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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 9.0

- Added `6_Advanced/warpAggregatedAtomicsCG`. Demonstrates warp aggregated atomics using Cooperative Groups.
- Added `6_Advanced/reductionMultiBlockCG`. Demonstrates single pass reduction using Multi Block Cooperative Groups.
- Added `6_Advanced/conjugateGradientMultiBlockCG`. Demonstrates a conjugate gradient solver on GPU using Multi Block Cooperative Groups.
- Added Cooperative Groups(CG) support to several samples notable ones to name are `6_Advanced/cdpQuadtree`, `6_Advanced/cdpAdvancedQuicksort`, `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.

1.2. 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/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`.

### 1.3. 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_CUDA_Libraries/grabcutNPP and 7_CUDA_Libraries/imageSegmentationNPP samples have been removed. These samples used the NPP graphcut APIs, which have been deprecated in CUDA 7.5.

1.4. 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 libNVRTC to measure the performance of kernel accurately.
- Added 0_Simple/inlinePTX_nvrtc. Demonstrates compilation of CUDA kernel having PTX embedded at runtime using libNVRTC.
- Added 0_Simple/matrixMul_nvrtc. Demonstrates compilation of matrix multiplication CUDA kernel at runtime using libNVRTC.
- Added 0_Simple/simpleAssert_nvrtc. Demonstrates compilation of CUDA kernel having assert() at runtime using libNVRTC.
- Added 0_Simple/simpleAtomicIntrinsics_nvrtc. Demonstrates compilation of CUDA kernel performing atomic operations at runtime using libNVRTC.
- Added 0_Simple/simpleTemplates_nvrtc. Demonstrates compilation of templatized dynamically allocated shared memory arrays CUDA kernel at runtime using libNVRTC.
- Added 0_Simple/simpleVoteIntrinsics_nvrtc. Demonstrates compilation of CUDA kernel which uses vote intrinsics at runtime using libNVRTC.
- Added 0_Simple/vectorAdd_nvrtc. Demonstrates compilation of CUDA kernel performing vector addition at runtime using libNVRTC.
- Added 4_Finance/binomialOptions_nvrtc. Demonstrates runtime compilation using libNVRTC of CUDA kernel which evaluates fair call price for a given set of European options under binomial model.
- Added 4_Finance/BlackScholes_nvrtc. Demonstrates runtime compilation using libNVRTC of CUDA kernel which evaluates fair call and put prices for a given set of European options by Black-Scholes formula.
- Added 4_Finance/quasirandomGenerator_nvrtc. Demonstrates runtime compilation using libNVRTC of CUDA kernel which implements Niederreiter Quasirandom Sequence Generator and Inverse Cumulative Normal Distribution functions for the generation of Standard Normal Distributions.
1.5. CUDA 6.5

- Added `7_CUDALibraries/cuHook`. Demonstrates how to build and use an intercept library with CUDA.
- Added `7_CUDALibraries/simpleCUFFT_callback`. Demonstrates how to compute a 1D-convolution of a signal with a filter using a user-supplied CUFFT callback routine, rather than a separate kernel call.
- Added `7_CUDALibraries/simpleCUFFT_MGPU`. Demonstrates how to compute a 1D-convolution of a signal with a filter by transforming both into frequency domain, multiplying them together, and transforming the signal back to time domain on Multiple GPUs.
- Added `7_CUDALibraries/simpleCUFFT_2d_MGPU`. Demonstrates how to compute a 2D-convolution of a signal with a filter by transforming both into frequency domain, multiplying them together, and transforming the signal back to time domain on Multiple GPUs.
- Removed `3_Imaging/cudaEncode`. Support for the CUDA Video Encoder (NVCUVENC) has been removed.
- Removed `4_Finance/ExcelCUDA2007`. The topic will be covered in a blog post at Parallel Forall.
- Removed `4_Finance/ExcelCUDA2010`. The topic will be covered in a blog post at Parallel Forall.
- The `4_Finance/binomialOptions` sample is now restricted to running on GPUs with SM architecture 2.0 or greater.
- The `4_Finance/quasirandomGenerator` sample is now restricted to running on GPUs with SM architecture 2.0 or greater.
- The `7_CUDALibraries/boxFilterNPP` sample now demonstrates how to use the static NPP libraries on Linux and Mac.
- The `7_CUDALibraries/conjugateGradient` sample now demonstrates how to use the static CUBLAS and CUSPARSE libraries on Linux and Mac.
- The `7_CUDALibraries/MersenneTwisterGP11213` sample now demonstrates how to use the static CURAND library on Linux and Mac.

1.6. CUDA 6.0

- New featured samples that support a new CUDA 6.0 feature called UVM-Lite
- Added `0_Simple/UnifiedMemoryStreams` - new CUDA sample that demonstrates the use of OpenMP and CUDA streams with Unified Memory on a single GPU.
- Added `1_Utilities/p2pBandwidthTestLatency` - new CUDA sample that demonstrates how measure latency between pairs of GPUs with P2P enabled and P2P disabled.
- Added `6_Advanced/StreamPriorities` - This sample demonstrates basic use of the new CUDA 6.0 feature stream priorities.
Added 7_CUDALibraries/ConjugateGradientUM - This sample implements a conjugate gradient solver on GPU using cuBLAS and cuSPARSE library, using Unified Memory.

1.7. CUDA 5.5

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

1.8. CUDA 5.0

- New directory structure for CUDA samples. Samples are classified accordingly to categories: 0_Simple, 1_Utilsites, 2_Graphics, 3_Imaging, 4_Finance, 5_Simulations, 6_Advanced, 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/cdpLU Decomposition** - 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.

