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Chapter 1. Overview

NVIDIA GPUs - beginning with the NVIDIA® Fermi™ generation - contain a video decoder engine (referred to as NVDEC in this document) which provides fully-accelerated hardware video decoding capability. NVDEC can be used for decoding bitstreams of various formats: AV1, H.264, HEVC (H.265), VP8, VP9, MPEG-1, MPEG-2, MPEG-4 and VC-1. NVDEC runs completely independent of compute/graphics engine.

NVIDIA provides software API and libraries for programming NVDEC. The software API, hereafter referred to as NVDECODE API lets developers access the video decoding features of NVDEC and interoperate NVDEC with other engines on the GPU.

NVDEC decodes the compressed video streams and copies the resulting YUV frames to video memory. With frames in video memory, video post processing can be done using CUDA. The NVDECODE API also provides CUDA-optimized implementation of commonly used post-processing operations such as scaling, cropping, aspect ratio conversion, de-interlacing and color space conversion to many popular output video formats. The client can choose to use the CUDA-optimized implementations provided by the NVDECODE API for these post-processing steps or choose to implement their own post-processing on the decoded output frames.

Decoded video frames can be presented to the display with graphics interoperability for video playback, passed directly to a dedicated hardware encoder (NVENC) for high-performance video transcoding, used for GPU accelerated inferencing or consumed further by CUDA or CPU-based processing.

1.1. Supported Codecs

The codecs supported by NVDECODE API are:

- MPEG-1,
- MPEG-2,
- MPEG-4,
- VC-1,
- H.264 (AVCHD) [8 bit],
- H.265 (HEVC) [8bit, 10 bit and 12 bit],
- VP8,
- VP9 [8bit, 10 bit and 12 bit],
Overview

- AV1 Main profile,
- Hybrid (CUDA + CPU) JPEG

Refer to Chapter 2 for complete details about the video capabilities for various GPUs.
Chapter 2. Video Decoder Capabilities

Table 1 shows the codec support and capabilities of the hardware video decoder for each GPU architecture.

<table>
<thead>
<tr>
<th>GPU Architecture</th>
<th>MPEG-1 &amp; MPEG-2</th>
<th>VC-1 &amp; MPEG-4</th>
<th>H.264/AVCHD</th>
<th>H.265/HEVC</th>
<th>VP8</th>
<th>VP9</th>
<th>AV1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fermi (GF1xx)</td>
<td>Maximum Resolution: 4080x4080</td>
<td>Maximum Resolution: 2048x1024 &amp; 1024x2048</td>
<td>Maximum Resolution: 4096x4096 Profile: Baseline, Main, High profile up to Level 4.1</td>
<td>Unsupported</td>
<td>Unsupported</td>
<td>Unsupported</td>
<td>Unsupported</td>
</tr>
<tr>
<td>Kepler (GK1xx)</td>
<td>Maximum Resolution: 4080x4080</td>
<td>Maximum Resolution: 2048x1024 &amp; 1024x2048</td>
<td>Maximum Resolution: 4096x4096 Profile: Main, High profile up to Level 4.1</td>
<td>Unsupported</td>
<td>Unsupported</td>
<td>Unsupported</td>
<td>Unsupported</td>
</tr>
<tr>
<td>First generation Maxwell (GM10x)</td>
<td>Maximum Resolution: 4080x4080</td>
<td>Maximum Resolution: 2048x1024 &amp; 1024x2048</td>
<td>Maximum Resolution: 4096x4096 Profile: Baseline, Main, High profile up to Level 5.1</td>
<td>Unsupported</td>
<td>Unsupported</td>
<td>Unsupported</td>
<td>Unsupported</td>
</tr>
<tr>
<td>Second generation Maxwell (GM20x, except GM206)</td>
<td>Maximum Resolution: 4080x4080</td>
<td>Maximum Resolution: 2048x1024 &amp; 1024x2048</td>
<td>Maximum Resolution: 4096x4096 Profile: Baseline, Main, High profile up to Level 5.1</td>
<td>Unsupported</td>
<td>Maximum Resolution: 4096x4096</td>
<td>Unsupported</td>
<td>Unsupported</td>
</tr>
<tr>
<td>GPU Architecture</td>
<td>MPEG-1 &amp; MPEG-2</td>
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<td>H.264/AVCHD</td>
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<td>VP9</td>
<td>AV1</td>
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</tr>
<tr>
<td><strong>GM206</strong></td>
<td>Maximum Resolution: 4080x4080</td>
<td>Maximum Resolution: 2048x1024 &amp; 1024x2048</td>
<td>Maximum Resolution: 4096x4096 Profile: Baseline, Main, High profile up to Level 5.1</td>
<td>Maximum Resolution: 4096x2304 Profile: Main profile up to Level 5.1 and main10 profile</td>
<td>Maximum Resolution: 4096x4096 Profile: Main profile up to Level 5.1 and main10 profile</td>
<td>Maximum Resolution: 4096x2304 Profile: Main profile up to Level 5.1 and main10 profile</td>
<td>Unsupported</td>
</tr>
<tr>
<td><strong>GP100</strong></td>
<td>Maximum Resolution: 4080x4080</td>
<td>Maximum Resolution: 2048x1024 &amp; 1024x2048</td>
<td>Maximum Resolution: 4096x4096 Profile: Baseline, Main, High profile up to Level 5.1</td>
<td>Maximum Resolution: 4096x4096 Profile: Main profile up to Level 5.1, main10 and main12 profile</td>
<td>Maximum Resolution: 4096x4096 Profile: Main profile up to Level 5.1, main10 and main12 profile</td>
<td>Maximum Resolution: 4096x4096 Profile: Main profile up to Level 5.1, main10 and main12 profile</td>
<td>Unsupported</td>
</tr>
<tr>
<td><strong>GP10x/ GV100/ Turing/GA100</strong></td>
<td>Maximum Resolution: 4080x4080</td>
<td>Maximum Resolution: 2048x1024 &amp; 1024x2048</td>
<td>Maximum Resolution: 4096x4096 Profile: Baseline, Main, High profile up to Level 5.1</td>
<td>Maximum Resolution: 8192x8192 Profile: Main profile up to Level 5.1, main10 and main12 profile</td>
<td>Maximum Resolution: 8192x8192 Profile: Main profile up to Level 5.1, main10 and main12 profile</td>
<td>Maximum Resolution: 8192x8192 Profile: Main profile up to Level 5.1, main10 and main12 profile</td>
<td>Unsupported</td>
</tr>
<tr>
<td><strong>GA10x</strong></td>
<td>Maximum Resolution: 4080x4080</td>
<td>Maximum Resolution: 2048x1024 &amp; 1024x2048</td>
<td>Maximum Resolution: 4096x4096 Profile: Baseline, Main, High profile up to Level 5.1</td>
<td>Maximum Resolution: 8192x8192 Profile: Main profile up to Level 5.1, main10 and main12 profile</td>
<td>Maximum Resolution: 8192x8192 Profile: Main profile up to Level 5.1, main10 and main12 profile</td>
<td>Maximum Resolution: 8192x8192 Profile: Main profile up to Level 5.1, main10 and main12 profile</td>
<td>Unsupported</td>
</tr>
</tbody>
</table>

