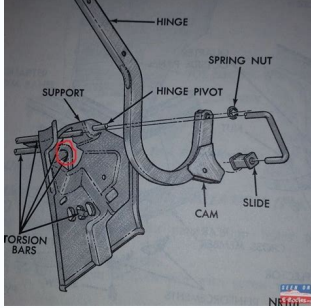




[illegible]

Chapter 1. Introduction to CUDA

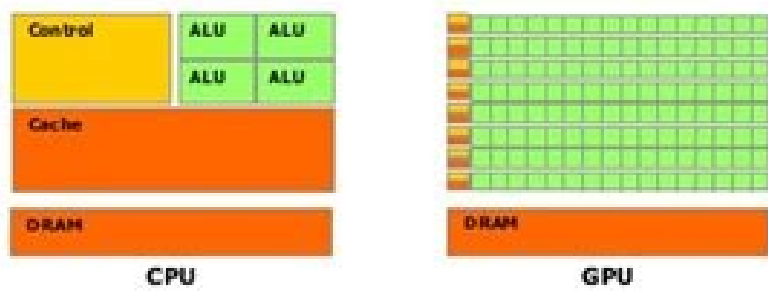


Figure 1-2. The GPU Devotes More Transistors to Data Processing

More specifically, the GPU is especially well-suited to address problems that can be expressed as data-parallel computations – the same program is executed on many data elements in parallel – with high arithmetic intensity – the ratio of arithmetic operations to memory operations. Because the same program is executed for each data element, there is a lower requirement for sophisticated flow control and because it is executed on many data elements and has high arithmetic intensity, the memory access latency can be hidden with calculations instead of big data caches.

Data-parallel processing maps data elements to parallel processing threads. Many applications that process large data sets such as arrays can use a data-parallel programming model to speed up the computations. In 3D rendering large sets of pixels and vertices are mapped to parallel threads. Similarly, image and media processing applications such as post-processing of rendered images, video encoding and decoding, image scaling, stereo vision, and pattern recognition can map image blocks and pixels to parallel processing threads. In fact, many algorithms outside the field of image rendering and processing are accelerated by data-parallel processing, from general signal processing or physics simulation to computational finance or computational biology.

Up until now, however, accessing all that computational power packed into the GPU and efficiently leveraging it for non-graphics applications remained tricky:

- ❑ The GPU could only be programmed through a graphics API imposing a high learning curve to the novice and the overhead of an inadequate API to the non-graphics application.
- ❑ The GPU DRAM could be read in a general way – GPU programs can *gather* data elements from any part of DRAM – but could not be written in a general way – GPU programs cannot *scatter* information to any part of DRAM –, removing a lot of the programming flexibility readily available on the CPU.
- ❑ Some applications were bottlenecked by the DRAM memory bandwidth, under-utilizing the GPU's computational power.

This document describes a novel hardware and programming model that is a direct answer to these problems and exposes the GPU as a truly generic data-parallel computing device.

Chapter 1. Introduction to CUDA

1.2 CUDA: A New Architecture for Computing on the GPU

CUDA stands for **Compute Unified Device Architecture** and is a new hardware and software architecture for issuing and managing computations on the GPU as a data-parallel computing device without the need of mapping them to a graphics API. It is available for the GeForce 8800 Series, Quadro FX 5600/4600, and beyond. The operating system's multitasking mechanism is responsible for managing the access to the GPU by several CUDA and graphics applications running concurrently.

The CUDA software stack is composed of several layers as illustrated in Figure 1-3: a hardware driver, an application programming interface (API) and its runtime, and two higher-level mathematical libraries of common usage, CUFFT and CUBLAS that are both described in separate documents. The hardware has been designed to support lightweight driver and runtime layers, resulting in high performance.

