel Launch:      Yes
  Device PCI Domain ID / Bus ID / location ID:   0 / 0 / 4
  Compute Mode:
     < Default (multiple host threads can use ::cudaSetDevice() with device simultaneously) >

deviceQuery, CUDA Driver = CUDART, CUDA Driver Version = 12.0, CUDA Runtime Version = 11.8, NumDevs = 1
Result = PASS
```

2. What is the Compute Capability of your GPU device? **ANSWER:** Felix Laptop with GTX 1050 ti Max-Q has a compute compatibility of 6.1. The NVIDIA T4 on Google Colab has a compute compatibility of 7.5

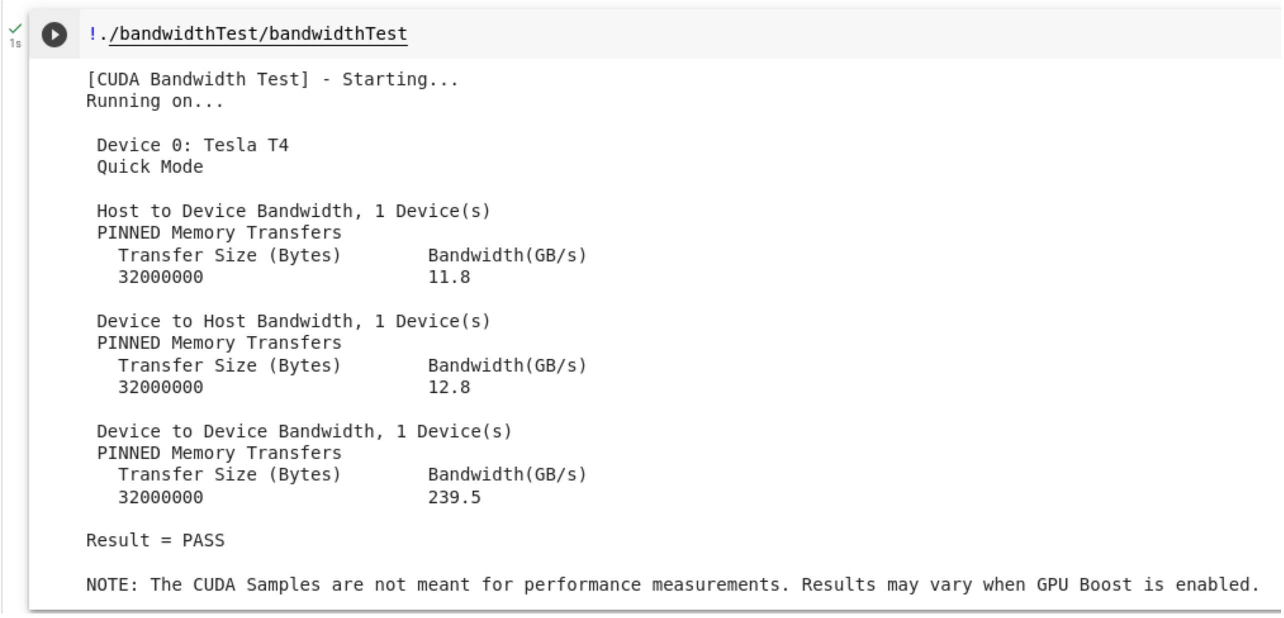
3. The screenshot of the output from running bandwidthTest test in /1_Utilities.

ANSWER: Screenshot from running bandwidthTest on Felix laptop



```
[CUDA Bandwidth Test] - Starting...
Running on...

 Device 0: NVIDIA GeForce GTX 1050 Ti with Max-Q Design
 Quick Mode

 Host to Device Bandwidth, 1 Device(s)
 PINNED Memory Transfers
   Transfer Size (Bytes)        Bandwidth(GB/s)
   32000000                     12.8

 Device to Host Bandwidth, 1 Device(s)
 PINNED Memory Transfers
   Transfer Size (Bytes)        Bandwidth(GB/s)
   32000000                     13.1

 Device to Device Bandwidth, 1 Device(s)
 PINNED Memory Transfers
   Transfer Size (Bytes)        Bandwidth(GB/s)
   32000000                     97.8

Result = PASS

NOTE: The CUDA Samples are not meant for performance measurements. Results may vary when GPU Boost is enabled.
```

Screenshot from running bandwidthTest on Google Colab



```
!./bandwidthTest/bandwidthTest

[CUDA Bandwidth Test] - Starting...
Running on...

 Device 0: Tesla T4
 Quick Mode

 Host to Device Bandwidth, 1 Device(s)
 PINNED Memory Transfers
   Transfer Size (Bytes)        Bandwidth(GB/s)
   32000000                     11.8

 Device to Host Bandwidth, 1 Device(s)
 PINNED Memory Transfers
   Transfer Size (Bytes)        Bandwidth(GB/s)
   32000000                     12.8

 Device to Device Bandwidth, 1 Device(s)
 PINNED Memory Transfers
   Transfer Size (Bytes)        Bandwidth(GB/s)
   32000000                     239.5

Result = PASS

NOTE: The CUDA Samples are not meant for performance measurements. Results may vary when GPU Boost is enabled.
```

4. How will you calculate the GPU memory bandwidth (in GB/s) using the output from deviceQuery? (Hint: memory bandwidth is typically determined by clock rate and bus width, and check what double date rate (DDR) may impact the bandwidth). Are they consistent with your results from bandwidthTest?

   ANSWER: To calculate the memory bus speed GB/s. First translate the memory buss width from bits to Bytes by dividing it by 8.Then take the Memory Clock rate and double it to to get the double data rate(DDR). After that take the new bus width [B] divided by the new memory clock lock speed [Hz] which then equals [B*Hz] = [B*(1/s)] = [B/s]. Lastly divide it 10^9 to make it [GB/s].

   Thus using the laptop case:

```
Bus Width:
128 bit/8 = 16 Bytes.

