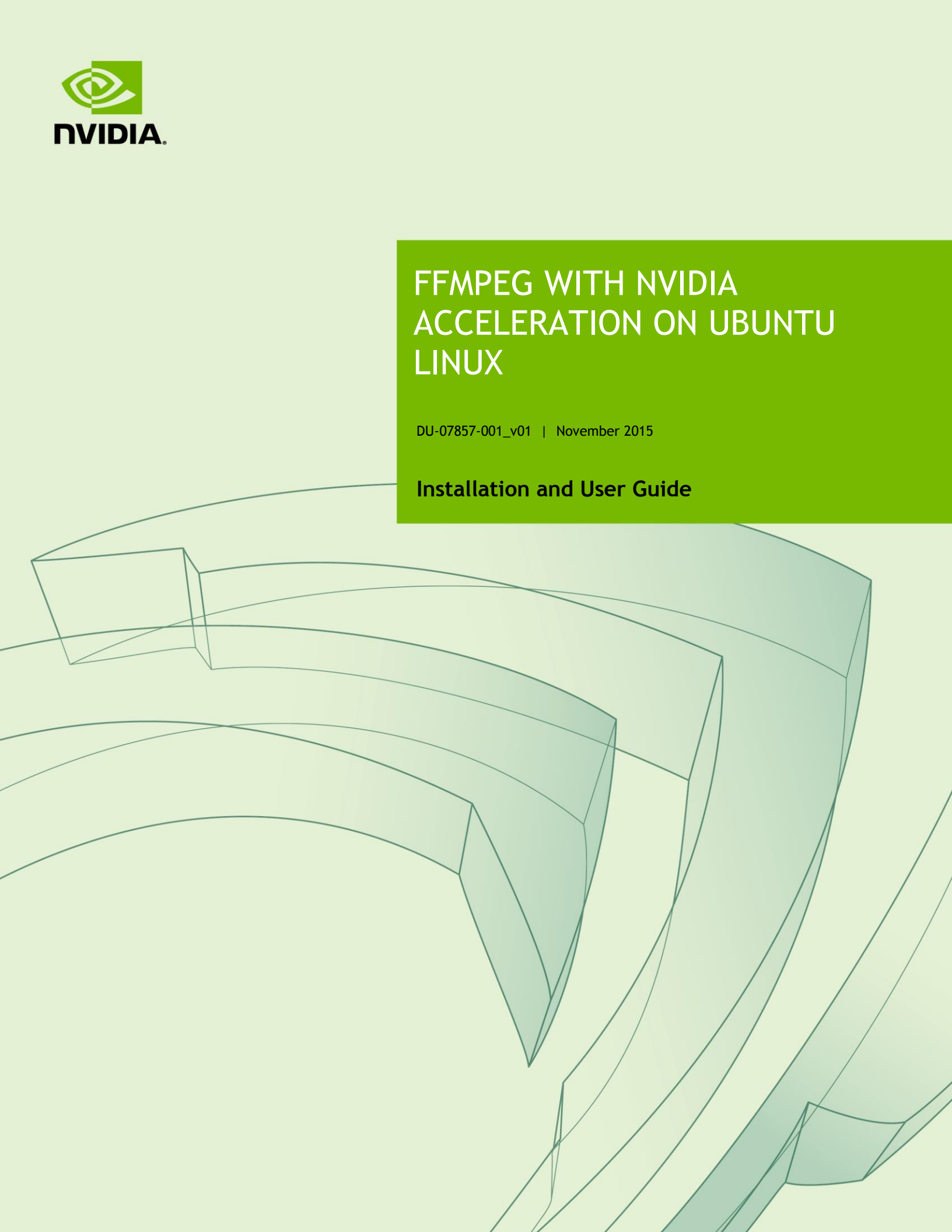

FFMPEG WITH NVIDIA ACCELERATION ON UBUNTU LINUX

DU-07857-001_v01 | November 2015

Installation and User Guide

DOCUMENT CHANGE HISTORY

DU-07857-001_v01

Version	Date	Authors	Description of Change
01	11/09/2015	ER	Initial release

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STEP-BY-STEP SETUP AND INSTALLATION

This chapter describes how to obtain and install the necessary software for using FFmpeg with Ubuntu Linux (from 14.04 on). **The tasks must be completed in the order that they appear**. When finished, you'll have FFmpeg with support for the following:

- NVIDIA
  - NVENC (NVIDIA H/W Fixed Function video encoder for h.264 and HEVC)
  - GPU zero-copy engine
  - GPU accelerated resizer
- libx264 (x264 open source video codec for h.264/AVC)

INITIAL SETUP

These instructions assume a fresh install of x86_64 (64bit) Ubuntu 14.04 LTS.

