CUDA Samples

Reference Manual
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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 11.2

- FreelImage is no longer distributed with the CUDA Samples. On Windows, see the Dependencies section for more details on how to set up FreelImage. On Linux, it is recommended to install FreelImage with your distribution’s package manager.

1.2. CUDA 11.1

- Added 2_Graphics/simpleVulkanMMAP. Demonstrates Vulkan CUDA Interop via cuMemMap APIs where CUDA buffer is imported in vulkan.
- Added 7_CUDALibraries/watershedSegmentationNPP. Demonstrates how to use the NPP watershed segmentation function.
- Added 7_CUDALibraries/batchedLabelMarkersAndLabelCompressionNPP. Demonstrates how to use the NPP label markers generation and label compression functions based on a Union Find (UF) algorithm including both single image and batched image versions.
- Deprecated Visual Studio 2015 support for all Windows supported samples.
- Dropped Visual Studio 2012, 2013 support from all the Windows supported samples.

1.3. 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_SemiRingSpMV`, `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`.

### 1.4. 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.

1.5. 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

1.6. 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.

1.7. 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.

1.8. 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.

### 1.9. 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.

### 1.10. CUDA 9.0

- **Added** `7_CUDALibraries/nvgraph_SpectralClustering`. Demonstrates Spectral Clustering using NVGRAPH Library.

- **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`, `6_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.

1.11. 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_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.
1.12. 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.

1.13. 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 executable.
- **Added** `0_Simple/clock_nvrtc`. Demonstrates how to compile clock function kernel at runtime using libNVTC to measure the performance of kernel accurately.
- **Added** `0_Simple/inlinePTX_nvrtc`. Demonstrates compilation of CUDA kernel having PTX embedded at runtime using libNVTC.
- **Added** `0_Simple/matrixMul_nvrtc`. Demonstrates compilation of matrix multiplication CUDA kernel at runtime using libNVTC.
- **Added** `0_Simple/simpleAssert_nvrtc`. Demonstrates compilation of CUDA kernel having assert() at runtime using libNVTC.
- **Added** `0_Simple/simpleAtomicIntrinsics_nvrtc`. Demonstrates compilation of CUDA kernel performing atomic operations at runtime using libNVTC.
- **Added** `0_Simple/simpleTemplates_nvrtc`. Demonstrates compilation of templatized dynamically allocated shared memory arrays CUDA kernel at runtime using libNVTC.
- **Added** `0_Simple/simpleVoteIntrinsics_nvrtc`. Demonstrates compilation of CUDA kernel which uses vote intrinsics at runtime using libNVTC.
- **Added** `0_Simple/vectorAdd_nvrtc`. Demonstrates compilation of CUDA kernel performing vector addition at runtime using libNVTC.
- 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.

### 1.14. 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 (NVENC) 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 CUBLAS andCUSPARSE libraries on Linux and Mac.

- The 7_CUDALibraries/MersenneTwisterGP11213 sample now demonstrates how to use the static CURAND library on Linux and Mac.
1.15. 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 `1Utilities/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.

1.16. 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 AMRv7 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.

1.17. 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/cdpLUDecomposition` - 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.

### 1.18. CUDA 4.2

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

### 1.19. 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 and the Windows 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\v11.2\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-11.2.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\v11.2\n
Each individual sample has its own set of solution files at:
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.

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

### 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>
<thead>
<tr>
<th>TARGET ARCH</th>
<th>TARGET OS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>linux</td>
<td>android</td>
</tr>
<tr>
<td>x86_64</td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td>aarch64</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>sbsa</td>
<td>YES</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
- 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 armv71, 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="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/libs. 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:
$ make TARGET_ARCH=<arch> TARGET_OS=<os> \
    EXTRA ldflags="-rpath-link=/opt/target/libs -L/opt/target/libs -- \
    unresolved-symbols=ignore-in-shared-libs" \n    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\v11.2\<category>\template
   ```
   to a directory of your own:
   ```
   C:\ProgramData\NVIDIA Corporation\CUDA Samples\v11.2\<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\v11.2\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

**Note: The default installation folder** `<SAMPLES_INSTALL_PATH>` **is**
```
NVIDIA_CUDA_11.2_Samples and <category> is one of the following: 0_Simple, 1_Utilitys, 2_Graphics, 3_Imaging, 4_Finance, 5_Simulations, 6_Advanced, 7_CUDALibraries.
```

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:
   ```
   cd <SAMPLES_INSTALL_PATH>/<category>
   cp -r template <myProject>
   ```
2. Edit the filenames of the project to suit your needs:
   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]:
   make
   To build the project as [debug], use “make dbg=1”:
   make dbg=1

5. Run the program:
   ../../../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.
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.

**Supported SM Architecture**

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, SM 8.6
CUDA API: cudaMallocManaged, cudaDeviceSynchronize, cudaFuncSetAttribute, 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

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>Linux, Windows</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.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>CDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architecture</td>
<td>Linux, Windows</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.

