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Chapter 1.
RELEASE NOTES

This section describes the release notes for the CUDA Samples only. For the release notes for the whole CUDA Toolkit, please see CUDA Toolkit Release Notes.

1.1. CUDA 11.0

- Added `0_Simple/globalToShmemAsyncCopy`. Demonstrates asynchronous copy of data from global to shared memory using cuda pipeline. Also demonstrates arrive-wait barrier for synchronization.
- Added `0_Simple/simpleAttributes`. Demonstrates the stream attributes that affect L2 Locality.
- Added `0_Simple/dmmaTensorCoreGemm`. Demonstrates double precision GEMM computation using the WMMA API for double precision employing the Tensor Cores. Also makes use of asynchronous copy from global to shared memory using cuda pipeline which leads to further performance gain.
- Added `0_Simple/bf16TensorCoreGemm`. Demonstrates __nv_bfloat16 (e8m7) GEMM computation using the WMMA API for __nv_bfloat16 employing the Tensor Cores. Also makes use of asynchronous copy from global to shared memory using cuda pipeline which leads to further performance gain.
- Added `0_Simple/tf32TensorCoreGemm`. Demonstrates tf32 (e8m10) GEMM computation using the WMMA API for tf32 employing the Tensor Cores. Also makes use of asynchronous copy from global to shared memory using cuda pipeline which leads to further performance gain.
- Added `0_Simple/simpleAWBarrier`. Demonstrates the arrive wait barriers.
- Added warp aggregated atomic multi bucket increments kernel using labeled_partition cooperative groups in `6_Advanced/warpAggregatedAtomicsCG` which can be used on compute capability 7.0 and above GPU architectures.
- Added `0_Simple/binaryPartitionCG`. Demonstrates binary_partition cooperative groups creation and usage in divergent path.
• Added 6_Advanced/cudaCompressibleMemory. Demonstrates compressible memory allocation using cuMemMap API.

• Removed 7_CUDALibraries/nvgraph_Pagerank, 7_CUDALibraries/nvgraph_SemiRingsSpMV, 7_CUDALibraries/nvgraph_SpectralClustering, 7_CUDALibraries/nvgraph_SSSP as the NVGRAPH library is dropped from CUDA Toolkit 11.0.

• Added two new reduction kernels in 6_Advanced/reduction one which demonstrates reduce_add_sync intrinsic supported on compute capability 8.0 and another which uses cooperative_groups::reduce function which does thread_block_tile level reduction introduced from CUDA 11.0.

• Added windows support to 6_Advanced/c++11_cuda.

1.2. CUDA 10.2

• Added 6_Advanced/jacobiCudaGraphs. Demonstrates Instantiated CUDA Graph Update usage.

• Added 0_Simple/memMapIPCDrv. Demonstrates Inter Process Communication using cuMemMap APIs with one process per GPU for computation.

• Added 0_Simple/vectorAddMMAP. Demonstrates how cuMemMap API allows the user to specify the physical properties of their memory while retaining the contiguous nature of their access, thus not requiring a change in their program structure.

• Added 0_Simple/simpleDrvRuntime. Demonstrates how CUDA Driver and Runtime APIs can work together to load cuda fatbinary of vector add kernel.


1.3. CUDA 10.1 Update 2

• Added 3_Imaging/vulkanImageCUDA. Demonstrates how to perform Vulkan Image-CUDA Interop.

• Added 7_CUDALibraries/nvJPEG_encoder. Demonstrates encoding of jpeg images using NVJPEG Library.

• Added Windows support to 7_CUDALibraries/nvJPEG.

• Removed DirectX SDK (June 2010 or newer) installation requirement, all the DirectX-CUDA samples now use DirectX from Windows SDK shipped with Microsoft Visual Studio 2012 or higher.
1.4. CUDA 10.1 Update 1

- Added 3_Imaging/NV12toBGRandResize. Demonstrates how to convert and resize NV12 frames to BGR planars frames using CUDA in batch.
- Added Visual Studio 2019 support to all the samples.

1.5. CUDA 10.1

- Added 0_Simple/immaTensorCoreGemm. Demonstrates integer GEMM computation using the Warp Matrix Multiply and Accumulate (WMMA) API for integers employing the Tensor Cores.
- Added 2_Graphics/simpleD3D12. Demonstrates Direct3D12 interoperability with CUDA.
- Added 7_CUDALibraries/nvJPEG. Demonstrates single and batched decoding of jpeg images using NVJPEG Library.
- Added 7_CUDALibraries/conjugateGradientCudaGraphs. Demonstrates conjugate gradient solver on GPU using CUBLAS/CUSPARSE library calls captured and called using CUDA Graph APIs.
- Updated 0_Simple/simpleIPC to work on Windows OS as well with TCC enabled GPUs.

1.6. CUDA 10.0

- Added 1_Utilities/UnifiedMemoryPerf. Demonstrates the performance comparison of Unified Memory and other types of memory like zero copy buffers, pageable, pagelocked memory on a single GPU.
- Added 2_Graphics/simpleVulkan. Demonstrates the Vulkan-CUDA Interop. CUDA imports the Vulkan vertex buffer and operates on it to create sinewave, and synchronizes with Vulkan through vulkan semaphores imported by CUDA.
- Added 0_Simple/simpleCudaGraphs. Demonstrates how to use CUDA Graphs through Graphs APIs and Stream Capture APIs.
- Removed 3_Imaging/cudaDecodeGL, 3_Imaging/cudaDecodeD3D9 as the cuvid library is dropped from CUDA Toolkit 10.0.
- Removed 6_Advanced/cdpLUDecomposition, 7_CUDALibraries/simpleDevLibCUBLAS as the CUBLAS Device library is dropped from CUDA Toolkit 10.0.
1.7. CUDA 9.2

- Added `7_CUDALibraries/boundSegmentsNPP`. Demonstrates `nppiLabelMarkers` to generate connected region segment labels.
- Added `6_Advanced/conjugateGradientMultiDeviceCG`. Demonstrates a conjugate gradient solver on multiple GPUs using Multi Device Cooperative Groups, also uses Unified Memory optimized using prefetching and usage hints.
- Updated `0_Simple/fp16ScalarProduct` to use fp16 native operators for `half2` and other fp16 features, it also compare results of using native vs intrinsics fp16 operations.

1.8. CUDA 9.0

- Added `6_Advanced/warpAggregatedAtomicsCG`. Demonstrates warp aggregated atomics using Cooperative Groups.
- Added `6_Advanced/reductionMultiBlockCG`. Demonstrates single pass reduction using Multi Block Cooperative Groups.
- Added `6_Advanced/conjugateGradientMultiBlockCG`. Demonstrates a conjugate gradient solver on GPU using Multi Block Cooperative Groups.
- Added Cooperative Groups(CG) support to several samples notable ones to name are `6_Advanced/cdpQuadtree`, `6_Advanced/cdpAdvancedQuicksort`, `5_Advanced/threadFenceReduction`, `3_Imaging/dxtc`, `4_Finance/MonteCarloMultiGPU`, `0_Simple/matrixMul_nvrtc`.
- Added `0_Simple/simpleCooperativeGroups`. Illustrates basic usage of Cooperative Groups within the thread block.
- Added `0_Simple/cudaTensorCoreGemm`. Demonstrates a GEMM computation using the Warp Matrix Multiply and Accumulate (WMMA) API introduced in CUDA 9, as well as the new Tensor Cores introduced in the Volta chip family.
- Updated `0_Simple/simpleVoteIntrinsics` to use newly added `_sync` equivalent of the vote intrinsics `_any`, `_all`.
- Updated `6_Advanced/shfl_scan` to use newly added `_sync` equivalent of the `shfl` intrinsics.

1.9. CUDA 8.0

- Added `7_CUDALibraries/FilterBorderControlNPP`. Demonstrates how any border version of an NPP filtering function can be used in the most common mode (with border control enabled), can be used to duplicate the results of the equivalent non-border version of the NPP function, and can be used to enable and disable
border control on various source image edges depending on what portion of the source image is being used as input.

- **Added 7_CUDALibraries/cannyEdgeDetectorNPP.** Demonstrates the recommended parameters to use with the nppiFilterCannyBorder_8u_C1R Canny Edge Detection image filter function. This function expects a single channel 8-bit grayscale input image. You can generate a grayscale image from a color image by first calling nppiColorToGray() or nppiRGBToGray(). The Canny Edge Detection function combines and improves on the techniques required to produce an edge detection image using multiple steps.

- **Added 7_CUDALibraries/cuSolverSp_LowlevelCholesky.** Demonstrates Cholesky factorization using cuSolverSP’s low level APIs.

- **Added 7_CUDALibraries/cuSolverSp_LowlevelQR.** Demonstrates QR factorization using cuSolverSP’s low level APIs.

- **Added 7_CUDALibraries/BiCGStab.** Demonstrates Bi-Conjugate Gradient Stabilized (BiCGStab) iterative method for nonsymmetric and symmetric positive definite linear systems using CUSPARSE and CUBLAS.

- **Added 7_CUDALibraries/nvgraph_Pagerank.** Demonstrates Page Rank computation using nvGRAPH Library.

- **Added 7_CUDALibraries/nvgraph_SemiRingSpMV.** Demonstrates Semi-Ring SpMV using nvGRAPH Library.

- **Added 7_CUDALibraries/nvgraph_SSSP.** Demonstrates Single Source Shortest Path(SSSP) computation using nvGRAPH Library.

- **Added 7_CUDALibraries/simpleCUBLASXT.** Demonstrates simple example to use CUBLAS-XT library.

- **Added 6_Advanced/c++11_cuda.** Demonstrates C++11 feature support in CUDA.

- **Added 1.Utilities/topologyQuery.** Demonstrates how to query the topology of a system with multiple GPU.

- **Added 0_Simple/fp16ScalarProduct.** Demonstrates scalar product calculation of two vectors of FP16 numbers.

- **Added 0_Simple/systemWideAtomics.** Demonstrates system wide atomic instructions on migratable memory.

- **Removed 0_Simple/template_runtime.** Its purpose is served by 0_Simple/template.

### 1.10. CUDA 7.5

- **Added 7_CUDALibraries/cuSolverDn_LinearSolver.** Demonstrates how to use the CUSOLVER library for performing dense matrix factorization using cuSolverDN’s LU, QR and Cholesky factorization functions.

- **Added 7_CUDALibraries/cuSolverRf.** Demonstrates how to use cuSolverRF, a sparse re-factorization package of the CUSOLVER library.

- **Added 7_CUDALibraries/cuSolverSp_LinearSolver.** Demonstrates how to use cuSolverSP which provides sparse set of routines for sparse matrix factorization.

The 2_Graphics/simpleD3D9, 2_Graphics/simpleD3D9Texture, 3_Imaging/cudaDecodeD3D9, and 5_Simulations/fluidsD3D9 samples have been modified to use the Direct3D 9Ex API instead of the Direct3D 9 API.
The 7_CUDALibraries/grabcutNPP and 7_CUDALibraries/imageSegmentationNPP samples have been removed. These samples used the NPP graphcut APIs, which have been deprecated in CUDA 7.5.

1.11. CUDA 7.0

- Removed support for Windows 32-bit builds.
- The Makefile x86_64=1 and ARMv7=1 options have been deprecated. Please use TARGET_ARCH to set the targeted build architecture instead.
- The Makefile GCC option has been deprecated. Please use HOST_COMPILER to set the host compiler instead.
- The CUDA Samples are no longer shipped as prebuilt binaries on Windows. Please use VS Solution files provided to build respective executables.
- Added 0_Simple/clock_nvrtc. Demonstrates how to compile clock function kernel at runtime using libNVRTC to measure the performance of kernel accurately.
- Added 0_Simple/inlinePTX_nvrtc. Demonstrates compilation of CUDA kernel having PTX embedded at runtime using libNVRTC.
- Added 0_Simple/matrixMul_nvrtc. Demonstrates compilation of matrix multiplication CUDA kernel at runtime using libNVRTC.
- Added 0_Simple/simpleAssert_nvrtc. Demonstrates compilation of CUDA kernel having assert() at runtime using libNVRTC.
- Added 0_Simple/simpleAtomicIntrinsics_nvrtc. Demonstrates compilation of CUDA kernel performing atomic operations at runtime using libNVRTC.
- Added 0_Simple/simpleTemplates_nvrtc. Demonstrates compilation of templatized dynamically allocated shared memory arrays CUDA kernel at runtime using libNVRTC.
- Added 0_Simple/simpleVoteIntrinsics_nvrtc. Demonstrates compilation of CUDA kernel which uses vote intrinsics at runtime using libNVRTC.
- Added 0_Simple/vectorAdd_nvrtc. Demonstrates compilation of CUDA kernel performing vector addition at runtime using libNVRTC.
- Added 4_Finance/binomialOptions_nvrtc. Demonstrates runtime compilation using libNVRTC of CUDA kernel which evaluates fair call price for a given set of European options under binomial model.
- Added 4_Finance/BlackScholes_nvrtc. Demonstrates runtime compilation using libNVRTC of CUDA kernel which evaluates fair call and put prices for a given set of European options by Black-Scholes formula.
- Added 4_Finance/quasirandomGenerator_nvrtc. Demonstrates runtime compilation using libNVRTC of CUDA kernel which implements Niederreiter Quasirandom Sequence Generator and Inverse Cumulative Normal Distribution functions for the generation of Standard Normal Distributions.

1.12. CUDA 6.5

- Added 7_CUDALibraries/cuHook. Demonstrates how to build and use an intercept library with CUDA.
Added 7_CUDALibraries/simpleCUFFT_callback. Demonstrates how to compute a 1D-convolution of a signal with a filter using a user-supplied CUFFT callback routine, rather than a separate kernel call.

Added 7_CUDALibraries/simpleCUFFT_MGPU. Demonstrates how to compute a 1D-convolution of a signal with a filter by transforming both into frequency domain, multiplying them together, and transforming the signal back to time domain on Multiple GPUs.

Added 7_CUDALibraries/simpleCUFFT_2d_MGPU. Demonstrates how to compute a 2D-convolution of a signal with a filter by transforming both into frequency domain, multiplying them together, and transforming the signal back to time domain on Multiple GPUs.

Removed 3_Imaging/cudaEncode. Support for the CUDA Video Encoder (NVCUVENC) has been removed.

Removed 4_Finance/ExcelCUDA2007. The topic will be covered in a blog post at Parallel Forall.

Removed 4_Finance/ExcelCUDA2010. The topic will be covered in a blog post at Parallel Forall.

The 4_Finance/binomialOptions sample is now restricted to running on GPUs with SM architecture 2.0 or greater.

The 4_Finance/quasirandomGenerator sample is now restricted to running on GPUs with SM architecture 2.0 or greater.

The 7_CUDALibraries/boxFilterNPP sample now demonstrates how to use the static NPP libraries on Linux and Mac.

The 7_CUDALibraries/conjugateGradient sample now demonstrates how to use the static CURAND library on Linux and Mac.

1.13. CUDA 6.0

New featured samples that support a new CUDA 6.0 feature called UVM-Lite

Added 0_Simple/UnifiedMemoryStreams - new CUDA sample that demonstrates the use of OpenMP and CUDA streams with Unified Memory on a single GPU.

Added 1_Utilities/p2pBandwidthTestLatency - new CUDA sample that demonstrates how measure latency between pairs of GPUs with P2P enabled and P2P disabled.

Added 6_Advanced/StreamPriorities - This sample demonstrates basic use of the new CUDA 6.0 feature stream priorities.