If you are using another Linux distribution make sure that the NVIDIA display driver is at least r352.39. There are no other host specific requirements other than being x86_64 (64bit).

1. Install Ubuntu workstation (or server*).
   *not tested
2. Boot the PC.
3. Log in as your username.
   You'll need **internet access** and **`sudo privilege`** to run this install sequence.
4. Install the build infrastructure packages.

```
~ $ sudo apt-get install build-essential git yasm unzip wget sysstat
```

Note: Before you begin to run commands to install FFmpeg you'll need to get some NVIDIA Ubuntu packages and the NVENC SDK.

5. Download the NVIDIA Ubuntu packages into a directory called *Ubuntu*.

```
cd ~
~ $ mkdir Ubuntu
~ $ cd Ubuntu
~/Ubuntu $
```

INSTALL THE DISPLAY DRIVER

1. To use NVENC on Linux the display driver must be version 352.39 or later. GPUs based on the Kepler or Maxwell architecture are supported.
2. There are two mechanisms to install NVIDIA display drivers.
   - Within the Ubuntu application management system (via .deb files)
   - A standalone installer (via .run files)

   These cannot be mixed together. Since we are assuming a fresh install in these instructions we will continue to use the Ubuntu system.

   NVIDIA Display Driver Ubuntu packages are released with each CUDA SDK. The CUDA 7.5 SDK repository from the NVIDIA developer's site has Display Driver r352.39 integrated.

   We will download the CUDA 7.5 SDK to use that driver.

   Note: If you wish to use a more current version of the Display Driver you can download it from http://www.nvidia.com/Download/index.aspx.
   Before installation you must first uninstall all NVIDIA Ubuntu packages. See step 9 below for instructions on stopping the desktop, unloading and uninstalling the Ubuntu driver.

   All the commands you will need to run are in **bold** below.

   Note: ONLY download the version that matches your OS.

3. You can manually download the driver following this link.

   https://developer.nvidia.com/cuda-downloads

4. Below is an example of downloading the Ubuntu 14.04 LTS deb (network) version. The network version is a small (2.1k) package that will go to the internet for the actual packages only when those parts are installed.