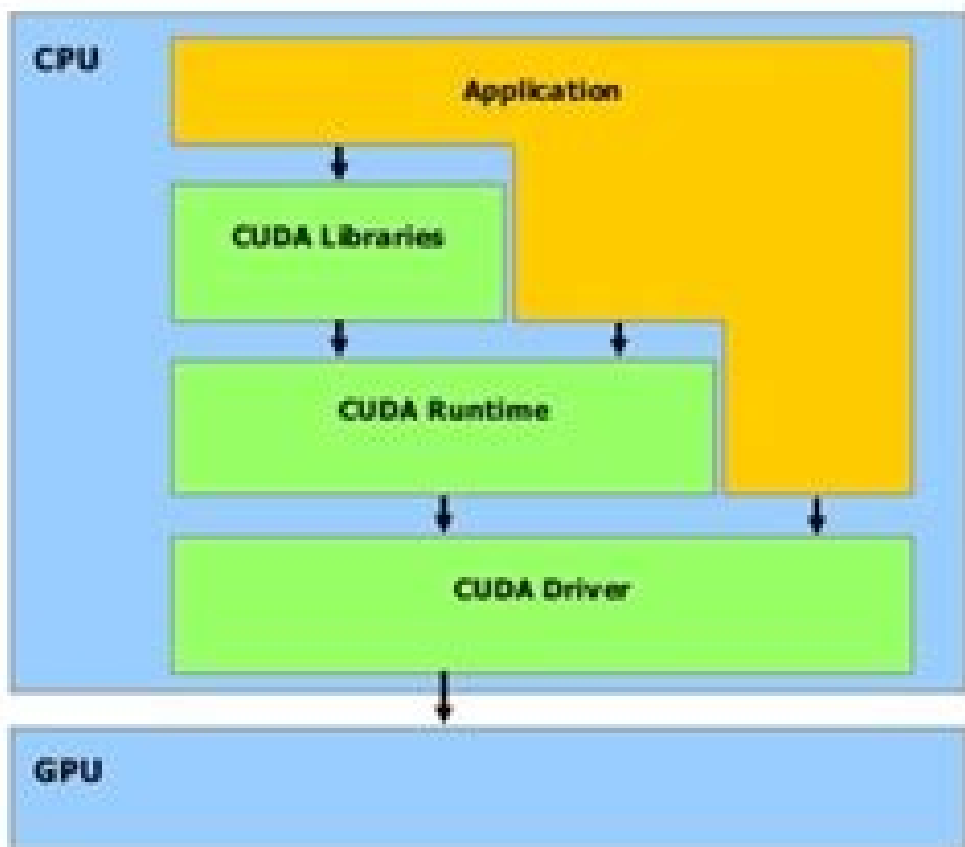


Figure 1-3. Compute Unified Device Architecture Software Stack

The CUDA API comprises an extension to the C programming language for a minimum learning curve (see Chapter 4).



NVIDIA CUDA Compute Unified Device Architecture

Programming Guide

Version 0.8.2

4/24/2007

Cuda 8 install. Cuda installation instructions. Cuda installation guide. Cuda installation guide linux.

