WARPING & BLENDING FOR MULTI-DISPLAY SYSTEM USING NVIDIA DESIGNWORKS

Doug Traill, GTC17

NVIDIA

THREE APIS

How to String out a 50 minute talk

- Why use NVIDA WARP API
- Linux
- New filtering methods

WARP & BLEND SDK

NVIDIA Provides APIs that allow other companies to build solutions.

3rd party software available from

scalable DISPLAY TECHNOLOGIES

VIOSO

play-out.com

Fraunhofer FOKUS

CHRISTIE

Pixelwix Inovative Media Solutions

cooLux A CHRISTIE COMPANY

IMMERSAVIEW

WARP AND BLEND

EXAMPLE USE CASES

Used in many different applications

CUSTOM HMDS

PROJECTION ENVIRONMENTS

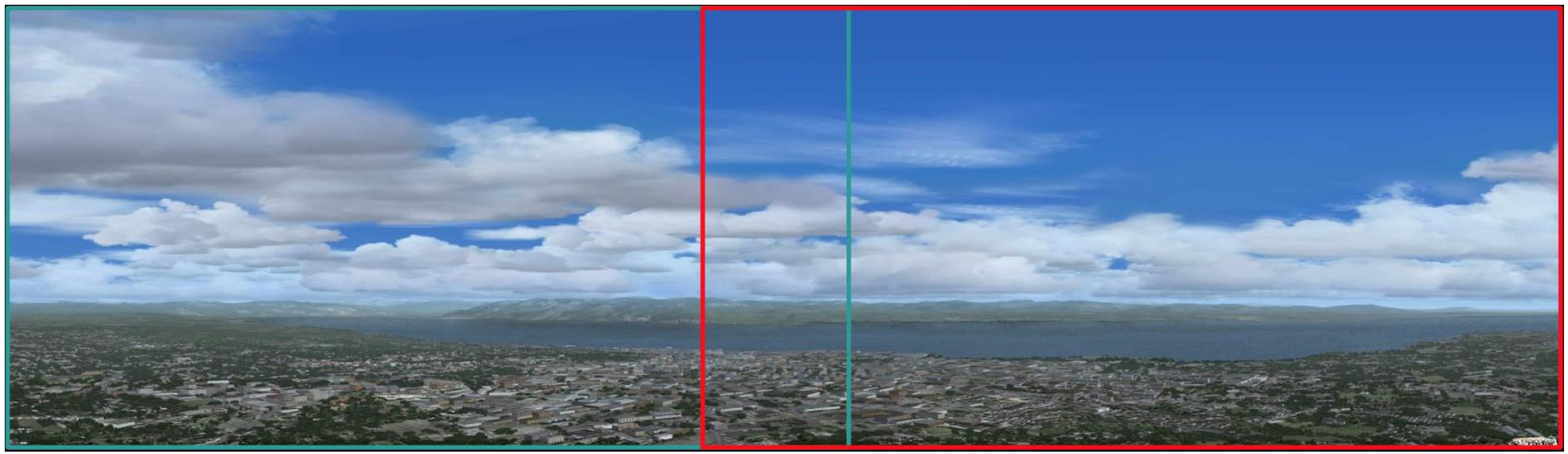
PROJECTION MAPPING

LARGE TILED WALLS

THE CHALLENGE

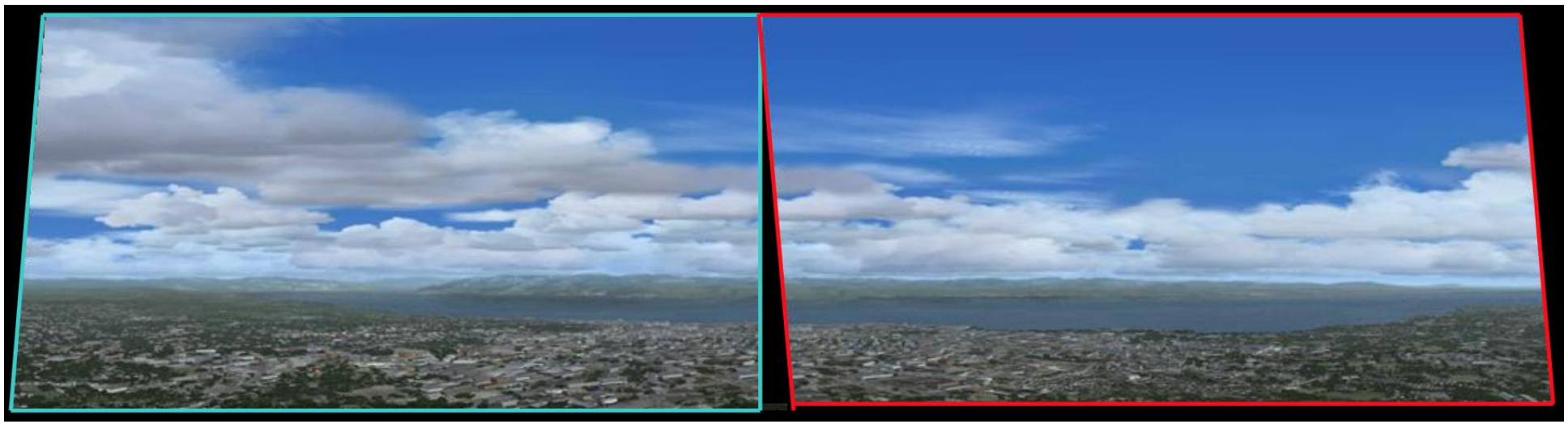
How do we create a seamless image?

