Assignment I: GPU programming environment

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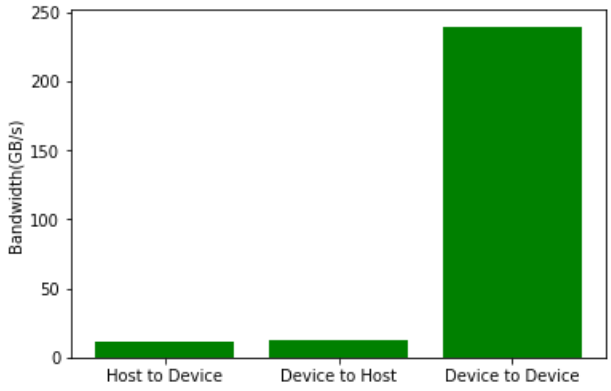
Tutorial: Using CUDA in Google Colab

Question: What GPU models did you get in your test?

Tesla T4

Exercise 2 - Bandwidth Test GPU-CPU on Google Colab

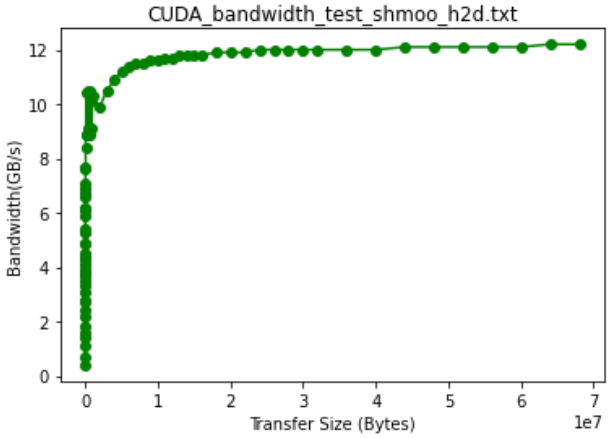
Bar plot in regular mode (transfer size 32000000 bytes):



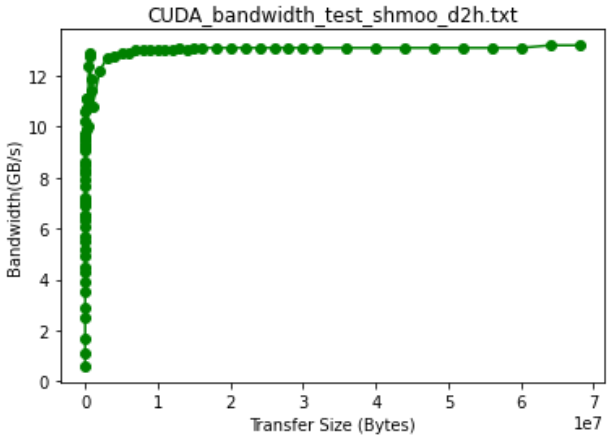
Explanation:
As it can be seen in the bar plot, the bandwidth of the device-to-device transfer is much higher than the bandwidth of the host-to-device and device-to-host transfers (approximately factor 20). The host-to-device and device-to-host transfers have a similar bandwidth. This is because the host-to-device and device-to-host communication uses PCIe which is much slower than the connection of the device to its own memory.
Host = CPU, device = GPU

Line plots in "shmoo" mode (increasing transfer sizes):

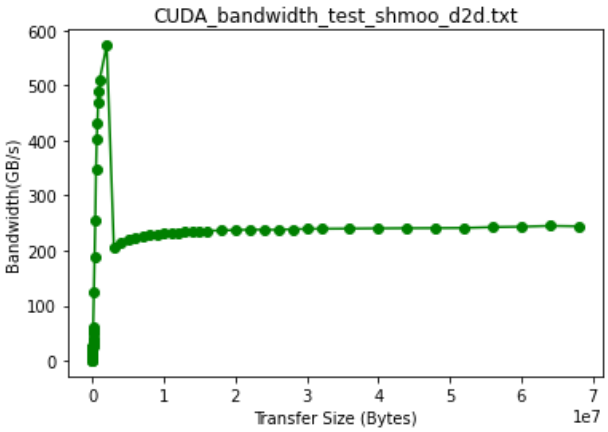
- Host to device (h2d):



- Device to host (d2h):



- Device to device (d2d):