[1] Supported only on select GP10x GPUs, all Turing GPUs and GA100
[2] VP9 10-bit and 12-bit decoding is supported on select GP10x GPUs, all Turing GPUs and GA100
Chapter 3. Video Decoder Pipeline

Decoder pipeline consists of three major components - Demuxer, Video Parser, and Video Decoder. The components are not dependent on each other and hence can be used independently. NVDECODE API provide API’s for NVIDIA video parser and NVIDIA video decoder. Of these, NVIDIA video parser is purely a software component and user can plug-in any parser in place of NVIDIA video parser, if required (e.g. FFmpeg parser).

Figure 1. Video decoder pipeline using NVDECODE API

At a high level the following steps should be followed for decoding any video content using NVDECODEAPI:

1. Create a CUDA context.
2. Query the decode capabilities of the hardware decoder.
3. Create the decoder instance(s).
4. De-Mux the content [like .mp4]. This can be done using third party software like FFmpeg.
5. Parse the video bitstream using parser provided by NVDECODE API or third-party parser such as FFmpeg.
6. Kick off the Decoding using NVDECODE API.
7. Obtain the decoded YUV for further processing.
8. Query the status of the decoded frame.
9. Depending on the decoding status, use the decoded output for further processing like rendering, inferencing, postprocessing etc.
10. If the application needs to display the output,
   ▶ Convert decoded YUV surface to RGBA.
   ▶ Map RGBA surface to DirectX or OpenGL texture.
   ▶ Draw texture to screen.
11. Destroy the decoder instance(s) after the completion of decoding process.
12. Destroy the CUDA context.

These steps are explained in this document and demonstrated in the sample application(s) included in the Video Codec SDK package.
Chapter 4. Using NVIDIA Video Decoder (NVDECODE API)

All NVDECODE APIs are exposed in two header-files: cuviddec.h and nvcuvid.h. These headers can be found under Interface folder in the Video Codec SDK package. The samples in NVIDIA Video Codec SDK statically load the library (which ships as a part of the SDK package for windows) functions and include cuviddec.h and nvcuvid.h in the source files. The Windows DLL nvcuvid.dll is included in the NVIDIA display driver for Windows. The Linux library libnvcuvid.so is included with NVIDIA display driver for Linux.

The following sections in this chapter explain the flow that should be followed to accelerate decoding using NVDECODE API.