Projectors we can overlap the edges to hide the seams



THE REALITY

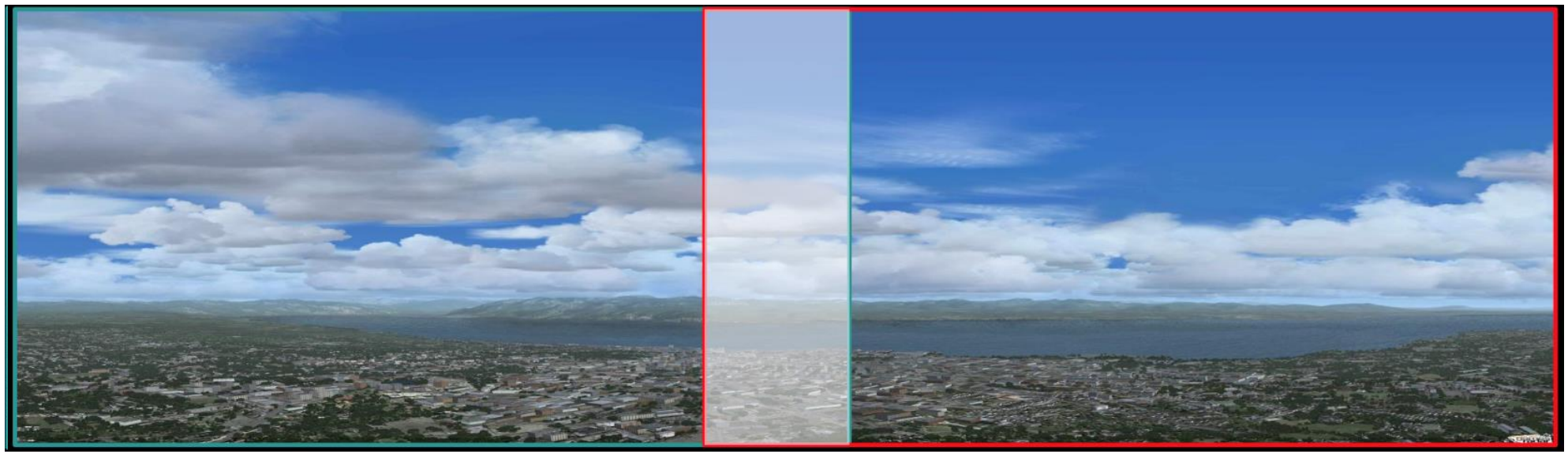
Screens and projector optics are never perfect



THE CHALLENGE

How do we create a seamless image?

If we just create an overlap then you are left with a hotspot – double brightness



NVIDIA SOLUTION

Aimed at developers – we don't provide our own application

- MOSAIC
  - ability to create a uniform desktop with overlap correction.
  - overlap correction helps maintain the correct aspect ratio - so a circle looks like a circle
- WARP & Blend
  - Warp – Geometry correction – so the projected image matches the display
  - Blend – intensity adjustment
  - Filtering – smooths aliasing caused by warping the image.