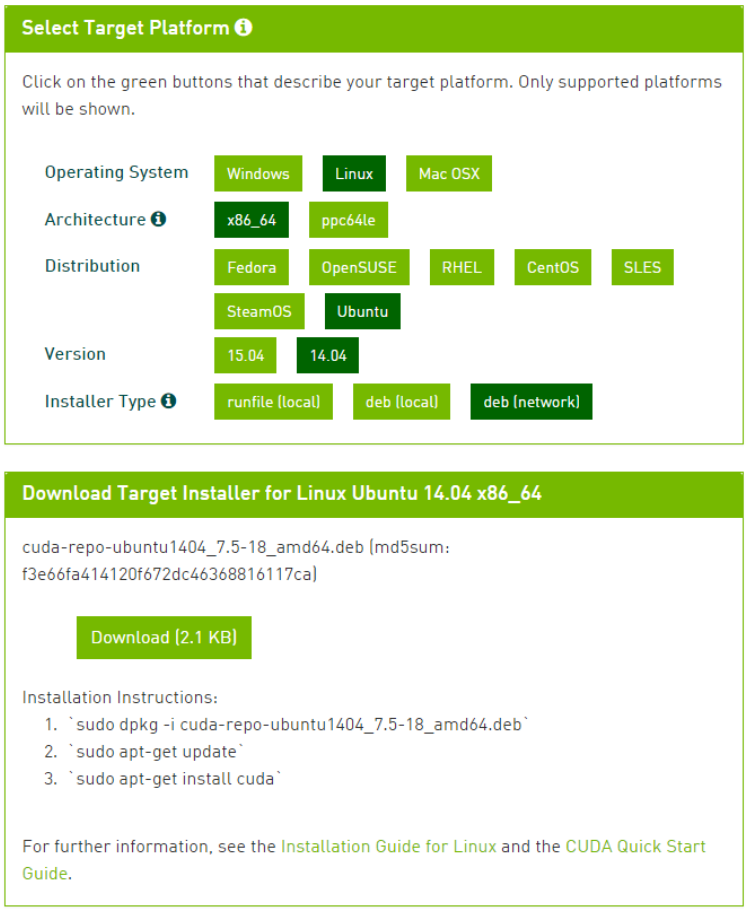


Figure 1 - Selecting the 64bit Ubuntu 14.04 LTS network Ubuntu package

5. Save the above file in the *~/Ubuntu* directory or use the command line utility *wget* to download the file using this URL.

```
~/Ubuntu $ wget
http://developer.download.nvidia.com/compute/cuda/repos/ubuntu1404/x86_64/cuda-repo-ubuntu1404_7.5-18_amd64.deb
```

6. If your computer will not always have internet access you can download the local version instead. It has the display driver and all the CUDA development packages so it is a sizable 1.9GB.

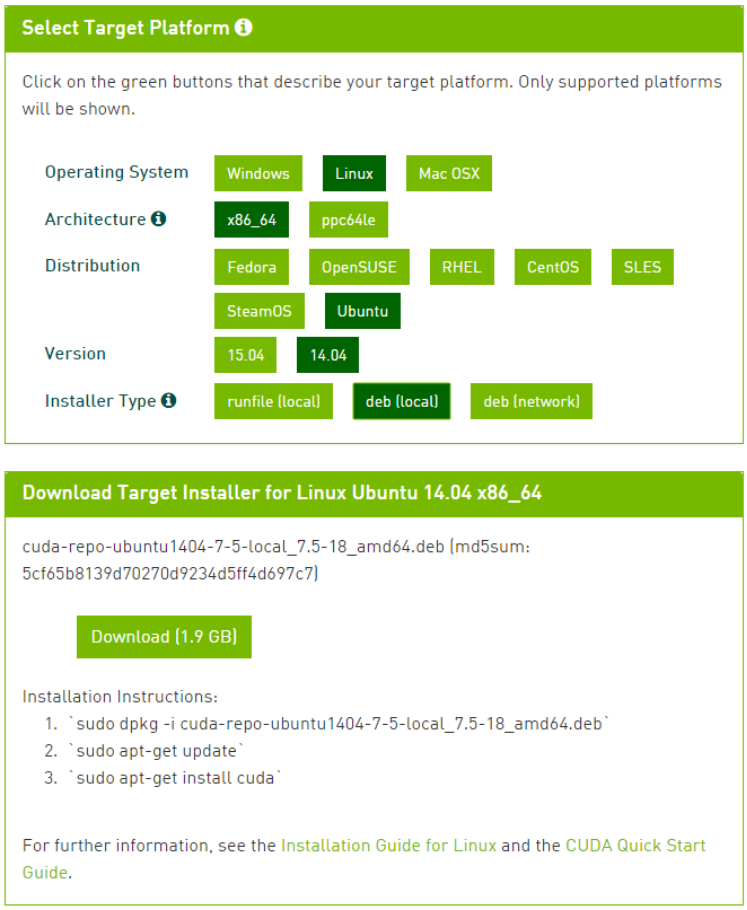


Figure 2 - Selecting the 64bit Ubuntu 14.04 LTS local Ubuntu package

7. Save the above file in the *~/Ubuntu* directory or use the command line utility *wget* to download the file using this URL.

```
~/Ubuntu $ wget
http://developer.download.nvidia.com/compute/cuda/7.5/Prod/local_installers/
cuda-repo-ubuntu1404-7-5-local_7.5-18_amd64.deb
```

8. Add the repository you downloaded to your local repository.

```
~/Ubuntu $ sudo dpkg -i cuda-repo-ubuntu1404*_7.5-18_amd64.deb

~/Ubuntu $ sudo apt-get update
```

9. Before we can install the NVIDIA display driver we will need to turn off the desktop and go back to a terminal prompt.

```
~/Ubuntu $ sudo service lightdm stop
```

10. If you do not see a text prompt you will need to change to another virtual console. To do that press Alt-F1 or Alt-F2. You will then see a login prompt. Login as usual.