Added 7_CUDALibraries/ConjugateGradientUM - This sample implements a conjugate gradient solver on GPU using cuBLAS and cuSPARSE library, using Unified Memory.
1.14. CUDA 5.5

- Linux makefiles have been updated to generate code for the AMRv7 architecture. Only the ARM hard-float floating point ABI is supported. Both native ARMv7 compilation and cross compilation from x86 is supported.
- Performance improvements in CUDA toolkit for Kepler GPUs (SM 3.0 and SM 3.5).
- Makefiles projects have been updated to properly find search default paths for OpenGL, CUDA, MPI, and OpenMP libraries for all OS Platforms (Mac, Linux x86, Linux ARM).
- Linux and Mac project Makefiles now invoke NVCC for building and linking projects.
- Added **0_Simple/cppOverload** - new CUDA sample that demonstrates how to use C++ overloading with CUDA.
- Added **6_Advanced/cdpBezierTessellation** - new CUDA sample that demonstrates an advanced method of implementing Bezier Line Tessellation using CUDA Dynamic Parallelism. Requires compute capability 3.5 or higher.
- Added **7_CUDALibraries/jpegNPP** - new CUDA sample that demonstrates how to use NPP for JPEG compression on the GPU.
- CUDA Samples now have better integration with Nsight Eclipse IDE.
- **6_Advanced/ptxjit** sample now includes a new API to demonstrate PTX linking at the driver level.

1.15. CUDA 5.0

- New directory structure for CUDA samples. Samples are classified accordingly to categories: **0_Simple, 1Utilities, 2Graphics, 3Imaging, 4Finance, 5Simulations, 6Advanced, and 7_CUDALibraries**
- Added **0_Simple/simpleIPC** - CUDA Runtime API sample is a very basic sample that demonstrates Inter Process Communication with one process per GPU for computation. Requires Compute Capability 2.0 or higher and a Linux Operating System.
- Added **0_Simple/simpleSeparateCompilation** - demonstrates a CUDA 5.0 feature, the ability to create a GPU device static library and use it within another CUDA kernel. This example demonstrates how to pass in a GPU device function (from the GPU device static library) as a function pointer to be called. Requires Compute Capability 2.0 or higher.
- Added **2_Graphics/bindlessTexture** - demonstrates use of cudaSurfaceObject, cudaTextureObject, and MipMap support in CUDA. Requires Compute Capability 3.0 or higher.
- Added **3_Imaging/stereoDisparity** - demonstrates how to compute a stereo disparity map using SIMD SAD (Sum of Absolute Difference) intrinsics. Requires Compute Capability 2.0 or higher.
Added 0_Simple/cdpSimpleQuicksort - demonstrates a simple quicksort implemented using CUDA Dynamic Parallelism. This sample requires devices with compute capability 3.5 or higher.

Added 0_Simple/cdpSimplePrint - demonstrates simple printf implemented using CUDA Dynamic Parallelism. This sample requires devices with compute capability 3.5 or higher.

Added 6_Advanced/cdpLUDeomposition - demonstrates LU Decomposition implemented using CUDA Dynamic Parallelism. This sample requires devices with compute capability 3.5 or higher.

Added 6_Advanced/cdpAdvancedQuicksort - demonstrates an advanced quicksort implemented using CUDA Dynamic Parallelism. This sample requires devices with compute capability 3.5 or higher.

Added 6_Advanced/cdpQuadtree - demonstrates Quad Trees implemented using CUDA Dynamic Parallelism. This sample requires devices with compute capability 3.5 or higher.

Added 7_CUDALibraries/simpleDevLibCUBLAS - implements a simple cuBLAS function calls that call GPU device API library running cuBLAS functions. cuBLAS device code functions take advantage of CUDA Dynamic Parallelism and requires compute capability of 3.5 or higher.

1.16. CUDA 4.2

Added segmentationTreeThrust - demonstrates a method to build image segmentation trees using Thrust. This algorithm is based on Boruvka’s MST algorithm.

1.17. CUDA 4.1

Added MersenneTwisterGP11213 - implements Mersenne Twister GP11213, a pseudorandom number generator using the cuRAND library.

Added HSOpticalFlow - When working with image sequences or video it’s often useful to have information about objects movement. Optical flow describes apparent motion of objects in image sequence. This sample is a Horn-Schunck method for optical flow written using CUDA.

Added volumeFiltering - demonstrates basic volume rendering and filtering using 3D textures.

Added simpleCubeMapTexture - demonstrates how to use texcubemap fetch instruction in a CUDA C program.

Added simpleAssert - demonstrates how to use GPU assert in a CUDA C program.

Chapter 2.
GETTING STARTED

The CUDA Samples are an educational resource provided to teach CUDA programming concepts. The CUDA Samples are not meant to be used for performance measurements.

For system requirements and installation instructions, please refer to the Linux Installation Guide, the Windows Installation Guide, and the Mac Installation Guide.

2.1. Getting CUDA Samples

Windows
On Windows, the CUDA Samples are installed using the CUDA Toolkit Windows Installer. By default, the CUDA Samples are installed in:

C:\ProgramData\NVIDIA Corporation\CUDA Samples\v11.0\n
The installation location can be changed at installation time.

Linux
On Linux, to install the CUDA Samples, the CUDA toolkit must first be installed. See the Linux Installation Guide for more information on how to install the CUDA Toolkit.

Then the CUDA Samples can be installed by running the following command, where <target_path> is the location where to install the samples:

$ cuda-install-samples-11.0.sh <target_path>

Mac OSX
On Mac OSX, to install the CUDA Samples, the CUDA toolkit must first be installed. See the Mac Installation Guide for more information on how to install the CUDA Toolkit.

Then the CUDA Samples can be installed by running the following command, where <target_path> is the location where to install the samples:

$ cuda-install-samples-11.0.sh <target_path>
2.2. Building Samples

Windows

The Windows samples are built using the Visual Studio IDE. Solution files (.sln) are provided for each supported version of Visual Studio, using the format:

* _vs<version>.sln - for Visual Studio <version>

Complete samples solution files exist at:

C:\ProgramData\NVIDIA Corporation\CUDA Samples\v11.0\n
Each individual sample has its own set of solution files at:

C:\ProgramData\NVIDIA Corporation\CUDA Samples\v11.0\<sample_dir>\n
To build/examine all the samples at once, the complete solution files should be used. To build/examine a single sample, the individual sample solution files should be used.

Linux

The Linux samples are built using makefiles. To use the makefiles, change the current directory to the sample directory you wish to build, and run make:

$ cd <sample_dir>
$ make

The samples makefiles can take advantage of certain options:

- **TARGET_ARCH=<arch>** - cross-compile targeting a specific architecture. Allowed architectures are x86_64, armv7l, aarch64, sbsa, and ppc64le.

  By default, TARGET_ARCH is set to HOST_ARCH. On a x86_64 machine, not setting TARGET_ARCH is the equivalent of setting TARGET_ARCH=x86_64.

  $ make TARGET_ARCH=x86_64
  $ make TARGET_ARCH=armv7l
  $ make TARGET_ARCH=aarch64
  $ make TARGET_ARCH=sbsa
  $ make TARGET_ARCH=ppc64le

  See [here](#) for more details.

- **dbg=1** - build with debug symbols

  $ make dbg=1

- **SMS="A B ..."** - override the SM architectures for which the sample will be built, where "A B . . ." is a space-delimited list of SM architectures. For example, to generate SASS for SM 35 and SM 50, use SMS="35 50".

  $ make SMS="35 50"

- **HOST_COMPILER=<host_compiler>** - override the default g++ host compiler. See the [Linux Installation Guide](#) for a list of supported host compilers.
Mac

The Mac samples are built using makefiles. To use the makefiles, change directory into the sample directory you wish to build, and run `make`:

```bash
$ make HOST_COMPILER=g++
```

### Making Mac Samples

The Mac samples are built using makefiles. To use the makefiles, change directory into the sample directory you wish to build, and run `make`:

```bash
$ cd <sample_dir>
$ make
```

The samples makefiles can take advantage of certain options:

- **dbg=1** - build with debug symbols
  ```bash
  $ make dbg=1
  ```

- **SMS="A B ..."** - override the SM architectures for which the sample will be built, where "A B ..." is a space-delimited list of SM architectures. For example, to generate SASS for SM 35 and SM 50, use `SMS="35 50"`.
  ```bash
  $ make SMS="A B ..."
  ```

- **HOST_COMPILER=<host_compiler>** - override the default clang host compiler. See the [Mac Installation Guide](#) for a list of supported host compilers.
  ```bash
  $ make HOST_COMPILER=clang
  ```

### 2.3. CUDA Cross-Platform Samples

This section describes the options used to build cross-platform samples. `TARGET_ARCH=<arch>` and `TARGET_OS=<os>` should be chosen based on the supported targets shown below. `TARGET_FS=<path>` can be used to point nvcc to libraries and headers used by the sample.

#### Table 1 Supported Target Arch/OS Combinations

<table>
<thead>
<tr>
<th>TARGET_ARCH</th>
<th>linux</th>
<th>darwin</th>
<th>android</th>
<th>qnx</th>
</tr>
</thead>
<tbody>
<tr>
<td>x86_64</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>aarch64</td>
<td>YES</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>sbssa</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
</tr>
</tbody>
</table>

**TARGET_ARCH**

The target architecture must be specified when cross-compiling applications. If not specified, it defaults to the host architecture. Allowed architectures are:

- **x86_64** - 64-bit x86 CPU architecture
- **aarch64** - 64-bit ARM CPU architecture, like that found on Jetson TX1 onwards
- **sbsa** - 64-bit ARM Server CPU architecture
TARGET_OS

The target OS must be specified when cross-compiling applications. If not specified, it defaults to the host OS. Allowed OSes are:

- **linux** - for any Linux distributions
- **darwin** - for Mac OS X
- **android** - for any supported device running Android
- **qnx** - for any supported device running QNX

TARGET_FS

The most reliable method to cross-compile the CUDA Samples is to use the TARGET_FS variable. To do so, mount the target’s filesystem on the host, say at /mnt/target. This is typically done using `exportfs`. In cases where `exportfs` is unavailable, it is sufficient to copy the target’s filesystem to /mnt/target. To cross-compile a sample, execute:

```bash
$ make TARGET_ARCH=<arch> TARGET_OS=<os> TARGET_FS=/mnt/target
```

Cross Compiling to Embedded ARM architectures

While cross compiling the samples from x86_64 installation to embedded ARM architectures, that is, **aarch64** or **armv7l**, if you intend to run the executable on tegra GPU then `SMS` variable need to override SM architectures to the tegra GPU through `SMS=<TEGRA_GPU_SM_ARCH>`, where `<TEGRA_GPU_SM_ARCH>` is the SM architecture of tegra GPU on which you want the generated binary to run on. For instance it can be `SMS="32 53 62 72"`. Note you can also add SM arch of discrete GPU to this list `<TEGRA_GPU_SM_ARCH>` if you intend to run on embedded board having discrete GPU as well. To cross compile a sample, execute:

```bash
$ make TARGET_ARCH=<arch> TARGET_OS=<os> SMS=<TEGRA_GPU_SM_ARCHS> TARGET_FS=/mnt/target
```

Copying Libraries

If the TARGET_FS option is not available, the libraries used should be copied from the target system to the host system, say at `/opt/target/` If the sample uses GL, the GL headers must also be copied, say at `/opt/target/include`. The linker must then be told where the libraries are with the `-rpath-link` and/or `-L` options. To ignore unresolved symbols from some libraries, use the `--unresolved-symbols` option as shown below. `SAMPLE_ENABLED` should be used to force the sample to build. For example, to cross-compile a sample which uses such libraries, execute:

```bash
$ make TARGET_ARCH=<arch> TARGET_OS=<os> \
EXTRA_LDFLAGS="-rpath-link=/opt/target/libs -L/opt/target/libs --unresolved-symbols=ignore-in-shared-libs" \
EXTRA_CCFLAGS="-I /opt/target/include" \
SAMPLE_ENABLED=1
```
2.4. Using CUDA Samples to Create Your Own CUDA Projects

2.4.1. Creating CUDA Projects for Windows

Creating a new CUDA Program using the CUDA Samples infrastructure is easy. We have provided a **template** project that you can copy and modify to suit your needs. Just follow these steps:

1. Copy the content of:
   
   ```
   C:\ProgramData\NVIDIA Corporation\CUDA Samples\v11.0\<category>\template
   ```

   to a directory of your own:

   ```
   C:\ProgramData\NVIDIA Corporation\CUDA Samples\v11.0\<category>\myproject
   ```

2. Edit the filenames of the project to suit your needs.

3. Edit the *.sln, *.vcproj and source files.
   
   Just search and replace all occurrences of **template** with **myproject**.

4. Build the 64-bit, release or debug configurations using:

   ```
   myproject_vs<version>.sln
   ```

5. Run **myproject.exe** from the release or debug directories located in:

   ```
   C:\ProgramData\NVIDIA Corporation\CUDA Samples\v11.0\bin\win64\[release|debug]
   ```

6. Now modify the code to perform the computation you require.

   See the **CUDA Programming Guide** for details of programming in CUDA.

2.4.2. Creating CUDA Projects for Linux

Creating a new CUDA Program using the NVIDIA CUDA Samples infrastructure is easy. We have provided a **template** project that you can copy and modify to suit your needs. Just follow these steps:
1. Copy the **template** project:

   ```bash
cd <SAMPLES_INSTALL_PATH>/<category>
cp -r template <myproject>
cd <SAMPLES_INSTALL_PATH>/<category>
```

2. Edit the filenames of the project to suit your needs:

   ```bash
   mv template.cu myproject.cu
   mv template_cpu.cpp myproject_cpu.cpp
   ```

3. Edit the **Makefile** and source files.

   Just search and replace all occurrences of **template** with **myproject**.

4. Build the project as (release):

   ```bash
   make
   ```

   To build the project as (debug), use "make dbg=1":

   ```bash
   make dbg=1
   ```

5. Run the program:

   ```bash
   ../../bin/x86_64/linux/release/myproject
   ```

6. Now modify the code to perform the computation you require.

   See the **CUDA Programming Guide** for details of programming in CUDA.

### 2.4.3. Creating CUDA Projects for Mac OS X

The default installation folder `<SAMPLES_INSTALL_PATH>` is: `/Developer/NVIDIA/CUDA-11.0/samples`

Creating a new CUDA Program using the NVIDIA CUDA Samples infrastructure is easy. We have provided a **template** project that you can copy and modify to suit your needs. Just follow these steps:

(<category> is one of the following: 0_Simple, 1_Utilities, 2_Graphics, 3_Imaging, 4_Finance, 5_Simulations, 6_Advanced, 7_CUDALibraries.)

1. Copy the template project:

   ```bash
   cd <SAMPLES_INSTALL_PATH>/<category>
cp -r template <myproject>
   ```

2. Edit the filenames of the project to suit your needs:

   ```bash
   mv template.cu myproject.cu
   mv template_cpu.cpp myproject_cpu.cpp
   ```

3. Edit the **Makefile** and source files.

   Just search and replace all occurrences of **template** with **myproject**.

4. Build the project as (release):

   ```bash
   make
   ```

   Note: To build the project as (debug), use "make dbg=1"

   ```bash
   make dbg=1
   ```

5. Run the program:

   ```bash
   ../../bin/x86_64/darwin/release/myproject
   ```

   (It should print **PASSED**.)
6. Now modify the code to perform the computation you require.
   See the CUDA Programming Guide for details of programming in CUDA.
Chapter 3.
SAMPLES REFERENCE

This document contains a complete listing of the code samples that are included with the NVIDIA CUDA Toolkit. It describes each code sample, lists the minimum GPU specification, and provides links to the source code and white papers if available.

The code samples are divided into the following categories:

**Simple Reference**
Basic CUDA samples for beginners that illustrate key concepts with using CUDA and CUDA runtime APIs.

