# Document History

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<table>
<thead>
<tr>
<th>Version</th>
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</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>June 6, 2023</td>
<td>Initial release</td>
</tr>
</tbody>
</table>
| 02      | October 2, 2023 | > Updated the “Introduction” section.  
> Updated the “GPU STREAM” section.  
> Added the “CPU STREAM” section.  
> Updated the information about the sustained GEMM.  
> Added information about CuFFT and attachments. |
| 03      | November 9, 2023 | > Modified to reflect initial launch                                                   |
# Table of Contents

Introduction ........................................................................................................................................................ 1

Libraries and Benchmarks ............................................................................................................................. 3
  
  GPU STREAM ................................................................................................................................................ 3
    Usage ........................................................................................................................................................... 3
    Commands ................................................................................................................................................ 3
    Interpreting the Results ....................................................................................................................... 3
  
  CPU STREAM................................................................................................................................................. 4
    Commands ................................................................................................................................................ 4
    Interpreting the Results ....................................................................................................................... 4

Basic Linear Algebra ................................................................................................................................... 5
  Usage ........................................................................................................................................................... 5
  Commands ................................................................................................................................................ 6
  Interpreting the Results ....................................................................................................................... 6

Fast Fourier Transforms .......................................................................................................................... 6
  Usage ........................................................................................................................................................... 6
  Commands ................................................................................................................................................ 7
  Interpreting the Results ....................................................................................................................... 7

NVBandwidth................................................................................................................................................ 7
  Commands to Run the Test ................................................................................................................... 7
  Interpreting the Results ....................................................................................................................... 7

Attachments ................................................................................................................................................. 8

Application Performance ............................................................................................................................... 9
  TPC-H Q1 and Q4 ........................................................................................................................................ 9
  Interpreting Results ................................................................................................................................... 9

DALI for ResNet50 .................................................................................................................................... 10
  Interpreting Results ................................................................................................................................. 10
List of Tables

Table 1. System Specifications ............................................................................................................... 2
Table 2. GPU STREAM Benchmark ........................................................................................................ 4
Table 3. CPU STREAM Benchmark ....................................................................................................... 5
Table 4. Sustained GEMM TFLOPs ...................................................................................................... 6
Table 5. Sustained FFT GFLOPs ......................................................................................................... 7
Table 6. NVBandwidth ........................................................................................................................ 8
Table 7. Interpreting the Results ........................................................................................................... 9
Table 8. Interpreting the Results ......................................................................................................... 10
Introduction

This application note provides NVIDIA GH200 benchmark data in comparison to the NVIDIA® DGX™ H100 platform. This initial version of the application note provides benchmarks for low-level performance metrics for bandwidth and throughput. However, this application note will be updated over time to include more workloads and application performance data.

The NVIDIA GH200 Grace Hopper™ Superchip architecture combines the groundbreaking performance of the NVIDIA Hopper GPU with the versatility of the NVIDIA Grace™ CPU that is connected with a high bandwidth and memory coherent NVIDIA NVLink® Chip-2-Chip (C2C) interconnect in a superchip and supports the new NVIDIA NVLink Switch System. The NVIDIA GH200 system is set with Ubuntu 22.04, NVIDIA CUDA® 12.3, and NVIDIA Driver 545.14. All NVIDIA GH200 benchmark numbers provided in this application note are preliminary and subject to change.

DGX H100 benchmark numbers were measured on an Intel Xeon Platinum 8480C system. The clocks were set to the maximum at 1,980 MHz for GPU and 2,619 MHz for GPU memory with ECC enabled on Ubuntu 22.04, CUDA 12, and NVIDIA Driver 525.85. All NVIDIA H100 SXM5 80 GB benchmark numbers are preliminary and are only presented for comparisons to GH200.

Partner benchmark results will vary based on a variety of factors such as ambient temperature, hardware, software, thermal design, and server configurations. These benchmark numbers are meant only as a reference data point.

Note: Run-to-run variation up to 3% in delivered performance on the same system is considered normal.