4.1. Video Parser

4.1.1. Creating a parser

Parser object can be created by calling cuvidCreateVideoParser() after filling the structure CUVIDPARSERPARAMS. The structure is filled with the following information about the stream to be decoded:

- CodecType: must be from enum cudaVideoCodec, indicating codec type of content like H.264, HEVC, VP9 etc.
- ulMaxNumDecodeSurfaces: This is the number of surfaces in parser’s DPB (decode picture buffer). This value may not be known at the parser initialization time and can be set to a dummy number like 1 to create parser object. The application must register a callback pfnSequenceCallback with the driver, which is called by the parser when the parser encounters the first sequence header or any changes in the sequence. This callback reports the minimum number of surfaces needed by parser’s DPB for correct decoding in CUVIDFORMAT::min_num_decode_surfaces. The sequence callback may return this value to the parser if wants to update CUVIDPARSERPARAMS::ulMaxNumDecodeSurfaces. The parser then overwrites CUVIDPARSERPARAMS::ulMaxNumDecodeSurfaces with the value returned by the sequence callback, if the return value of the sequence callback is greater than 1 [see description about pfnSequenceCallback below]. Therefore, for optimum memory allocation, decoder object creation should be deferred until CUVIDPARSERPARAMS::ulMaxNumDecodeSurfaces is known, so that the decoder object can be created with required
number of buffers, such that CUVIDDECODECREATEINFO::ulNumDecodeSurfaces = CUVIDPARSERPARAMS::ulMaxNumDecodeSurfaces.

- **ulMaxDisplayDelay**: Max display callback delay. 0 = no delay
- **pfnSequenceCallback**: Application must register a function to handle any sequence change. Parser triggers this callback for initial sequence header or when it encounters a video format change. Return value from sequence callback is interpreted by the driver as follows:
  - 0: fail
  - 1: succeeded, but the driver should not override CUVIDPARSERPARAMS::ulMaxNumDecodeSurfaces
  - >1: succeeded, and the driver should override CUVIDPARSERPARAMS::ulMaxNumDecodeSurfaces with this return value
- **pfnDecodePicture**: Parser triggers this callback when bitstream data for one frame is ready. In the case of field pictures, there may be two decode calls per one display call since two fields make up one frame. Return value from this callback is interpreted as:
  - 0: fail
  - ≥1: succeeded
- **pfnDisplayPicture**: Parser triggers this callback when a frame in display order is ready. Return value from this callback is interpreted as:
  - 0: fail
  - ≥1: succeeded

### 4.1.2. Parsing the packets

Packets extracted from demultiplexer are fed into the parser using cuvidParseVideoData(). The parser triggers callbacks registered while creating parser object synchronously from within cuvidParseVideoData(), whenever there is sequence change or a picture is ready to be decoded and/or displayed. If the callback returns failure, it will be propagated by cuvidParseVideoData() to the application.

The decoded result gets associated with a picture-index value in the CUVIDPICPARAMS structure, which is also provided by the parser. This picture index is used to map the decoded frames to CUDA memory.

### 4.1.3. Destroying parser

You need to call cuvidDestroyVideoParser() to destroy the parser object and free up all the allocated resources.
4.2. Video Decoder

4.2.1. Querying decode capabilities

The API `cuvidGetDecoderCaps()` lets you query the capabilities of underlying hardware video decoder.

As illustrated in Table 1, different GPUs have hardware decoders with different capabilities. Therefore, to ensure your application works on all generations of GPU hardware, it is highly recommended that the application queries the hardware capabilities and makes appropriate decision based on presence/absence of the desired capability/functionality.

The API `cuvidGetDecoderCaps()` lets you query the capabilities of underlying hardware video decoder. The calling thread should have a valid CUDA context associated with it.

The client needs to fill in the following fields of `CUVIDDECODECAPS` before calling `cuvidGetDecoderCaps()`.

- **eCodecType**: Codec type [AV1, H.264, HEVC, VP9, JPEG etc.]
- **eChromaFormat**: 4:2:0, 4:4:4, etc.
- **nBitDepthMinus8**: 0 for 8-bit, 2 for 10-bit, 4 for 12-bit

When `cuvidGetDecoderCaps()` is called, the underlying driver fills up the remaining fields of `CUVIDDECODECAPS`, indicating the support for the queried capabilities, supported output formats and the maximum and minimum resolutions the hardware supports.