### 1.9. CUDA 4.2
- Added **segmentationTreeThrust** - demonstrates a method to build image segmentation trees using Thrust. This algorithm is based on Boruvka's MST algorithm.

### 1.10. 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.
- Added **grabcutNPP** - CUDA implementation of Rother et al. GrabCut approach using the 8 neighborhood NPP Graphcut primitive introduced in CUDA 4.1. (C.
Chapter 2.
GETTING STARTED

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

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

2.1. Getting CUDA Samples

Windows

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

C:\ProgramData\NVIDIA Corporation\CUDA Samples\v9.0\n
The installation location can be changed at installation time.

Linux

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

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

$ cuda-install-samples-9.0.sh <target_path>

Mac OSX

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

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

$ cuda-install-samples-9.0.sh <target_path>
2.2. Building Samples

Windows

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

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

Complete samples solution files exist at:

C:\ProgramData\NVIDIA Corporation\CUDA Samples\v9.0\n
Each individual sample has its own set of solution files at:

C:\ProgramData\NVIDIA Corporation\CUDA Samples\v9.0\<sample_dir>\n
To build/examine all the samples at once, the complete solution files should be used. To build/examine a single sample, the individual sample solution files should be used.

Some samples require that the Microsoft DirectX SDK (June 2010 or newer) be installed and that the VC++ directory paths are properly set up (Tools > Options...). Check DirectX Dependencies section for details.

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, 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=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 20 and SM 30, use SMS="20 30".
$ make SMS="20 30"

- **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++

### Mac

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

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

The samples makefiles can take advantage of certain options:

- **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 20 and SM 30, use `SMS="20 30"`.

  $ make SMS="A B ..."

- **HOST_COMPILER=<host_compiler>** - override the default clang host compiler. See the Mac Installation Guide for a list of supported host compilers.

  $ make HOST_COMPILER=clang

### 2.3. CUDA Cross-Platform Samples

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

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

<table>
<thead>
<tr>
<th>TARGET ARCH</th>
<th>TARGET OS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>linux</td>
</tr>
<tr>
<td>x86_64</td>
<td>YES</td>
</tr>
<tr>
<td>armv7l</td>
<td>YES</td>
</tr>
<tr>
<td>aarch64</td>
<td>NO</td>
</tr>
<tr>
<td>ppc64le</td>
<td>YES</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
- **armv7l** - 32-bit ARM CPU architecture, like that found on Jetson TK1
- **aarch64** - 64-bit ARM CPU architecture, found on certain Android systems
- **ppc64le** - 64-bit little-endian IBM POWER8 architecture

TARGET_OS

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

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

TARGET_FS

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

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

2.4.1. Creating CUDA Projects for Windows

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

1. Copy the content of:

   C:\ProgramData\NVIDIA Corporation\CUDA Samples\v9.0\<category>\template

   to a directory of your own:

   C:\ProgramData\NVIDIA Corporation\CUDA Samples\v9.0\<category>\myproject

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

3. Edit the *.sln, *.vcproj and source files.

   Just search and replace all occurrences of template with myproject.

4. Build the 32-bit and/or 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\v9.0\bin\win[32|64]\[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

The default installation folder <SAMPLES_INSTALL_PATH> is NVIDIA_CUDA_9.0_Samples and <category> is one of the following: 0_Simple, 1_Utility, 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>cd <SAMPLES_INSTALL_PATH>/<category>
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.

2.4.3. Creating CUDA Projects for Mac OS X

The default installation folder <SAMPLES_INSTALL_PATH> is: /Developer/NVIDIA/CUDA-9.0/samples

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

(<category>) is one of the following: 0_Simple, 1Utilities, 2Graphics, 3Imaging, 4Finance, 5Simulations, 6Advanced, 7CUDALibraries.

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

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

5. Run the program:
   
   ../../bin/x86_64/darwin/release/myproject

   (It should print PASSED.)

6. Now modify the code to perform the computation you require.
   See the CUDA Programming Guide for details of programming in CUDA.
Chapter 3.
SAMPLES REFERENCE

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

The code samples are divided into the following categories:

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

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

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

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

Finance Reference
Samples that demonstrate parallel algorithms for financial computing.

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

Advanced Reference
Samples that illustrate advanced algorithms implemented with CUDA.

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

3.1. Simple Reference
asyncAPI
This sample uses CUDA streams and events to overlap execution on CPU and GPU.
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.

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

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.

Dependencies: CDP
Key Concepts: CUDA Dynamic Parallelism
Supported OSes: Linux, Windows, OS X
clock - Clock

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

- **CUDA API**: cudaMemcpy, cudaMemcpy, cudaMemcpy
- **Key Concepts**: Performance Strategies
- **Supported OSes**: Linux, Windows, OS X

clock_nvrtc - Clock libNVRTC

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

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

- **Dependencies**: NVRTC
- **CUDA API**: cuMemAlloc, cuLaunchKernel, cudaMemcpy, cudaMemcpy
- **Key Concepts**: Performance Strategies, Runtime Compilation
- **Supported OSes**: Linux, Windows, OS X

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.