11. We now need to unload and remove the existing NVIDIA drivers. First we will see what is loaded.

```
~/Ubuntu $ lsmod | grep nvidia
nvidia_uvm             76757  0
nvidia               8604684  1 nvidia_uvm
drm                   303102  1 nvidia
```

Remove each module in the reverse order of use. In the printout above you can see that *nvidia* is used by *nvidia_uvm* so we have to remove *nvidia_uvm* that first then *nvidia*.

```
~/Ubuntu $ sudo rmmod nvidia_uvm
~/Ubuntu $ sudo rmmod nvidia
```

12. Once no NVIDIA modules are loaded we can uninstall the driver

```
~/Ubuntu $ sudo apt-get remove nvidia*
```

Note: If you are using a newer display driver skip step 13 below and run the standalone installer instead. Click Accept and click through all the default options.

e.g. `~/Ubuntu $ sudo ./NVIDIA-Linux-x86_64-352.55.run`

13. Install the NVIDIA display driver bundled in the CUDA 7.5 SDK repository you downloaded from above.

```
~/Ubuntu $ sudo apt-get install nvidia-352
```

14. Once installed restart the desktop.

```
~/Ubuntu $ sudo service lightdm start
~/Ubuntu $ sudo restart
```

NVENC SDK

1. Get the NVENC SDK from the NVIDIA developer's site.

   https://developer.nvidia.com/nvidia-video-codec-sdk

   By clicking the link below or downloading via *"wget"*, you are confirming that you have read and agree to be bound by the NVIDIA VIDEO CODEC SDK LICENSE AGREEMENT.

   http://developer.download.nvidia.com/compute/nvenc/v5.0/nvenc_5.0.1_sdk.zip

2. Copy the NVENC SDK to ~/Development.

```
~ $ mkdir Development

~ $ cd Development

~/Development $ wget
    http://developer.download.nvidia.com/compute/nvenc/v5.0/nvenc_5.0.1_sdk
    .zip

~/Development $ unzip nvenc_5.0.1_sdk.zip
```

3. Copy the NVENC headers to */usr/local/include* to make it easier later.

```
~/Development $ sudo cp nvenc_5.0.1_sdk/Samples/common/inc/*.h
    /usr/local/include
```

CUDA UTILITY

1. Download and install a light-weight library to communicate with the CUDA display driver.

```
~/Development/ $ wget
    http://developer.download.nvidia.com/compute/redist/ffmpeg/1511-
    patch/cudautils.zip
```

2. Copy the CUDA utility to ~/Development/.

```
~/Development/ $ unzip cudautils.zip

~/Development/cudautils/ $ cd cudautils
```

3. Build the CUDA utility.

```
~/Development/cudautils/ $ make

~/Development/cudautils/ $ cd ..

~/Development/ $
```

OPEN SOURCE LIBRARIES

Download and install all the open source libraries.

1. Get x264.

```
~/Development $ git clone git://git.videolan.org/x264.git

~/Development $ cd x264
```

2. Configure x264.

```
~/Development/x264 $ ./configure \
                            --disable-cli \
                            --enable-static \
                            --enable-shared \
                            --enable-strip
```

3. Build x264.

```
~/Development/x264 $ make -j 10
```

4. Install x264.

```
~/Development/x264 $ sudo make install

~/Development/x264 $ sudo ldconfig

~/Development/x264 $ cd ..

~/Development/ $
```

BUILD IT ALL TOGETHER...

1. Get FFmpeg.

```
~/Development/ $ git clone git://source.ffmpeg.org/ffmpeg.git
```

2. Download the NVIDIA acceleration.

```
~/Development/ $ wget
    http://developer.download.nvidia.com/compute/redist/ffmpeg/1511-
    patch/ffmpeg_NVIDIA_gpu_acceleration.patch

~/Development/ $ cd ffmpeg
```

3. Apply the NVIDIA acceleration patch. Note that this patch was created against the git master commit:

```
commit b83c849e8797fbb972ebd7f2919e0f085061f37f

Date:   Tue Nov 10 04:14:55 2015 +010

~/Development/ffmpeg $ git apply ../ffmpeg_NVIDIA_gpu_acceleration.patch
```

4. Configure FFmpeg with NVENC, NVRESIZE and x264 support.

```
~/Development/ffmpeg $ cd ..

~/Development/ $ mkdir ffmpeg_build

~/Development/ $ cd ffmpeg_build

~/Development/ffmpeg_build $ ../ffmpeg/configure  --enable-nonfree \
                                                   --enable-nvenc \
                                                   --enable-nvresize \
                                                   --extra-cflags=-I../cudautils \
                                                   --extra-ldflags=-L../cudautils \
                                                   --enable-gpl \
                                                   --enable-libx264
```