HISTORICAL APPROACHES

DEDICATED H/W

Expensive

Limited bandwidth – DP1.2

Additional Complexity

Performance Delay

SPECIALIST PROJECTORS

Limited Choice

Expensive

CUSTOM SOFTWARE

Sometimes built into an application

Performance hit as resolution increases

Not easy to implement – until now.

NVIDIA'S SOLUTION

We can do this on the GPU!

- GPUs are inherently parallel and already have the pixel Information
  - Fast for image processing operations
- GPUs are designed for imaging, texturing and raster operations (compared with external boxes using FPGAs)
- Perform the transformation in the display pipeline before the pixels get scanned out
- By doing this on the GPU, we have more flexibility: high quality filtering, integration with SLI Mosaic, etc.

SUPPORTED ON

Ultimate Double Precision performance
Dual slot FF with Sync support

Quadro GP100

Ultimate 3D performance & Interactivity
Dual slot FF with Sync support

Quadro P6000

Demanding 3D content & Interactivity
Dual slot FF with Sync support

Quadro P5000

Performance 3D content
Single slot FF with Sync support

Quadro P4000

Video and basic 3D content
Low profile for SFF systems

Quadro P1000

2-way SLI support

2-way NV-Link

Video and basic 3D content
Single slot FF with 8 display outputs

NVS 810

Quadro SyncII Support – 4 GPUs

HOW ITS DONE: WARP & BLEND WORKFLOW

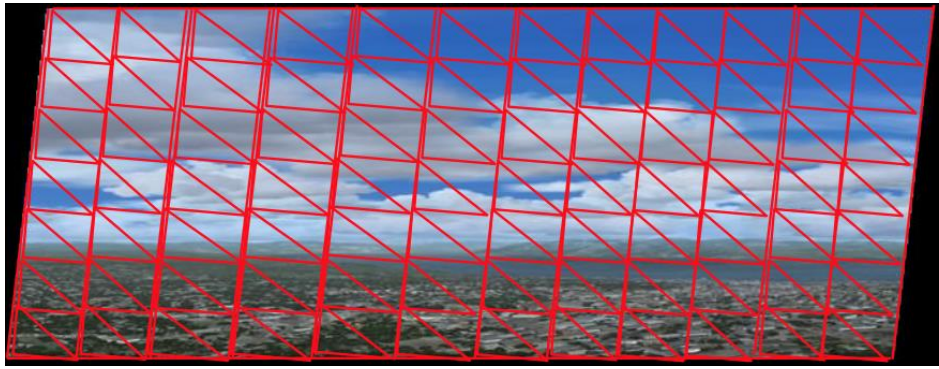
Define the Warp + Blend zone

Different approaches

- Camera based calibration
- GUI alignment
- Pre-defined shapes

Define Warp Mesh

- Define your mesh
- Define the texture co-ordinates to implement distortion



Typical Mesh is from “4” to “2 million” polygons

HOW ITS DONE: OVERALL WORKFLOW

SET MOSAIC

MOSAIC Enables a single Desktop

Define the display GRID by rows and cols i.e. 1x3

Define Bezel or Overlap correction

CALCULATE WARP + BLEND

NVIDIA Doesn't provide specific APIs for this.

APPLY

Apply to each display output

For 1x3 array we apply 3 separate Warp/Meshes

Set Intensity adjustment for blending

Set the filtering method.

NVAPI

Programmatically on Windows

Public & NDA Version

- Public – developer.nvidia.com
  - Most functions available – MOSAIC, WARP etc NO Custom Resolution.

NDA – registered developer with NDA. NVIDIA provides access to partner network for download

  - All functions available – including custom resolution
  - More SDK examples

Structure versions

  - Each structure in NVAPI contains a version field that must be set.
  - NV_XXX.version = NV_XXX_VER;

displayIds – unique identifier for each display attached. Includes GPU info.