The following pseudo-code illustrates how to query the capabilities of NVDEC.

```c
CUVIDDECODECAPS decodeCaps = {};  // set IN params for decodeCaps
decodeCaps.eCodecType = cudaVideoCodec_HEVC; // HEVC
decodeCaps.eChromaFormat = cudaVideoChromaFormat_420; // YUV 4:2:0
decodeCaps.nBitDepthMinus8 = 2; // 10 bit
result = cuvidGetDecoderCaps(&decodeCaps);
```

Returned parameters from API can be interpreted as below to validate if content can be decoded on underlying hardware:

```c
// Check if content is supported
if (!decodecaps.bIsSupported){
    NVDEC_THROW_ERROR("Codec not supported on this GPU", CUDA_ERROR_NOT_SUPPORTED);
}
// validate the content resolution supported on underlying hardware
if ((coded_width > decodecaps.nMaxWidth) ||
     (coded_height > decodecaps.nMaxHeight)){
    NVDEC_THROW_ERROR("Resolution not supported on this GPU", CUDA_ERROR_NOT_SUPPORTED);
}
// Max supported macroblock count CodedWidth*CodedHeight/256 must be <= nMaxMBCount
if ((coded_width>>4)*(coded_height>>4) > decodecaps.nMaxMBCount){
    NVDEC_THROW_ERROR("MBCount not supported on this GPU", CUDA_ERROR_NOT_SUPPORTED);
}
```

Using NVIDIA Video Decoder (NVDECODE API)
In most situations, bit-depth and chroma subsampling to be used at the decoder output is same as that at the decoder input (i.e. in the content). In certain cases, however, it may be necessary to have the decoder produce output with bit-depth and chroma subsampling different from that used in the input bitstream. In general, it’s always a good idea to first check if the desired output bit-depth and chroma subsampling format is supported before creating the decoder. This can be done in the following way:

```c
// Check supported output format
if (decodecaps.nOutputFormatMask & (1<<cudaVideoSurfaceFormat_NV12)){
    // Decoder supports output surface format NV12
}
if (decodecaps.nOutputFormatMask & (1<<cudaVideoSurfaceFormat_P010)){
    // Decoder supports output surface format P010
}
```

The API `cuvidGetDecoderCaps()` also returns histogram related capabilities of the underlying GPU. Histogram data is collected by NVDEC during the decoding process resulting in zero performance penalty. NVDEC computes the histogram data for only the luma component of decoded output, not on post-processed frame (i.e. when scaling, cropping, etc. applied). In case of AV1 when film gain is enabled, histogram data is collected on the decoded frame prior to the application of the film grain.

```c
// Check if histogram is supported
if (decodecaps.bIsHistogramSupported){
    nCounterBitDepth = decodecaps.nCounterBitDepth; // histogram counter bit depth
    nMaxHistogramBins = decodecaps.nMaxHistogramBins; // Max number of histogram bins
}
```

Histogram data is calculated as:

```
Histogram_Bin[pixel_value >> (pixel_bitDepth - log2(nMaxHistogramBins))]++;
```

### 4.2.2. Creating a Decoder

Before creating the decoder instance, user needs to have a valid CUDA context which will be used in the entire decoding process.

The decoder instance can be created by calling `cuvidCreateDecoder()` after filling the structure `CUVIDCODECREATEINFO`. The structure `CUVIDCODECREATEINFO` should be filled up with the following information about the stream to be decoded:

- **CodecType**: must be from `enum cudaVideoCodec`. It represents codec type of content like H.264, HEVC, VP9 etc.
- **ulWidth, ulHeight**: coded width and coded height in pixels.
- **ulMaxWidth, ulMaxHeight**: max width and max height that decoder support in case of resolution change. When there is resolution change (new resolution \(\leq ulMaxWidth, ulMaxHeight\)) in video stream, app can reconfigure decoder using `cuvidReconfigureDecoder()` API instead of destroy and recreate the decoder. If `ulMaxWidth` or `ulMaxHeight` is set to 0, `ulMaxWidth` and `ulMaxHeight` are set to `ulWidth` and `ulHeight` respectively.
- **ChromaFormat**: must be from `enum cudaVideoChromaFormat`. It represents chroma format of content like 4:2:0, 4:4:4, etc.
‣ **bitDepthMinus8**: bit-depth minus 8 of video stream to be decoded like 0 for 8-bit, 2 for 10-bit, 4 for 12-bit.

‣ **ulNumDecodeSurfaces**: Referred to as decode surfaces elsewhere in this document, this is the number of surfaces that the driver will internally allocate for storing the decoded frames. Using a higher number ensures better pipelining but increases GPU memory consumption. For correct operation, minimum value is defined in \texttt{CUVIDEOFORMAT::min\_num\_decode\_surfaces} and can be obtained from first sequence callback from Nvidia parser. The NVDEC engine writes decoded data to one of these surfaces. These surfaces are not accessible by the user of NVDECODE API, but the mapping stage, which includes decoder output format conversion, scaling, cropping etc.) use these surfaces as input surfaces.

‣ **ulNumOutputSurfaces**: This is the maximum number of output surfaces that the client will simultaneously map to decode surfaces for further processing using \texttt{cuvidMapVideoFrame()}. These surfaces have postprocessed decoded output to be used by client. The driver internally allocates the corresponding number of surfaces (referred as output surfaces in this document). Client will have access to output surfaces. Refer to section Preparing the decoded frame for further processing to understand the definition of map.