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Architecture</td>
<td>Linux, Windows</td>
</tr>
<tr>
<td>CUDA API</td>
<td>cudaMalloc, cudaFree, cudaMemcpy</td>
</tr>
<tr>
<td>Key Concepts</td>
<td>Performance Strategies</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows</td>
</tr>
</tbody>
</table>
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.

**Dependencies**
- NVRTC

**Supported SM**

**Architecture**
- 7.2, SM 7.5, SM 8.0, SM 8.6

**CUDA API**
- cuMemAlloc, cuLaunchKernel, cuMemcpyHtoD, cuMemFree

**Key Concepts**
- Performance Strategies, Runtime Compilation

**Supported OSes**
- Linux, Windows

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.

**Supported SM**

**Architecture**
- 7.2, SM 7.5, SM 8.0, SM 8.6

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

**Supported OSes**
- Linux, Windows

cppOverload

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

**Supported SM**

**Architecture**
- 7.2, SM 7.5, SM 8.0, SM 8.6

**CUDA API**
- cudaFuncSetCacheConfig, cudaFuncGetAttributes

**Key Concepts**
- C++ Function Overloading, CUDA Streams and Events

**Supported OSes**
- Linux, Windows

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, cudaFree, cudaMemcpy

**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.

**Supported SM Architecture**
SM 7.0, SM 7.2, SM 7.5, SM 8.0, SM 8.6

**CUDA API**
cudaMallocManaged, cudaDeviceSynchronize, cudaFuncSetAttribute,
cudaEventCreate, cudaEventRecord, cudaEventSynchronize,
cudaEventElapsedTime, cudaFree

**Key Concepts**
Matrix Multiply, WMMA, Tensor Cores

**Supported OSes**
Linux, Windows

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.

**Supported SM Architecture**
SM 8.0, SM 8.6

**CUDA API**
cudaMallocManaged, cudaDeviceSynchronize, cudaFuncSetAttribute,
cudaEventCreate, cudaEventRecord, cudaEventSynchronize,
cudaEventElapsedTime, cudaFree

**Key Concepts**
Matrix Multiply, WMMA, Tensor Cores

**Supported OSes**
Linux, Windows

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**
- `cudaMalloc`, `cudaMallocHost`, `cudaMemcpy`, `cudaFree`, `cudaFreeHost`

**Key Concepts**
- CUDA Runtime API

**Supported OSes**
- Linux, Windows

---

**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**
- SM 7.0, SM 7.2, SM 7.5, SM 8.0, SM 8.6

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

**Key Concepts**
- CUDA Runtime API, Linear Algebra, CPP11 CUDA

**Supported OSes**
- Linux, Windows

---

**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, SM 8.6</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>
<th></th>
<th></th>
</tr>
</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</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, cuMemcpyDtoH</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</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.

- **CUDA API**: cudaEventCreate, cudaEventRecord, cudaEventQuery, cudaEventDestroy, cudaEventElapsedTime, cudaEventSynchronize, cudaMalloc, cudaFree, cudaMemcpy
- **Key Concepts**: CUDA Runtime API, Linear Algebra
- **Supported OSes**: Linux, Windows

**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
- **CUDA API**: cuModuleLoad, cuModuleLoadDataEx, cuModuleGetFunction, cuMemAlloc, cuMemFree, cudaMemcpyHtoD, cudaMemcpyDtoH, cuLaunchKernel
- **Key Concepts**: CUDA Runtime API, Linear Algebra, Runtime Compilation
- **Supported OSes**: Linux, Windows
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.

**Dependencies**
- CUBLAS

**Supported SM Architecture**

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

**Key Concepts**
- CUDA Runtime API, Performance Strategies, Linear Algebra, CUBLAS

**Supported OSes**
- Linux, Windows

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.

**Supported SM Architecture**

**CUDA API**
- cuModuleLoad, cuModuleLoadDataEx, cuModuleGetFunction, cuMemAlloc, cuMemFree, cuMemcpyHtoD, cuMemcpyDtoH, cuLaunchKernel

**Key Concepts**
- CUDA Driver API, Matrix Multiply

**Supported OSes**
- Linux, Windows
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**

**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, cudaMemcpy, cudaFree, cudaFreeHost, cudaMemcpy

**Key Concepts**
- Assert

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

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.

- **Dependencies**: NVRTC
- **CUDA API**: cuLaunchKernel
- **Key Concepts**: Assert, Runtime Compilation
- **Supported OSes**: Linux, Windows

simpleAtomicIntrinsics - Simple Atomic Intrinsics

A simple demonstration of global memory atomic instructions.

- **CUDA API**: cudaMemcpy, cudaFree, cudaMemcpy, cudaFreeHost
- **Key Concepts**: Atomic Intrinsics
- **Supported OSes**: Linux, Windows

simpleAtomicIntrinsics_nvrtc - Simple Atomic Intrinsics with libNVRTC

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.