**Utilities Reference**
Utility samples that demonstrate how to query device capabilities and measure GPU/CPU bandwidth.

**Graphics Reference**
Graphical samples that demonstrate interoperability between CUDA and OpenGL or DirectX.

**Imaging Reference**
Samples that demonstrate image processing, compression, and data analysis.

**Finance Reference**
Samples that demonstrate parallel algorithms for financial computing.

**Simulations Reference**
Samples that illustrate a number of simulation algorithms implemented with CUDA.

**Advanced Reference**
Samples that illustrate advanced algorithms implemented with CUDA.

**Cudalibraries Reference**
Samples that illustrate how to use CUDA platform libraries (NPP, NVJPEG, NVGRAPH cuBLAS, cuFFT, cuSPARSE, cuSOLVER and cuRAND).

### 3.1. Simple Reference

**asyncAPI**
This sample uses CUDA streams and events to overlap execution on CPU and GPU.
bf16TensorCoreGemm - bfloat16 Tensor Core GEMM

A CUDA sample demonstrating __nv_bfloat16 (e8m7) GEMM computation using the Warp Matrix Multiply and Accumulate (WMMA) API introduced with CUDA 11 in Ampere chip family tensor cores for faster matrix operations. This sample also uses async copy provided by cuda pipeline interface for gmem to shmem async loads which improves kernel performance and reduces register pressure.

Supported SM Architecture: SM 8.0

CUDA API: cudaMallocManaged, cudaMemcpyAsync, cudaDeviceSynchronize, cudaEventCreate, cudaEventRecord, cudaEventSynchronize, cudaEventElapsedTime, cudaFree

Key Concepts: Matrix Multiply, WMMA, Tensor Cores

Supported OSes: Linux, Windows

binaryPartitionCG - Binary Partition Cooperative Groups

This sample is a simple code that illustrates binary partition cooperative groups and reduce within the thread block.


Key Concepts: Cooperative Groups

Supported OSes: Linux, Windows, OS X

cdpSimplePrint - Simple Print (CUDA Dynamic Parallelism)

This sample demonstrates simple printf implemented using CUDA Dynamic Parallelism. This sample requires devices with compute capability 3.5 or higher.
This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>CDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architecture</td>
<td>7.2, SM 7.5, SM 8.0</td>
</tr>
<tr>
<td>Key Concepts</td>
<td>CUDA Dynamic Parallelism</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows, OS X</td>
</tr>
</tbody>
</table>

cdpSimpleQuicksort - Simple Quicksort (CUDA Dynamic Parallelism)

This sample demonstrates simple quicksort implemented using CUDA Dynamic Parallelism. This sample requires devices with compute capability 3.5 or higher.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

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<td>CUDA Dynamic Parallelism</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows, OS X</td>
</tr>
</tbody>
</table>

clock - Clock

This example shows how to use the clock function to measure the performance of block of threads of a kernel accurately.

| Architecture   | 7.2, SM 7.5, SM 8.0 |
| CUDA API       | cudaMalloc, cudaFree, cudaMemcpy |
| Key Concepts   | Performance Strategies |
| Supported OSes | Linux, Windows, OS X |
clock_nvrtc - Clock libNVRTC

This example shows how to use the clock function using libNVRTC to measure the performance of block of threads of a kernel accurately.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>NVRTC</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUDA API</td>
<td>cuMemAlloc, cuLaunchKernel, cuMemcpyHtoD, cuMemFree</td>
</tr>
<tr>
<td>Key Concepts</td>
<td>Performance Strategies, Runtime Compilation</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows, OS X</td>
</tr>
</tbody>
</table>

cppIntegration - C++ Integration

This example demonstrates how to integrate CUDA into an existing C++ application, i.e. the CUDA entry point on host side is only a function which is called from C++ code and only the file containing this function is compiled with nvcc. It also demonstrates that vector types can be used from cpp.

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Architecture</td>
<td>7.2, SM 7.5, SM 8.0</td>
</tr>
<tr>
<td>CUDA API</td>
<td>cudaMalloc, cudaFree, cudaMemcpy</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows, OS X</td>
</tr>
</tbody>
</table>

cppOverload

This sample demonstrates how to use C++ function overloading on the GPU.

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Architecture</td>
<td>7.2, SM 7.5, SM 8.0</td>
</tr>
<tr>
<td>CUDA API</td>
<td>cudaFuncSetCacheConfig, cudaFuncGetAttributes</td>
</tr>
<tr>
<td>Key Concepts</td>
<td>C++ Function Overloading, CUDA Streams and Events</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows, OS X</td>
</tr>
</tbody>
</table>

This sample demonstrates CUDA-NvSciBuf/NvSciSync Interop. Two CPU threads import the NvSciBuf and NvSciSync into CUDA to perform two image processing algorithms on a ppm image - image rotation in 1st thread & rgba to grayscale conversion of rotated image in 2nd thread.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**
- NVSCI

**Supported SM Architecture**

**CUDA API**
- cudaImportExternalMemory, cudaExternalMemoryGetMappedBuffer, cudaExternalMemoryGetMappedMipmappedArray, cudaImportExternalSemaphore, cudaSignalExternalSemaphoresAsync, cudaWaitExternalSemaphoresAsync, cudaDestroyExternalSemaphore, cudaDestroyExternalMemory

**Key Concepts**
- CUDA NvSci Interop, Data Parallel Algorithms, Image Processing

**Supported OSes**
- Linux

<---

cudaOpenMP

This sample demonstrates how to use OpenMP API to write an application for multiple GPUs.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**
- OpenMP

**Supported SM Architecture**

**CUDA API**
- cudaMalloc, cudaMemcpy, cudaMemcpyAsync

**Key Concepts**
- CUDA Systems Integration, OpenMP, Multithreading

**Supported OSes**
- Linux, Windows
cudaTensorCoreGemm - CUDA Tensor Core GEMM

CUDA sample demonstrating a GEMM computation using the Warp Matrix Multiply and Accumulate (WMMA) API introduced in CUDA 9. This sample demonstrates the use of the new CUDA WMMA API employing the Tensor Cores introduced in the Volta chip family for faster matrix operations. In addition to that, it demonstrates the use of the new CUDA function attribute `cudaFuncAttributeMaxDynamicSharedMemorySize` that allows the application to reserve an extended amount of shared memory than it is available by default.

<table>
<thead>
<tr>
<th>Supported SM Architecture</th>
<th>SM 7.0, SM 7.2, SM 7.5, SM 8.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUDA API</td>
<td><code>cudaMallocManaged</code>, <code>cudaDeviceSynchronize</code>, <code>cudaFuncSetAttribute</code>, <code>cudaEventCreate</code>, <code>cudaEventRecord</code>, <code>cudaEventSynchronize</code>, <code>cudaEventElapsedTime</code>, <code>cudaFree</code></td>
</tr>
<tr>
<td>Key Concepts</td>
<td>Matrix Multiply, WMMA, Tensor Cores</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows</td>
</tr>
</tbody>
</table>

dmmaTensorCoreGemm - Double Precision Tensor Core GEMM

CUDA sample demonstrates double precision GEMM computation using the Double precision Warp Matrix Multiply and Accumulate (WMMA) API introduced with CUDA 11 in Ampere chip family tensor cores for faster matrix operations. This sample also uses async copy provided by cuda pipeline interface for gmem to shmem async loads which improves kernel performance and reduces register pressure.

<table>
<thead>
<tr>
<th>Supported SM Architecture</th>
<th>SM 8.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUDA API</td>
<td><code>cudaMallocManaged</code>, <code>cudaDeviceSynchronize</code>, <code>cudaFuncSetAttribute</code>, <code>cudaEventCreate</code>, <code>cudaEventRecord</code>, <code>cudaEventSynchronize</code>, <code>cudaEventElapsedTime</code>, <code>cudaFree</code></td>
</tr>
<tr>
<td>Key Concepts</td>
<td>Matrix Multiply, WMMA, Tensor Cores</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows</td>
</tr>
</tbody>
</table>

fp16ScalarProduct - FP16 Scalar Product

Calculates scalar product of two vectors of FP16 numbers.
This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**

- FP16

**Supported SM Architecture**


**CUDA API**

- cudaMemcpy, cudaMallocHost, cudaMemcpy, cudaFree, cudaFreeHost

**Key Concepts**

- CUDA Runtime API

**Supported OSes**

- Linux, Windows, OS X

---

### globalToShmemAsyncCopy - Global Memory to Shared Memory Async Copy

This sample implements matrix multiplication which uses asynchronous copy of data from global to shared memory when on compute capability 8.0 or higher. Also demonstrates arrive-wait barrier for synchronization.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**

- CPP11

**Supported SM Architecture**


**CUDA API**

- cudaEventCreate, cudaEventRecord, cudaEventQuery, cudaEventDestroy, cudaEventElapsedTime, cudaEventSynchronize, cudaMemcpy

**Key Concepts**

- CUDA Runtime API, Linear Algebra, CPP11 CUDA

**Supported OSes**

- Linux, Windows, OS X

---

### immaTensorCoreGemm - Tensor Core GEMM Integer MMA

CUDA sample demonstrating a integer GEMM computation using the Warp Matrix Multiply and Accumulate (WMMA) API for integer introduced in CUDA 10. This sample demonstrates the use of the CUDA WMMA API employing the Tensor Cores introduced in the Volta chip family for faster matrix operations. In addition to that, it demonstrates the use of the new CUDA function attribute
cudaFuncAttributeMaxDynamicSharedMemorySize that allows the application to reserve an extended amount of shared memory than it is available by default.

<table>
<thead>
<tr>
<th>Supported SM Architecture</th>
<th>SM 7.2, SM 7.5, SM 8.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUDA API</td>
<td>cudaMallocManaged, cudaDeviceSynchronize, cudaFuncSetAttribute, cudaEventCreate, cudaEventRecord, cudaEventSynchronize, cudaEventElapsedTime, cudaFree</td>
</tr>
<tr>
<td>Key Concepts</td>
<td>Matrix Multiply, WMMA, Tensor Cores</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows</td>
</tr>
</tbody>
</table>

**inlinePTX - Using Inline PTX**

A simple test application that demonstrates a new CUDA 4.0 ability to embed PTX in a CUDA kernel.

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>CUDA API</td>
<td>cudaMalloc, cudaMallocHost, cudaFree, cudaFreeHost, cudaMemcpy</td>
</tr>
<tr>
<td>Key Concepts</td>
<td>Performance Strategies, PTX Assembly, CUDA Driver API</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows, OS X</td>
</tr>
</tbody>
</table>

**inlinePTX_nvrtc - Using Inline PTX with libNVRTC**

A simple test application that demonstrates a new CUDA 4.0 ability to embed PTX in a CUDA kernel.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>NVRTC</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUDA API</td>
<td>cuMemAlloc, cuLaunchKernel, cudaMemcpyDtoH</td>
</tr>
<tr>
<td>Key Concepts</td>
<td>Performance Strategies, PTX Assembly, CUDA Driver API, Runtime Compilation</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows, OS X</td>
</tr>
</tbody>
</table>
**matrixMul - Matrix Multiplication (CUDA Runtime API Version)**

This sample implements matrix multiplication which makes use of shared memory to ensure data reuse, the matrix multiplication is done using tiling approach. It has been written for clarity of exposition to illustrate various CUDA programming principles, not with the goal of providing the most performant generic kernel for matrix multiplication.

**Supported SM Architecture**

**CUDA API**
- cudaEventCreate, cudaEventRecord, cudaEventQuery, cudaEventDestroy, cudaEventElapsedTime, cudaEventSynchronize, cudaMalloc, cudaFree, cudaMemcpy

**Key Concepts**
- CUDA Runtime API, Linear Algebra

**Supported OSes**
- Linux, Windows, OS X

---

**matrixMul_nvrtc - Matrix Multiplication with libNVRTC**

This sample implements matrix multiplication and is exactly the same as Chapter 6 of the programming guide. It has been written for clarity of exposition to illustrate various CUDA programming principles, not with the goal of providing the most performant generic kernel for matrix multiplication. To illustrate GPU performance for matrix multiply, this sample also shows how to use the new CUDA 4.0 interface for CUBLAS to demonstrate high-performance performance for matrix multiplication.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**
- NVRTC

**Supported SM Architecture**

**CUDA API**
- cuModuleLoad, cuModuleLoadDataEx, cuModuleGetFunction, cuMemAlloc, cuMemFree, cudaMemcpy, cudaMemcpyHtoD, cudaMemcpyDtoH, cuLaunchKernel

**Key Concepts**
- CUDA Runtime API, Linear Algebra, Runtime Compilation

**Supported OSes**
- Linux, Windows, OS X
matrixMulCUBLAS - Matrix Multiplication (CUBLAS)

This sample implements matrix multiplication from Chapter 3 of the programming guide. To illustrate GPU performance for matrix multiply, this sample also shows how to use the new CUDA 4.0 interface for CUBLAS to demonstrate high-performance performance for matrix multiplication.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>CUBLAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUDA API</td>
<td>cudaEventCreate, cudaEventRecord, cudaEventQuery, cudaEventDestroy, cudaEventElapsedTime, cudaMemcpy, cublasCreate, cublasSgemm</td>
</tr>
<tr>
<td>Key Concepts</td>
<td>CUDA Runtime API, Performance Strategies, Linear Algebra, CUBLAS</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows, OS X</td>
</tr>
</tbody>
</table>

matrixMulDrv - Matrix Multiplication (CUDA Driver API Version)

This sample implements matrix multiplication and uses the new CUDA 4.0 kernel launch Driver API. It has been written for clarity of exposition to illustrate various CUDA programming principles, not with the goal of providing the most performant generic kernel for matrix multiplication. CUBLAS provides high-performance matrix multiplication.

| CUDA API | cuModuleLoad, cuModuleLoadDataEx, cuModuleGetFunction, cuMemAlloc, cuMemFree, cuMemcpyHtoD, cuMemcpyDtoH, cuLaunchKernel |
| Key Concepts | CUDA Driver API, Matrix Multiply |
| Supported OSes | Linux, Windows, OS X |
memMapIPCDrv - Memmap IPC Driver API

This CUDA Driver API sample is a very basic sample that demonstrates Inter Process Communication using cuMemMap APIs with one process per GPU for computation. Requires Compute Capability 3.0 or higher and a Linux Operating System, or a Windows Operating System.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**
- IPC

**Supported SM Architecture**

**CUDA API**
- cuModuleLoad, cuModuleLoadDataEx, cuModuleGetFunction, cuLaunchKernel,
- cuMemcpyDtoHAsync, cuDeviceGetAttribute, cuDeviceCanAccessPeer,
- cuStreamCreate, cuStreamSynchronize, cuCtxCreate, cuCtxDestroy,
- cuOccupancyMaxActiveBlocksPerMultiprocessor,
- cuMemGetAllocationGranularity, cuMemAddressReserve, cuMemCreate,
- cuMemRelease, cuCtxSetCurrent, cuMemExportToShareableHandle,
- cuMemImportFromShareableHandle, cuMemMap, cuMemSetAccess,
- cuMemUnmap, cuMemAddressFree

**Key Concepts**
- CUDA Driver API, cuMemMap IPC, MMAP

**Supported OSes**
- Linux, Windows

simpleAssert

This CUDA Runtime API sample is a very basic sample that implements how to use the assert function in the device code. Requires Compute Capability 2.0.