- **CUDA API**: cudaMemcpy, cudaMemcpy
- **Supported OSes**: Linux, Windows, OS X
cppOverload

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


**CUDA API**: cudaFuncSetCacheConfig, cudaFuncGetAttributes

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

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

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


**CUDA API**: cudaMemcpy, 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
### 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
- SM 5.3, SM 6.0, SM 6.1, SM 6.2, SM 7.0

#### Architecture
- CUDA API
- cudaMalloc, cudaMallocHost, cudaMemcpy, cudaFree, cudaFreeHost

#### Key Concepts
- CUDA Runtime API

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

### inlinePTX - Using Inline PTX
A simple test application that demonstrates a new CUDA 4.0 ability to embed PTX in a CUDA kernel.

#### Supported SM

#### Architecture
- 6.2, SM 7.0

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

#### Key Concepts
- Performance Strategies, PTX Assembly, CUDA Driver API

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

### 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.

**Dependencies**  
NVRTC  

**Supported SM Architecture**  

**CUDA API**  
cuMemAlloc, cuLaunchKernel, cudaMemcpyDtoH

**Key Concepts**  
Performance Strategies, PTX Assembly, CUDA Driver API, Runtime Compilation

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

---

**matrixMul - Matrix Multiplication (CUDA Runtime API Version)**

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.

**Supported SM Architecture**  

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

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

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

---

**matrixMul_nvrtc - Matrix Multiplication with libNVRTC**

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

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

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.
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.

- **CUDA API**: cudaMalloc, cudaMallocHost, 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**: NVTC
- **CUDA API**: cuLaunchKernel
- **Key Concepts**: Assert, Runtime Compilation
- **Supported OSes**: Linux, Windows

simpleAtomicIntrinsics - Simple Atomic Intrinsics

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

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

<table>
<thead>
<tr>
<th>Supported SM Architecture</th>
<th>CUDA API</th>
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</table>

Key Concepts

<table>
<thead>
<tr>
<th>Supported OSes</th>
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</thead>
<tbody>
<tr>
<td>Linux, Windows, OS X</td>
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</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.

Supported SM Architecture

<table>
<thead>
<tr>
<th>CUDA API</th>
</tr>
</thead>
<tbody>
<tr>
<td>cudaStreamCreate, cudaMemcpyAsync, cudaMemcpyHtoD, cudaMemcpyDtoH, cudaMemcpyAsync</td>
</tr>
</tbody>
</table>

Key Concepts

<table>
<thead>
<tr>
<th>Supported OSes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linux, Windows, OS X</td>
</tr>
</tbody>
</table>

simpleCooperativeGroups - Simple Cooperative Groups

This sample is a simple code that illustrates basic usage of cooperative groups within the thread block.
simpleCubemapTexture - Simple Cubemap Texture

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

**Supported SM Architecture**

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

**Key Concepts**
Texture, Volume Processing

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

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 2.0 or higher and a Linux 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**
cudaIpcGetEventHandlet, cudaIpcOpenMemHandle, cudaIpcCloseMemHandle, cudaFreeHost, cudaMemcpy

**Key Concepts**
CUDA Systems Integration, Peer to Peer, InterProcess Communication

**Supported OSes**
Linux
simpleLayeredTexture - Simple Layered Texture

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

**Supported SM Architecture**

**CUDA API**
- cudaMemcpy3D
- cudaMemcpy

**Key Concepts**
- Texture, Volume Processing

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

simpleMPI

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

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

**Dependencies**
- MPI

**Supported SM Architecture**

**CUDA API**
- cudaMemcpy

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

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

simpleMultiCopy - Simple Multi Copy and Compute

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

**Supported SM Architecture**

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

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

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

Supported OSes
Linux, Windows, OS X

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

Supported SM

Key Concepts
Occupancy Calculator

Supported OSes
Linux, Windows, OS X

simpleP2P - Simple Peer-to-Peer Transfers with Multi-GPU
This application demonstrates CUDA APIs that support Peer-To-Peer (P2P) copies, Peer-To-Peer (P2P) addressing, and Unified Virtual Memory Addressing (UVA) between multiple GPUs. In general, P2P is supported between two same GPUs with some exceptions, such as some Tesla and Quadro GPUs.

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

**Dependencies**
- only-64-bit

**Supported SM Architecture**

**CUDA API**
- cudaDeviceCanAccessPeer, cudaDeviceEnablePeerAccess,
cudaDeviceDisablePeerAccess, cudaEventCreateWithFlags,
cudaEventElapsedTime, cudaMemcpy

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

**Supported OSes**
- Linux, Windows

---

**simplePitchLinearTexture - Pitch Linear Texture**

**Use of Pitch Linear Textures**

**Supported SM Architecture**

**CUDA API**
- cudaMallocPitch, cudaMallocArray, cudaMemcpy2D, cudaMemcpyToArray,
cudaBindTexture2D, cudaBindTextureToArray, cudaCreateChannelDesc,
cudaMalloc, cudaFree, cudaFreeArray, cudaUnbindTexture, cudaMemcpy2D

**Key Concepts**
- Texture, Image Processing

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

---

**simplePrintf**

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

**Supported SM Architecture**

**CUDA API**
- cudaPrintfDisplay, cudaPrintfEnd

**Key Concepts**
- Debugging

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

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

Supported SM Architecture

Key Concepts
Separate Compilation

Supported OSes
Linux, Windows, OS X

simpleStreams

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

Supported SM Architecture

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

Key Concepts
Asynchronous Data Transfers, CUDA Streams and Events

Supported OSes
Linux, Windows, OS X

simpleSurfaceWrite - Simple Surface Write

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

Supported SM Architecture

CUDA API
cudaMalloc, cudaMallocArray, cudaMemcpy, cudaMalloc, cudaFree, cudaMemcpy, cudaFreeArray, cudaMemcpy

cudaMallocArray, cudaMemcpy, cudaMalloc, cudaFree, cudaMemcpy, cudaFreeArray, cudaMemcpy

cudaMallocArray, cudaMemcpy, cudaMalloc, cudaFree, cudaMemcpy, cudaFreeArray, cudaMemcpy

cudaMallocArray, cudaMemcpy, cudaMalloc, cudaFree, cudaMemcpy, cudaFreeArray, cudaMemcpy

cudaMallocArray, cudaMemcpy, cudaMalloc, cudaFree, cudaMemcpy, cudaFreeArray, cudaMemcpy