- **Dependencies**: NVRTC
### 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>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CUDA API</td>
<td>cuMemAlloc, cuMemFree, cuMemcpyHtoD, cuLaunchKernel</td>
</tr>
<tr>
<td>Key Concepts</td>
<td>Atomic Intrinsics, Runtime Compilation</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows</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, SM 8.6</td>
</tr>
<tr>
<td>CUDA API</td>
<td>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

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

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**: cudaMemcpy3D, cudaMemcpy, cudaMemcpy3DArray, cudaFreeArray, cudaFree, cudaMemcpy3DArray, cudaMalloc, cudaMalloc3DArray, cudaCreateChannelDesc, cudaBindTextureToArray, cudaMalloc, cudaFree, cudaMemcpy
- **Key Concepts**: Texture, Volume Processing
- **Supported OSes**: Linux, Windows
simpleCudaGraphs - Simple CUDA Graphs

A demonstration of CUDA Graphs creation, instantiation and launch using Graphs APIs and Stream Capture APIs.

Supported SM Architecture  

CUDA API  
cudaStreamBeginCapture, cudaStreamEndCapture, cudaLaunchHostFunc, cudaGraphCreate, cudaGraphLaunch, cudaGraphInstantiate, cudaGraphAddHostNode, cudaGraphAddMemcpyNode, cudaGraphAddKernelNode, cudaGraphAddMemsetNode, cudaGraphExecDestroy, cudaGraphDestroy

Key Concepts  
CUDA Graphs, Stream Capture

Supported OSes  
Linux, Windows

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.

Supported SM Architecture  

CUDA API  
cuModuleLoadData, cuModuleGetFunction, cuLaunchKernel, cudaMemcpy, cudaMalloc, cudaStreamCreateWithFlags

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

Supported OSes  
Linux, Windows

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.

Dependencies  
IPC
simpleLayeredTexture - Simple Layered Texture

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

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CUDA API</td>
<td>cudaMalloc, cudaMalloc3DArray, cudaMemcpy3D, cudaCreateChannelDesc, cudaBindTextureToArray, cudaMalloc, cudaFree, cudaFreeArray, cudaMemcpy</td>
</tr>
<tr>
<td>Key Concepts</td>
<td>Texture, Volume Processing</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>MPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUDA API</td>
<td>cudaMemcpy, cudaFree, cudaMemcpy</td>
</tr>
<tr>
<td>Key Concepts</td>
<td>CUDA Systems Integration, MPI, Multithreading</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows</td>
</tr>
</tbody>
</table>
simpleMultiCopy - Simple Multi Copy and Compute

Supported in GPUs with Compute Capability 1.1, overlapping compute with one memcopy 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.

**Supported SM Architecture**

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

**Key Concepts**
- CUDA Streams and Events, Asynchronous Data Transfers, Overlap Compute and Copy, GPU Performance

**Supported OSes**
- Linux, Windows

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

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
**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.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>only-64-bit</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUDA API</td>
<td>cudaDeviceCanAccessPeer, cudaDeviceEnablePeerAccess, cudaDeviceDisablePeerAccess, cudaEventCreateWithFlags, cudaEventElapsedTime, cudaMemcpy</td>
</tr>
<tr>
<td>Key Concepts</td>
<td>Performance Strategies, Asynchronous Data Transfers, Unified Virtual Address Space, Peer to Peer Data Transfers, Multi-GPU</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows</td>
</tr>
</tbody>
</table>

**simplePitchLinearTexture - Pitch Linear Texture**

Use of Pitch Linear Textures

| CUDA API | cudaMemcpy2D, cudaMemcpyToArray, cudaBindTexture2D, cudaBindTextureToArray, cudaMemcpy2D, cudaMemcpy2D, cudaMemcpy2D, cudaMemcpy2D |
| Key Concepts | Texture, Image Processing |
| Supported OSes | Linux, Windows |
simplePrintf

This basic CUDA Runtime API sample demonstrates how to use the printf function in the device code.


Key Concepts: Debugging

Supported OSes: Linux, Windows

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.


Key Concepts: Separate Compilation

Supported OSes: Linux, Windows

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.


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

Key Concepts: Asynchronous Data Transfers, CUDA Streams and Events

Supported OSes: Linux, Windows

simpleSurfaceWrite - Simple Surface Write

Simple example that demonstrates the use of 2D surface references [Write-to-Texture]
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.

**Supported SM Architecture**


**Key Concepts**

Texture, Surface Writes, Image Processing

**Supported OSes**

Linux, Windows

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

**Supported SM Architecture**


**Key Concepts**

C++ Templates, Runtime Compilation

**Supported OSes**

Linux, Windows

simpleTexture - Simple Texture

Simple example that demonstrates use of Textures in CUDA.