**Supported SM Architecture**

**CUDA API**
- cudaMalloc, cudaMallocHost, cudaFree, cudaFreeHost, cudaMemcpy

**Key Concepts**
- Assert

**Supported OSes**
- Linux, Windows
simpleAssert_nvrtc - simpleAssert with libNVRT

This CUDA Runtime API sample is a very basic sample that implements how to use the assert function in the device code. Requires Compute Capability 2.0.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>NVRTC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architecture</td>
<td>7.2, SM 7.5, SM 8.0</td>
</tr>
<tr>
<td>CUDA API</td>
<td>cuLaunchKernel</td>
</tr>
<tr>
<td>Key Concepts</td>
<td>Assert, Runtime Compilation</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows</td>
</tr>
</tbody>
</table>

simpleAtomicIntrinsics - Simple Atomic Intrinsics

A simple demonstration of global memory atomic instructions. Requires Compute Capability 2.0 or higher.

| Architecture   | 7.2, SM 7.5, SM 8.0 |
| CUDA API       | cudaMalloc, cudaFree, cudaMemcpy, cudaMemcpyHost |
| Key Concepts   | Atomic Intrinsics |
| Supported OSes | Linux, Windows, OS X |

simpleAtomicIntrinsics_nvrtc - Simple Atomic Intrinsics with libNVRT

A simple demonstration of global memory atomic instructions. This sample makes use of NVRTC for Runtime Compilation.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>NVRTC</th>
</tr>
</thead>
</table>
simpleAttributes

This CUDA Runtime API sample is a very basic example that implements how to use the stream attributes that affect L2 locality. Performance improvement due to use of L2 access policy window can only be noticed on Compute capability 8.0 or higher.

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>CUDA API</td>
<td>cuCtxResetPersistingL2Cache, cudaDeviceSetLimit, cudaFree, cudaMemcpy, cudaMalloc, cudaMemcpyAsync, cudaStreamCreate, cudaMemcpyAsync</td>
</tr>
<tr>
<td>Key Concepts</td>
<td>Attributes usage on stream</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows, OS X</td>
</tr>
</tbody>
</table>

simpleAWBarrier - Simple Arrive Wait Barrier

A simple demonstration of arrive wait barriers.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>CPP11, MBCG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supported SM Architecture</td>
<td>SM 7.0, SM 7.2, SM 7.5, SM 8.0</td>
</tr>
<tr>
<td>CUDA API</td>
<td>cudaMalloc, cudaMemcpyAsync</td>
</tr>
<tr>
<td>Key Concepts</td>
<td>Arrive Wait Barrier</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows</td>
</tr>
</tbody>
</table>
simpleCallback - Simple CUDA Callbacks

This sample implements multi-threaded heterogeneous computing workloads with the new CPU callbacks for CUDA streams and events introduced with CUDA 5.0.

- **CUDA API**: cudaStreamCreate, cudaMemcpyAsync, cudaStreamAddCallback, cudaStreamDestroy
- **Key Concepts**: CUDA Streams, Callback Functions, Multithreading
- **Supported OSes**: Linux, Windows, OS X

simpleCooperativeGroups - Simple Cooperative Groups

This sample is a simple code that illustrates basic usage of cooperative groups within the thread block.

- **Key Concepts**: Cooperative Groups
- **Supported OSes**: Linux, Windows, OS X

simpleCubemapTexture - Simple Cubemap Texture

Simple example that demonstrates how to use a new CUDA 4.1 feature to support cubemap Textures in CUDA C.

- **CUDA API**: cudaMalloc, cudaMalloc3DArray, cudaMemcpy3D, cudaCreateChannelDesc, cudaBindTextureToArray, cudaMALLOC, cudaFree, cudaFreeArray, cudaMemcpy
- **Key Concepts**: Texture, Volume Processing
- **Supported OSes**: Linux, Windows, OS X

simpleCudaGraphs - Simple CUDA Graphs

A demonstration of CUDA Graphs creation, instantiation and launch using Graphs APIs and Stream Capture APIs.
### simpleDrvRuntime - Simple Driver-Runtime Interaction

A simple example which demonstrates how CUDA Driver and Runtime APIs can work together to load cuda fatbinary of vector add kernel and performing vector addition.

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Architecture</td>
<td>7.2, SM 7.5, SM 8.0</td>
</tr>
<tr>
<td>CUDA API</td>
<td>cudaStreamBeginCapture, cudaStreamEndCapture, cudaLaunchHostFunc, cudaGraphCreate, cudaGraphLaunch, cudaGraphInstantiate, cudaGraphAddHostNode, cudaGraphAddMemcpyNode, cudaGraphAddKernelNode, cudaGraphAddMemsetNode, cudaGraphExecDestroy, cudaGraphDestroy</td>
</tr>
<tr>
<td>Key Concepts</td>
<td>CUDA Graphs, Stream Capture</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows, OS X</td>
</tr>
</tbody>
</table>

### simpleIPC

This CUDA Runtime API sample is a very basic sample that demonstrates Inter Process Communication with one process per GPU for computation. Requires Compute Capability 3.0 or higher and a Linux Operating System, or a Windows Operating System with TCC enabled GPUs.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>IPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architecture</td>
<td>7.2, SM 7.5, SM 8.0</td>
</tr>
<tr>
<td>CUDA API</td>
<td>cudaIpcGetEventHandle, cudaIpcOpenMemHandle, cudaIpcCloseMemHandle, cudaMemcpyAsync</td>
</tr>
<tr>
<td>Key Concepts</td>
<td>CUDA Systems Integration, Peer to Peer, InterProcess Communication</td>
</tr>
</tbody>
</table>
simpleLayeredTexture - Simple Layered Texture

Simple example that demonstrates how to use a new CUDA 4.0 feature to support layered Textures in CUDA C.


**CUDA API**: cudaMalloc, cudaMalloc3DArray, cudaMemcpy3D, cudaCreateChannelDesc, cudaBindTextureToArray, cudaMalloc, cudaFree, cudaFreeArray, cudaMemcpy

**Key Concepts**: Texture, Volume Processing

**Supported OSes**: Linux, Windows

simpleMPI

Simple example demonstrating how to use MPI in combination with CUDA.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**: MPI


**CUDA API**: cudaMalloc, cudaFree, cudaMemcpy

**Key Concepts**: CUDA Systems Integration, MPI, Multithreading

**Supported OSes**: Linux, Windows, OS X

simpleMultiCopy - Simple Multi Copy and Compute

Supported in GPUs with Compute Capability 1.1, overlapping compute with one memcpy is possible from the host system. For Quadro and Tesla GPUs with Compute Capability 2.0, a second overlapped copy operation in either direction at full speed is possible (PCI-e is symmetric). This sample illustrates the usage of CUDA streams to achieve overlapping of kernel execution with data copies to and from the device.

simpleMultiGPU - Simple Multi-GPU

This application demonstrates how to use the new CUDA 4.0 API for CUDA context management and multi-threaded access to run CUDA kernels on multiple-GPUs.

**Supported SM Architecture**

**CUDA API**
cudaEventCreate, cudaEventRecord, cudaEventQuery, cudaEventDestroy, cudaEventElapsedTime, cudaMemcpyAsync

**Key Concepts**
Asynchronous Data Transfers, CUDA Streams and Events, Multithreading, Multi-GPU

**Supported OSes**
Linux, Windows, OS X

simpleOccupancy

This sample demonstrates the basic usage of the CUDA occupancy calculator and occupancy-based launch configurator APIs by launching a kernel with the launch configurator, and measures the utilization difference against a manually configured launch.

**Supported SM Architecture**

**Key Concepts**
Occupancy Calculator

**Supported OSes**
Linux, Windows, OS X

simpleP2P - Simple Peer-to-Peer Transfers with Multi-GPU

This application demonstrates CUDA APIs that support Peer-To-Peer (P2P) copies, Peer-To-Peer (P2P) addressing, and Unified Virtual Memory Addressing (UVA) between multiple GPUs. In general, P2P is supported between two same GPUs with some exceptions, such as some Tesla and Quadro GPUs.
This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**
- only-64-bit

**Supported SM Architecture**

**CUDA API**
- cudaMemcpy, cudaMemcpy2D, cudaMemcpyToArray, cudaMemcpy2D, cudaMemcpyToArray, cudaMemcpy2D

**Key Concepts**
- Performance Strategies, Asynchronous Data Transfers, Unified Virtual Address Space, Peer to Peer Data Transfers, Multi-GPU

**Supported OSes**
- Linux, Windows

---

**simplePitchLinearTexture - Pitch Linear Texture**

**Use of Pitch Linear Textures**

**Supported SM Architecture**

**CUDA API**
- cudaMallocPitch, cudaMemcpy2D, cudaMemcpyToArray, cudaMemcpy2D, cudaMemcpyToArray, cudaMemcpy2D

**Key Concepts**
- Texture, Image Processing

**Supported OSes**
- Linux, Windows, OS X

---

**simplePrintf**

This CUDA Runtime API sample is a very basic sample that implements how to use the printf function in the device code. Specifically, for devices with compute capability less than 2.0, the function cuPrintf is called; otherwise, printf can be used directly.

**Supported SM Architecture**

**CUDA API**
- cudaPrintfDisplay, cudaPrintfEnd

**Key Concepts**
- Debugging

**Supported OSes**
- Linux, Windows, OS X
simpleSeparateCompilation - Simple Static GPU Device Library

This sample demonstrates a CUDA 5.0 feature, the ability to create a GPU device static library and use it within another CUDA kernel. This example demonstrates how to pass in a GPU device function (from the GPU device static library) as a function pointer to be called. This sample requires devices with compute capability 2.0 or higher.

**Supported SM Architecture**

**Key Concepts**
Separate Compilation

**Supported OSes**
Linux, Windows, OS X

simpleStreams

This sample uses CUDA streams to overlap kernel executions with memory copies between the host and a GPU device. This sample uses a new CUDA 4.0 feature that supports pinning of generic host memory. Requires Compute Capability 2.0 or higher.

**Supported SM Architecture**

**CUDA API**
cudaEventCreate, cudaEventRecord, cudaEventQuery, cudaEventDestroy, cudaEventElapsedTime, cudaMemcpyAsync

**Key Concepts**
Asynchronous Data Transfers, CUDA Streams and Events

**Supported OSes**
Linux, Windows, OS X

simpleSurfaceWrite - Simple Surface Write

Simple example that demonstrates the use of 2D surface references (Write-to-Texture)

**Supported SM Architecture**

**CUDA API**
cudaMalloc, cudaMallocArray, cudaBindSurfaceToArray, cudaBindTextureToArray, cudaCreateChannelDesc, cudaMalloc, cudaFree, cudaFreeArray, cudaMemcpy

**Key Concepts**
Texture, Surface Writes, Image Processing

**Supported OSes**
Linux, Windows, OS X
simpleTemplates - Simple Templates

This sample is a templatized version of the template project. It also shows how to correctly templatize dynamically allocated shared memory arrays.

- **Key Concepts**: C++ Templates
- **Supported OSes**: Linux, Windows, OS X

simpleTemplates_nvrtc - Simple Templates with libNVRTC

This sample is a templatized version of the template project. It also shows how to correctly templatize dynamically allocated shared memory arrays.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

- **Dependencies**: NVRTC
- **Key Concepts**: C++ Templates, Runtime Compilation
- **Supported OSes**: Linux, Windows, OS X

simpleTexture - Simple Texture

Simple example that demonstrates use of Textures in CUDA.

- **CUDA API**: cudaMalloc, cudaMallocArray, cudaMemcpyToArray, cudaCreateChannelDesc, cudaBindTextureToArray, cudaMalloc, cudaFree, cudaFreeArray, cudaMemcpy
- **Key Concepts**: CUDA Runtime API, Texture, Image Processing
- **Supported OSes**: Linux, Windows, OS X
simpleTextureDrv - Simple Texture (Driver Version)

Simple example that demonstrates use of Textures in CUDA. This sample uses the new CUDA 4.0 kernel launch Driver API.

**Supported SM Architecture**

**CUDA API**
cuModuleLoad, cuModuleLoadDataEx, cuModuleGetFunction, cuLaunchKernel, cuCtxSynchronize, cuMemcpyDtoH, cuMemAlloc, cuMemFree, cuArrayCreate, cuArrayDestroy, cuCtxDetach, cuMemcpy2D, cuModuleGetTexRef, cuTexRefSetArray, cuTexRefSetAddressMode, cuTexRefSetFilterMode, cuTexRefSetFlags, cuTexRefSetFormat, cuParamSetTexRef

**Key Concepts**
CUDA Driver API, Texture, Image Processing

**Supported OSes**
Linux, Windows, OS X

simpleVoteIntrinsics - Simple Vote Intrinsics

Simple program which demonstrates how to use the Vote (any, all) intrinsic instruction in a CUDA kernel. Requires Compute Capability 2.0 or higher.

**Supported SM Architecture**

**CUDA API**
cudaMalloc, cudaFree, cudaMemcpy, cudaFreeHost

**Key Concepts**
Vote Intrinsics

**Supported OSes**
Linux, Windows, OS X

simpleVoteIntrinsics_nvrtc - Simple Vote Intrinsics with libNVRTC

Simple program which demonstrates how to use the Vote (any, all) intrinsic instruction in a CUDA kernel with runtime compilation using NVRTC APIs. Requires Compute Capability 2.0 or higher.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**
NVRTC
simpleZeroCopy

This sample illustrates how to use Zero MemCopy, kernels can read and write directly to pinned system memory.

supported SM Architecture
7.2, SM 7.5, SM 8.0

CUDA API

cuMemAlloc, cuMemFree, cuMemcpyHtoD, cuMemFree

cudaEventCreate, cudaEventRecord, cudaEventQuery, cudaEventDestroy,
cudaEventElapsedTime, cudaHostAlloc, cudaHostGetDevicePointer,
cudaHostRegister, cudaHostUnregister, cudaFreeHost

Key Concepts

Performance Strategies, Pinned System Paged Memory, Vector Addition

Supported OSes
Linux, Windows, OS X

Whitepaper
CUDA2.2PinnedMemoryAPIs.pdf

systemWideAtomics - System wide Atomics

A simple demonstration of system wide atomic instructions.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies
UVM

Supported SM Architecture

CUDA API

cudaMalloc, cudaFree, cudaMemcpy, cudaFreeHost

Key Concepts

Atomic Intrinsics, Unified Memory

Supported OSes
Linux
**template - Template**

A trivial template project that can be used as a starting point to create new CUDA projects.

- **CUDA API**: cudaMalloc, cudaFree, cudaDeviceSynchronize, cudaMemcpy
- **Key Concepts**: Device Memory Allocation
- **Supported OSes**: Linux, Windows, OS X

**tf32TensorCoreGemm - tf32 Tensor Core GEMM**

A CUDA sample demonstrating tf32 (e8m10) GEMM computation using the Warp Matrix Multiply and Accumulate (WMMA) API introduced with CUDA 11 in Ampere chip family tensor cores for faster matrix operations. This sample also uses async copy provided by cuda pipeline interface for gmem to shmem async loads which improves kernel performance and reduces register pressure.

- **Supported SM Architecture**: SM 8.0
- **CUDA API**: cudaMalloc, cudaDeviceSynchronize, cudaFuncSetAttribute, cudaEventCreate, cudaEventRecord, cudaEventSynchronize, cudaEventElapsedTime, cudaFree
- **Key Concepts**: Matrix Multiply, WMMA, Tensor Cores
- **Supported OSes**: Linux, Windows

**UnifiedMemoryStreams - Unified Memory Streams**

This sample demonstrates the use of OpenMP and streams with Unified Memory on a single GPU.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

- **Dependencies**: OpenMP, UVM, CUBLAS
- **CUDA API**: cudaMallocManaged, cudaStreamAttachManagedMem
vectorAdd - Vector Addition

This CUDA Runtime API sample is a very basic sample that implements element by element vector addition. It is the same as the sample illustrating Chapter 3 of the programming guide with some additions like error checking.