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cudaMallocArray, cudaMemcpy, cudaMalloc, cudaFree, cudaMemcpy, cudaFreeArray, cudaMemcpy

cudaMallocArray, cudaMemcpy, cudaMalloc, cudaFree, cudaMemcpy, cudaFreeArray, cudaMemcpy

cudaMallocArray, cudaMemcpy, cudaMalloc, cudaFree, cudaMemcpy, cudaFreeArray, cudaMemcopy

Key Concepts
Texture, Surface Writes, Image Processing

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

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

Supported SM Architecture

Key Concepts
C++ Templates

Supported OSes
Linux, Windows, OS X

simpleTemplates_nvrtc - Simple Templates with libNVRTC

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

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

Dependencies
NVRTC

Supported SM Architecture

Key Concepts
C++ Templates, Runtime Compilation

Supported OSes
Linux, Windows, OS X

simpleTexture - Simple Texture

Simple example that demonstrates use of Textures in CUDA.

Supported SM Architecture

CUDA API
cudaMalloc, cudaMemcpyToAlignment, cudaMemcpyToArray, cudaMemcpyToArray, cudaMemcpyToAlignment, cudaMemcpyToArray, cudaMemcpyToAlignment, cudaMemcpyToArray, cudaMemcpyToArray, cudaMemcpyToArray

Key Concepts
CUDA Runtime API, Texture, Image Processing

Supported OSes
Linux, Windows, OS X
simpleTextureDrv - Simple Texture (Driver Version)

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

**Supported SM Architecture**
- SM 7.0

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

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

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

simpleVoteIntrinsics - Simple Vote Intrinsics

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

**Supported SM Architecture**
- SM 7.0

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

**Key Concepts**
- Vote Intrinsics

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

simpleVoteIntrinsics_nvrtc - Simple Vote Intrinsics with libNVRTC

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

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

**Dependencies**
- NVRTC
simpleZeroCopy

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

**Supported SM Architecture**

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

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

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

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**
SM 6.0, SM 6.1, SM 6.2, SM 7.0

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

**Key Concepts**
Atomic Intrinsics, Unified Memory

**Supported OSes**
Linux
template - Template

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

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

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**: cudaMemcpyManaged, cudaStreamAttachManagedMem
- **Key Concepts**: CUDA Systems Integration, OpenMP, CUBLAS, Multithreading, Unified Memory, CUDA Streams and Events
- **Supported OSes**: Linux, Windows, OS X

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.

- **CUDA API**: cudaEventCreate, cudaEventRecord, cudaEventQuery, cudaEventDestroy, cudaEventElapsedTime, cudaEventSynchronize, cudaMemcpy, cudaMemcpyManaged
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

CUDA API
- cuMemAlloc, cuMemFree, cuMemcpyHtoD, cuMemcpyDtoH

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

Supported OSes
- Linux, Windows, OS X

vectorAddDrv - Vector Addition Driver API

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

Supported SM

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

Key Concepts
- CUDA Driver API, Vector Addition

Supported OSes
- Linux, Windows, OS X
3.2. Utilities Reference

bandwidthTest - Bandwidth Test

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

Supported SM  
Architecture  
CUDA API  
cudaSetDevice, cudaHostAlloc, cudaFree, cudaMallocHost, cudaFreeHost, cudaMemcpy, cudaMemcpyAsync, cudaEventCreate, cudaEventRecord, cudaEventDestroy, cudaDeviceSynchronize, cudaEventElapsedTime
Key Concepts  
CUDA Streams and Events, Performance Strategies
Supported OSes  
Linux, Windows, OS X

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, OS X

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
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
6.2, SM 7.0

CUDA API
cudaDeviceCanAccessPeer, cudaDeviceEnablePeerAccess,
cudaDeviceDisablePeerAccess, cudaEventCreateWithFlags,
cudaEventElapsedTime, cudaMemcpy

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

Supported OSes
Linux, Windows, OS X

topologyQuery - Topology Query

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

Supported SM Architecture
6.2, SM 7.0

CUDA API
cudaDeviceGetP2PAttribute, cudaGetDeviceAttribute, cudaGetDeviceCount

Key Concepts
Performance Strategies, Multi-GPU

Supported OSes
Linux, Windows, OS X

3.3. Graphics Reference

bindlessTexture - Bindless Texture

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

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

**Dependencies**  
X11, GL

**Supported SM Architecture**  

**CUDA API**  

**Key Concepts**  
Graphics Interop, Texture

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

### Mandelbrot

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

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

**Dependencies**  
X11, GL

**Supported SM Architecture**  

**CUDA API**  

**Key Concepts**  
Graphics Interop, Data Parallel Algorithms

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

### marchingCubes - Marching Cubes Isosurfaces

This sample extracts a geometric isosurface from a volume dataset using the marching cubes algorithm. It uses the scan (prefix sum) function from the Thrust library to perform stream compaction.
This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**
- X11, GL