‣ **OutputFormat**: Output surface format defined as enum \texttt{cudaVideoSurfaceFormat}. This output format must be one of supported format obtained in \texttt{decodecaps.nOutputFormatMask} in \texttt{cuvidGetDecoderCaps()}. If an unsupported output format is passed, API will fail with error \texttt{CUDA\_ERROR\_NOT\_SUPPORTED}.

‣ **ulTargetWidth, ulTargetHeight**: This is resolution of output surfaces. For use-case which involve no scaling, these should be set to \texttt{ulWidth, ulHeight}, respectively.

‣ **DeinterlaceMode**: This should be set to \texttt{cudaVideoDeinterlaceMode\_Weave} or \texttt{cudaVideoDeinterlaceMode\_Bob} for progressive content and \texttt{cudaVideoDeinterlaceMode\_Adaptive} for interlaced content. \texttt{cudaVideoDeinterlaceMode\_Adaptive} yields better quality but increases memory consumption.

‣ **ulCreationFlags**: It is defined as enum \texttt{cudaVideoCreateFlags}. It is optional to explicitly define this flag. Driver will pick appropriate mode if not defined.

‣ **ulIntraDecodeOnly**: Set this flag to 1 to instruct the driver that the content being decoded contains only I/IDR frames. This helps the driver optimize memory consumption. Do not set this flag if content has non-intra frames.

‣ **enableHistogram**: Set this flag to 1 to enable histogram data collection.

The \texttt{cuvidCreateDecoder()} call fills \texttt{CUvideodecoder} with the decoder handle which should be retained till the decode session is active. The handle needs to be passed along with other NVDECODE API calls.

The user can also specify the following parameters in the \texttt{CUVIDDECODECREATEINFO} to control the final output:

‣ **Scaling dimension**

‣ **Cropping dimension**

‣ **Dimension if the user wants to change the aspect ratio**
The following code demonstrates the setup of decoder in case of scaling, cropping, or aspect ratio conversion.

```c
// Scaling. Source size is 1280x960. Scale to 1920x1080.
CUresult rResult;
unsigned int uScaleW, uScaleH;
uScaleW = 1920;
uScaleH = 1080;
...
CUVIDCODECREATEINFO stDecodeCreateInfo;
memset(&stDecodeCreateInfo, 0, sizeof(CUVIDCODECREATEINFO));
... // Setup the remaining structure members
stDecodeCreateInfo.ulTargetWidth = uScaleWidth;
stDecodeCreateInfo.ulTargetHeight = uScaleHeight;
rResult = cuvidCreateDecoder(&hDecoder, &stDecodeCreateInfo);
...
```

```c
// Cropping. Source size is 1280x960
CUresult rResult;
unsigned int uCropL, uCropR, uCropT, uCropB;
uCropL = 30;
uCropR = 700;
uCropT = 20;
uCropB = 500;
...
CUVIDCODECREATEINFO stDecodeCreateInfo;
memset(&stDecodeCreateInfo, 0, sizeof(CUVIDCODECREATEINFO));
// Setup the remaining structure members
...
stDecodeCreateInfo.display_area.left  = uCropL;
stDecodeCreateInfo.display_area.right = uCropR;
stDecodeCreateInfo.display_area.top   = uCropT;
stDecodeCreateInfo.display_area.bottom = uCropB;
rResult = cuvidCreateDecoder(&hDecoder, &stDecodeCreateInfo);
...
```

```c
// Aspect Ratio Conversion. Source size is 1280x960(4:3). Convert to 16:9
CUresult rResult;
unsigned int uCropL, uCropR, uCropT, uCropB;
uDispAR_L = 0;
uDispAR_R = 1280;
uDispAR_T = 70;
uDispAR_B = 790;
...
CUVIDCODECREATEINFO stDecodeCreateInfo;
memset(&stDecodeCreateInfo, 0, sizeof(CUVIDCODECREATEINFO));
... // setup structure members
stDecodeCreateInfo.target_rect.left   = uDispAR_L;
stDecodeCreateInfo.target_rect.right = uDispAR_R;
stDecodeCreateInfo.target_rect.top    = uDispAR_T;
stDecodeCreateInfo.target_rect.bottom = uDispAR_B;
rResult = cuvidCreateDecoder(&hDecoder, &stDecodeCreateInfo);
...
```

### 4.2.3. Decoding the frame/field

After de-muxing and parsing, the client can submit the bitstream which contains a frame or field of data to hardware for decoding. To accomplish this use these steps:

- Fill up the **CUVIDPICPARAMS** structure.
The client needs to fill the structure with parameters derived during the parsing process. 
CUVIDPICPARAMS contains a structure specific to every supported codec which should also be filled.

Call cuvidDecodePicture() and pass the decoder handle and the pointer to CUVIDPICPARAMS. cuvidDecodePicture() starts the decoding on NVDEC.