**Supported SM Architecture**

simpleTextureDrv - Simple Texture (Driver Version)

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

**Supported SM Architecture**

**CUDA API**
cudaMalloc, cudaMemcpyToArray, cudaCreateChannelDesc, cudaMemcpyToArray, cudaMemcpy, cudaMemcpyToArray, cudaMalloc, cudaMemcpyToArray, cudaMemcpy, cudaFree, cudaFreeArray, cudaMemcpyToArray, cudaMemcpy

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

**Supported OSes**
Linux, Windows

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, cudaMemcpy, cudaMemcpy, cudaMemcpyToHost, cudaMemcpy, cudaMemcpy, cudaMalloc, cudaMemcpy, cudaMemcpy, cudaMemcpy, cudaMemcpy, cudaMemcpy, cudaMemcpy, cudaMemcpy, cudaMemcpy

**Key Concepts**
Vote Intrinsics

**Supported OSes**
Linux, Windows
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

**Supported SM Architecture**

**CUDA API**
- cuMemAlloc, cuMemFree, cuMemcpyHtoD, cuMemFree

**Key Concepts**
- Vote Intrinsics, CUDA Driver API, Runtime Compilation

**Supported OSes**
- Linux, Windows

simpleZeroCopy

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

**Supported SM Architecture**

**CUDA API**
- cudaEventCreate, cudaEventRecord, cudaEventQuery, cudaEventDestroy, cudaEventElapsedTime, cudaHostAlloc, cudaHostGetDevicePointer, cudaHostRegister, cudaHostUnregister, cudaFreeHost

**Key Concepts**
- Performance Strategies, Pinned System Paged Memory, Vector Addition

**Supported OSes**
- Linux, Windows

**Whitepaper**
- CUDA2.2PinnedMemoryAPIs.pdf

streamOrderedAllocation - stream Ordered Allocation

This sample demonstrates stream ordered memory allocation on a GPU using cudaMallocAsync and cudaMemPool family of APIs.
streamOrderedAllocationP2P - stream Ordered Allocation Peer-to-Peer access

This sample demonstrates peer-to-peer access of stream ordered memory allocated using cudaMallocAsync and cudaMemPool family of APIs.

**Supported SM Architecture**

**CUDA API**
- cudaMallocAsync, cudaFreeAsync, cudaMemPoolSetAttribute, cudaDeviceGetDefaultMemPool

**Key Concepts**
- Performance Strategies

**Supported OSes**
- Linux, Windows

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**
- cudaMemcpy

**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.
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, SM 8.6
CUDA API: cudaMalloc, cudaDeviceSynchronize, cudaMemcpy, cudaMemcpyAsync, 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
Key Concepts: CUDA Systems Integration, OpenMP, CUBLAS, Multithreading, Unified Memory, CUDA Streams and Events
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

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

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.
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.

3.2. Utilities Reference

bandwidthTest - Bandwidth Test

This is a simple test program to measure the memcopy bandwidth of the GPU and memcpyp 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.
deviceQuery - Device Query

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

**Supported SM Architecture**

**CUDA API**

**Key Concepts**
- CUDA Runtime API, Device Query

**Supported OSes**
- Linux, Windows

deviceQueryDrv - Device Query Driver API

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

**Supported SM Architecture**

**CUDA API**
- cuInit, cuDeviceGetCount, cuDeviceComputeCapability, cuDriverGetVersion, cuDeviceTotalMem, cuDeviceGetAttribute

**Key Concepts**
- CUDA Driver API, Device Query

**Supported OSes**
- Linux, Windows

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.

**Supported SM Architecture**

**CUDA API**

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

A simple example on how to query the topology of a system with multiple GPU.

**Supported SM Architecture**
- SM 3.5
- SM 3.7
- SM 5.0
- SM 5.2
- SM 5.3
- SM 6.0
- SM 6.1
- SM 6.2
- SM 7.0
- SM 7.2
- SM 7.5
- SM 8.0
- SM 8.6

**CUDA API**
- cudaDeviceGetP2PAttribute
- cudaGetDeviceAttribute
- cudaGetDeviceCount

**Key Concepts**
- Performance Strategies
- Multi-GPU

**Supported OSes**
- Linux
- Windows

---

**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.

**Dependencies**
- UVM

**Supported SM Architecture**
- SM 3.5
- SM 3.7
- SM 5.0
- SM 5.2
- SM 5.3
- SM 6.0
- SM 6.1
- SM 6.2
- SM 7.0
- SM 7.2
- SM 7.5
- SM 8.0
- SM 8.6

**CUDA API**
- cudaMallocManaged
- cudaStreamAttachMemAsync
- cudaMemcpyAsync
- cudaMallocHost

**Key Concepts**
- CUDA Systems Integration
- Unified Memory
- CUDA Streams and Events
- Pinned System Paged Memory

**Supported OSes**
- Linux
- Windows

---

**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.

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.