**Supported SM Architecture**

**CUDA API**
cudaEventCreate, cudaEventRecord, cudaEventQuery, cudaEventDestroy, cudaEventElapsedTime, cudaEventSynchronize, cudaMalloc, cudaFree, cudaMemcpy

**Key Concepts**
CUDA Runtime API, Vector Addition

**Supported OSes**
Linux, Windows, OS X

vectorAdd_nvrtc - Vector Addition with libNVRTC

This CUDA Driver API sample uses NVRTC for runtime compilation of vector addition kernel. Vector addition kernel demonstrated is the same as the sample illustrating Chapter 3 of the programming guide.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**
NVRTC

**Supported SM Architecture**

**CUDA API**
cuMemAlloc, cuMemFree, cuMemcpyHtoD, cuMemcpyDtoH

**Key Concepts**
CUDA Driver API, Vector Addition, Runtime Compilation

**Supported OSes**
Linux, Windows, OS X

vectorAddDrv - Vector Addition Driver API

This Vector Addition sample is a basic sample that is implemented element by element. It is the same as the sample illustrating Chapter 3 of the programming guide with some
additions like error checking. This sample also uses the new CUDA 4.0 kernel launch Driver API.

**Supported SM Architecture**


**CUDA API**

cuModuleLoad, cuModuleLoadDataEx, cuModuleGetFunction, cuMemAlloc, cuMemFree, cuMemcpyHtoD, cuMemcpyDtoH, cuLaunchKernel

**Key Concepts**

CUDA Driver API, Vector Addition

**Supported OSes**

- Linux, Windows, OS X

---

**vectorAddMMAP - Vector Addition cuMemMap**

This sample replaces the device allocation in the vectorAddDrv sample with cuMemMap-ed allocations. This sample demonstrates that the cuMemMap api allows the user to specify the physical properties of their memory while retaining the contiguos nature of their access, thus not requiring a change in their program structure.

**Supported SM Architecture**


**CUDA API**


**Key Concepts**

CUDA Driver API, Vector Addition, MMAP

**Supported OSes**

- Linux, Windows

---

### 3.2. Utilities Reference

**bandwidthTest - Bandwidth Test**

This is a simple test program to measure the memcopy bandwidth of the GPU and memcpy bandwidth across PCI-e. This test application is capable of measuring device to device copy bandwidth, host to device copy bandwidth for pageable and page-locked memory, and device to host copy bandwidth for pageable and page-locked memory.

**Supported SM Architecture**

**deviceQuery - Device Query**

This sample enumerates the properties of the CUDA devices present in the system.

- **CUDA API**: cudaSetDevice, cudaGetDeviceCount, cudaGetDeviceProperties, cudaDriverGetVersion, cudaRuntimeGetVersion
- **Key Concepts**: CUDA Runtime API, Device Query
- **Supported OSes**: Linux, Windows, OS X

**deviceQueryDrv - Device Query Driver API**

This sample enumerates the properties of the CUDA devices present using CUDA Driver API calls.

- **CUDA API**: cuInit, cuDeviceGetCount, cuDeviceComputeCapability, cuDriverGetVersion, cuDeviceTotalMem, cuDeviceGetAttribute
- **Key Concepts**: CUDA Driver API, Device Query
- **Supported OSes**: Linux, Windows, OS X

**p2pBandwidthLatencyTest - Peer-to-Peer Bandwidth Latency Test with Multi-GPUs**

This application demonstrates the CUDA Peer-To-Peer (P2P) data transfers between pairs of GPUs and computes latency and bandwidth. Tests on GPU pairs using P2P and without P2P are tested.

### CUDA API

### Key Concepts
- Performance Strategies, Asynchronous Data Transfers, Unified Virtual Address Space, Peer to Peer Data Transfers, Multi-GPU

### Supported OSes
- Linux, Windows, OS X

---

### topologyQuery - Topology Query
A simple example on how to query the topology of a system with multiple GPUs

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CUDA API</td>
<td>cudaDeviceGetP2PAttribute, cudaGetDeviceAttribute, cudaGetDeviceCount</td>
</tr>
<tr>
<td>Key Concepts</td>
<td>Performance Strategies, Multi-GPU</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows, OS X</td>
</tr>
</tbody>
</table>

---

### UnifiedMemoryPerf - Unified and other CUDA Memories Performance
This sample demonstrates the performance comparison using matrix multiplication kernel of Unified Memory with/without hints and other types of memory like zero copy buffers, pageable, pagelocked memory performing synchronous and Asynchronous transfers on a single GPU.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>UVM</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUDA API</td>
<td>cudaMallocManaged, cudaMemcpyAsync, cudaMemcpyAsync, cudaMemcpyAsync, cudaMemcpyAsync</td>
</tr>
<tr>
<td>Key Concepts</td>
<td>CUDA Systems Integration, Unified Memory, CUDA Streams and Events, Pinned System Paged Memory</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows, OS X</td>
</tr>
</tbody>
</table>
3.3. Graphics Reference

bindlessTexture - Bindless Texture

This example demonstrates use of cudaSurfaceObject, cudaTextureObject, and MipMap support in CUDA. A GPU with Compute Capability SM 3.0 is required to run the sample.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies
X11, GL

Supported SM

Architecture
7.2, SM 7.5, SM 8.0

CUDA API
cudaGraphicsMapResources, cudaGraphicsUnmapResources,
cudaGraphicsResourceGetMappedPointer, cudaGraphicsRegisterResource,
cudaGraphicsGLRegisterBuffer, cudaGraphicsUnregisterResource

Key Concepts
Graphics Interop, Texture

Supported OSes
Linux, Windows, OS X

Mandelbrot

This sample uses CUDA to compute and display the Mandelbrot or Julia sets interactively. It also illustrates the use of "double single" arithmetic to improve precision when zooming a long way into the pattern. This sample uses double precision. Thanks to Mark Granger of NewTek who submitted this code sample.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies
X11, GL

Supported SM

Architecture
7.2, SM 7.5, SM 8.0

CUDA API
cudaGraphicsMapResources, cudaGraphicsUnmapResources,
cudaGraphicsResourceGetMappedPointer, cudaGraphicsRegisterResource,
cudaGraphicsGLRegisterBuffer, cudaGraphicsUnregisterResource
marchingCubes - Marching Cubes Isosurfaces

This sample extracts a geometric isosurface from a volume dataset using the marching cubes algorithm. It uses the scan (prefix sum) function from the Thrust library to perform stream compaction.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**
- X11, GL

**Supported SM Architecture**

**CUDA API**

**Key Concepts**
- OpenGL Graphics Interop, Vertex Buffers, 3D Graphics, Physically Based Simulation

**Supported OSes**
- Linux, Windows, OS X

simpleD3D10 - Simple Direct3D10 (Vertex Array)

Simple program which demonstrates interoperability between CUDA and Direct3D10. The program generates a vertex array with CUDA and uses Direct3D10 to render the geometry. A Direct3D Capable device is required.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**
- DirectX

**Supported SM Architecture**

**CUDA API**
cudaGraphicsSubResourceGetMappedArray, cudaMemcpy2DToArray, cudaGraphicsUnregisterResource

**Key Concepts**
Graphics Interop, 3D Graphics

**Supported OSes**
Windows

### simpleD3D10RenderTarget - Simple Direct3D10 Render Target

Simple program which demonstrates interop of render targets between Direct3D10 and CUDA. The program uses RenderTarget positions with CUDA and generates a histogram with visualization. A Direct3D10 Capable device is required.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**
DirectX

**Supported SM**

**CUDA API**

**Key Concepts**
Graphics Interop, Texture

**Supported OSes**
Windows

### simpleD3D10Texture - Simple D3D10 Texture

Simple program which demonstrates how to interoperate CUDA with Direct3D10 Texture. The program creates a number of D3D10 Textures (2D, 3D, and CubeMap) which are generated from CUDA kernels. Direct3D then renders the results on the screen. A Direct3D10 Capable device is required.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**
DirectX
simpleD3D11 - Simple D3D11

Simple program which demonstrates how to use the CUDA D3D11 External Resource Interoperability APIs to update D3D11 buffers from CUDA and synchronize between D3D11 and CUDA with Keyed Mutexes.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies: DirectX
Key Concepts: Graphics Interop, Texture
Supported OSes: Windows

simpleD3D11Texture - Simple D3D11 Texture

Simple program which demonstrates Direct3D11 Texture interoperability with CUDA. The program creates a number of D3D11 Textures (2D, 3D, and CubeMap) which are written to from CUDA kernels. Direct3D then renders the results on the screen. A Direct3D Capable device is required.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies: DirectX
CUDA API: cudaD3D11GetDevice, cudaMemcpy2DFromArray
Key Concepts: Graphics Interop, Image Processing
Supported OSes: Windows
## simpleD3D12 - Simple D3D12 CUDA Interop

A program which demonstrates Direct3D12 interoperability with CUDA. The program creates a sinewave in DX12 vertex buffer which is created using CUDA kernels. DX12 and CUDA synchronizes using DirectX12 Fences. Direct3D then renders the results on the screen. A DirectX12 Capable NVIDIA GPU is required on Windows10 or higher OS.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>DirectX12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architecture</td>
<td>7.2, SM 7.5, SM 8.0</td>
</tr>
<tr>
<td>CUDA API</td>
<td>cudaWaitExternalSemaphoresAsync, cudaSignalExternalSemaphoresAsync, cudaImportExternalSemaphore, cudaExternalMemoryGetMappedBuffer, cudaImportExternalMemory, cudaDestroyExternalSemaphore, cudaDestroyExternalMemory</td>
</tr>
<tr>
<td>Key Concepts</td>
<td>Graphics Interop, CUDA DX12 Interop, Image Processing</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Windows</td>
</tr>
</tbody>
</table>

## simpleD3D9 - Simple Direct3D9 (Vertex Arrays)

Simple program which demonstrates interoperability between CUDA and Direct3D9. The program generates a vertex array with CUDA and uses Direct3D9 to render the geometry. A Direct3D capable device is required.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>DirectX12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architecture</td>
<td>7.2, SM 7.5, SM 8.0</td>
</tr>
<tr>
<td>CUDA API</td>
<td>cudaWaitExternalSemaphoresAsync, cudaSignalExternalSemaphoresAsync, cudaImportExternalSemaphore, cudaExternalMemoryGetMappedBuffer, cudaImportExternalMemory, cudaDestroyExternalSemaphore, cudaDestroyExternalMemory</td>
</tr>
<tr>
<td>Key Concepts</td>
<td>Graphics Interop, CUDA DX12 Interop, Image Processing</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Windows</td>
</tr>
</tbody>
</table>
simpleD3D9Texture - Simple D3D9 Texture

Simple program which demonstrates Direct3D9 Texture interoperability with CUDA. The program creates a number of D3D9 Textures (2D, 3D, and CubeMap) which are written to from CUDA kernels. Direct3D then renders the results on the screen. A Direct3D capable device is required.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

simpleGL - Simple OpenGL

Simple program which demonstrates interoperability between CUDA and OpenGL. The program modifies vertex positions with CUDA and uses OpenGL to render the geometry.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.
simpleGLES - Simple OpenGLES

Demonstrates data exchange between CUDA and OpenGL ES (aka Graphics interop). The program modifies vertex positions with CUDA and uses OpenGL ES to render the geometry.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

simpleGLES_EGLOutput - Simple OpenGLES EGLOutput

Demonstrates data exchange between CUDA and OpenGL ES (aka Graphics interop). The program modifies vertex positions with CUDA and uses OpenGL ES to render the geometry, and shows how to render directly to the display using the EGLOutput mechanism and the DRM library.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.
simpleGLES_screen - Simple OpenGLES on Screen

Demonstrates data exchange between CUDA and OpenGL ES (aka Graphics interop). The program modifies vertex positions with CUDA and uses OpenGL ES to render the geometry.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

simpleTexture3D - Simple Texture 3D

Simple example that demonstrates use of 3D Textures in CUDA.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.
simpleVulkan - Vulkan CUDA Interop Sinewave

This sample demonstrates Vulkan CUDA Interop. CUDA imports the Vulkan vertex buffer and operates on it to create sinewave, and synchronizes with Vulkan through Vulkan semaphores imported by CUDA. This sample depends on Vulkan SDK, GLFW3 libraries, for building this sample please refer to "Build_instructions.txt" provided in this sample's directory.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies: X11, VULKAN

SLID3D10Texture - SLI D3D10 Texture

Simple program which demonstrates SLI with Direct3D10 Texture interoperability with CUDA. The program creates a D3D10 Texture which is written to from a CUDA kernel. Direct3D then renders the results on the screen. A Direct3D Capable device is required.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.
**volumeFiltering - Volumetric Filtering with 3D Textures and Surface Writes**

This sample demonstrates 3D Volumetric Filtering using 3D Textures and 3D Surface Writes.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**  
X11, GL

**Supported SM**  

**CUDA API**  

**Key Concepts**  
Graphics Interop, Image Processing, 3D Textures, Surface Writes

**Supported OSes**  
Linux, Windows, OS X

---

**volumeRender - Volume Rendering with 3D Textures**

This sample demonstrates basic volume rendering using 3D Textures.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**  
X11, GL
3.4. Imaging Reference

bicubicTexture - Bicubic B-spline Interpolation

This sample demonstrates how to efficiently implement a Bicubic B-spline interpolation filter with CUDA texture.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies
- X11, GL

Supported SM

Architecture
- 7.2, SM 7.5, SM 8.0

CUDA API
- cudaGraphicsMapResources, cudaGraphicsUnmapResources,
  cudaGraphicsResourceGetMappedPointer, cudaGraphicsRegisterResource,
  cudaGraphicsGLRegisterBuffer, cudaGraphicsUnregisterResource

Key Concepts
- Graphics Interop, Image Processing

Supported OSes
- Linux, Windows, OS X

bilateralFilter - Bilateral Filter

Bilateral filter is an edge-preserving non-linear smoothing filter that is implemented with CUDA with OpenGL rendering. It can be used in image recovery and denoising. Each pixel is weight by considering both the spatial distance and color distance between its neighbors. Reference:"C. Tomasi, R. Manduchi, Bilateral Filtering for Gray and Color Images, proceeding of the ICCV, 1998, http://users.soe.ucsc.edu/~manduchi/Papers/ICCV98.pdf"

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample
will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**  
X11, GL

**Supported SM Architecture**  

**CUDA API**  

**Key Concepts**  
Graphics Interop, Image Processing

**Supported OSes**  
Linux, Windows, OS X

### boxFilter - Box Filter

Fast image box filter using CUDA with OpenGL rendering.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**  
X11, GL

**Supported SM Architecture**  

**CUDA API**  

**Key Concepts**  
Graphics Interop, Image Processing

**Supported OSes**  
Linux, Windows, OS X

### convolutionFFT2D - FFT-Based 2D Convolution

This sample demonstrates how 2D convolutions with very large kernel sizes can be efficiently implemented using FFT transformations.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**  
CUFFT
Supported SM Architecture CUDA API Key Concepts Supported OSes
cufftPlan2d, cufftExecR2C, cufftExecC2R, cufftDestroy Image Processing, CUFFT Library Linux, Windows, OS X

**convolutionSeparable - CUDA Separable Convolution**

This sample implements a separable convolution filter of a 2D signal with a gaussian kernel.

Supported SM Architecture Key Concepts Supported OSes

**convolutionTexture - Texture-based Separable Convolution**

Texture-based implementation of a separable 2D convolution with a gaussian kernel. Used for performance comparison against convolutionSeparable.

Supported SM Architecture Key Concepts Supported OSes

**dct8x8 - DCT8x8**

This sample demonstrates how Discrete Cosine Transform (DCT) for blocks of 8 by 8 pixels can be performed using CUDA: a naive implementation by definition and a more traditional approach used in many libraries. As opposed to implementing DCT in a fragment shader, CUDA allows for an easier and more efficient implementation.