**Supported SM Architecture**

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

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

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

---

**simpleD3D10 - Simple Direct3D10 (Vertex Array)**

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

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

**Dependencies**
- DirectX

**Supported SM Architecture**

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

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

**Supported OSes**
- Windows
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

Supported Architecture

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

Supported Architecture

CUDA API
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
Key Concepts: Graphics 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
simpleD3D9Texture - Simple D3D9 Texture

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

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

Dependencies DirectX
CUDA API cudaD3D9GetDevice, cudaD3D9SetDirect3DDevice,
cudaGraphicsD3D9RegisterResource, cudaGraphicsResourceSetMapFlags,
cudaGraphicsSubResourceGetMappedArray, cudaMemcpy2DToArray,
cudaMemcpy3D, cudaGraphicsUnregisterResource

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
CUDA API cudaGLSetGLDevice, cudaGraphicsMapResources,
cudaGraphicsUnmapResources, cudaGraphicsResourceGetMappedPointer,
samples Reference

www.nvidia.com
CUDA Samples
TRM-06704-001_v9.0 | 40


Key Concepts
Graphics Interop, Vertex Buffers, 3D Graphics

Supported OSes
Linux, Windows, OS X

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

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
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.

Dependencies: screen, GLES


Key Concepts: Graphics Interop, Vertex Buffers, 3D Graphics

Supported OSes: Linux

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.

Dependencies: X11, GL


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

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

---

**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**

**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.

**Dependencies**
X11, GL

**Supported SM Architecture**
volumeRender - Volume Rendering with 3D Textures

This sample demonstrates basic volume rendering using 3D Textures.

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

Dependencies X11, GL
Key Concepts Graphics Interop, Image Processing, 3D Textures
Supported OSes Linux, Windows, OS X

3.4. Imaging Reference

bicubicTexture - Bicubic B-spline Interpolation

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

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

Dependencies X11, GL


Key Concepts: Graphics Interop, Image Processing

Supported OSes: Linux, Windows, OS X

bilateralFilter - Bilateral Filter

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

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

Dependencies: X11, GL


Key Concepts: Graphics Interop, Image Processing

Supported OSes: Linux, Windows, OS X

boxFilter - Box Filter

Fast image box filter using CUDA with OpenGL rendering.

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

convolutionSeparable - CUDA Separable Convolution

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

cudaDecodeD3D9 - CUDA Video Decoder D3D9 API

This sample demonstrates how to efficiently use the CUDA Video Decoder API to decode MPEG-2, VC-1, or H.264 sources. YUV to RGB conversion of video is accomplished with CUDA kernel. The output result is rendered to a D3D9 surface. The decoded video is not displayed on the screen, but with -displayvideo at the command line parameter, the video output can be seen. Requires a Direct3D capable device and 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: DirectX


cudaDecodeGL - CUDA Video Decoder GL API

This sample demonstrates how to efficiently use the CUDA Video Decoder API to decode video sources based on MPEG-2, VC-1, and H.264. YUV to RGB conversion of video is accomplished with CUDA kernel. The output result is rendered to a OpenGL surface. The decoded video is black, but can be enabled with -displayvideo added to the command line. 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**
- X11, GL, cuvid

**Supported SM Architecture**

**CUDA API**

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

**Supported OSes**
- Linux, Windows

**Whitepaper**
- CUDA_Video_Decoder.pdf
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, OS X

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, OS X

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


Key Concepts: Cooperative Groups, Image Processing, Image Compression

Supported OSes: Linux, Windows, OS X

Whitepaper: cuda_dxtc.pdf

EGLStream_CUDA_CrossGPU
Demonstrates CUDA and EGL Streams interop, where consumer’s EGL Stream is on one GPU and producer’s on other and both consumer-producer are different processes.
This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

**Dependencies**

- EGL

**Supported SM Architecture**


**CUDA API**


**Key Concepts**

- EGLStreams Interop

**Supported OSes**

- Linux

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**CUDA_EGLStreams_Interop - EGLStreams CUDA Interop**

Demonstrates data exchange between CUDA and EGL Streams.

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

**Dependencies**

- EGL

**Supported SM Architecture**


**CUDA API**


**Key Concepts**

- EGLStreams Interop

**Supported OSes**

- Linux
histogram - CUDA Histogram

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

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

HSOpticalFlow - Optical Flow

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

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

imageDenoising - Image denoising

This sample demonstrates two adaptive image denoising techniques: KNN and NLM, based on computation of both geometric and color distance between texels. While both techniques are implemented in the DirectX SDK using shaders, massively speeded up variation of the latter technique, taking advantage of shared memory, is implemented in addition to DirectX counterparts.

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

- **Dependencies**: X11, GL
- **Key Concepts**: Image Processing
- **Supported OSes**: Linux, Windows, OS X
postProcessGL - Post-Process in OpenGL

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

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

Dependencies
- X11, GL

Supported SM Architecture

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

Key Concepts
- Graphics Interop, Image Processing

Supported OSes
- Linux, Windows, OS X

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

Supported SM Architecture

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

Key Concepts
- Graphics Interop, Image Processing

Supported OSes
- Linux, Windows, OS X
simpleCUDA2GL - CUDA and OpenGL Interop of Images

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

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

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>X11, GL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key Concepts</td>
<td>Graphics Interop, Image Processing, Performance Strategies</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows, OS X</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>
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<td>Graphics Interop, Image Processing</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows, OS X</td>
</tr>
</tbody>
</table>
stereoDisparity - Stereo Disparity Computation (SAD SIMD Intrinsics)

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

- **Key Concepts**: Image Processing, Video Intrinsics
- **Supported OSes**: Linux, Windows, OS X

### 3.5. Finance Reference

binomialOptions - Binomial Option Pricing

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

- **Key Concepts**: Computational Finance
- **Supported OSes**: Linux, Windows, OS X
- **Whitepaper**: binomialOptions.pdf

binomialOptions_nvrtc - Binomial Option Pricing with libNVRTC

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

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

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

**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, OS X
- **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
- **Key Concepts**: Computational Finance, Runtime Compilation
- **Supported OSes**: Linux, Windows, OS X

**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, OS X

### Whitepaper
- MonteCarlo.pdf

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**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.