Explanation:
As it can be seen in the line plots, for all three types of transfers, first, the bandwidth increases approximately linear and then at some point (e.g., at 3MB for the device-to-device case) the bandwidth drops. For the host-to-device and device-to-host transfers the drop is rather small and the bandwidth grows afterwards still to a higher level than before. At some point, the bandwidth saturates.
For the device-to-device transfer the drop is much bigger and the bandwidth does not reach the same speed afterwards as before. It saturates at a much lower level.
The explanation for the approx. linear growth at the beginning is probably that the “transfer time is the sum of a fixed overhead plus a variable portion growing linearly with the number of bytes transferred” (source). The fixed overhead is there because for smaller payloads the overhead due to the packet headers (of for example PCIe) is more significant. Furthermore, the transfer has to be initialized and that always takes the same amount of time independent of the transfer size. The saturation occurs because at some point the overhead converges to a minimum possible percentage (e.g., dependent on the packet size and the size of the header).
However, the reason of the drop is more complicated. One idea would be that with an increasing transfer size at some point a second packet is required which only carries a small payload. Hence the overhead due to the header would be large. However, if that would be the reason, you would get a periodic behavior where you reach the same speed after the drop as before.
A second idea could be that the DRAM memory of the GPU gets full with an increasing amount of data and that first data from the GPU has to be sent to the CPU before new data can be received. However, this argument is also not completely logical as the transfer size at the drops is much lower than the size of the DRAM memory of modern GPUs (typically several GBs).
The last possible reason could be that with a smaller transfer size the data still fully fits into the cache of the GPU. And with a higher transfer size the DRAM memory or a lower level cache has to be queried which takes more time which results in the drop.

Output of bandwidth test: `./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                      11.9

 Device to Host Bandwidth, 1 Device(s)
 PINNED Memory Transfers
   Transfer Size (Bytes)  Bandwidth(GB/s)
   32000000                      12.9

 Device to Device Bandwidth, 1 Device(s)
 PINNED Memory Transfers
   Transfer Size (Bytes)  Bandwidth(GB/s)
   32000000                      239.6

Result = PASS

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

Output of bandwidth test in "shmoo" mode: `./bandwidthTest/bandwidthTest --mode=shmoo`

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

 Device 0: Tesla T4
 Shmoo Mode

................................................................................
 Host to Device Bandwidth, 1 Device(s)
 PINNED Memory Transfers
   Transfer Size (Bytes)  Bandwidth(GB/s)
   1000                          0.5
   2000                          0.9
   3000                          1.3
   4000                          1.7
   5000                          2.0
   6000                          2.1
   7000                          2.4
   8000                          2.9
   9000                          3.0
   10000                 3.3
   11000                 3.5
   12000                 3.8
   13000                 4.0
   14000                 4.2
   15000                 4.4
   16000                 4.4
   17000                 4.5
   18000                 4.6
   19000                 4.9
   20000                 5.0
   22000                 4.7
   24000                 5.3
   26000                 5.3
   28000                 5.3
   30000                 5.6
   32000                 5.6
   34000                 6.2
   36000                 6.1
   38000                 6.6
   40000                 6.4
   42000                 6.5
   44000                 6.8
   46000                 6.9
   48000                 7.1
   50000                 7.2
   60000                 7.8
```

```
   70000                 1.0
   80000                 8.6
   90000                 8.9
   100000                        9.1
   200000                        7.9
   300000                        10.2
   400000                        8.6
   500000                        9.5
   600000                        8.6
   700000                        9.6
   800000                        8.8
   900000                        9.6
   1000000                       9.2
   2000000                       9.5
   3000000                       9.3
   4000000                       9.9
   5000000                       10.0
   6000000                       10.4
   7000000                       10.5
   8000000                       10.6
   9000000                       10.8
   10000000                      10.9
   11000000                      11.1
   12000000                      11.1
   13000000                      11.1
   14000000                      11.4
   15000000                      11.4
   16000000                      11.4
   18000000                      11.5
   20000000                      11.5
   22000000                      11.5
   24000000                      11.6
   26000000                      11.7
   28000000                      11.7
   30000000                      11.7
   32000000                      11.8
   36000000                      11.9
   40000000                      11.9
   44000000                      11.9
   48000000                      11.9
   52000000                      11.9
   56000000                      11.9
   60000000                      12.0
   64000000                      12.0
   68000000                      12.0