4.2.4. Preparing the decoded frame for further processing

Call cuvidMapVideoFrame() to get the CUDA device pointer and the pitch of the output surface that holds the decoded and post-processed frame.

The cuvidDecodePicture() instructs the NVDEC hardware engine to start the decoding of the frame/field. However, successful completion of cuvidMapVideoFrame() indicates that the decoding process is completed and that the decoded YUV frame is converted from the format generated by NVDEC to the YUV format specified in CUVIDDECODERCREATEINFO::OutputFormat.

The cuvidMapVideoFrame() API takes the decode surface index (nPicIdx) as input and maps it to one of available output surfaces, post-processes the decoded frame and copy to output surface and returns the CUDA device pointer and associated pitch of the output surfaces. This operation performed by cuvidMapVideoFrame() is referred to as mapping in this document.

After processing on the frame is complete, cuvidUnmapVideoFrame() must be called to make the output surface available for storing other decoded and post-processed frames.

If you continuously fail to call the corresponding cuvidUnmapVideoFrame() after cuvidMapVideoFrame(), then cuvidMapVideoFrame() will eventually fail. At most CUVIDDECODERCREATEINFO::ulNumOutputSurfaces frames can be mapped at a time.

cuvidMapVideoFrame() is a blocking call as it waits for decoding to complete. If cuvidMapVideoFrame() is called on same CPU thread as cuvidDecodePicture(), it will block cuvidDecodePicture() as well. In this case, the application will not be able to submit decode packets to NVDEC until mapping is complete. It can be avoided by performing the mapping operation on a CPU thread (referred as mapping thread) different from the one calling cuvidDecodePicture() (referred as decoding thread).

When using the NVIDIA parser from NVDECODE API, the application can implement a producer-consumer queue between decoding thread (as producer) and mapping thread (as consumer). The queue can contain picture indexes (or other unique identifiers) for frames being decoded. The parser can run on the decoding thread. The decoding thread can add the picture index to the queue in display callback and return immediately from callback to continue decoding subsequent frames as they become available. On the other side, the mapping thread monitors the queue. If it sees the queue has non-zero length, it dequeues the entry and calls cuvidMapVideoFrame(...) with nPicIdx as the picture index. The decoding thread must not reuse the corresponding decode picture buffer for storing the decoded output until its entry is consumed and freed by the mapping thread.

This sample code demonstrates how to use cuvidMapVideoFrame() and cuvidUnmapVideoFrame().

```c
// MapFrame: Call cuvidMapVideoFrame and get the devptr and associated
// pitch. Copy this surface (in device memory) to host memory using
```
// CUDA device to host memcpy.
bool MapFrame()
{
    CUVIDPAREDSPINFO stDispInfo;
    CUVIDPROCPARAMS stProcParams;
    CUREsult rResult;
    unsigned long long cuDevPtr = 0;
    int nPitch, nPicIdx, frameSize;
    unsigned char* pHostPtr = nullptr;
    memset(&stDispInfo, 0, sizeof(CUVIDPAREDSPINFO));
    memset(&stProcParams, 0, sizeof(CUVIDPROCPARAMS));
    >/********************************************************/
    */ setup stProcParams
    >/********************************************************/
    // retrieve the frames from the Frame Display Queue. This Queue is
    // is populated in HandlePictureDisplay.
    if (g_pFrameQueue->dequeue(&stDispInfo))
    {
        nPicIdx = stDispInfo.picture_index;
        rResult = cuvidMapVideoFrame(&hDecoder, nPicIdx, &cuDevPtr,
                                      &nPitch, &stProcParams);
        frameSize = (ChromaFormat == cudaVideoChromaFormat_444) ? nPitch * (3*nheight) :
                              nPitch * (nheight + (nheight + 1) / 2);
        // use CUDA based Device to Host memcpy
        rResult = cuMemAllocHost((void**) &pHostPtr, frameSize);
        if (pHostPtr)
        {
            rResult = cuMemcpyDtoH(pHostPtr, cuDevPtr, frameSize);
        }
        rResult = cuvidUnmapVideoFrame(&hDecoder, cuDevPtr);
    }
    ... // Dump YUV to a file
    if (pHostPtr)
    {
        cuMemFreeHost(pHostPtr);
    }
    ...
}

In a multi-instance decoding use-case, NVDEC could be the bottleneck, so there wouldn’t be a
significant benefit to calling cuvidMapVideoFrame() and cuvidDecodePicture() on different
CPU threads. cuvidDecodePicture() will stall if the wait queue on the NVDEC inside driver is
full. Sample applications in Video Codec SDK are using mapping and decode calls on the same
CPU thread, for simplicity.