Important: All benchmark numbers are preliminary and represent performance at the launch of NVIDIA GH200 Grace Hopper Superchip and will be updated once the products become generally available. The CUDA and NVIDIA driver software stack with DL frameworks and applications are continuously updated, so the performance will vary over time. Refer to the NVIDIA performance page (https://developer.nvidia.com/deep-learning-performance-training-inference and https://developer.nvidia.com/hpc-application-performance) for the latest DL and HPC performance results.
Table 1. System Specifications

<table>
<thead>
<tr>
<th>System Specification</th>
<th>NVIDIA DGX H100</th>
<th>NVIDIA GH200 Grace Hopper Superchip</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPU</td>
<td>8x NVIDIA H100 80 GB</td>
<td>1x NVIDIA H100 96 GB</td>
</tr>
<tr>
<td>CPU</td>
<td>Dual Intel Xeon Platinum 8480C, 2 GHz, 56 cores</td>
<td>Grace CPU, 3.1 GHz, 72 cores</td>
</tr>
<tr>
<td>System memory</td>
<td>2 TB DDR5</td>
<td>120 GB LPDDR5X</td>
</tr>
</tbody>
</table>
Libraries and Benchmarks

NVIDIA CUDA-X™, which is built on CUDA, is a collection of libraries, tools, and technologies that deliver dramatically higher performance compared to CPU-only alternatives across multiple application domains—from artificial intelligence (AI) to high performance computing (HPC).

There are also many CUDA code samples included as part of the CUDA toolkit. We have presented a few to highlight GH200.

GPU STREAM

NVIDIA provides an optimized CUDA implementation for the STREAM benchmark for measuring memory bandwidth on a NVIDIA Hopper GPU. In addition to the four kernels in STREAM, this implementation also includes basic load and store tests to measure read and write memory bandwidth.

Usage

- 
  > -n<elements>: number of double precision-floating point elements
  > -d<device>: determine which GPU to use
  > -r<random>: use random inputs or not

Commands

$ ./stream_vectorized_double_test -n1308622848

Interpreting the Results

NVIDIA H100 SXM5 80GB has 80 GB of HBM3 with a peak memory bandwidth of 3,352GB/s and NVIDIA GH200 Hopper GPU have 96GB of HBM3 with a peak memory bandwidth of 4,023 GB/s.
Table 2. GPU STREAM Benchmark

<table>
<thead>
<tr>
<th>STREAM</th>
<th>GPU Memory Bandwidth (GB/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DGX H100 80GB</td>
</tr>
<tr>
<td>Copy</td>
<td>3067</td>
</tr>
<tr>
<td>Scale</td>
<td>3060</td>
</tr>
<tr>
<td>Add</td>
<td>3128</td>
</tr>
<tr>
<td>Triad</td>
<td>3132</td>
</tr>
</tbody>
</table>

CPU STREAM

The STREAM benchmark is a simple, synthetic benchmark program that measures sustainable main memory bandwidth in MB/s and the corresponding computation rate for simple vector kernels on a CPU.

The following command downloads and compiles STREAM with a total memory footprint of approximately 2.7GB, which is sufficient to exceed the L3 cache without excessive runtime. The general rule for running STREAM is that each array must be at least four times the size of the sum of the last-level caches that were used in the run, or 1 million elements, whichever is larger.

To run STREAM, set the number of OpenMP threads (OMP_NUM_THREADS) and the numactl flags according to the following example. Use OMP_PROC_BIND=spread to distribute the threads evenly over all available cores and maximize bandwidth.

Commands

```bash
gcc -Ofast -march=native -fopenmp \
    -DSTREAM_ARRAY_SIZE=120000000 -DNTIMES=200 \
    -o stream_openmp.exe stream.c
OMP_NUM_THREADS=72 OMP_PROC_BIND=spread numactl -m0 ./stream_openmp.exe
```

Interpreting the Results

NVIDIA GH200 Grace CPU has 120 GB of LPDDR5X with peak memory bandwidth of 512 GB/s or 480 GB of LPDDR5X with a peak memory bandwidth of 384 GB/s.
Table 3. CPU STREAM Benchmark

<table>
<thead>
<tr>
<th>STREAM</th>
<th>CPU Memory Bandwidth (GB/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GH200 120 GB</td>
</tr>
<tr>
<td>Copy</td>
<td>459</td>
</tr>
<tr>
<td>Scale</td>
<td>450</td>
</tr>
<tr>
<td>Add</td>
<td>437</td>
</tr>
<tr>
<td>Triad</td>
<td>438</td>
</tr>
</tbody>
</table>

Basic Linear Algebra

The NVIDIA cuBLAS library is a fast GPU-accelerated implementation of the standard basic linear algebra subroutines (BLAS). NVIDIA provides the test binary, and cublasMatmulBench, that controls all test parameters for general matrix multiplication (GEMM) where the input data are all random numbers. This is provided for customers who would like to run GEMM tests for informational purposes only.