5. Build FFmpeg.

```
~/Development/ffmpeg_build $ make -j 10
```

6. Check that FFmpeg works. If NVENC and libx264 built properly you should get them in this list of encoders. We can filter the list down to h.264 encoders with "*grep 264*".

```
~/Development/ffmpeg_build $ ./ffmpeg -encoders | grep 264
ffmpeg version N-76328-g1b82a00 Copyright (c) 2000-2015 the FFmpeg developers
  built with gcc 4.8 (Ubuntu 4.8.4-2ubuntu1~14.04)
  configuration: --enable-nonfree --enable-nvenc --enable-nvresize --extra-cflags=-I../cudautils
     --extra-ldflags=-L../cudautils --enable-gpl --enable-libx264
  libavutil      55.  4.100 / 55.  4.100
  libavcodec     57. 12.100 / 57. 12.100
  libavformat    57. 11.100 / 57. 11.100
  libavdevice    57.  0.100 / 57.  0.100
  libavfilter     6. 14.100 /  6. 14.100
  libswscale      4.  0.100 /  4.  0.100
  libswresample   2.  0.100 /  2.  0.100
  libpostproc    54.  0.100 / 54.  0.100
 V..... libx264              libx264 H.264 / AVC / MPEG-4 AVC / MPEG-4 part 10 (codec h264)
 V..... libx264rgb           libx264 H.264 / AVC / MPEG-4 AVC / MPEG-4 part 10 RGB (codec h264)
 V..... nvenc                NVIDIA NVENC h264 encoder (codec h264)
 V..... nvenc_h264           NVIDIA NVENC h264 encoder (codec h264)
```

7. Check that FFmpeg has the NVRESIZE video filter. We can filter the list down with "*grep nvresize*".

```
~/Development/ffmpeg_build $ ./ffmpeg -filters | grep nvresize
ffmpeg version N-76328-g1b82a00 Copyright (c) 2000-2015 the FFmpeg developers
  built with gcc 4.8 (Ubuntu 4.8.4-2ubuntu1~14.04)
  configuration: --enable-nonfree --enable-nvenc --enable-nvresize --extra-cflags=-I../cudautils
     --extra-ldflags=-L../cudautils --enable-gpl --enable-libx264
  libavutil      55.  4.100 / 55.  4.100
  libavcodec     57. 12.100 / 57. 12.100
  libavformat    57. 11.100 / 57. 11.100
  libavdevice    57.  0.100 / 57.  0.100
  libavfilter     6. 14.100 /  6. 14.100
  libswscale      4.  0.100 /  4.  0.100
  libswresample   2.  0.100 /  2.  0.100
  libpostproc    54.  0.100 / 54.  0.100
... nvresize         V->N       GPU accelerated video resizer.
```

8. Install FFmpeg.

```
~/Development/ffmpeg_build $ sudo make install

~/Development/ffmpeg_build $ sudo ldconfig

~/Development/ffmpeg_build $ cd ..

~/Development/ $ cd ..

~/ $
```

USING FFMPEG WITH NVENC

The following command lines will compare NVENC to x264:

TRANSCODE PERFORMANCE

This comparison will measure the time taken to transcode an input file to h.264 @5Mbps. It will copy the audio track to the output (if present).

In the interest of space and avoiding line wrapping in this document the Linux "continue command on next line" operator will be used ('\') to wrap the command to the next line.

Using NVENC:

```
~/ $ time ffmpeg -y -i <mp4 input file> \
                -vcodec nvenc -b:v 5M \
                -acodec copy \
                <OUTPUT.mp4>
```

Using x264:

```
~/ $ time ffmpeg -y -i <INPUT.mp4> \
                -vcodec libx264 -b:v 5M \
                -acodec copy \
                OUTPUT.mp4
```

MEASURING CPU AND GPU UTILIZATION

When comparing NVENC to x264 it is useful to monitor the CPU and GPU utilization. To do this we will use two command line tools.