..............................................................................
 Device to Host Bandwidth, 1 Device(s)
 PINNED Memory Transfers
   Transfer Size (Bytes)  Bandwidth(GB/s)
   1000                          0.5
   2000                          1.1
   3000                          1.6
   4000                          2.3
   5000                          3.0
   6000                          3.0
   7000                          3.7
   8000                          4.3
   9000                          4.3
   10000                 5.0
   11000                 5.3
   12000                 5.6
   13000                 5.8
   14000                 6.0
   15000                 6.3
   16000                 6.5
   17000                 6.7
   18000                 6.6
   19000                 7.1
   20000                 6.9
   22000                 7.4
   24000                 7.8
   26000                 8.1
   28000                 8.3
   30000                 8.5
   32000                 8.7
   34000                 8.7
```

```
   36000                 9.1
   38000                 9.2
   40000                 9.4
   42000                 9.5
   44000                 9.5
   46000                 9.7
   48000                 9.8
   50000                 9.9
   60000                 10.1
   70000                 10.6
   80000                 10.8
   90000                 11.1
   100000                        11.2
   200000                        10.1
   300000                        9.0
   400000                        10.2
   500000                        10.5
   600000                        12.4
   700000                        12.2
   800000                        11.4
   900000                        11.3
   1000000                       10.6
   2000000                       11.1
   3000000                       11.9
   4000000                       12.0
   5000000                       12.2
   6000000                       12.5
   7000000                       12.6
   8000000                       12.7
   9000000                       12.8
   10000000                      12.8
   11000000                      12.9
   12000000                      12.9
   13000000                      12.9
   14000000                      12.9
   15000000                      12.9
   16000000                      13.0
   18000000                      13.0
   20000000                      13.0
   22000000                      13.1
   24000000                      13.1
   26000000                      13.1
   28000000                      13.1
   30000000                      13.1
   32000000                      13.1
   36000000                      13.1
   40000000                      13.1
   44000000                      13.1
   48000000                      13.1
   52000000                      13.1
   56000000                      13.1
   60000000                      13.1
   64000000                      13.1
   68000000                      13.2

.....................................................................................
 Device to Device Bandwidth, 1 Device(s)
 PINNED Memory Transfers
   Transfer Size (Bytes)  Bandwidth(GB/s)
   1000                          0.5
   2000                          1.1
   3000                          1.7
   4000                          1.9
   5000                          2.9
   6000                          3.5
   7000                          4.1
   8000                          4.8
   9000                          5.3
   10000                 6.0
   11000                 5.0
   12000                 6.7
   13000                 7.7
   14000                 7.5
   15000                 9.1
   16000                 8.8
   17000                 9.5
   18000                 9.7
```

```
   19000                10.6
   20000                12.1
   22000                12.7
   24000                14.4
   26000                15.5
   28000                16.9
   30000                18.5
   32000                17.4
   34000                18.1
   36000                20.4
   38000                22.2
   40000                24.1
   42000                24.8
   44000                24.1
   46000                26.6
   48000                28.2
   50000                30.1
   60000                37.6
   70000                40.8
   80000                47.2
   90000                55.3
   100000                        58.5
   200000                       120.8
   300000                       183.6
   400000                       231.5
   500000                       308.1
   600000                       336.0
   700000                       431.9
   800000                       466.8
   900000                       487.6
   1000000                      508.0
   2000000                      548.8
   3000000                      207.5
   4000000                      214.4
   5000000                      220.3
   6000000                      223.5
   7000000                      226.3
   8000000                      228.5
   9000000                      229.4
   10000000                     231.0
   11000000                     232.0
   12000000                     232.7
   13000000                     234.1
   14000000                     234.8
   15000000                     235.4
   16000000                     235.7
   18000000                     236.5
   20000000                     237.2
   22000000                     237.7
   24000000                     237.9
   26000000                     238.2
   28000000                     238.7
   30000000                     239.0
   32000000                     239.5
   36000000                     239.8
   40000000                     240.2
   44000000                     240.5
   48000000                     240.6
   52000000                     240.9
   56000000                     241.0
   60000000                     241.1
   64000000                     242.3
   68000000                     241.4

Result = PASS

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