NV-CONTROL

Programmatically on Linux

Source code/samples: ftp://download.nvidia.com/XFree86/nvidia-settings/

Samples include:

- nv-control-targets.c - print out system info – including connected displays
- nv-control-dpy.c – different options including generating custom modelines and printing out current modeline in use
- nv-control-framelock.c - Quadro Sync II card setup and control
- nv-control-events.c – Events – including sync events
- nv-control-warpblend.c – Warp and blend sample

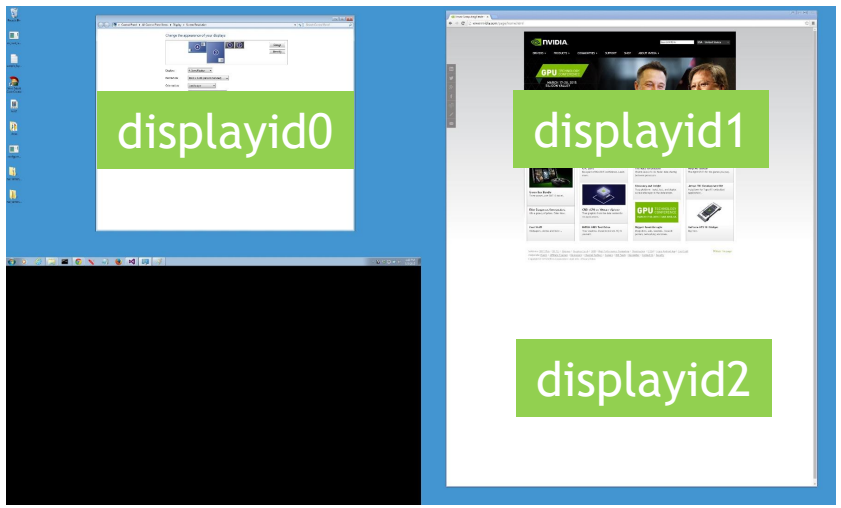
GET CURRENT DISPLAY INFO (WINDOWS)

These are in the NVAPI SDK NDA Samples

Info.cpp (EDID Locking sample)

Function: `getInfo`

Returns a list of all connected DisplayIds, active displays, port names and GPU names etc.



GET CURRENT DISPLAY INFO (LINUX)

- Query the number of Xscreens
- Query attached displays per Xscreen.
- Query attached displays per screen

```
ret = XNVCTRLQueryTargetBinaryData
        (dpy,
        NV_CTRL_TARGET_TYPE_GPU,
        gpu, // target_id
        0,      // display_mask
        NV_CTRL_BINARY_DATA_XSCREENS_USING_GPU,
        (unsigned char **)&pData,
        &len);

for (j = 1; j <= pData[0]; j++) {.
screen = pData[j];
ret = XNVCTRLQueryTargetBinaryData
        (dpy,
         NV_CTRL_TARGET_TYPE_X_SCREEN,
                  screen, // target_id
                           0, // display_mask

        NV_CTRL_BINARY_DATA_DISPLAYS_ASSIGNED_TO_
XSCREEN,
        (unsigned char **)&pDisplayData,
                  &len);

}
```

MOSAIC ENUMERATING DISPLAY GRIDS

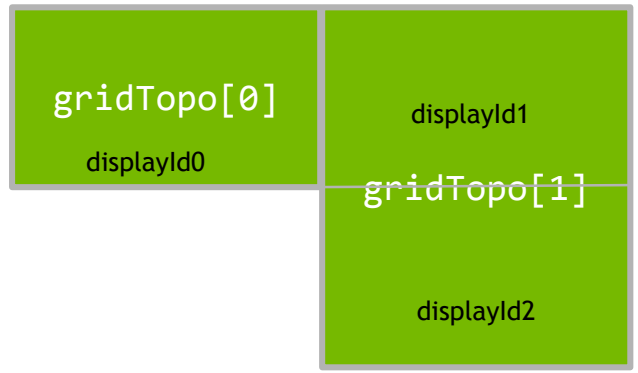
Windows

Get Number of Grids

```
NvU32 gridcount

NvAPI_MOSAIC_EnumDisplayGrids (NULL, &gridcount)
```

Get Grid Topology

```
NV_MOSAIC_GRID_TOPO *gridTopo = new NV_MOSAIC_GRID_TOPO[16];

gridTopo->version = NV_MOSAIC_GRID_TOPO_VER;

NvAPI_Mosaic_EnumDisplayGrids(gridTopo, &gridCount);
```



console MOSAIC 2x1

console

```
gridTopo[0].displayCount = 1
gridTopo[0].rows=1
gridTopo[0].columns =1
gridTopo[0].displays ={displayId0}
gridTopo[0].displaysettings = 1920,1200,60, 8bpp
```