CPU Utilization

The important column is the cpu “us” (user) utilization.

```
ubuntu@localmachine:~$ vmstat -w -n 1

procs ---------------memory-------------- ---swap-- -----io---- -system-- ------cpu-----
 r  b      swpd      free      buff     cache   si   so    bi    bo   in     cs us sy id wa st
 9  0     29748    187236    170928    445720    0    0   384     0 4522 10101 81  0 19  0  0
 5  0     29748    183020    170928    449664    0    0  2432     0 4668 11630 80  0 19  0  0
12  0     29748    179424    170936    452716    0    0  2304    12 4571 11792 75  0 25  0  0
 9  0     29748    176820    170936    455496    0    0  1408    52 4809 10742 83  0 17  0  0
14  0     29748    174092    170936    458180    0    0  1536     0 4925 10767 84  0 15  0  0
15  1     29748    170992    170936    460920    0    0  1664     0 4652 10504 80  0 20  0  0
```

GPU Utilization

The NVENC utilization can be seen in the “enc” column. The “sm” column is the CUDA workload. We will use this later when doing GPU resize.

```
ubuntu@localmachine:~$ nvidia-smi dmon -i 0

# gpu    pwr  temp    sm   mem   enc   dec  mclk  pclk
# Idx      W     C     %     %     %     %   MHz   MHz
    0     82    35    12     4    86     0  3304  1151
    0     82    35    11     4    90     0  3304  1151
    0     83    35    11     4    93     0  3304  1151
    0     83    35    12     5    92     0  3304  1151
    0     83    36    11     4    94     0  3304  1151
    0     83    36     9     4    96     0  3304  1151
```

MULTIPLE OUTPUTS FROM AN INPUT (1:N)

In many scenarios multiple output formats are created at the same time from the input format.

Software resize is CPU intensive and quickly bottlenecks the ability to encode. For that reason, NVIDIA has implemented a GPU zero-copy engine to share frames between plugins as well as a video filter that does GPU resize ("nvresize").

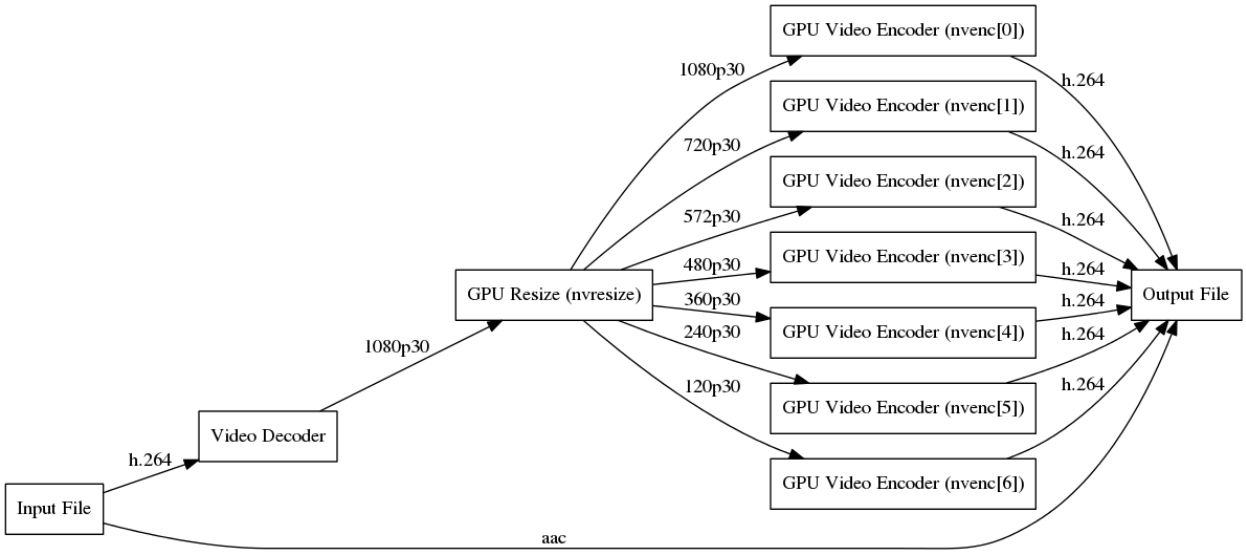


Figure 3 - A typical 1:n resize scenario

In the Figure above the video is resized into 7 formats and combined as different video streams in a single output container. The audio stream is copied from the input container to the new output container.