### Supported SM Architecture

### Key Concepts
- Computational Finance

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

---

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

This sample implements Niederreiter Quasirandom Sequence Generator and Inverse Cumulative Normal Distribution functions for the generation of Standard Normal Distributions, compiling the CUDA kernels involved at runtime using 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, OS X
SobolQRNG - Sobol Quasirandom Number Generator

This sample implements Sobol Quasirandom Sequence Generator.

**Supported SM Architecture**
- SM 3.0
- SM 3.2
- 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

**Key Concepts**
- Computational Finance

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

---

3.6. Simulations Reference

**fluidsD3D9 - Fluids (Direct3D Version)**

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

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

**Dependencies**
- DirectX

**Supported SM Architecture**
- SM 3.0
- SM 3.2
- 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

**CUDA API**
- cudaD3D9SetGLDevice
- cudaGraphicsMapResources
- cudaGraphicsUnmapResources
- cudaGraphicsResourceGetMappedPointer
- cudaGraphicsRegisterResource
- cudaGraphicsGLRegisterBuffer
- cudaGraphicsUnregisterResource

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

**Supported OSes**
- Windows

---

**fluidsGL - Fluids (OpenGL Version)**

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

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


CUDA API


Key Concepts

Graphics Interop, Data Parallel Algorithms, Physically-Based Simulation

Supported OSes

Linux, Windows, OS X

Whitepaper

nbody_gems3_ch31.pdf

**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.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>screen, GLES</th>
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<td>Key Concepts</td>
<td>Graphics Interop, Data Parallel Algorithms, Physically-Based Simulation</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux</td>
</tr>
</tbody>
</table>

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.

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

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

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

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

**Whitepaper**
- particles.pdf

smokeParticles - Smoke Particles

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

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

**Dependencies**
- X11, GL

**Supported SM Architecture**

**CUDA API**
- cudaGLSetGLDevice, cudaGraphicsMapResources,
- cudaGraphicsUnmapResources, cudaGraphicsResourceGetMappedPointer,
VFlokingD3D10

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.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>DirectX</th>
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<tbody>
<tr>
<td>Key Concepts</td>
<td>Graphics Interop, Data Parallel Algorithms, Physically-Based Simulation, Performance Strategies</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Windows</td>
</tr>
</tbody>
</table>

3.7. Advanced Reference

alignedTypes - Aligned Types

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

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

---

**c++11_cuda - C++11 CUDA**

This sample demonstrates C++11 feature support in CUDA. It scans an 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

**Supported SM**

**Supported OSes**
- Linux, OS X

---

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

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

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

**Dependencies**
- CDP

**Supported SM**

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

---
cdpBezierTessellation - Bezier Line Tessellation (CUDA Dynamic Parallelism)

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

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

Dependencies
CDP

Supported SM

Key Concepts
CUDA Dynamic Parallelism

Supported OSes
Linux, Windows, OS X

cdpLU Decomposition - LU Decomposition (CUDA Dynamic Parallelism)

This sample demonstrates LU Decomposition 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, CUBLAS

Supported SM

Key Concepts
CUDA Dynamic Parallelism

Supported OSes
Linux, Windows, OS X

cdpQuadtree - Quad Tree (CUDA Dynamic Parallelism)

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

**Dependencies**
- CDP

**Supported SM Architecture**

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

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

### 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, OS X

### 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**
- SM 6.0, SM 6.1, SM 6.2, SM 7.0

**Key Concepts**
- Unified Memory, Linear Algebra, Cooperative Groups, MultiBlock Cooperative Groups
**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.

- **Key Concepts**: Linear Algebra
- **Supported OSes**: Linux, Windows, OS X

**fastWalshTransform - Fast Walsh Transform**

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

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

**FDTD3d - CUDA C 3D FDTD**

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

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

**FunctionPointers - Function Pointers**

This sample illustrates how to use function pointers and implements the Sobel Edge Detection filter for 8-bit monochrome images.
This sample depends on other applications or libraries to be present on the system to either build or run. If these dependencies are not available on the system, the sample will not be installed. If these dependencies are available, but not installed, the sample will waive itself at build time.