Supported SM Architecture Key Concepts
dwtHaar1D - 1D Discrete Haar Wavelet Decomposition

Discrete Haar wavelet decomposition for 1D signals with a length which is a power of 2.

**Supported SM Architecture**

**Key Concepts**
Image Processing, Video Compression

**Supported OSes**
Linux, Windows, OS X

---

dxtc - DirectX Texture Compressor (DXTC)

High Quality DXT Compression using CUDA. This example shows how to implement an existing computationally-intensive CPU compression algorithm in parallel on the GPU, and obtain an order of magnitude performance improvement.

**Supported SM Architecture**

**Key Concepts**
Cooperative Groups, Image Processing, Image Compression

**Supported OSes**
Linux, Windows, OS X

**Whitepaper**
cuda_dxtc.pdf

---

EGLStream_CUDA_CrossGPU

Demonstrates CUDA and EGL Streams interop, where consumer’s EGL Stream is on one GPU and producer’s on other and both consumer-producer are different processes.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**
EGL

**Supported SM Architecture**

**CUDA API**
cuDeviceGet, cuDeviceGetAttribute, cuDeviceComputeCapability, cuDeviceGetCount, cuDeviceGetName, cuGraphicsResourceGetMappedEglFrame,
cuEGLStreamConsumerAcquireFrame, cuEGLStreamConsumerReleaseFrame, cuEGLStreamProducerReturnFrame, cuEGLStreamProducerPresentFrame, cuCtxCreate, cuMemAlloc, cuMemFree, cuMemcpy3D, cuStreamCreate, cuCtxPushCurrent, cuCtxPopCurrent, cuCtxDestroy

Key Concepts
EGLStreams Interop

Supported OSes
Linux

### EGLStreams_CUDA_Interop - EGLStreams CUDA Interop

Demonstrates data exchange between CUDA and EGL Streams.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies
EGL

Supported SM

CUDA API
cuDeviceGet, cuDeviceGetAttribute,
cuDeviceGetComputeCapability, cuDeviceGetCount,
cuDeviceGetName, cuGraphicsResourceGetMappedEglFrame,
cuEGLStreamConsumerAcquireFrame, cuEGLStreamConsumerReleaseFrame, cuEGLStreamProducerPresentFrame, cuCtxCreate, cuMemAlloc, cuMemFree, cuMemcpy3D, cuStreamCreate, cuCtxPushCurrent, cuCtxPopCurrent, cuCtxDestroy

Key Concepts
EGLStreams Interop

Supported OSes
Linux

### EGLSync_CUDA_Interop - EGLSync CUDA Event Interop

Demonstrates interoperability between CUDA Event and EGL Sync/EGL Image using which one can achieve synchronization on GPU itself for GL-EGL-CUDA operations instead of blocking CPU for synchronization.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies
EGL, EGLSync, X11, GLES
CUDA API | cuDeviceGet, cuDeviceGetAttribute, cuDeviceComputeCapability, cuDeviceGetCount, cuDeviceGetName, cuCtxCreate, cuMemAlloc, cuMemFree, cuMemcpy3D, cuStreamCreate, cuCtxPushCurrent, cuCtxPopCurrent, cuCtxDestroy
Key Concepts | EGLSync-CUDAEvent Interop, EGLImage-CUDA Interop
Supported OSes | Linux

histogram - CUDA Histogram
This sample demonstrates efficient implementation of 64-bin and 256-bin histogram.

Key Concepts | Image Processing, Data Parallel Algorithms
Supported OSes | Linux, Windows, OS X
Whitepaper | histogram.pdf

HSOpticalFlow - Optical Flow
Variational optical flow estimation example. Uses textures for image operations. Shows how simple PDE solver can be accelerated with CUDA.

Key Concepts | Image Processing, Data Parallel Algorithms
Supported OSes | Linux, Windows, OS X
Whitepaper | OpticalFlow.pdf

imageDenoising - Image denoising
This sample demonstrates two adaptive image denoising techniques: KNN and NLM, based on computation of both geometric and color distance between texels. While both techniques are implemented in the DirectX SDK using shaders, massively speeded up variation of the latter technique, taking advantage of shared memory, is implemented in addition to DirectX counterparts.
This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**

- X11, GL

**Supported SM Architecture**


**Key Concepts**

- Image Processing

**Supported OSes**

- Linux, Windows, OS X

**Whitepaper**

- imageDenoising.pdf

---

**NV12toBGRandResize**

This code shows two ways to convert and resize NV12 frames to BGR 3 planars frames using CUDA in batch. Way-1, Convert NV12 Input to BGR @ Input Resolution-1, then Resize to Resolution#2. Way-2, resize NV12 Input to Resolution#2 then convert it to BGR Output. NVIDIA HW Decoder, both dGPU and Tegra, normally outputs NV12 pitch format frames. For the inference using TensorRT, the input frame needs to be BGR planar format with possibly different size. So, conversion and resizing from NV12 to BGR planar is usually required for the inference following decoding. This CUDA code provides a reference implementation for conversion and resizing.

**Supported SM Architecture**


**CUDA API**

- cudaMemcpy2D, cudaMemcpy2D

**Key Concepts**

- Graphics Interop, Image Processing, Video Processing

**Supported OSes**

- Linux, Windows, OS X

---

**postProcessGL - Post-Process in OpenGL**

This sample shows how to post-process an image rendered in OpenGL using CUDA.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**

- X11, GL

**Supported SM Architecture**

recursiveGaussian - Recursive Gaussian Filter

This sample implements a Gaussian blur using Deriche’s recursive method. The advantage of this method is that the execution time is independent of the filter width.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

- **Dependencies**: X11, GL
- **Key Concepts**: Graphics Interop, Image Processing
- **Supported OSes**: Linux, Windows, OS X

simpleCUDA2GL - CUDA and OpenGL Interop of Images

This sample shows how to copy CUDA image back to OpenGL using the most efficient methods.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

- **Dependencies**: X11, GL
- **Key Concepts**: Graphics Interop, Image Processing
- **Supported OSes**: Linux, Windows, OS X
SobelFilter - Sobel Filter

This sample implements the Sobel edge detection filter for 8-bit monochrome images.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies: X11, GL


Key Concepts: Graphics Interop, Image Processing

Supported OSes: Linux, Windows, OS X

stereoDisparity - Stereo Disparity Computation (SAD SIMD Intrinsics)

A CUDA program that demonstrates how to compute a stereo disparity map using SIMD SAD (Sum of Absolute Difference) intrinsics. Requires Compute Capability 2.0 or higher.


Key Concepts: Image Processing, Video Intrinsics

Supported OSes: Linux, Windows, OS X

vulkanImageCUDA - Vulkan Image - CUDA Interop

This sample demonstrates Vulkan Image - CUDA Interop. CUDA imports the Vulkan image buffer, performs box filtering over it, and synchronizes with Vulkan through vulkan semaphores imported by CUDA. This sample depends on Vulkan SDK, GLFW3 libraries, for building this sample please refer to "Build_instructions.txt" provided in this sample's directory.
This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

<table>
<thead>
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<td>CUDA API</td>
<td>cudaImportExternalMemory, cudaExternalMemoryGetMappedMipmappedArray, cudaImportExternalSemaphore, cudaSignalExternalSemaphoresAsync, cudaWaitExternalSemaphoresAsync, cudaDestroyExternalSemaphore, cudaDestroyExternalMemory</td>
</tr>
<tr>
<td>Key Concepts</td>
<td>Graphics Interop, CUDA Vulkan Interop, Data Parallel Algorithms</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows</td>
</tr>
</tbody>
</table>

### 3.5. Finance Reference

**binomialOptions - Binomial Option Pricing**

This sample evaluates fair call price for a given set of European options under binomial model.

| Key Concepts             | Computational Finance |
| Supported OSes           | Linux, Windows, OS X |
| Whitepaper               | binomialOptions.pdf |

**binomialOptions_nvrtc - Binomial Option Pricing with libNVRTC**

This sample evaluates fair call price for a given set of European options under binomial model. This sample makes use of NVRTC for Runtime Compilation.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.
**BlackScholes - Black-Scholes Option Pricing**

This sample evaluates fair call and put prices for a given set of European options by Black-Scholes formula.

**BlackScholes_nvrtc - Black-Scholes Option Pricing with libNVRTC**

This sample evaluates fair call and put prices for a given set of European options by Black-Scholes formula, compiling the CUDA kernels involved at runtime using NVRTC.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**MonteCarloMultiGPU - Monte Carlo Option Pricing with Multi-GPU support**

This sample evaluates fair call price for a given set of European options using the Monte Carlo approach, taking advantage of all CUDA-capable GPUs installed in the system.
This sample uses double precision hardware if a GTX 200 class GPU is present. The sample also takes advantage of CUDA 4.0 capability to supporting using a single CPU thread to control multiple GPUs.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

<table>
<thead>
<tr>
<th>Dependencies</th>
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<tbody>
<tr>
<td>Architecture</td>
<td>7.2, SM 7.5, SM 8.0</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows, OS X</td>
</tr>
<tr>
<td>Whitepaper</td>
<td>MonteCarlo.pdf</td>
</tr>
</tbody>
</table>

**quasirandomGenerator - Niederreiter Quasirandom Sequence Generator**

This sample implements Niederreiter Quasirandom Sequence Generator and Inverse Cumulative Normal Distribution functions for the generation of Standard Normal Distributions.

| Architecture       | 7.2, SM 7.5, SM 8.0 |
| Key Concepts       | Computational Finance |
| Supported OSes     | Linux, Windows, OS X |

**quasirandomGenerator_nvrtc - Niederreiter Quasirandom Sequence Generator with libNVRTC**

This sample implements Niederreiter Quasirandom Sequence Generator and Inverse Cumulative Normal Distribution functions for the generation of Standard Normal Distributions, compiling the CUDA kernels involved at runtime using NVRT.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>NVRT</th>
</tr>
</thead>
</table>

**Supported SM Architecture**

**Key Concepts**
Computational Finance, Runtime Compilation

**Supported OSes**
Linux, Windows, OS X

---

**SobolQRNG - Sobol Quasirandom Number Generator**

This sample implements Sobol Quasirandom Sequence Generator.

**Supported SM Architecture**

**Key Concepts**
Computational Finance

**Supported OSes**
Linux, Windows, OS X

---

### 3.6. Simulations Reference

**fluidsD3D9 - Fluids (Direct3D Version)**

An example of fluid simulation using CUDA and CUFFT, with Direct3D 9 rendering. A Direct3D Capable device is required.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**
DirectX

**Supported SM Architecture**

**CUDA API**

**Key Concepts**
Graphics Interop, CUFFT Library, Physically-Based Simulation

**Supported OSes**
Windows

---

**fluidsGL - Fluids (OpenGL Version)**

An example of fluid simulation using CUDA and CUFFT, with OpenGL rendering.
This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**

- X11, GL, CUFFT

**Supported SM Architecture**


**CUDA API**


**Key Concepts**

- Graphics Interop, CUFFT Library, Physically-Based Simulation

**Supported OSes**

- Linux, Windows, OS X

**Whitepaper**

- fluidsGL.pdf

---

**fluidsGLES - Fluids (OpenGLES Version)**

An example of fluid simulation using CUDA and CUFFT, with OpenGLES rendering.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**

- X11, GLES, CUFFT

**Supported SM Architecture**


**CUDA API**


**Key Concepts**

- Graphics Interop, CUFFT Library, Physically-Based Simulation

**Supported OSes**

- Linux

---

**nbody - CUDA N-Body Simulation**

This sample demonstrates efficient all-pairs simulation of a gravitational n-body simulation in CUDA. This sample accompanies the GPU Gems 3 chapter "Fast N-Body Simulation with CUDA". With CUDA 5.5, performance on Tesla K20c has increased to over 1.8TFLOP/s single precision. Double Performance has also improved on all Kepler and Fermi GPU architectures as well. Starting in CUDA 4.0, the nBody sample has been
updated to take advantage of new features to easily scale the n-body simulation across multiple GPUs in a single PC. Adding "-numbodies=<bodies>" to the command line will allow users to set # of bodies for simulation. Adding “-numdevices=<N>” to the command line option will cause the sample to use N devices (if available) for simulation. In this mode, the position and velocity data for all bodies are read from system memory using “zero copy” rather than from device memory. For a small number of devices (4 or fewer) and a large enough number of bodies, bandwidth is not a bottleneck so we can achieve strong scaling across these devices.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

<table>
<thead>
<tr>
<th>Dependencies</th>
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<tr>
<td>Key Concepts</td>
<td>Graphics Interop, Data Parallel Algorithms, Physically-Based Simulation</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows, OS X</td>
</tr>
<tr>
<td>Whitepaper</td>
<td>nbody_gems3_ch31.pdf</td>
</tr>
</tbody>
</table>

**nbody_opengles - CUDA N-Body Simulation with GLES**

This sample demonstrates efficient all-pairs simulation of a gravitational n-body simulation in CUDA. Unlike the OpenGL nbody sample, there is no user interaction. This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

<table>
<thead>
<tr>
<th>Dependencies</th>
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</thead>
<tbody>
<tr>
<td>Key Concepts</td>
<td>Graphics Interop, Data Parallel Algorithms, Physically-Based Simulation</td>
</tr>
</tbody>
</table>
nbody_screen - CUDA N-Body Simulation on Screen

This sample demonstrates efficient all-pairs simulation of a gravitational n-body simulation in CUDA. Unlike the OpenGL nbody sample, there is no user interaction.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**

- screen, GLES

**Supported SM Architecture**


**CUDA API**


**Key Concepts**

- Graphics Interop, Data Parallel Algorithms, Physically-Based Simulation

**Supported OSes**

- Linux

---

oceanFFT - CUDA FFT Ocean Simulation

This sample simulates an Ocean height field using CUFFT Library and renders the result using OpenGL.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**

- X11, GL, CUFFT

**Supported SM Architecture**


**CUDA API**


**Key Concepts**

- Graphics Interop, Image Processing, CUFFT Library

**Supported OSes**

- Linux, Windows, OS X
particles - Particles

This sample uses CUDA to simulate and visualize a large set of particles and their physical interaction. Adding "-particles=<N>" to the command line will allow users to set # of particles for simulation. This example implements a uniform grid data structure using either atomic operations or a fast radix sort from the Thrust library.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies
X11, GL

Supported SM

CUDA API
cudaGraphicsMapResources, cudaGraphicsUnmapResources,
cudaGraphicsResourceGetMappedPointer, cudaGraphicsRegisterResource,
cudaGraphicsGLRegisterBuffer, cudaGraphicsUnregisterResource

Key Concepts
Graphics Interop, Data Parallel Algorithms, Physically-Based Simulation, Performance Strategies

Supported OSes
Linux, Windows, OS X

Whitepaper
particles.pdf

smokeParticles - Smoke Particles

Smoke simulation with volumetric shadows using half-angle slicing technique. Uses CUDA for procedural simulation, Thrust Library for sorting algorithms, and OpenGL for graphics rendering.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies
X11, GL

Supported SM

CUDA API
cudaGraphicsMapResources, cudaGraphicsUnmapResources,
cudaGraphicsResourceGetMappedPointer, cudaGraphicsRegisterResource,
cudaGraphicsGLRegisterBuffer, cudaGraphicsUnregisterResource

Key Concepts
Graphics Interop, Data Parallel Algorithms, Physically-Based Simulation
VFlockingD3D10

The sample models formation of V-shaped flocks by big birds, such as geese and cranes. The algorithms of such flocking are borrowed from the paper "V-like formations in flocks of artificial birds" from Artificial Life, Vol. 14, No. 2, 2008. The sample has CPU- and GPU-based implementations. Press 'g' to toggle between them. The GPU-based simulation works many times faster than the CPU-based one. The printout in the console window reports the simulation time per step. Press 'r' to reset the initial distribution of birds.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies
- DirectX