Click on the green buttons that describe your target platform. Only supported platforms will be shown. Do you want to cross-compile? Click on the green buttons that describe your host platform. Only supported platforms will be shown. See the Release Notes and EULA. After compilation, find and run deviceQueryfrom . If the CUDA software is installed and configured correctly, the output for deviceQuery should look similar to that shown in Figure 1. Figure 1. Valid Results from deviceQuery CUDA Sample The exact appearance and the output lines might be different on your system. The important outcomes are that a device was found (the first highlighted line), that the device matches the one on your system (the second highlighted line), and that the test passed (the final highlighted line). If a CUDA-capable device and the CUDA Driver are installed but deviceQuery reports that no CUDA-capable devices are present, this likely means that the /dev/nvidia* files are missing or have the wrong permissions. On systems where SELinux is enabled, you might need to temporarily disable this security feature to run deviceQuery. To do this, type: setenforce 0 from the command line as the superuser. Running the bandwidthTest program ensures that the system and the CUDA-capable device are able to communicate correctly. Its output is shown in Figure 2. Figure 2. Valid Results from bandwidthTest CUDA Sample Note that the measurements for your CUDA-capable device description will vary from system to system. The important point is that you obtain measurements, and that the second-to-last line (in Figure 2) confirms that all necessary tests passed. Should the tests not pass, make sure you have a CUDA-capable NVIDIA GPU on your system and make sure it is properly installed. If you run into difficulties with the link step (such as libraries not being found), consult the Linux Release Notes found in . If you want to train deep neural networks, you should probably be familiar with packages like Caffe, Keras, TensorFlow, Theano, and Torch. These libraries use GPU computation power that you will probably want to use to further speed up training, which can be very long on CPU. No news so far, specially if you are an experienced machine learning engineer. However, the experience of installing CUDA on Ubuntu may be very frustrating. These are the most frequent causes: You were greeted by a black screen after installing Nvidia Driver You got stuck in "login loop" after installing Nvidia Driver When you tried to run the base installer (cuda_linux.run) you received this lovely message (specially on EC2 instances) : "The driver installation is unable to locate the kernel source. Please make sure that the kernel source packages are installed and set up correctly. If you know that the kernel source packages are installed and set up correctly, you may pass the location of the kernel source with the '--kernel-source-path' flag." Even though there are tons of tutorials over the web, I have lost a considerable amount of time and I have spent days installing CUDA on Ubuntu over different computers, whether laptops or desktops. You might be familiar with most of the steps presented here, so don't mind jumping a few steps until you find something useful. Kill your current X server session by pressing CTRL+ALT+F1 and login using your credentials. sudo service lightdm stop X is an application that manages one or more graphic displays. Makes total sense to disable it since its main component is responsible for resizing and moving of windows, decorative elements, title bars, minimize, close buttons, etc. [Ref] 1. Update your system sudo apt-get update sudo apt-get upgrade -y sudo apt-get dist-upgrade -y Keeping your system up to date is essential, right? Ubuntu images are not updated constantly and you are probably using a snapshot from a point in time. [Ref] 2. Install build-essential package sudo apt-get install build-essential If some library needs a C/C++ compiler, you need to install build-essential. [Ref] 3. Blacklist the "nouveau" driver echo -e "blacklist nouveaublacklist lbn-nouveaoptions nouveau modeset=0alias nouveau offias lbn-nouveau off" | sudo tee /etc/modprobe.d/blacklist-nouveau.conf echo options nouveau modeset=0 | sudo tee -a /etc/modprobe.d/nouveau-kms.conf sudo update-initramfs -u Reboot the computer and repeat step 1. Nouveau is a free and open-source driver developed by reverse engineering Nvidia's proprietary Linux drivers. We can't use it for multiple reasons: inferior performance compared to Nvidia's proprietary graphics device drivers, no CUDA support, and we need to configure the xserver accordingly to avoid black screen/login loop issues, in other words, let's disable conflicting modules. 4. Install linux kernel modules When asked about grub changes select choose package maintainers version. apt-get install linux-image-extra-virtual This is tricky. Especially if you are using an EC2 instance. This link gives you a good explanation why this is needed. However, I will quote the important piece: "Nvidia's driver depends on the drm module, but that's not included in the default 'virtual' ubuntu that's on the cloud (as it usually has no graphics). It's available in the linux-image-extra-virtual package (and linux-image-generic supposedly), but just installing those directly will install the drm module for the NEWEST available kernel, not the one we're currently running. Hence, we need to specify the version manually. This command will probably need to be re-run every time you upgrade the kernel and reboot." 5. Install linux source and headers apt-get install linux-source apt-get source linux-image-\${uname -r} apt-get install linux-headers-\${uname -r} This is also needed to avoid the "unable to locate the kernel source" message! CUDA toolkit documentation may not be very appealing to some, but I will also quote another important piece that explicitly says: "The CUDA Driver requires that the kernel headers and development packages for the running version of the kernel be installed at the time of the driver installation, as well whenever the driver is rebuilt. For example, if your system is running kernel version 3.17.4-301, the 3.17.4-301 kernel headers and development packages must also be installed." 