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.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>X11, GL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key Concepts</td>
<td>OpenGL Graphics Interop, Vertex Buffers, 3D Graphics, Physically Based Simulation</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows</td>
</tr>
</tbody>
</table>

**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.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>DirectX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key Concepts</td>
<td>Graphics Interop, 3D Graphics</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Windows</td>
</tr>
</tbody>
</table>
**simpleD3D10RenderTarget - Simple Direct3D10 Render Target**

Simple program which demonstrates interop of rendertargets 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

**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

**Supported SM**

**CUDA API**

**Key Concepts**
Graphics Interop, Texture
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

Supported SM

CUDA API
- cudaD3D11GetDevice, cudaImportExternalSemaphore, cudaImportExternalMemory, cudaExternalMemoryGetMappedBuffer

Key Concepts
- Graphics Interop, Image Processing

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

Supported SM

CUDA API

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.

**Dependencies**
- DirectX

**Supported SM Architecture**

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

**Key Concepts**
- Graphics Interop, CUDA DX12 Interop, Image Processing

**Supported OSes**
- Windows

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.

**Dependencies**
- DirectX

**Supported SM Architecture**

**CUDA API**

**Key Concepts**
- Graphics Interop

**Supported OSes**
- Windows
simpleD3D9Texture - Simple D3D9 Texture

Simple program which demonstrates Direct3D 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.

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

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.

- **Dependencies**: X11, GL
- **Key Concepts**: Graphics Interop, Vertex Buffers, 3D Graphics
- **Supported OSes**: Linux, Windows
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.

**Dependencies**
- X11, GLES

**Supported SM Architecture**

**CUDA API**

**Key Concepts**
- Graphics Interop, Vertex Buffers, 3D Graphics

**Supported OSes**
- Linux

---

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.

**Dependencies**
- EGLOutput, GLES

**Supported SM Architecture**

**CUDA API**

**Key Concepts**
- Graphics Interop, Vertex Buffers, 3D Graphics

**Supported OSes**
- Linux
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.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>screen, GLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key Concepts</td>
<td>Graphics Interop, Vertex Buffers, 3D Graphics</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>X11, GL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key Concepts</td>
<td>Graphics Interop, Image Processing, 3D Textures, Surface Writes</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>X11, VULKAN</th>
</tr>
</thead>
<tbody>
<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>

simpleVulkanMMAP - Vulkan CUDA Interop
PI Approximation

This sample demonstrates Vulkan CUDA Interop via cuMemMap APIs. CUDA exports buffers that Vulkan imports as vertex buffer. CUDA invokes kernels to operate on vertices 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>
<tr>
<th>Dependencies</th>
<th>X11, VULKAN</th>
</tr>
</thead>
</table>
CUDA API:
cuDeviceGetAttribute, cuMemAddressReserve, cuMemCreate,
cuMemRelease, cuCtxSetCurrent, cuMemExportToShareableHandle,
cuMemImportFromShareableHandle, cuMemMap, cuMemSetAccess,
cuMemUnmap, cuMemAddressFree, cudaGetDeviceProperties,
cudaImportExternalMemory, cudaExternalMemoryGetMappedBuffer,
cudaImportExternalSemaphore, cudaImportExternalSemaphore,
cudaSignalExternalSemaphoresAsync, cudaWaitExternalSemaphoresAsync,
cudaDestroyExternalSemaphore, cudaDestroyExternalMemory

Key Concepts:
cuMemMap IPC, MMAP, Graphics Interop, CUDA Vulkan Interop, Data Parallel Algorithms

Supported OSes:
Linux, Windows

---

**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.

**Dependencies:** DirectX

**Supported SM Architecture:**

**CUDA API:**
cudaD3D10GetDevice, cudaD3D10SetDirect3DDevice,
cudaGraphicsD3D10RegisterResource, cudaGraphicsResourceSetMapFlags,
cudaGraphicsSubResourceGetMappedArray, cudaMemcpy2DToArray,
cudaGraphicsUnregisterResource

**Key Concepts:** Performance Strategies, Graphics Interop, Image Processing, 2D Textures

**Supported OSes:** Windows

---

**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.
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.

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
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 weighted 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.

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.
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
CUDA API: cufftPlan2d, cufftExecR2C, cufftExecC2R, cufftDestroy
Key Concepts: Image Processing, CUFFT Library
Supported OSes: Linux, Windows

convolutionSeparable - CUDA Separable Convolution

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

Key Concepts: Image Processing, Data Parallel Algorithms
Supported OSes: Linux, Windows
Whitepaper: convolutionSeparable.pdf
convolutionTexture - Texture-based Separable Convolution

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


Key Concepts: Image Processing, Texture, Data Parallel Algorithms

Supported OSes: Linux, Windows

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.