However, we encourage customers to focus on delivered performance on real workloads. Even though Peak TFLOPs and GEMM performance are important to maximizing throughput, it is not a reliable predictor of application performance. There are many factors including software frameworks, memory bandwidth, kernel launch times, system CPU <-> GPU bandwidth, and architectural changes between GPU generations.

Usage

- \(-P=\text{bisb\_imma}, \text{hsh}, \text{sss}, \text{ddd}\): input precision, compute precision, output precision
- \(-m=\text{int}, -n=\text{int}, -k=\text{int}\): MNK parameters
- \(-T=1000\): number of times to run back-to-back
- \(-a=1\): set GEMM layout to TN
- \(-b=1\): set GEMM layout to NT
- \(-b=0\): set beta to zero
- \(-a=1, -b=1, -c=1, -d=1\): allocate matrices in CPU memory and then zero-copy data to GPU memory
Commands

- FP8: `./cublasMatmulBench -P=qqssq -m=4224 -n=2048 -k=16384 -T=1000 -ta=1 -B=0`
- INT8: `./cublasMatmulBench -P=bisb_imma -m=8192 -n=4224 -k=16384 -T=1000 -ta=1 -B=0`
- FP16: `./cublasMatmulBench -P=hsh -m=12288 -n=9216 -k=32768 -T=1000 -tb=1 -B=0`
- BF16: `./cublasMatmulBench -P=tst -m=12288 -n=9216 -k=32768 -T=1000 -tb=1 -B=0`
- TF32: `./cublasMatmulBench -P=sss_fast_tf32 -m=8192 -n=4224 -k=16384 -T=1000 -ta=1 -B=0`
- FP64: `./cublasMatmulBench -P=ddd -m=4224 -n=2048 -k=16384 -T=1000 -tb=1 -B=0`
- FP32: `./cublasMatmulBench -P=sss -m=4224 -n=2048 -k=16384 -T=1000 -tb=1 -B=0`

Interpreting the Results

GEMM results were run on a single NVIDIA Hopper GPU. Performance may vary if running problem sizes other than the ones provided, which were selected to provide the best performance on an NVIDIA Hopper GPU.

<table>
<thead>
<tr>
<th>Datatype</th>
<th>GH200 Peak TFLOPs</th>
<th>GH200 GEMM TFLOPs</th>
<th>%SOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>FP8</td>
<td>1979</td>
<td>1514</td>
<td>76%</td>
</tr>
<tr>
<td>INT8</td>
<td>1979</td>
<td>1685</td>
<td>85%</td>
</tr>
<tr>
<td>FP16</td>
<td>989</td>
<td>848</td>
<td>86%</td>
</tr>
<tr>
<td>BF16</td>
<td>989</td>
<td>813</td>
<td>82%</td>
</tr>
<tr>
<td>TF32</td>
<td>495</td>
<td>480</td>
<td>97%</td>
</tr>
<tr>
<td>FP64</td>
<td>67</td>
<td>66</td>
<td>98%</td>
</tr>
<tr>
<td>FP32</td>
<td>67</td>
<td>54</td>
<td>80%</td>
</tr>
</tbody>
</table>

Fast Fourier Transforms

The CUDA Fast Fourier Transform library (cuFFT) provides GPU-accelerated FFT implementations. NVIDIA provides the test binary, cufftBench, that controls all test parameters and a test script that performs a specific FFT problem size.

Usage

- `-R=<single|multi>`: single or multi-GPU
- `-xsize=<int> -ysize=<int> -zsize=<int>`: array of sizes
- `--type=<c2cf|c2ci|r2c|c2r>`: complex and real-valued input and output
- `--precision=<half|single|double>`
- `--rank=<1d|2d|3d>`: 1D, 2D and 3D transforms
- `--ngpus=<int>`: number of GPUs
- `--zerocopy=1`: allocate data in CPU memory and then zero-copy data to GPU memory

### Commands

```
$ ./cufftBench -R=single -xsize=512 -ysize=512 -zsize=512 -type=c2cf -precision=double -rank=3d
```

### Interpreting the Results

cuFFT results using a NVIDIA Hopper GPU were run on NVIDIA DGX H100 and NVIDIA GH200.