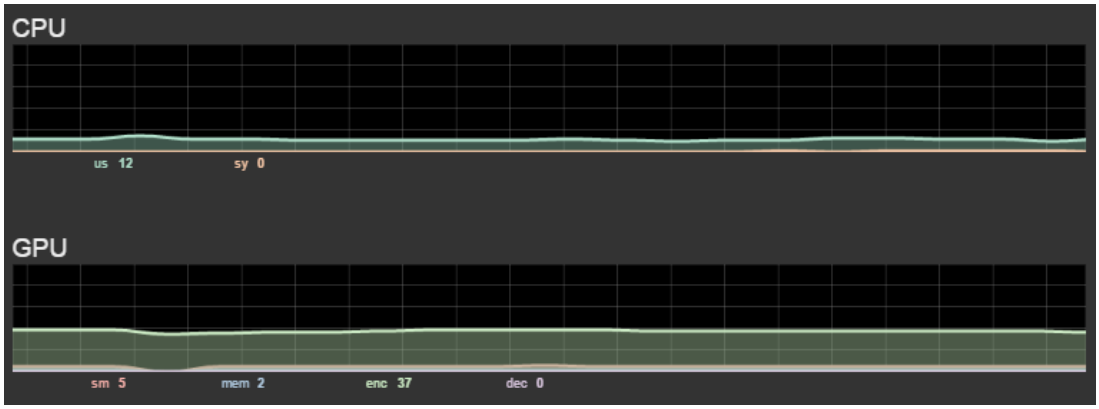
Resize Example

In the following example we will take a 1080p30 input file and downsize it to 5 formats, each stream is encoded with NVENC and then the output stream is put in its own container output file along with a copy of the audio (if present).

- Software resize provided resized frames at 75fps (375fps total - using 37% NVENC utilization).
- GPU resize provided resized frames at 190fps (950fps total - capped by 100% NVENC utilization).

Software based resize:

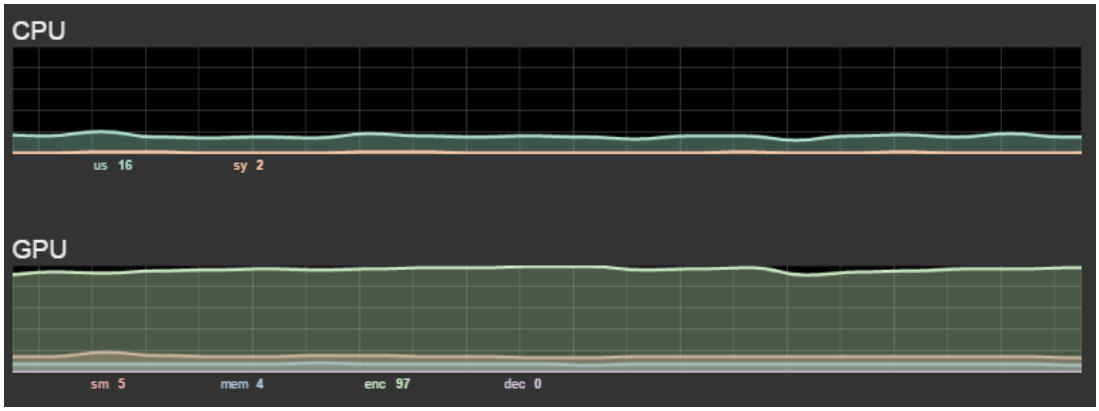
```
~/ $ time ffmpeg -y -i INPUT.mp4 \
   -acodec copy -vcodec nvenc -b:v 5M -s hd1080 out1sw.mkv \
   -acodec copy -vcodec nvenc -b:v 4M -s hd720  out2sw.mkv \
   -acodec copy -vcodec nvenc -b:v 3M -s hd480  out3sw.mkv \
   -acodec copy -vcodec nvenc -b:v 2M -s wvga   out4sw.mkv \
   -acodec copy -vcodec nvenc -b:v 1M -s cif    out5sw.mkv
```



GPU Accelerated Resize

Note how the pipe character '|' has to be escaped "\|" for a bash shell.

```
~/ $ time ffmpeg -y -i INPUT.mp4 -filter_complex \

      nvresize=5:s=hd1080\|hd720\|hd480\|wvga\|cif:readback=0[out0][out1]
            [out2][out3][out4] \

      -map [out0] -acodec copy -vcodec nvenc -b:v 5M out0nv.mkv \

      -map [out1] -acodec copy -vcodec nvenc -b:v 4M out1nv.mkv \

      -map [out2] -acodec copy -vcodec nvenc -b:v 3M out2nv.mkv \

      -map [out3] -acodec copy -vcodec nvenc -b:v 2M out3nv.mkv \

      -map [out4] -acodec copy -vcodec nvenc -b:v 1M out4nv.mkv
```



TRANSCODE QUALITY

The above performance tests relied heavily on the default parameters. The quality of the output has not been optimized. We can make the output better by adjusting some of the encoding parameters.