Supported SM Architecture

CUDA API

Key Concepts
- Graphics Interop, Data Parallel Algorithms, Physically-Based Simulation, Performance Strategies

Supported OSes
- Windows

3.7. Advanced Reference

alignedTypes - Aligned Types

A simple test, showing huge access speed gap between aligned and misaligned structures.
**c++11_cuda - C++11 CUDA**

This sample demonstrates C++11 feature support in CUDA. It scans a input text file and prints no. of occurrences of x, y, z, w characters.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

- **Dependencies**: CPP11
- **Key Concepts**: CPP11 CUDA
- **Supported OSes**: Linux, Windows, OS X

**cdpAdvancedQuicksort - Advanced Quicksort (CUDA Dynamic Parallelism)**

This sample demonstrates an advanced quicksort implemented using CUDA Dynamic Parallelism. This sample requires devices with compute capability 3.5 or higher.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

- **Dependencies**: CDP
- **Key Concepts**: Cooperative Groups, CUDA Dynamic Parallelism
- **Supported OSes**: Linux, Windows, OS X
cdpBezierTessellation - Bezier Line Tessellation (CUDA Dynamic Parallelism)

This sample demonstrates bezier tessellation of lines implemented using CUDA Dynamic Parallelism. This sample requires devices with compute capability 3.5 or higher.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

<table>
<thead>
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<tr>
<td>Key Concepts</td>
<td>CUDA Dynamic Parallelism</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows, OS X</td>
</tr>
</tbody>
</table>

cdpQuadtree - Quad Tree (CUDA Dynamic Parallelism)

This sample demonstrates Quad Trees implemented using CUDA Dynamic Parallelism. This sample requires devices with compute capability 3.5 or higher.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

<table>
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<th>Dependencies</th>
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<td>Architecture</td>
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<tr>
<td>Key Concepts</td>
<td>Cooperative Groups, CUDA Dynamic Parallelism</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows, OS X</td>
</tr>
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</table>

concurrentKernels - Concurrent Kernels

This sample demonstrates the use of CUDA streams for concurrent execution of several kernels on devices of compute capability 2.0 or higher. Devices of compute capability 1.x will run the kernels sequentially. It also illustrates how to introduce dependencies between CUDA streams with the new cudaStreamWaitEvent function introduced in CUDA 3.2
conjugateGradientMultiBlockCG - conjugateGradient using MultiBlock Cooperative Groups

This sample implements a conjugate gradient solver on GPU using Multi Block Cooperative Groups, also uses Unified Memory.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies
UVM, MBCG

Supported SM

Key Concepts
Unified Memory, Linear Algebra, Cooperative Groups, MultiBlock Cooperative Groups

Supported OSes
Linux, Windows

conjugateGradientMultiDeviceCG - conjugateGradient using MultiDevice Cooperative Groups

This sample implements a conjugate gradient solver on multiple GPUs using Multi Device Cooperative Groups, also uses Unified Memory optimized using prefetching and usage hints.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies
UVM, MDCG, CPP11

Supported SM
CUDA API

cudaMemAdvise, cudaMemPrefetchAsync, cudaLaunchCooperativeKernelMultiDevice, cudaStreamSynchronize, cudaOccupancyMaxActiveBlocksPerMultiprocessor

Key Concepts

Unified Memory, Linear Algebra, Cooperative Groups, MultiDevice Cooperative Groups

Supported OSes

Linux, Windows

cudaCompressibleMemory - CUDA Compressible Memory

This sample demonstrates the compressible memory allocation using cuMemMap API.

Supported SM


CUDA API

cuMemAlloc, cuMemFree, cuDeviceGetAttribute, cuMemGetAllocationGranularity, cuMemAddressReserve, cuMemCreate, cuMemMap, cuMemSetAccess, cuMemUnmap, cuMemAddressFree cudaMalloc, cudaFree

Key Concepts

CUDA Driver API, Compressible Memory, MMAP

Supported OSes

Linux, Windows

eigenvalues - Eigenvalues

The computation of all or a subset of all eigenvalues is an important problem in Linear Algebra, statistics, physics, and many other fields. This sample demonstrates a parallel implementation of a bisection algorithm for the computation of all eigenvalues of a tridiagonal symmetric matrix of arbitrary size with CUDA.

Supported SM


Key Concepts

Linear Algebra

Supported OSes

Linux, Windows, OS X

Whitepaper

eigenvalues.pdf

fastWalshTransform - Fast Walsh Transform

Naturally(Hadamard)-ordered Fast Walsh Transform for batching vectors of arbitrary eligible lengths that are power of two in size.

Supported SM

Key Concepts | Linear Algebra, Data-Parallel Algorithms, Video Compression
---|---
Supported OSes | Linux, Windows, OS X

FDTD3d - CUDA C 3D FDTD

This sample applies a finite differences time domain progression stencil on a 3D surface.

---|---
Supported OSes | Linux, Windows, OS X

FunctionPointers - Function Pointers

This sample illustrates how to use function pointers and implements the Sobel Edge Detection filter for 8-bit monochrome images.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

---|---
Supported OSes | Linux, Windows, OS X

interval - Interval Computing

Interval arithmetic operators example. Uses various C++ features (templates and recursion). The recursive mode requires Compute SM 2.0 capabilities.

---|---
Supported OSes | Linux, Windows, OS X
jacobiCudaGraphs - Jacobi CUDA Graphs
Demonstrates Instantiated CUDA Graph Update with Jacobi Iterative Method using cudaGraphExecKernelNodeSetParams() and cudaGraphExecUpdate() approach.

Supported SM
7.2, SM 7.5, SM 8.0

CUDA API
cudaStreamBeginCapture, cudaStreamEndCapture, cudaGraphCreate, cudaGraphLaunch, cudaGraphInstantiate, cudaGraphExecUpdate, cudaGraphExecKernelNodeSetParams, cudaGraphGetNodes, cudaGraphNodeGetType, cudaGraphExecDestroy, cudaGraphDestroy

Key Concepts
CUDA Graphs, Stream Capture, Instantiated CUDA Graph Update, Cooperative Groups

Supported OSes
Linux, Windows, OS X

lineOfSight - Line of Sight
This sample is an implementation of a simple line-of-sight algorithm: Given a height map and a ray originating at some observation point, it computes all the points along the ray that are visible from the observation point. The implementation is based on the Thrust library.

Supported SM
7.2, SM 7.5, SM 8.0

Supported OSes
Linux, Windows, OS X

matrixMulDynlinkJIT - Matrix Multiplication (CUDA Driver API version with Dynamic Linking Version)
This sample revisits matrix multiplication using the CUDA driver API. It demonstrates how to link to CUDA driver at runtime and how to use JIT (just-in-time) compilation from PTX code. It has been written for clarity of exposition to illustrate various CUDA programming principles, not with the goal of providing the most performant generic kernel for matrix multiplication. CUBLAS provides high-performance matrix multiplication.

Supported SM
7.2, SM 7.5, SM 8.0

CUDA API
cuModuleLoad, cuModuleLoadDataEx, cuModuleGetFunction, cuMemAlloc, cuMemcpyHtoD, cuMemcpyDtoH, cuLaunchKernel
Key Concepts: CUDA Driver API, CUDA Dynamically Linked Library
Supported OSes: Linux, Windows, OS X

mergeSort - Merge Sort
This sample implements a merge sort (also known as Batcher’s sort), algorithms belonging to the class of sorting networks. While generally subefficient on large sequences compared to algorithms with better asymptotic algorithmic complexity (i.e. merge sort or radix sort), may be the algorithms of choice for sorting batches of short-to mid-sized (key, value) array pairs. Refer to the excellent tutorial by H. W. Lang http://www.iti.fh-flensburg.de/lang/algorithmen/sortieren/networks/indexen.htm

Key Concepts: Data-Parallel Algorithms
Supported OSes: Linux, Windows, OS X

newdelete - NewDelete
This sample demonstrates dynamic global memory allocation through device C++ new and delete operators and virtual function declarations available with CUDA 4.0.

Supported OSes: Linux, Windows, OS X

ptxjit - PTX Just-in-Time compilation
This sample uses the Driver API to just-in-time compile (JIT) a Kernel from PTX code. Additionally, this sample demonstrates the seamless interoperability capability of the CUDA Runtime and CUDA Driver API calls. For CUDA 5.5, this sample shows how to use cuLink* functions to link PTX assembly using the CUDA driver at runtime.

Key Concepts: CUDA Driver API
Supported OSes: Linux, Windows, OS X
radixSortThrust - CUDA Radix Sort (Thrust Library)

This sample demonstrates a very fast and efficient parallel radix sort uses Thrust library. The included RadixSort class can sort either key-value pairs (with float or unsigned integer keys) or keys only.

**Supported SM Architecture**

**Key Concepts**
- Data-Parallel Algorithms, Performance Strategies

**Supported OSes**
- Linux, Windows, OS X

**Whitepaper**
- readme.txt

reduction - CUDA Parallel Reduction

A parallel sum reduction that computes the sum of a large arrays of values. This sample demonstrates several important optimization strategies for Data-Parallel Algorithms like reduction using shared memory, __shfl_down_sync and __reduce_add_sync.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**
- CPP11

**Supported SM Architecture**

**Key Concepts**
- Data-Parallel Algorithms, Performance Strategies

**Supported OSes**
- Linux, Windows, OS X

reductionMultiBlockCG - Reduction using MultiBlock Cooperative Groups

This sample demonstrates single pass reduction using Multi Block Cooperative Groups. This sample requires devices with compute capability 6.0 or higher having compute preemption.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.
scalarProd - Scalar Product
This sample calculates scalar products of a given set of input vector pairs.

Supported SM Architecture
7.2, SM 7.5, SM 8.0

Supported OSes
Linux, Windows, OS X

scan - CUDA Parallel Prefix Sum (Scan)
This example demonstrates an efficient CUDA implementation of parallel prefix sum, also known as "scan". Given an array of numbers, scan computes a new array in which each element is the sum of all the elements before it in the input array.

Supported SM Architecture
7.2, SM 7.5, SM 8.0

Supported OSes
Linux, Windows, OS X

segmentationTreeThrust - CUDA Segmentation Tree Thrust Library
This sample demonstrates an approach to the image segmentation trees construction. This method is based on Boruvka’s MST algorithm.

Supported SM Architecture
7.2, SM 7.5, SM 8.0

Supported OSes
Linux, Windows, OS X
shfl_scan - CUDA Parallel Prefix Sum with Shuffle Intrinsics (SHFL_Scan)

This example demonstrates how to use the shuffle intrinsic __shfl_up to perform a scan operation across a thread block. A GPU with Compute Capability SM 3.0 is required to run the sample.

- **Key Concepts**: Data-Parallel Algorithms, Performance Strategies
- **Supported OSes**: Linux, Windows, OS X

simpleHyperQ

This sample demonstrates the use of CUDA streams for concurrent execution of several kernels on devices which provide HyperQ (SM 3.5). Devices without HyperQ (SM 2.0 and SM 3.0) will run a maximum of two kernels concurrently.

- **Key Concepts**: CUDA Systems Integration, Performance Strategies
- **Supported OSes**: Linux, Windows, OS X
- **Whitepaper**: HyperQ.pdf

sortingNetworks - CUDA Sorting Networks

This sample implements bitonic sort and odd-even merge sort (also known as Batcher’s sort), algorithms belonging to the class of sorting networks. While generally subefficient, for large sequences compared to algorithms with better asymptotic algorithmic complexity (i.e. merge sort or radix sort), this may be the preferred algorithms of choice for sorting batches of short-sized to mid-sized (key, value) array pairs. Refer to an excellent tutorial by H. W. Lang http://www.itl.fh-flensburg.de/lang/algorithmen/sortieren/networks/indexen.htm

- **Key Concepts**: Data-Parallel Algorithms
- **Supported OSes**: Linux, Windows, OS X
StreamPriorities - Stream Priorities

This sample demonstrates basic use of stream priorities.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**
- Stream-Priorities

**Supported SM Architecture**

**Key Concepts**
- CUDA Streams and Events

**Supported OSes**
- Linux, OS X

threadFenceReduction

This sample shows how to perform a reduction operation on an array of values using the thread Fence intrinsic to produce a single value in a single kernel (as opposed to two or more kernel calls as shown in the "reduction" CUDA Sample). Single-pass reduction requires global atomic instructions (Compute Capability 2.0 or later) and the _threadfence() intrinsic (CUDA 2.2 or later).

**Supported SM Architecture**

**Key Concepts**
- Cooperative Groups, Data-Parallel Algorithms, Performance Strategies

**Supported OSes**
- Linux, Windows, OS X

threadMigration - CUDA Context Thread Management

Simple program illustrating how to the CUDA Context Management API and uses the new CUDA 4.0 parameter passing and CUDA launch API. CUDA contexts can be created separately and attached independently to different threads.

**Supported SM Architecture**

**CUDA API**
- cuCtxCreate, cuCtxDestroy, cuModuleLoad, cuModuleLoadDataEx, cuModuleGetFunction, cuLaunchKernel, cuMemcpyDtoH, cuCtxPushCurrent, cuCtxPopCurrent

**Key Concepts**
- CUDA Driver API
transpose - Matrix Transpose

This sample demonstrates Matrix Transpose. Different performance are shown to achieve high performance.

- **Key Concepts**: Performance Strategies, Linear Algebra
- **Supported OSes**: Linux, Windows, OS X
- **Whitepaper**: MatrixTranspose.pdf

warpAggregatedAtomicsCG - Warp Aggregated Atomics using Cooperative Groups

This sample demonstrates how using Cooperative Groups (CG) to perform warp aggregated atomics to single and multiple counters, a useful technique to improve performance when many threads atomically add to a single or multiple counters.