Key Concepts: Image Processing, Video Compression

Supported OSes: Linux, Windows

Whitepaper: dct8x8.pdf

dwtHaar1D - 1D Discrete Haar Wavelet Decomposition

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


Key Concepts: Image Processing, Video Compression

Supported OSes: Linux, Windows

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.
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

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
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

Supported SM Architecture

CUDA API
- cuDeviceGet, cuDeviceGetAttribute, cuDeviceComputeCapability,
cuDeviceGetCount, cuDeviceGetName,
cuGraphicsResourceGetMappedEglFrame,
cuEGLStreamConsumerAcquireFrame,
cuEGLStreamConsumerReleaseFrame,
cuEGLStreamProducerPresentFrame, cuCtxCreate, cuMemAlloc,
cuMemFree, cudaMemcpy3D, 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.
**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
- **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
- **Key Concepts**: Image Processing
- **Supported OSes**: Linux, Windows
- **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, cudaMemcpy3D, cudaMemcpyManaged

**Key Concepts**
- Graphics Interop, Image Processing, Video Processing

**Supported OSes**
- Linux, Windows

### 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**

**CUDA API**

**Key Concepts**
- Graphics Interop, Image Processing

**Supported OSes**
- Linux, Windows

### 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
### 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.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>X11, GL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key Concepts</td>
<td>Graphics Interop, Image Processing</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows</td>
</tr>
</tbody>
</table>

### 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.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>X11, GL</th>
</tr>
</thead>
</table>
### CUDA API
- `cudaGraphicsMapResources`, `cudaGraphicsUnmapResources`,
- `cudaGraphicsResourceGetMappedPointer`, `cudaGraphicsRegisterResource`,
- `cudaGraphicsGLRegisterBuffer`, `cudaGraphicsUnregisterResource`

### Key Concepts
- Graphics Interop, Image Processing

### Supported OSes
- Linux, Windows

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### 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.

#### Supported SM Architecture

#### Key Concepts
- Image Processing, Video Intrinsics

#### Supported OSes
- Linux, Windows

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### 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.

#### Dependencies
- X11, VULKAN

#### Supported SM Architecture

#### CUDA API
- `cudaImportExternalMemory`,
- `cudaExternalMemoryGetMappedMipmappedArray`,
- `cudaImportExternalSemaphore`, `cudaSignalExternalSemaphoresAsync`,
- `cudaWaitExternalSemaphoresAsync`, `cudaDestroyExternalSemaphore`,
- `cudaDestroyExternalMemory`

#### Key Concepts
- Graphics Interop, CUDA Vulkan Interop, Data Parallel Algorithms

#### Supported OSes
- Linux, Windows
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
- **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.

- **Dependencies**: NVRTC
- **Key Concepts**: Computational Finance, Runtime Compilation
- **Supported OSes**: Linux, Windows

BlackScholes - Black-Scholes Option Pricing

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

- **Key Concepts**: Computational Finance
- **Supported OSes**: Linux, Windows
- **Whitepaper**: BlackScholes.pdf
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.

**Dependencies**
- NVRTC

**Supported SM Architecture**

**Key Concepts**
- Computational Finance, Runtime Compilation

**Supported OSes**
- Linux, Windows

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 use 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.

**Dependencies**
- CURAND

**Supported SM Architecture**

**Supported OSes**
- Linux, Windows

**Whitepaper**
- MonteCarlo.pdf
**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.

- **Key Concepts**: Computational Finance
- **Supported OSes**: Linux, Windows

**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 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.

- **Dependencies**: NVRTC
- **Key Concepts**: Computational Finance, Runtime Compilation
- **Supported OSes**: Linux, Windows

**SobolQRNG - Sobol Quasirandom Number Generator**

This sample implements Sobol Quasirandom Sequence Generator.

- **Key Concepts**: Computational Finance
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**
- Linux, 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
**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.

**Dependencies**

- X11, GL

**Supported SM Architecture**

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.

Dependencies
- X11, GLES

Supported SM

CUDA API

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

Supported OSes
- Linux

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
# 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**
- cufftPlan2d, cufftExecR2C, cufftExecC2R, cufftDestroy

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

**Supported OSes**
- Linux

# 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 Architecture**
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

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.
### 3.7. Advanced Reference

#### alignedTypes - Aligned Types

A simple test, showing huge access speed gap between aligned and misaligned structures.

| Key Concepts | Performance Strategies |
| Supported OSes | Linux, Windows |

#### 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 |
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

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.

Dependencies: CDP
Key Concepts: CUDA Dynamic Parallelism
Supported OSes: Linux, Windows

cdpQuadttree - 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.

**Dependencies**
- CDP

**Supported SM Architecture**

**Key Concepts**
- Cooperative Groups, CUDA Dynamic Parallelism

**Supported OSes**
- Linux, Windows

**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

**Supported SM Architecture**

**Key Concepts**
- Performance Strategies

**Supported OSes**
- Linux, Windows

**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 Architecture**

**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 Architecture**: SM 6.0, SM 6.1, SM 6.2, SM 7.0, SM 7.2, SM 7.5, SM 8.0, SM 8.6
- **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.