Clock Rate:
3504 MHz*2 = 7008 MHz.
```

```
Memory bus speed = (16 * (7008 * 10^6)) / 10^9 = 112.128 GB/s.
```

Exercise 3 - Rodinia CUDA benchmarks and Comparison with CPU

1. Compile both OMP and CUDA versions of your selected benchmarks. Do you need to make any changes in Makefile?

   ANSWER: When running the CUDA version of particalfilter the compute capability had to be changed to match Felix laptop GPU by changing `sm_13` to `sm_61` on line 12 and line 15 in the makefile.

   When running hotspot3D the first line in the makefile as incorrect and neededto be changed from

   `include ~/rodinia_3.0/common/make.config`
   to
   `include ../../common/make.config`

2. Ensure the same input problem is used for OMP and CUDA versions. Report and compare their execution time.

   ANSWER:

   ### Running particalfilter

   OpenMP

   ```
   make clean
   make openmp

   cat run
   ./particle_filter -x 128 -y 128 -z 10 -np 100000
   ```

   RESULTS:

   ```
   ./run
   ENTIRE PROGRAM TOOK 5.897769
   ```

   CUDA

   ```
   make clean
   make all

   cat run
   ./particlefilter_naive -x 128 -y 128 -z 10 -np 100000
   ```

RESULTS:

```
./run
ENTIRE PROGRAM TOOK 1.680555
```

Running hotspot3D

OpenMP:

```
  make clean
  make 3D

  cat run
  ./3D 512 8 10000 ../../data/hotspot3D/power_512x8
../../data/hotspot3D/temp_512x8 output.out

  ./run
```

RESULTS:

```
12 threads running
Time: 38.112 (s)
Accuracy: 4.856862e-05
```

CUDA

```
  make clean
  make release

  cat run
  ./3D 512 8 10000 ../../data/hotspot3D/power_512x8
../../data/hotspot3D/temp_512x8 output.out

  ./run
```

RESULTS:

```
  Time: 9.737 (s)
  Accuracy: 4.096975e-05
```

3. Do you observe expected speedup on GPU compared to CPU? Why or Why not?

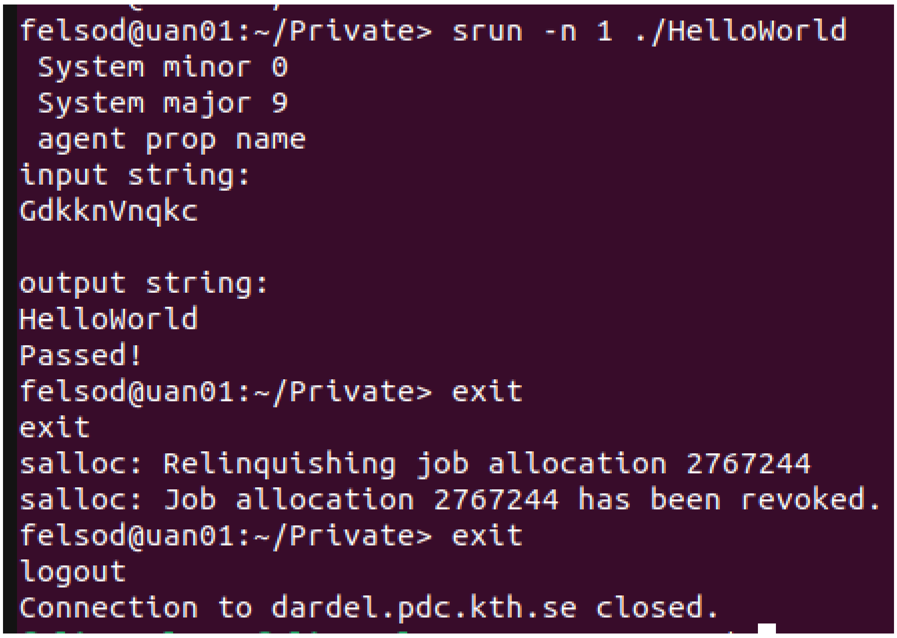
   ANSWER: For both workloads the CUDA version ran faster. This is most likley since all the workload were easily parallelizable. When running the programs with fewer iterations/smaller values (for example amount of particles in the particlefilter) the CPU and GPU had comparable speeds but when incresing the amount of particles in parallel the CUDA program ran much faster.

Exercise 4 - Run a HelloWorld on AMD GPU

1. How do you launch the code on GPU on Dardel supercomputer? **ANSWER:**

```
ssh -o GSSAPIAuthentication=yes felsod@dardel.pdc.kth.se
cd Private
<ADD FILES NEEDED HERE>
make
salloc -A edu23.dd2360 -p gpu -N 1 -t 00:10:00
srun -n 1 ./HelloWorld
```

2. Include a screenshot of your output from Dardel **ANSWER:** Screenshot from running Dardel



```
felsod@uan01:~/Private> srun -n 1 ./HelloWorld
 System minor 0
 System major 9
 agent prop name
input string:
GdkknVnqkc

output string:
HelloWorld
Passed!
felsod@uan01:~/Private> exit
exit
salloc: Relinquishing job allocation 2767244
salloc: Job allocation 2767244 has been revoked.
felsod@uan01:~/Private> exit
logout
Connection to dardel.pdc.kth.se closed.
```