- **Key Concepts**: Cooperative Groups, Atomic Intrinsics
- **Supported OSes**: Linux, Windows, OS X

3.8. Cudalibraries Reference

batchCUBLAS

A CUDA Sample that demonstrates how using batched CUBLAS API calls to improve overall performance.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

- **Dependencies**: CUBLAS
boundSegmentsNPP - Bound Segments NPP

An NPP CUDA Sample that demonstrates using nppiLabelMarkers to generate connected region segment labels in an 8-bit grayscale image then compressing the sparse list of generated labels into the minimum number of uniquely labeled regions in the image using nppiCompressMarkerLabels. Finally a boundary is added surrounding each segmented region in the image using nppiBoundSegments.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies
- FreiImage, NPP

Supported SM

Supported OSes
- Linux, Windows, OS X

boxFilterNPP - Box Filter with NPP

A NPP CUDA Sample that demonstrates how to use NPP FilterBox function to perform a Box Filter.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies
- FreiImage, NPP

Supported SM

Supported OSes
- Linux, Windows, OS X
cannyEdgeDetectorNPP - Canny Edge Detector NPP

An NPP CUDA Sample that demonstrates the recommended parameters to use with the nppiFilterCannyBorder_8u_C1R Canny Edge Detection image filter function. This function expects a single channel 8-bit grayscale input image. You can generate a grayscale image from a color image by first calling nppiColorToGray() or nppiRGBToGray(). The Canny Edge Detection function combines and improves on the techniques required to produce an edge detection image using multiple steps.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies
Freelimage, NPP

Supported SM

Key Concepts
Performance Strategies, Image Processing, NPP Library

Supported OSes
Linux, Windows, OS X

conjugateGradient - ConjugateGradient

This sample implements a conjugate gradient solver on GPU using CUBLAS and CUSPARSE library.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies
CUBLAS, CUSPARSE

Supported SM

Key Concepts
Linear Algebra, CUBLAS Library, CUSPARSE Library

Supported OSes
Linux, Windows, OS X

conjugateGradientCudaGraphs - Conjugate Gradient using Cuda Graphs

This sample implements a conjugate gradient solver on GPU using CUBLAS and CUSPARSE library calls captured and called using CUDA Graph APIs.
This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**  |  CUBLAS, CUSPARSE
---|---
**CUDA API**  |  cudaStreamBeginCapture, cudaStreamEndCapture, cudaGraphCreate, cudaGraphLaunch, cudaGraphInstantiate, cudaGraphExecDestroy, cudaGraphDestroy
**Key Concepts**  |  Linear Algebra, CUBLAS Library, CUSPARSE Library
**Supported OSes**  |  Linux, Windows, OS X

**conjugateGradientPrecond** - Preconditioned Conjugate Gradient

This sample implements a preconditioned conjugate gradient solver on GPU using CUBLAS and CUSPARSE library.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**  |  CUBLAS, CUSPARSE
---|---
**Key Concepts**  |  Linear Algebra, CUBLAS Library, CUSPARSE Library
**Supported OSes**  |  Linux, Windows, OS X

**conjugateGradientUM** - ConjugateGradientUM

This sample implements a conjugate gradient solver on GPU using CUBLAS and CUSPARSE library, using Unified Memory.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.
cuHook - CUDA Interception Library
This sample demonstrates how to build and use an intercept library with CUDA. The library has to be loaded via LD_PRELOAD, e.g. LD_PRELOAD=<full_path>/libcuhook.so.1 ./cuHook

Supported SM

Supported OSes
Linux

cuSolverDn_LinearSolver - cuSolverDn Linear Solver
A CUDA Sample that demonstrates cuSolverDN’s LU, QR and Cholesky factorization. This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Supported SM

Supported OSes
Linux, Windows, OS X

cuSolverRf - cuSolverRf Refactorization
A CUDA Sample that demonstrates cuSolver’s refactorization library - CUSOLVERRF. This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Supported OSes
Linux, Windows, OS X
cuSolverSp_LinearSolver - cuSolverSp Linear Solver

A CUDA Sample that demonstrates cuSolverSP’s LU, QR and Cholesky factorization.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies: CUSOLVER, CUSPARSE
Key Concepts: Linear Algebra, CUSOLVER Library
Supported OSes: Linux, Windows, OS X

cuSolverSp_LowlevelCholesky - cuSolverSp Lowlevel Cholesky Solver

A CUDA Sample that demonstrates Cholesky factorization using cuSolverSP’s low level APIs.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies: CUSOLVER, CUSPARSE
Key Concepts: Linear Algebra, CUSOLVER Library
Supported OSes: Linux, Windows, OS X

cuSolverSp_LowlevelQR - cuSolverSp Lowlevel QR Solver

A CUDA Sample that demonstrates QR factorization using cuSolverSP’s low level APIs.
This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**  
CUSOLVER, CUSPARSE

**Supported SM Architecture**  

**Key Concepts**  
Linear Algebra, CUSOLVER Library

**Supported OSes**  
Linux, Windows, OS X

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**FilterBorderControlNPP - Filter Border Control NPP**

This sample demonstrates how any border version of an NPP filtering function can be used in the most common mode, with border control enabled. Mentioned functions can be used to duplicate the results of the equivalent non-border version of the NPP functions. They can be also used for enabling and disabling border control on various source image edges depending on what portion of the source image is being used as input.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**  
FreeImage, NPP

**Supported SM Architecture**  

**Key Concepts**  
Performance Strategies, Image Processing, NPP Library

**Supported OSes**  
Linux, Windows, OS X

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**freelImageInteropNPP - FreImage and NPP Interopability**

A simple CUDA Sample demonstrate how to use FreImage library with NPP.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**  
Freimage, NPP
histEqualizationNPP - Histogram Equalization with NPP

This CUDA Sample demonstrates how to use NPP for histogram equalization for image data.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies
Freimage, NPP

Supported SM

Key Concepts
Image Processing, Performance Strategies, NPP Library

Supported OSes
Linux, Windows, OS X

MC_EstimatePiInlineP - Monte Carlo Estimation of Pi (inline PRNG)

This sample uses Monte Carlo simulation for Estimation of Pi (using inline PRNG). This sample also uses the NVIDIA CURAND library.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies
CURAND

Supported SM

Key Concepts
Random Number Generator, Computational Finance, CURAND Library

Supported OSes
Linux, Windows, OS X
**MC_EstimatePiInlineQ - Monte Carlo Estimation of Pi (inline QRNG)**

This sample uses Monte Carlo simulation for Estimation of Pi (using inline QRNG). This sample also uses the NVIDIA CURAND library.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

- **Dependencies**: CURAND
- **Key Concepts**: Random Number Generator, Computational Finance, CURAND Library
- **Supported OSes**: Linux, Windows, OS X

**MC_EstimatePiP - Monte Carlo Estimation of Pi (batch PRNG)**

This sample uses Monte Carlo simulation for Estimation of Pi (using batch PRNG). This sample also uses the NVIDIA CURAND library.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

- **Dependencies**: CURAND
- **Key Concepts**: Random Number Generator, Computational Finance, CURAND Library
- **Supported OSes**: Linux, Windows, OS X

**MC_EstimatePiQ - Monte Carlo Estimation of Pi (batch QRNG)**

This sample uses Monte Carlo simulation for Estimation of Pi (using batch QRNG). This sample also uses the NVIDIA CURAND library.
This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**
CURAND

**Supported SM**

**Supported OSes**
Linux, Windows, OS X

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**MC_SingleAsianOptionP - Monte Carlo Single Asian Option**

This sample uses Monte Carlo to simulate Single Asian Options using the NVIDIA CURAND library.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**
CURAND

**Supported SM**

**Supported OSes**
Linux, Windows, OS X

---

**MersenneTwisterGP11213**

This sample demonstrates the Mersenne Twister random number generator GP11213 in cuRAND.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**
CURAND

**Supported SM**
nvJPEG - NVJPEG simple

A CUDA Sample that demonstrates single and batched decoding of jpeg images using NVJPEG Library.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies: NVJPEG


Key Concepts: Image Decoding, NVJPEG Library

Supported OS: Linux, Windows

nvJPEG_encoder - NVJPEG Encoder

A CUDA Sample that demonstrates single encoding of jpeg images using NVJPEG Library.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies: NVJPEG


Key Concepts: Image Encoding, NVJPEG Library

Supported OS: Linux, Windows

randomFog - Random Fog

This sample illustrates pseudo- and quasi- random numbers produced by CURAND.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample
will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**simpleCUBLAS - Simple CUBLAS**

Example of using CUBLAS using the new CUBLAS API interface available in CUDA 4.0.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**simpleCUBLASXT - Simple CUBLAS XT**

Example of using CUBLAS-XT library.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.
simpleCUFFT - Simple CUFFT

Example of using CUFFT. In this example, CUFFT is used to compute the 1D-convolution of some signal with some filter by transforming both into frequency domain, multiplying them together, and transforming the signal back to time domain. cuFFT plans are created using simple and advanced API functions.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies  
CUFFT

Supported SM  

Architecture  
7.2, SM 7.5, SM 8.0

Key Concepts  
Image Processing, CUFFT Library

Supported OSes  
Linux, Windows, OS X

simpleCUFFT_2d_MGPU - SimpleCUFFT_2d_MGPU

Example of using CUFFT. In this example, CUFFT is used to compute the 2D-convolution of some signal with some filter by transforming both into frequency domain, multiplying them together, and transforming the signal back to time domain on Multiple GPU.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

Dependencies  
CUFFT

Supported SM  

Architecture  
7.2, SM 7.5, SM 8.0

Key Concepts  
Image Processing, CUFFT Library

Supported OSes  
Linux, Windows, OS X

simpleCUFFT_callback - Simple CUFFT Callbacks

Example of using CUFFT. In this example, CUFFT is used to compute the 1D-convolution of some signal with some filter by transforming both into frequency domain, multiplying them together, and transforming the signal back to time domain.
The difference between this example and the Simple CUFFT example is that the multiplication step is done by the CUFFT kernel with a user-supplied CUFFT callback routine, rather than by a separate kernel call.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**simpleCUFFT_MGPU - Simple CUFFT_MGPU**

Example of using CUFFT. In this example, CUFFT is used to compute the 1D-convolution of some signal with some filter by transforming both into frequency domain, multiplying them together, and transforming the signal back to time domain on Multiple GPU.

This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.
Chapter 4.
DEPENDENCIES

Some CUDA Samples rely on third-party applications and/or libraries, or features provided by the CUDA Toolkit and Driver, to either build or execute. These dependencies are listed below.

If a sample has a dependency that is not available on the system, the sample will not be installed. If a sample has a third-party dependency that is available on the system, but is not installed, the sample will waive itself at build time.

Each sample’s dependencies are listed in the Samples Reference section.

Third-Party Dependencies

These third-party dependencies are required by some CUDA samples. If available, these dependencies are either installed on your system automatically, or are installable via your system’s package manager (Linux) or a third-party website.

**FreImage**

FreImage is an open source imaging library. FreImage can usually be installed on Linux using your distribution’s package manager system. FreImage can also be downloaded from the FreImage website. FreImage is also redistributed with the CUDA Samples.

**Message Passing Interface**

MPI (Message Passing Interface) is an API for communicating data between distributed processes. A MPI compiler can be installed using your Linux distribution’s package manager system. It is also available on some online resources, such as Open MPI. On Windows, to build and run MPI-CUDA applications one can install MS-MPI SDK.

**Only 64-Bit**

Some samples can only be run on a 64-bit operating system.
DirectX

DirectX is a collection of APIs designed to allow development of multimedia applications on Microsoft platforms. For Microsoft platforms, NVIDIA’s CUDA Driver supports DirectX. Several CUDA Samples for Windows demonstrates CUDA-DirectX Interoperability, for building such samples one needs to install Microsoft Visual Studio 2012 or higher which provides Microsoft Windows SDK for Windows 8.

DirectX 12

DirectX 12 is a collection of advanced low-level programming APIs which can reduce driver overhead, designed to allow development of multimedia applications on Microsoft platforms starting with Windows 10 OS onwards. For Microsoft platforms, NVIDIA’s CUDA Driver supports DirectX. Few CUDA Samples for Windows demonstrates CUDA-DirectX12 Interoperability, for building such samples one needs to install Windows 10 SDK or higher, with VS 2015 or VS 2017.

OpenGL

OpenGL is a graphics library used for 2D and 3D rendering. On systems which support OpenGL, NVIDIA’s OpenGL implementation is provided with the CUDA Driver.

OpenGL ES

OpenGL ES is an embedded systems graphics library used for 2D and 3D rendering. On systems which support OpenGL ES, NVIDIA’s OpenGL ES implementation is provided with the CUDA Driver.

Vulkan

Vulkan is a low-overhead, cross-platform 3D graphics and compute API. Vulkan targets high-performance realtime 3D graphics applications such as video games and interactive media across all platforms. On systems which support Vulkan, NVIDIA’s Vulkan implementation is provided with the CUDA Driver. For building and running Vulkan applications one needs to install the Vulkan SDK.

OpenMP

OpenMP is an API for multiprocessing programming. OpenMP can be installed using your Linux distribution’s package manager system. It usually comes preinstalled with GCC. It can also be found at the OpenMP website.

Screen

Screen is a windowing system found on the QNX operating system. Screen is usually found as part of the root filesystem.
X11

X11 is a windowing system commonly found on *-nix style operating systems. X11 can be installed using your Linux distribution's package manager, and comes preinstalled on Mac OS X systems.

EGL

EGL is an interface between Khronos rendering APIs (such as OpenGL, OpenGL ES or OpenVG) and the underlying native platform windowing system.

EGLOutput

EGLOutput is a set of EGL extensions which allow EGL to render directly to the display.

EGLSync

EGLSync is a set of EGL extensions which provides sync objects that are synchronization primitive, representing events whose completion can be tested or waited upon.

NVSCI

NvSci is a set of communication interface libraries out of which CUDA interops with NvSciBuf and NvSciSync. NvSciBuf allows applications to allocate and exchange buffers in memory. NvSciSync allows applications to manage synchronization objects which coordinate when sequences of operations begin and end.

CUDA Features

These CUDA features are needed by some CUDA samples. They are provided by either the CUDA Toolkit or CUDA Driver. Some features may not be available on your system.

CUFFT Callback Routines

CUFFT Callback Routines are user-supplied kernel routines that CUFFT will call when loading or storing data. These callback routines are only available on Linux x86_64 and ppc64le systems.

CUDA Dynamic Paralellism

CDP (CUDA Dynamic Paralellism) allows kernels to be launched from threads running on the GPU. CDP is only available on GPUs with SM architecture of 3.5 or above.
Multi-block Cooperative Groups

Multi Block Cooperative Groups (MBCG) extends Cooperative Groups and the CUDA programming model to express inter-thread-block synchronization. MBCG is available on GPUs with Pascal and higher architecture.

Multi-Device Cooperative Groups

Multi Device Cooperative Groups extends Cooperative Groups and the CUDA programming model enabling thread blocks executing on multiple GPUs to cooperate and synchronize as they execute. This feature is available on GPUs with Pascal and higher architecture.

CUDA Interprocess Communication

IPC (Interprocess Communication) allows processes to share device pointers.

CUFFT

CUFFT (CUDA Fast Fourier Transform) is a GPU-accelerated FFT library.

CURAND

CURAND (CUDA Random Number Generation) is a GPU-accelerated RNG library.

CUSPARSE

CUSPARSE (CUDA Sparse Matrix) provides linear algebra subroutines used for sparse matrix calculations.

CUSOLVER

CUSOLVER library is a high-level package based on the CUBLAS and CUSPARSE libraries. It combines three separate libraries under a single umbrella, each of which can be used independently or in concert with other toolkit libraries. The intent of CUSOLVER is to provide useful LAPACK-like features, such as common matrix factorization and triangular solve routines for dense matrices, a sparse least-squares solver and an eigenvalue solver. In addition cuSolver provides a new refactorization library useful for solving sequences of matrices with a shared sparsity pattern.
NPP
NPP (NVIDIA Performance Primitives) provides GPU-accelerated image, video, and signal processing functions.

NVJPEG
NVJPEG library provides high-performance, GPU accelerated JPEG decoding functionality for image formats commonly used in deep learning and hyperscale multimedia applications.

NVRTC
NVRTC (CUDA RunTime Compilation) is a runtime compilation library for CUDA C++.

Stream Priorities
Stream Priorities allows the creation of streams with specified priorities. Stream Priorities is only available on GPUs with SM architecture of 3.5 or above.

Unified Virtual Memory
UVM (Unified Virtual Memory) enables memory that can be accessed by both the CPU and GPU without explicit copying between the two. UVM is only available on Linux and Windows systems.

16-bit Floating Point
FP16 is a 16-bit floating-point format. One bit is used for the sign, five bits for the exponent, and ten bits for the mantissa. FP16 is only available on specific mobile platforms.

C++11 CUDA
NVCC Support of C++11 features.
Chapter 5.
KEY CONCEPTS AND ASSOCIATED SAMPLES

The tables below describe the key concepts of the CUDA Toolkit and lists the samples that illustrate how that concept is used.

**Basic Key Concepts**

*Basic Concepts demonstrates how to make use of CUDA features.*

**Table 2 Basic Key Concepts and Associated Samples**

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CUDA Samples

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**Advanced Key Concepts**

*Advanced Concepts demonstrate advanced techniques and algorithms implemented with CUDA.*
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The tables below list the samples associated with each CUDA API.

### CUDA Driver API Samples

The table below lists the samples associated with each CUDA Driver API.

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Answers to frequently asked questions about CUDA can be found at http://developer.nvidia.com/cuda-faq and in the CUDA Toolkit Release Notes.
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