- **CUDA API**: cuMemAlloc, cuMemFree, cuDeviceGetAttribute, cuMemGetAllocationGranularity, cuMemAddressReserve, cuMemCreate, cuMemMap, cuMemSetAccess, cuMemUnmap, cuMemAddressFree, cudaMemcpy
- **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 Architecture**

**Key Concepts**
Linear Algebra

**Supported OSes**
Linux, Windows

---

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 Architecture**

**Key Concepts**
Linear Algebra, Data-Parallel Algorithms, Video Compression

**Supported OSes**
Linux, Windows

---

FDTD3d - CUDA C 3D FDTD

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

**Supported SM Architecture**

**Key Concepts**
Performance Strategies

**Supported OSes**
Linux, Windows

---

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.

**Dependencies**
X11, GL

**Supported SM Architecture**

**Key Concepts**
Graphics Interop, Image Processing
interval - Interval Computing

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

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Key Concepts</td>
<td>Recursion, Templates</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows</td>
</tr>
</tbody>
</table>

jacobiCudaGraphs - Jacobi CUDA Graphs

Demonstrates Instantiated CUDA Graph Update with Jacobi Iterative Method using cudaGraphExecKernelNodeSetParams() and cudaGraphExecUpdate() approach.

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>CUDA API</td>
<td>cudaStreamBeginCapture, cudaStreamEndCapture, cudaGraphCreate, cudaGraphLaunch, cudaGraphInstantiate, cudaGraphExecUpdate, cudaGraphExecKernelNodeSetParams, cudaGraphGetNodes, cudaGraphNodeGetType, cudaGraphExecDestroy, cudaGraphDestroy</td>
</tr>
<tr>
<td>Key Concepts</td>
<td>CUDA Graphs, Stream Capture, Instantiated CUDA Graph Update, Cooperative Groups</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows</td>
</tr>
</tbody>
</table>

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.

<table>
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<tr>
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<tbody>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows</td>
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</tbody>
</table>
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

CUDA API
- cuModuleLoad, cuModuleLoadDataEx, cuModuleGetFunction, cuMemAlloc, cuMemFree, cuMemcpyHtoD, cuMemcpyDtoH, cuLaunchKernel

Key Concepts
- CUDA Driver API, CUDA Dynamically Linked Library

Supported OSes
- Linux, Windows

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

Supported SM

Key Concepts
- Data-Parallel Algorithms

Supported OSes
- Linux, Windows

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 SM

Supported OSes
- Linux, Windows
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.

**Supported SM Architecture**


**Key Concepts**

CUDA Driver API

**Supported OSes**

Linux, Windows

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

Whitepaper

readme.txt

test - 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
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.

Dependencies: MBCG, CPP11
Architecture: Cooperative Groups, MultiBlock Cooperative Groups
Supported OSes: Linux, Windows

scalarProd - Scalar Product

This sample calculates scalar products of a given set of input vector pairs.

Architecture: Linear Algebra
Supported OSes: Linux, Windows

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.

Architecture: Data-Parallel Algorithms, Performance Strategies
Supported OSes: Linux, Windows
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**  

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

**Supported OSes**  
Linux, Windows

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.

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

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.

**Supported SM Architecture**  

**Key Concepts**  
CUDA Systems Integration, Performance Strategies

**Supported OSes**  
Linux, Windows

**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](http://www.itl.fh-flensburg.de/lang/algorithmen/sortieren/networks/indexen.htm)

**Supported SM Architecture**

**Key Concepts**
- Data-Parallel Algorithms

**Supported OSes**
- Linux, Windows

---

**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

---

**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
### threadMigration - CUDA Context Thread Management

Simple program illustrating how to use 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.

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>CUDA API</td>
<td>cuCtxCreate, cuCtxDestroy, cuModuleLoad, cuModuleLoadDataEx, cuModuleGetFunction, cuLaunchKernel, cuMemcpyDtoH, cuCtxPushCurrent, cuCtxPopCurrent</td>
</tr>
<tr>
<td>Key Concepts</td>
<td>CUDA Driver API</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows</td>
</tr>
</tbody>
</table>

### transpose - Matrix Transpose

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

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Key Concepts</td>
<td>Performance Strategies, Linear Algebra</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows</td>
</tr>
</tbody>
</table>

**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.

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Key Concepts</td>
<td>Cooperative Groups, Atomic Intrinsics</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>CUBLAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key Concepts</td>
<td>Linear Algebra, CUBLAS Library</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows</td>
</tr>
</tbody>
</table>

**batchedLabelMarkersAndLabelCompressionNPP**

- Batched Label Markers And Label Compression NPP

An NPP CUDA Sample that demonstrates how to use the NPP label markers generation and label compression functions based on a Union Find (UF) algorithm including both single image and batched image versions.