5. Install CUDA 8.0 Run the following commands:- ---- Your log may be similar to this: Do you accept the previously read EULA? (accept/decline/quit): accept Install NVIDIA Accelerated Graphics Driver for Linux-x86_64 375.26? ((y)es/(n)o/(q)uit): y Install the CUDA 8.0 Toolkit? ((y)es/(n)o/(q)uit): ((y)es/(n)o/(q)uit): y Enter Toolkit Location [default is /usr/local/cuda-8.0]: Do you want to install a symbolic link at /usr/local/cuda? ((y)es/(n)o/(q)uit): y Install the CUDA 8.0 Samples? ((y)es/(n)o/(q)uit): y Enter CUDA Samples Location [default is /home/user]: /usr/local/cuda-8.0 The "--override" is needed so you don't get the error, "Toolkit: Installation Failed. Using unsupported Compiler." The "--no-opengl-lib" prevents the driver installation from installing NVIDIA's GL libraries. Useful for systems where the display is driven by a non-NVIDIA GPU. In such systems, NVIDIA's GL libraries could prevent X from loading properly. This flag is very important to avoid getting stuck in "login loop" or black screen! Wait.. something is still not quite right! I am still receiving a message saying 'the driver installation is unable to locate the kernel source'. Even though I am using the flag --kernel-source-path= !!!! So.. let's check the following log file: sudo vi /var/log/nvidia-installer.log It says: "ERROR: The kernel module failed to load, because it was not signed by a key that is trusted by the kernel. Please try installing the driver again, and sign the kernel module when prompted to do so. ERROR: Unable to load the kernel module 'nvidia.ko'. This happens most frequently when this kernel module was built against the wrong or improperly configured kernel sources, with a version of gcc that differs from the one used to build the target kernel, or if a driver such as rivafb, nvidiafb, or nouveau is present and prevents the NVIDIA kernel module from obtaining ownership of the NVIDIA graphics device(s), or no NVIDIA GPU installed in this system is supported by this NVIDIA Linux graphics driver release." Usually the error "Unable to load the kernel module 'nvidia.ko'" is associated with dkms and installing linux kernel modules on step 4 might be enough. [See here] However, my experience installing CUDA on a desktop computer showed me something different. Especially because of what the first paragraph says! And there you have it: Many linux distributions require modules to be cryptographically signed by a key trusted by the kernel when these modules are loaded into kernels running on UEFI systems with Secure Boot enabled. For those who did not get the last piece, the Unified Extensible Firmware Interface (UEFI) is a specification that defines a software interface between an operating system and platform firmware. UEFI replaces the Basic Input/Output System (BIOS) firmware interface originally present in all IBM PC-compatible personal computers. Here, you can find details about how to generate signing keys in nvidia-installer. Easy alternative? Disable UEFI Secure Boot (if possible), or use a kernel that doesn't require signed modules. How to disable Secure Boot on Ubuntu, then!/? Since Ubuntu kernel build 4.4.0-21.37 this can be fixed by running: sudo apt install mokutil sudo mokutil Since questions may arise, see third party kernel modules on UEFI with enabled Secure Boot and the consequences of disabling it. I hope after this you were able to see the "beautiful" nvidia-smi message on your terminal, similar to the one above. Wheels (precompiled binary packages) are available for Linux and Windows. Package names are different depending on your CUDA Toolkit version. CUDA Command v10.2 (x86_64) pip install cupy-cuda102 -f v11.0 (x86_64) pip install cupy-cuda110 v11.1 (x86_64) pip install cupy-cuda111 v11.2 or later (x86_64) pip install cupy-cuda11x v11.2 or later (aarch64 - JetPack 5 / Arm SBSA) pip install cupy-cuda11x -f Note To enable features provided by additional CUDA libraries (cuTENSOR / NCCL / cuDNN), you need to install them manually. If you installed CuPy via wheels, you can use the installer command below to setup these libraries in case you don't have a previous installation: \$ python -m cupyx.tools.install_library --cuda 11.x --library cutensor Note Append --pre -f options to install pre-releases (e.g., pip install cupy-cuda11x --pre -f . When using wheels, please be careful not to install multiple CuPy packages at the same time. Any of these packages and cupy package (source installation) conflict with each other. Please make sure that only one CuPy package (cupy or cupy-cudaXX where XX is a CUDA version) is installed: Conda/Anaconda is a cross-platform package management solution widely used in scientific computing and other fields. The above pip install instruction is compatible with conda environments. Alternatively, for both Linux (x86_64, ppc64le, aarch64-sbsa) and Windows once the CUDA driver is correctly set up, you can also install CuPy from the conda-forge channel: \$ conda install -c conda-forge cupy and conda will install a pre-built CuPy binary package for you, along with the CUDA runtime libraries (cudatoolkit). It is not necessary to install CUDA Toolkit in advance. Conda has a built-in mechanism to determine and install the latest version of cudatoolkit supported by your driver. However, if for any reason you need to force-install a particular CUDA version (say 11.0), you can do: \$ conda install -c conda-forge cupy cudatoolkit=11.0 Note cuDNN, cuTENSOR, and NCCL are available on conda-forge as optional dependencies. The following command can install them all at once: \$ conda install -c conda-forge cupy cudnn cutensor nccl Each of them can also be installed separately as needed. Note If you encounter any problem with CuPy installed from conda-forge, please feel free to report to cupy-feedstock, and we will help investigate if it is just a packaging issue in conda-forge's recipe or a real issue in CuPy. Note If you did not install CUDA Toolkit by yourself, the nvcc compiler might not be available, as the cudatoolkit package from conda-forge does not include the nvcc compiler toolchain. If you would like to use it from a local CUDA installation, you need to make sure the version of CUDA Toolkit matches that of cudatoolkit to avoid surprises. Use of wheel packages is recommended whenever possible. However, if wheels cannot meet your requirements (e.g., you are running non-Linux environment or want to use a version of CUDA / cuDNN / NCCL not supported by wheels), you can also build CuPy from source. Note CuPy source build requires g++-6 or later. For Ubuntu 18.04, run apt-get install g++-6. For Ubuntu 16.04, CentOS 6 or 7, follow the instructions here. Note When installing CuPy from source, features provided by additional CUDA libraries will be disabled if these libraries are not available at the build time. See Installing cuDNN and NCCL for the instructions. Note If you upgrade or downgrade the version of CUDA Toolkit, cuDNN, NCCL or cuTENSOR, you may need to reinstall CuPy. See Reinstalling CuPy for details. You can install the latest stable release version of the CuPy source package via pip. If you want to install the latest development version of CuPy from a cloned Git repository: \$ git clone --recursive \$ cd cupy \$ pip install . Note Cython 0.29.22 or later is required to build CuPy from source. It will be automatically installed during the build process if not available.

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