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

**interval - Interval Computing**

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

| Key Concepts | Recursion, Templates |
| Supported OSes | Linux, Windows, OS X |

**lineOfSight - Line of Sight**

This sample is an implementation of a simple line-of-sight algorithm: Given a height map and a ray originating at some observation point, it computes all the points along the ray that are visible from the observation point. The implementation is based on the Thrust library (http://code.google.com/p/thrust/).

| Supported OSes | Linux, Windows, OS X |

**matrixMulDynlinkJIT - Matrix Multiplication (CUDA Driver API version with Dynamic Linking Version)**

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

<table>
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<tr>
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<tbody>
<tr>
<td>CUDA API</td>
<td>cuModuleLoad, cuModuleLoadDataEx, cuModuleGetFunction, cuMemAlloc, cuMemFree, cuMemcpyHtoD, cuMemcpyDtoH, cuLaunchKernel</td>
</tr>
<tr>
<td>Key Concepts</td>
<td>CUDA Driver API, CUDA Dynamically Linked Library</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows, OS X</td>
</tr>
</tbody>
</table>

**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

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<tbody>
<tr>
<td>Key Concepts</td>
<td>Data-Parallel Algorithms</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows, OS X</td>
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</table>

**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.

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

**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.
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.

<table>
<thead>
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<tbody>
<tr>
<td>Key Concepts</td>
<td>CUDA Driver API</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows, OS X</td>
</tr>
<tr>
<td>Whitepaper</td>
<td>readme.txt</td>
</tr>
</tbody>
</table>

reduction - CUDA Parallel Reduction

A parallel sum reduction that computes the sum of a large arrays of values. This sample demonstrates several important optimization strategies for 1:Data-Parallel Algorithms like reduction.

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<tbody>
<tr>
<td>Key Concepts</td>
<td>Data-Parallel Algorithms, Performance Strategies</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows, OS X</td>
</tr>
</tbody>
</table>

reductionMultiBlockCG - Reduction using MultiBlock Cooperative Groups

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

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

Supported SM Architecture
6.2, SM 7.0

Key Concepts
Linear Algebra

Supported OSes
Linux, Windows, OS X

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

Supported SM Architecture
6.2, SM 7.0

Key Concepts
Data-Parallel Algorithms, Performance Strategies

Supported OSes
Linux, Windows, OS X

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

Supported SM Architecture
6.2, SM 7.0

Key Concepts
Data-Parallel Algorithms, Performance Strategies

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

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

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

simpleHyperQ

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

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

sortingNetworks - CUDA Sorting Networks

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

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

This sample demonstrates basic use of stream priorities.

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

- **Dependencies**: Stream-Priorities
- **Key Concepts**: CUDA Streams and Events
- **Supported OSes**: Linux, OS X

threadFenceReduction

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

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

threadMigration - CUDA Context Thread Management

Simple program illustrating how to 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.

- **CUDA API**: cuCtxCreate, cuCtxDestroy, cuModuleLoad, cuModuleLoadDataEx, cuModuleGetFunction, cuLaunchKernel, cuMemcpyDtoH, cuCtxPushCurrent, cuCtxPopCurrent
- **Key Concepts**: CUDA Driver API
 transpose - Matrix Transpose
This sample demonstrates Matrix Transpose. Different performance are shown to achieve high performance.

Supported SM  
Architecture  
Key Concepts  
Supported OSes  
Whitepaper

warpAggregatedAtomicsCG - Warp Aggregated Atomics using Cooperative Groups
This sample demonstrates how using Cooperative Groups (CG) to perform warp aggregated atomics, a useful technique to improve performance when many threads atomically add to a single counter.

Supported SM  
Architecture  
Key Concepts  
Supported OSes

3.8. Cudalibraries Reference

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

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

Dependencies
BiCGStab

A CUDA Sample that demonstrates Bi-Conjugate Gradient Stabilized (BiCGStab) iterative method for nonsymmetric and symmetric positive definite (s.p.d.) linear systems using CUSPARSE and CUBLAS.

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  CUSPARSE, CUBLAS
Key Concepts  Linear Algebra, CUBLAS Library, CUSPARSE Library
Supported OSes  Linux, Windows, OS X

boxFilterNPP - Box Filter with NPP

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

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

Dependencies  Freimage, NPP
Key Concepts  Performance Strategies, Image Processing, NPP Library
Supported OSes  Linux, Windows, OS X
cannyEdgeDetectorNPP - Canny Edge Detector NPP

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

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

<table>
<thead>
<tr>
<th>Dependencies</th>
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<td>Architecture</td>
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<tr>
<td>Key Concepts</td>
<td>Performance Strategies, Image Processing, NPP Library</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows, OS X</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Dependencies</th>
<th>CUBLAS, CUSPARSE</th>
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<tbody>
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<td>Architecture</td>
<td>6.2, SM 7.0</td>
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<tr>
<td>Key Concepts</td>
<td>Linear Algebra, CUBLAS Library, CUSPARSE Library</td>
</tr>
<tr>
<td>Supported OSes</td>
<td>Linux, Windows, OS X</td>
</tr>
</tbody>
</table>

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, OS X

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### 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, OS X

---

### cuHook - CUDA Interception Library

This sample demonstrates how to build and use an intercept library with CUDA. The library has to be loaded via LD_PRELOAD, e.g. LD_PRELOAD=<full_path>/libcuhook.so.1 ./cuHook

**Supported SM Architecture**  

**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.

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**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.

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**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.

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**cuSolverSp_LowlevelCholesky - cuSolverSp Lowlevel Cholesky Solver**

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

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

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

**cuSolverSp_LowlevelQR - cuSolverSp Lowlevel QR Solver**

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

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

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

**FilterBorderControlNPP - Filter Border Control NPP**

This NPP CUDA Sample 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.
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 OSes Linux, Windows, OS X

freImageInteropNPP - FreeImage and NPP Interopability

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

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

dependencies  Freimage, NPP
Supported OSes Linux, Windows, OS X

histEqualizationNPP - Histogram Equalization with NPP

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

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

dependencies  Freimage, NPP
Supported OSes Linux, Windows, OS X

www.nvidia.com
CUDA Samples
Supported OSes: Linux, Windows, OS X

**jpegNPP - JPEG encode/decode and resize with NPP**

This sample demonstrates a simple image processing pipeline. First, a JPEG file is huffman decoded and inverse DCT transformed and dequantized. Then the different planes are resized. Finally, the resized image is quantized, forward DCT transformed and huffman encoded.