4.2.5. Getting histogram data buffer

Histogram data is collected by NVDEC during the decoding process resulting in zero
performance penalty. NVDEC computes the histogram data for only the luma component of
decoded output, not on post-processed frame(i.e. when scaling, cropping, etc. applied). In case
of AV1 when film gain is enabled, histogram data is collected on the decoded frame prior to the
application of the film grain.

cuvidMapVideoFrame() API returns the CUDA device pointer of histogram data buffer along
with output surface if CUVIDCODECREATEINFO::enableHistogram flag is set while creating
decoder (using API cuvidCreateDecoder()). CUDA device pointer of histogram buffer can be
obtained from CUVIDPROCPARAMS::histogram_dptr.

The histogram buffer is mapped to the output buffer in the driver, so cuvidUnmapVideoFrame() unmaps
the histogram buffer along with the output surface.
The following code demonstrates how to use `cuvidMapVideoFrame()` and `cuvidUnmapVideoFrame()` for accessing the histogram buffer.

```c
// MapFrame: Call cuvidMapVideoFrame and get the output frame and associated histogram buffer CUDA device pointer
CUVIDPROCPARAMS stProcParams;
CUresult rResult;
unsigned long long cuOutputFramePtr = 0, cuHistogramPtr = 0;
int nPitch;
int histogram_size = (decodecaps.nCounterBitDepth / 8) * decodecaps.nMaxHistogramBins;
unsigned char *pHistogramPtr = nullptr;
memset(&stProcParams, 0, sizeof(CUVIDPROCPARAMS));
/**********************************************************
 *   setup stProcParams
 **********************************************************/
stProcParams.histogram_dptr = &cuHistogramPtr;
rResult = cuvidMapVideoFrame(&hDecoder, nPicIdx, &cuOutputFramePtr, &nPitch, &stProcParams);
// allocate histogram buffer for cuMemcpy
rResult = cuMemAllocHost((void**)&pHistogramPtr, histogram_size);
if (pHistogramPtr)
{
    rResult = cuMemcpyDtoH(pHistogramPtr, cuHistogramPtr, histogram_size);
}
// unmap output frame
rResult = cuvidUnmapVideoFrame(&hDecoder, cuOutputFramePtr);
...}
```

### 4.2.6. Querying the decoding status

After the decoding starts, `cuvidGetDecodeStatus()` can be called at any time to query the status of decoding of that frame. The underlying driver fills the status of decoding in `CUVIDGETDECODESTATUS::*pDecodeStatus`.

The NVDECODEAPI currently reports the following statuses:

- Decoding is in progress.
- Decoding of the frame completed successfully.
- The bitstream for the frame was corrupted and concealed by NVDEC.
- The bitstream for the frame was corrupted, however could not be concealed by NVDEC.

The API is expected to help in the scenarios where the client needs to take a further decision based on the decoding status of the frame, for e.g. whether to carry out inferencing on the frame or not.

The NVDEC can detect a limited number of errors depending on the codec. This API is supported for HEVC, H264 and JPEG on Maxwell and above generation GPUs.

### 4.2.7. Reconfiguring the decoder

Using `cuvidReconfigureDecoder()` the user can reconfigure the decoder if there is a change in the resolution and/or post processing parameters of the bitstream without having to destroy
the ongoing decoder instance, and create a new one thereby saving time (and latency) in the process.

In the earlier SDKs the user had to destroy the existing decoder instance and create a new decoder instance for handling any change in decoder resolution or post-processing parameters (like scaling ratio, cropping dimensions etc.).

The API can be used in scenarios where the bitstream undergoes changes in resolution, for example when the encoder (on server side) changes image resolution frequently to adhere to Quality of Service (QoS) constraints.

Here are the steps to use the cuvidReconfigureDecoder().

1. Specify CUVIDDECODECREATEINFO::ulMaxWidth and CUVIDDECODECREATEINFO::ulMaxHeight while calling cuvidCreateDecoder(). Choose the values of CUVIDDECODECREATEINFO::ulMaxWidth and CUVIDDECODECREATEINFO::ulMaxHeight to ensure that the resolution of the bitstream is never exceeded during the entire decoding process.

   Note: The values of CUVIDDECODECREATEINFO::ulMaxWidth and CUVIDDECODECREATEINFO::ulMaxHeight cannot be changed within a session and if you want to change the values, the decoding session should be destroyed and recreated.

2. During the process of decoding, you need to change the bitstream or change postprocessing parameters and you need to call cuvidReconfigureDecoder(). This call should be made from CUVIDPARSERPARAMS::pfnSequenceCallback when the bitstream changes. The parameters you want to reconfigure should be filled up in ::CUVIDRECONFIGUREDECODERINFO.

   Note: CUVIDRECONFIGUREDECODERINFO::ulWidth and CUVIDRECONFIGUREDECODERINFO::ulHeight must be equal to or smaller than CUVIDDECODECREATEINFO::ulMaxWidth and CUVIDDECODECREATEINFO::ulMaxHeight respectively or else the cuvidReconfigureDecoder() would fail.

The API is supported for all codecs supported by NVDECODEAPI.