MOSAIC 2x1

```
gridTopo[1].displayCount = 2
gridTopo[1].rows=2
gridTopo[1].columns =1
gridTopo[1].displays ={displayId1, displayId2}
gridTopo[1].displaysettings = 1920,1080,60, 8bpp
```

MOSAIC – PSEUDO CODE

Some Pseudo Code Windows

Enumerate current grids

Helpful to populate info

no_grid =2

Console display – Grid[0]

Create a 1 by 1 grid

Choose default timings

Grid[1] – this is MOSAIC layout

rows/columns i.e. 4 rows 1 cols (choose based on layout)

Set resolution based on custom timing

```
NvAPI_Mosaic_SetDisplayGrids(grid, no_grid, 0);
```

MOSAIC TIPS

- Sort the GPUs based on PCIe slot info
  - Enumeration of the GPUs returned by NVAPI is just a list – doesn't indicate position.
  - Enumeration position can change based on configuration.
  - For PCIe info
    - NvAPI_GPU_GetBusId & NvAPI_GPU_GetBusSlotId
- Validate the display Grid –returns list of failure codes
  - NvAPI_Mosaic_ValidateDisplayGrids
- Check for non-mitigating applications
  - Apps that are likely to crash when - Multi-GPU MOSAIC is set – general apps running OGL context.
    - Includes Chrome browser etc.
  - NvAPI_GPU_QueryActiveApps & NvAPI_QueryNonMigratableApps

MOSAIC ON LINUX

xorg.conf

Single GPU

(bezel or overlap)

```
Option "MetaModes" "1920x1080 +0+0, 1920x1080 +1920+0,
1920x1080 +0+1080, 1920x1080 +1920+1080"
Option  "nvidiaXineramaInfo" "FALSE"
```

Dual GPU
(no sync)

(bezel)

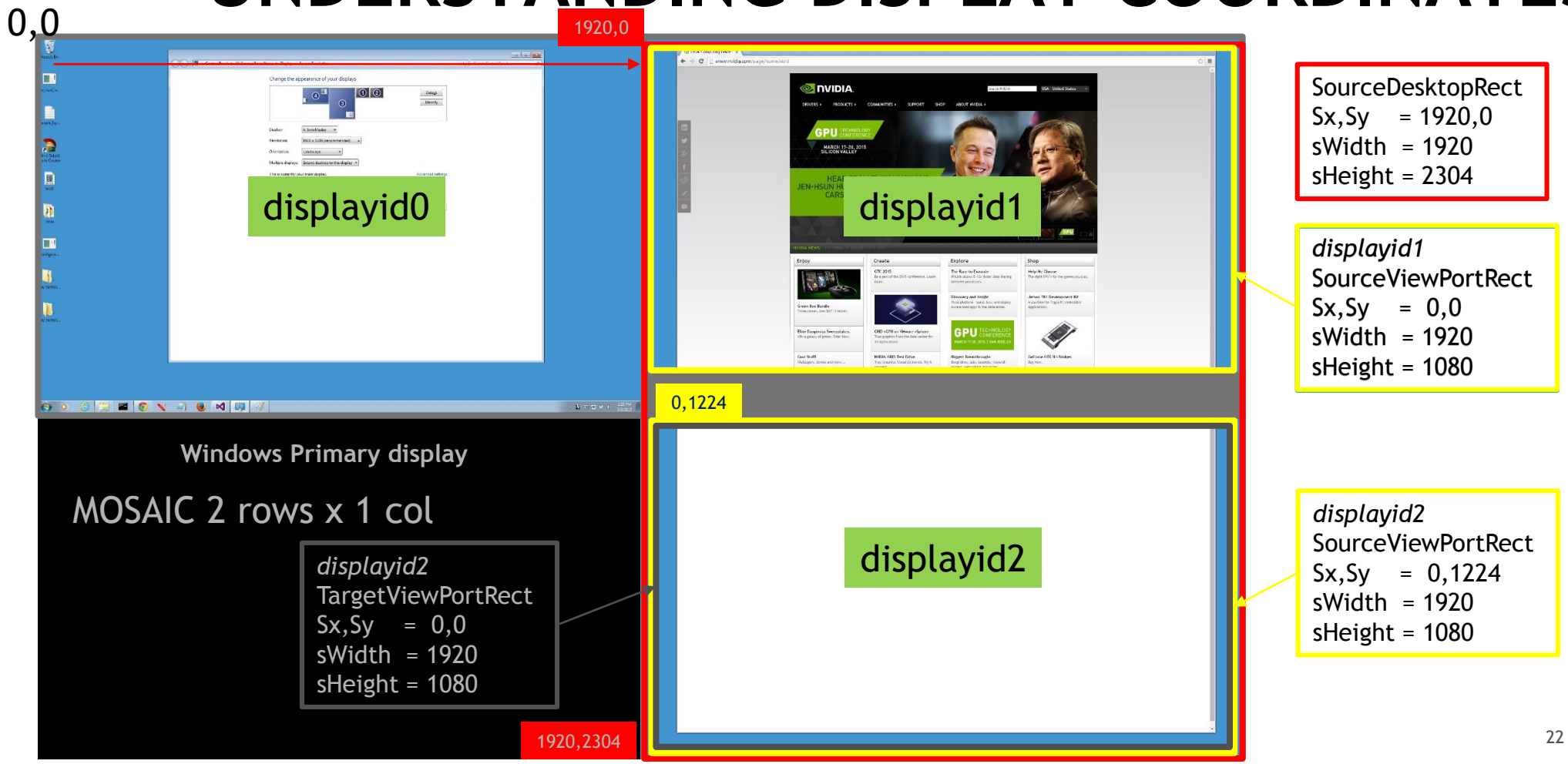
```
Option "BaseMosaic"   "TRUE"
Option "MetaModes" "GPU-0.DFP-0: 1920x1080 +0+0, GPU-0.DFP-1:
1920x1080 +1950+0, GPU-1.DFP-0: 1920x1080 +0+1100, GPU-1.DFP-1:
1920x1080 +1950+1100"
Option "nvidiaXineramaInfo" "FALSE"
```