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
- **CUDA API**: nppGetGpuComputeCapability, nppiDCTInitAlloc, nppiDecodeHuffmanScanHost_JPEG_8u16s_P3R, nppiDCTQuantInv8x8LS_JPEG_16s8u_C1R_NEW, nppiResizeSqrPixel_8u_C1R, nppiEncodeHuffmanGetSize, nppiDCTFree

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

---

**MC_EstimatePiInlineP - Monte Carlo Estimation of Pi (inline PRNG)**

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

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

- **Dependencies**: CURAND
- **Key Concepts**: Random Number Generator, Computational Finance, CURAND Library
- **Supported OSes**: Linux, Windows, OS X
MC_EstimatePiInlineQ - Monte Carlo Estimation of Pi (inline QRNG)

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

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

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

MC_EstimatePiP - Monte Carlo Estimation of Pi (batch PRNG)

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

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

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

MC_EstimatePiQ - Monte Carlo Estimation of Pi (batch QRNG)

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

### Dependencies
- CURAND

### Supported SM Architecture

### Key Concepts
- Random Number Generator, Computational Finance, CURAND Library

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

---

**MC_SingleAsianOptionP - Monte Carlo Single Asian Option**

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

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

### Dependencies
- CURAND

### Supported SM Architecture

### Key Concepts
- Random Number Generator, Computational Finance, CURAND Library

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

---

**MersenneTwisterGP11213**

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

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

### Dependencies
- CURAND

### Supported SM Architecture
**nvgraph_Pagerank - NVGRAPH Page Rank**

A CUDA Sample that demonstrates Page Rank computation using NVGRAPH 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**
- NVGRAPH

**Supported SM Architecture**

**Key Concepts**
- Graph Analytics, NVGRAPH Library

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

---

**nvgraph_SemiRingSpMV - NVGRAPH Semi-Ring SpMV**

A CUDA Sample that demonstrates Semi-Ring SpMV using NVGRAPH 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**
- NVGRAPH

**Supported SM Architecture**

**Key Concepts**
- Graph Analytics, NVGRAPH Library

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

---

**nvgraph_SpectralClustering - NVGRAPH Spectral Clustering**

A CUDA Sample that demonstrates Spectral Clustering using NVGRAPH 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**
- NVGRAPH

**Supported SM Architecture**

**Key Concepts**
- Graph Analytics, NVGRAPH Library

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

---

**nvgraph_SSSP - NVGRAPH Single Source Shortest Path**

A CUDA Sample that demonstrates Single Source Shortest Path (SSSP) computation using NVGRAPH 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**
- NVGRAPH

**Supported SM Architecture**

**Key Concepts**
- Graph Analytics, NVGRAPH Library

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

---

**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**

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

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

**Dependencies**
- CUBLAS

**Supported SM Architecture**

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

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

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.

**Dependencies**
- CUBLAS

**Supported SM Architecture**

**Key Concepts**
- CUBLAS-XT Library

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

simpleCUFFT - Simple CUFFT

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

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

### Supported SM

### Architecture
- 6.2, SM 7.0

### Key Concepts
- Image Processing, CUFFT Library

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

---

**simpleCUFFT_2d_MGPU - SimpleCUFFT_2d_MGPU**

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

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

### Dependencies
- CUFFT

### Supported SM

### Architecture
- 6.2, SM 7.0

### Key Concepts
- Image Processing, CUFFT Library

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

---

**simpleCUFFT_callback - Simple CUFFT Callbacks**

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

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

### Dependencies
- callback, CUFFT

### Supported SM

### Architecture
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
**Architecture** 6.2, SM 7.0
**Key Concepts** Image Processing, CUFFT Library
**Supported OSes** Linux, Windows, OS X

**simpleDevLibCUBLAS - simpleDevLibCUBLAS GPU Device API Library Functions (CUDA Dynamic Parallelism)**

This sample implements a simple CUBLAS function calls that call GPU device API library running CUBLAS functions. This sample requires a SM 3.5 capable device.

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, CUBLAS
**Architecture** cublasCreate, cublasSetVector, cublasSgemm, cudaMalloc, cudaFree, cudaMemcpy
**CUDA API** CUDA Dynamic Parallelism, Linear Algebra
**Supported OSes** Linux, Windows, OS X
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.

FreeImage

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

Message Passing Interface

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

Only 64-Bit

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

DirectX is a collection of APIs designed to allow development of multimedia applications on Microsoft platforms. For Microsoft platforms, NVIDIA’s CUDA Driver supports DirectX. Several CUDA Samples for Windows demonstrates CUDA-DirectX Interoperability, for building such samples one needs to install Direct X SDK (June 2010 or newer), this is required to be installed on Windows 7, Windows 10 and Windows Server 2008, Other Windows OSes do not need to explicitly install the DirectX SDK.

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.

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.
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 Parallelism

CDP (CUDA Dynamic Parallelism) 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 on Linux systems.

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. IPC is only available on Linux x86_64 and ppc64le systems.

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.

NVGRAPH

NVGRAPH is a GPU-accelerated graph analytics library.

NVRTC

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

NVCUVID

NVCUVID (NVIDIA CUDA Video Decoder) provides GPU-accelerated video decoding capabilities.

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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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

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

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