4.2.8. Destroying the decoder

You need to call cuvidDestroyDecoder() to destroy the decoder session and free up all the allocated decoder resources.

4.3. Writing an Efficient Decode Application

The NVDEC engine on NVIDIA GPUs is a dedicated hardware block, which decodes the input video bitstream in supported formats. A typical video decode application consists of these stages:

1. De-Muxing
2. Video bitstream parsing and decoding
3. Preparing the frame for further processing

Of these, de-muxing and parsing are not hardware accelerated and therefore outside the scope of this document. The de-muxing can be performed using third party components such as FFmpeg, which provides support for many multiplexed video formats. The sample applications included in the SDK demonstrate de-muxing using FFmpeg.

Similarly, post-decode or video post-processing (such as scaling, color space conversion, noise reduction, color enhancement etc.) can be effectively performed using user-defined CUDA kernels.

The post-processed frames can then be sent to the display engine for displaying on the screen, if required.

**Note:** This operation is outside the scope of NVDECODE APIs.

An optimized implementation should use independent threads for de-muxing, parsing, bitstream decode and processing as explained here:

1. **De-muxing:** This thread demultiplexes the media file and makes the raw bit-stream available for parser to consume.
2. **Parsing and decoding:** This thread does the parsing of the bitstream and kicks off decoding by calling `cuvidDecodePicture()`.
3. **Mapping and making the frame available for further processing:** This thread checks if there are any decoded frames available. If yes, then it should call `cuvidMapVideoFrame()` to get the CUDA device pointer and pitch of the frame. The frame can then be used for further processing.

The NVDEC driver internally maintains a queue of 4 frames for efficient pipelining of operations. This pipeline does not imply any decoding delay for decoding. The decoding starts as soon as the first frame is queued, but the application can continue queuing up input frames so long as space is available without stalling. Typically, by the time application has queued 2-3 frames, decoding of the first frame is complete and the pipeline continues. This pipeline ensures that the hardware decoder is utilized to the maximum extent possible.

For performance intensive and low latency video codec applications, ensure the PCIE link width is set to the maximum available value. PCIE link width currently configured can be obtained by running command ‘nvidia-smi -q’. PCIE link width can be configured in the system’s BIOS settings.

In the use cases where there is frequent change of decode resolution and/or post processing parameters, NVIDIA recommends using `cuvidReconfigureDecoder()` instead of destroying the existing decoder instance and recreating a new one.

Use these steps for optimizing video memory usage:

1. Make `CUVIDDECODECREATEINFO::ulNumDecodeSurfaces = CUVIDEOFORMAT::min_num_decode_surfaces`. This will ensure that the underlying driver allocates minimum number of decode surfaces to correctly decode the sequence. In case there is reduction in decoder performance, clients can slightly increase `CUVIDDECODECREATEINFO::ulNumDecodeSurfaces`. It is therefore recommended to
choose the optimal value of `CUVIDCODECREATEINFO::ulNumDecodeSurfaces` to ensure right balance between decoder throughput and memory consumption.

2. `CUVIDCODECREATEINFO::ulNumOutputSurfaces` should be decided optimally after due experimentation for balancing decoder throughput and memory consumption.

3. `CUVIDCODECREATEINFO::DeinterlaceMode` should be set “cudaVideoDeinterlaceMode::cudaVideoDeinterlaceMode_Weave” or “cudaVideoDeinterlaceMode::cudaVideoDeinterlaceMode_Bob”. For interlaced contents, choosing cudaVideoDeinterlaceMode::cudaVideoDeinterlaceMode_Adaptive results to higher quality but increases memory consumption. Using cudaVideoDeinterlaceMode::cudaVideoDeinterlaceMode_Weave or cudaVideoDeinterlaceMode::cudaVideoDeinterlaceMode_Bob results to minimum memory consumption though it may result in lesser video quality. In case “CUVIDCODECREATEINFO::DeinterlaceMode” is not specified by the client, the underlying display driver sets it to “cudaVideoDeinterlaceMode::cudaVideoDeinterlaceMode_Adaptive” which results to higher memory consumption. Therefore, choose the right value of `CUVIDCODECREATEINFO::DeinterlaceMode` depending on the requirement.

4. While decoding multiple streams it is recommended to allocate minimum number of CUDA contexts and share it across sessions. This saves the memory overhead associated with the CUDA context creation.

5. `CUVIDCODECREATEINFO::ulIntraDecodeOnly` should be set to 1 if it is known beforehand that the sequence contains Intra frames only. This feature is supported only for HEVC, H.264 and VP9. However, decoding might fail if the flag is enabled in case of supported codecs for regular bit streams having P and/or B frames.

The sample applications included with the Video Codec SDK are written to demonstrate the functionality of various APIs, but they may not be fully optimized. Therefore, be sure your application is well-designed, with various stages in the decode-postprocess-display pipeline structured in an efficient manner to achieve desired performance and memory consumption.
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