These parameters are generic FFmpeg commands so they apply to NVENC and x264. The following commands can be run again using x264 for comparison to NVENC by changing the "vcodec" from "nvenc" to "libx264".

In the following examples we will add a tuning one by one. Each change is highlighted in yellow.

Presets

First we will use a higher quality preset. The NVENC "slow" preset turns on 2-pass encoding. This improves the rate control as well as the quality. We'll discuss rate control later in these examples.

```
~/ $ time ffmpeg -y -i INPUT.mp4 \
        -vcodec nvenc -preset slow -b:v 5M \
        -acodec copy \
        OUTPUT.mp4
```

VBV Buffer

The H.264 standard includes a section called the VUI information. This describes how fast the video stream can be transmitted and the size of the FIFO buffer on the target decoder. Defining the VUI buffer size (VBV) as well as the maximum rate it can be filled controls how much the current bitrate can deviate from the target bitrate. A good size for the VBV is 2 seconds of video - thus twice the size of the desired target bitrate. In this example, let's allow it to fill at twice the target bitrate.

```
~/ $ time ffmpeg -y -i INPUT.mp4 \
        -vcodec nvenc -preset slow -b:v 5M \
                -maxrate 10M -bufsize:v 10M -bf 2 -ref 1 \
        -acodec copy \
        OUTPUT.mp4
```

B-Frames

Next we will add B-frames. These are the most efficient frames in the H.264 standard.

We will also limit to one reference frame (for broader H.264 player compatibility). Reference frames are the frames that can be referred to by B frames.

```
~/ $ time ffmpeg -y -i INPUT.mp4 \
        -vcodec nvenc -preset slow -b:v 5M \
                    -maxrate 10M -bufsize:v 10M -bf 2 -ref 1 \
                    -bf 2 -ref 1 \
        -acodec copy \
        OUTPUT.mp4
```

Group of Pictures (GOP)

Next we will define the order of I, P, and B frames. A collection of these is called a GOP. When you seek back and forth on video you must start at a GOP boundary. For internet video this is typically 5 seconds. For control over the experience, for example on Blu-ray, it's 1 second. Let's use a 5-second GOP in this example and assume the input is 30fps - thus the GOP is 30x5 = 150.

Setting the number of B-frames and the GOP defines the order of I, P, and B frames.

For example: B-frames = 2, GOP = 15 would result in

```
I   P   B   B   P   B   B   P   B   B   P   B   B   P   I
1   2   3   4   5   6   7   8   9   10  11  12  13  14  15
```

```
~/ $ time ffmpeg -y -i INPUT.mp4 \
        -vcodec nvenc -preset slow -b:v 5M \
                    -maxrate 10M -bufsize:v 10M -bf 2 -ref 1 \
                    -bf 2 -ref 1 -g 150 \
        -acodec copy \
        OUTPUT.mp4
```

Adjusting Bit Budget Ratio Between I, P, & B Frames

Next we will adjust the ratio of bits used in I, P and B frames. By adjusting this bias we can tune the overall perceived quality. This parameter is content dependent. The values in this example are for real world videos not computer generated video content like animated stories or computer gameplay.

```
~/ $ time ffmpeg -y -i INPUT.mp4 \
        -vcodec nvenc -preset slow -b:v 5M \
                    -maxrate 10M -bufsize:v 10M -bf 2 -ref 1 \
                    -bf 2 -ref 1 -g 150 \
                    -i_qfactor 1.1 -b_qfactor 1.25 \
        -acodec copy \
        OUTPUT.mp4
```

Setting Quantization Limits

Quantization is the complexity of each frame. By setting maximum and minimum limits we can control how wide the deviation is from the target bitrate. A quantization (“qp”) of 1 is basically lossless. Anything above 30 is really complex. For this example we’ll use a range of 1..50.

```
~/ $ time ffmpeg -y -i INPUT.mp4 \
        -vcodec nvenc -preset slow -b:v 5M \
                    -maxrate 10M -bufsize:v 10M -bf 2 -ref 1 \
                    -bf 2 -ref 1 -g 150 \
                    -i_qfactor 1.1 -b_qfactor 1.25 \
                    -qmin 1 -qmax 50 \
        -acodec copy \
        OUTPUT.mp4
```