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>NPP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key Concepts</td>
<td>Performance Strategies, Image Processing, NPP Library, Using NPP Batch Functions</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows</td>
</tr>
</tbody>
</table>
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**
- **FreImage, NPP**

**Supported SM**

**Architecture**
- Linux, Windows

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**
- **FreImage, NPP**

**Supported SM**

**Architecture**
- Linux, Windows

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**
FreImage, NPP

**Supported SM**

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

**Supported OSes**
Linux, Windows

### 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

### 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
**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

**Supported SM Architecture**  

**Key Concepts**  
Linear Algebra, CUBLAS Library, CUSPARSE Library

**Supported OSes**  
Linux, Windows

---

**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.

**Dependencies**  
UVM, CUBLAS, CUSPARSE

**Supported SM Architecture**  

**Key Concepts**  
Unified Memory, Linear Algebra, CUBLAS Library, CUSPARSE Library

**Supported OSes**  
Linux, Windows
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 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.

Dependencies: CUSOLVER, CUBLAS,CUSPARSE


Key Concepts: Linear Algebra, CUSOLVER Library

Supported OSes: Linux, Windows

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.

Dependencies: CUSOLVER, CUBLAS,CUSPARSE


Key Concepts: Linear Algebra, CUSOLVER Library

Supported OSes: Linux, Windows
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

**Supported SM Architecture**

**Key Concepts**
- Linear Algebra, CUSOLVER Library

**Supported OSes**
- Linux, Windows

cuSolverSp_LowlevelCholesky - cuSolverSp LowlevelCholesky 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

**Supported SM Architecture**

**Key Concepts**
- Linear Algebra, CUSOLVER Library

**Supported OSes**
- Linux, Windows

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.
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
FreelImage, NPP
Supported SM
Key Concepts
Performance Strategies, Image Processing, NPP Library
Supported OSes
Linux, Windows

freeImageInteropNPP - FreelImage and NPP Interopability

A simple CUDA Sample demonstrate how to use FreelImage 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
FreelImage, NPP
Supported SM
Key Concepts
Performance Strategies, Image Processing, NPP Library
Supported OSes
Linux, Windows
**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**: FreiImage, NPP
- **Key Concepts**: Image Processing, Performance Strategies, NPP Library
- **Supported OSes**: Linux, Windows

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

**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.

**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**

**Supported SM**


**Key Concepts**

- Random Number Generator, Computational Finance, CURAND Library

**Supported OSes**

- Linux, Windows

---

**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**


**Key Concepts**

- Random Number Generator, Computational Finance, CURAND Library

**Supported OSes**

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

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
Key Concepts: Computational Finance, CURAND Library
Supported OSes: Linux, Windows

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**

**Supported SM**

**Architecture**
- 7.2, SM 7.5, SM 8.0, SM 8.6

**Key Concepts**
- Image Decoding, NVJPEG Library

**Supported OSes**
- 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**

**Supported SM**

**Architecture**
- 7.2, SM 7.5, SM 8.0, SM 8.6

**Key Concepts**
- Image Encoding, NVJPEG Library

**Supported OSes**
- 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.

**Dependencies**
- **X11, GL, CURAND**

**Supported SM**

**Architecture**
- 7.2, SM 7.5, SM 8.0, SM 8.6

**Key Concepts**
- 3D Graphics, CURAND Library

**Supported OSes**
- Linux, Windows

---

**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.
**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
- **Key Concepts**: Image Processing, CUFFT Library
- **Supported OSes**: Linux, Windows

**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.

- **Dependencies**: callback, CUFFT
- **Key Concepts**: Image Processing, CUFFT Library
- **Supported OSes**: Linux
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.

**Dependencies**
- CUFFT

**Supported SM Architecture**

**Key Concepts**
- Image Processing, CUFFT Library

**Supported OSes**
- Linux, Windows

watershedSegmentationNPP - Watershed Segmentation NPP

An NPP CUDA Sample that demonstrates how to use the NPP watershed segmentation function.

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**
- NPP

**Supported SM Architecture**

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

**Supported OSes**
- Linux, Windows
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.

Freelmage

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

To set up Freelmage on a Windows system, extract the Freelmage DLL distribution into the 7_CUDALibraries/common/ folder such that 7_CUDALibraries/common/Freelmage/Dist/x64/ contains the .h, .dll, and .lib files.

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.

CUBLAS
CUBLAS (CUDA Basic Linear Algebra Subroutines) is a GPU-accelerated version of the BLAS library.

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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### Advanced Key Concepts

Advanced Concepts demonstrate advanced techniques and algorithms implemented with CUDA.

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Chapter 6. CUDA API and Associated Samples

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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### CUDA Runtime API Samples

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Chapter 7. Frequently Asked Questions

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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