<table>
<thead>
<tr>
<th>FFT Performance (GFLOPs)</th>
<th>DGX H100</th>
<th>GH200</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4065</td>
<td>4867</td>
</tr>
</tbody>
</table>

### NVBandwidth

This application is a tool for bandwidth measurements on NVIDIA GPUs.

### Commands to Run the Test

```
$ git clone https://github.com/NVIDIA/nvbandwidth
$ sudo ./debian_install.sh
$ cmake .
$ make
$ ./nvbandwidth
```

### Interpreting the Results

NVIDIA® NVLink®-C2C is an NVIDIA memory coherent, high-bandwidth, and low-latency superchip interconnect that delivers up to 900 GB/s total, bidirectional bandwidth.

Looking at `host_to_device_memcpy_sm` and `device_to_host_memcpy_sm`, each row represents measured single directional bandwidth between host and device for a single GPU.
Table 6. NVBandwidth

<table>
<thead>
<tr>
<th>NVBandwidth</th>
<th>NVLink-C2C Bandwidth (GB/s)</th>
<th>GH200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Host to device</td>
<td></td>
<td>419</td>
</tr>
<tr>
<td>Device to host</td>
<td></td>
<td>371</td>
</tr>
</tbody>
</table>

Attachments

The following files are attached to this application note:

- stream_test.nv7z
- cublasMatmulBench.nv7z
- cufftBench.nv7z
- scripts_and_binaries_for_apps.nv7z

To access the attached files, click the Attachment icon on the left-hand toolbar on this PDF (using Adobe Acrobat Reader or Adobe Acrobat). Select the file and use the Tool Bar options (Open, Save) to retrieve the documents. Files with the .nv7z extension must be renamed to .7z and extracted using the 7-Zip file archive software.
Application Performance

TPC-H Q1 and Q4

**Note:** Instructions and binaries to run this benchmark are in the scripts_and_binaries_for_apps.nvz directory.

The TPC-H is a decision support benchmark. It consists of a suite of business-oriented ad-hoc queries and concurrent data modifications. The queries and the data populating the database have been chosen to have broad industry-wide relevance.

This benchmark illustrates decision support systems that examine large volumes of data, execute queries with a high degree of complexity, and give answers to critical business questions. This benchmark supports TPC-H Query 4, which includes a join operation of two large database tables and a group-by aggregation, and TPC-H Query 1, which is a group-by aggregation query.

Interpreting Results

This TPC-H benchmark using a NVIDIA Hopper GPU was run on NVIDIA DGX H100 and NVIDIA GH200. The database accesses on the CPU memory are faster on GH200 due to the higher NVIDIA NVLink-C2C bandwidth. Query q4 with compression is query with compressed input data, which reduces data transfer time to the GPU.

<table>
<thead>
<tr>
<th>TPC-H Query</th>
<th>DGX H100</th>
<th>GH200</th>
</tr>
</thead>
<tbody>
<tr>
<td>q1</td>
<td>439</td>
<td>66</td>
</tr>
<tr>
<td>q4 with compression</td>
<td>154</td>
<td>26</td>
</tr>
<tr>
<td>q4 without compression</td>
<td>74</td>
<td>23</td>
</tr>
</tbody>
</table>
DALI for ResNet50

Note: Instructions to run this benchmark are in the scripts_and_binaries_for_apps.nv7z directory.

The NVIDIA Data Loading Library (DALI) is a portable, open-source library for decoding and augmenting images, videos, and speech to accelerate deep learning applications. DALI reduces latency and training time, mitigating bottlenecks, by overlapping training and pre-processing. It provides a drop-in replacement for built in data loaders and data iterators in popular deep learning frameworks for easy integration or retargeting to different frameworks.

Interpreting Results

DALI (v1.30) for ResNet50 using a single NVIDIA Hopper GPU was run on NVIDIA DGX H100 and NVIDIA GH200. Faster data access to the CPU memory through NVIDIA NVLink-C2C and a higher CPU/GPU ratio with GH200 provides boosts the data processing performance by 1.5x.

Table 8. Interpreting the Results

<table>
<thead>
<tr>
<th>DALI for RN50</th>
<th>Images</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DGX H100</td>
</tr>
<tr>
<td>Typical ResNet50 data processing pipeline running on ImageNet like JPEG test data set (VGA, WXGA, HD). Image decoding-&gt;random resized crop-&gt;normalization and random flip to 224x224, NCHW format, FP16</td>
<td>19,885</td>
</tr>
</tbody>
</table>
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