SLI, NVLINK
or Quadro Sync II

(bezel or overlap)

```
Option "SLI"   "MOSAIC"
Option "MetaModes" "GPU-0.DFP-0: 1920x1080 +0+0, GPU-0.DFP-1:
1920x1080 +1820+0, GPU-1.DFP-0: 1920x1080 +0+1000, GPU-1.DFP-1:
1920x1080 +1820+1000"
Option "nvidiaXineramaInfo"
```

UNDERSTANDING DISPLAY COORDINATES



UNDERSTANDING DISPLAY COORDINATES

NvAPI_GPU_GetScanoutConfigurationEx
(displayId, scanInfo)

scanInfo.sourceDesktopRect – Sx, Sy, sWidth, sHeight

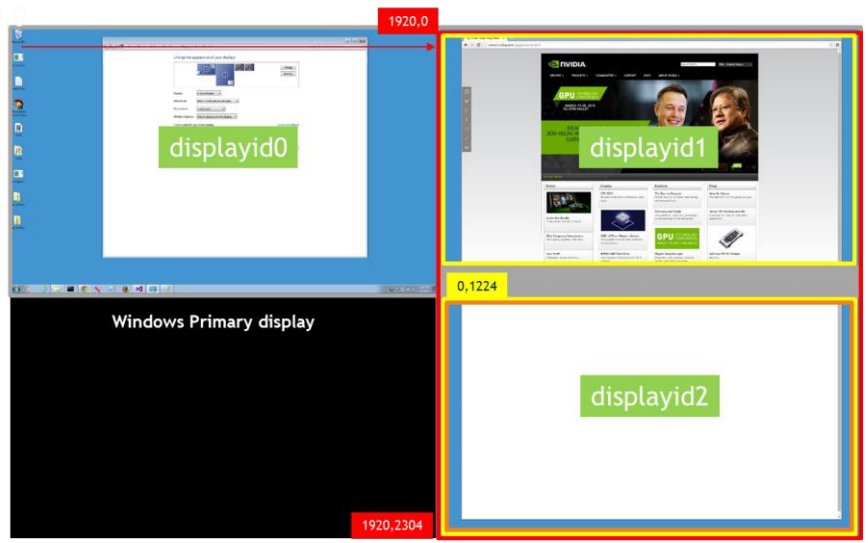
All displayId that are part of MOSAIC grid will return same sourceDesktopRect.

scanInfo.sourceViewPortRect – Sx, Sy, sWidth, sHeight

Gives the values related to the Desktop size.

scanInfo.targetViewPortRect – Sx, Sy, sWidth, sHeight

Gives the values related to the physical display.



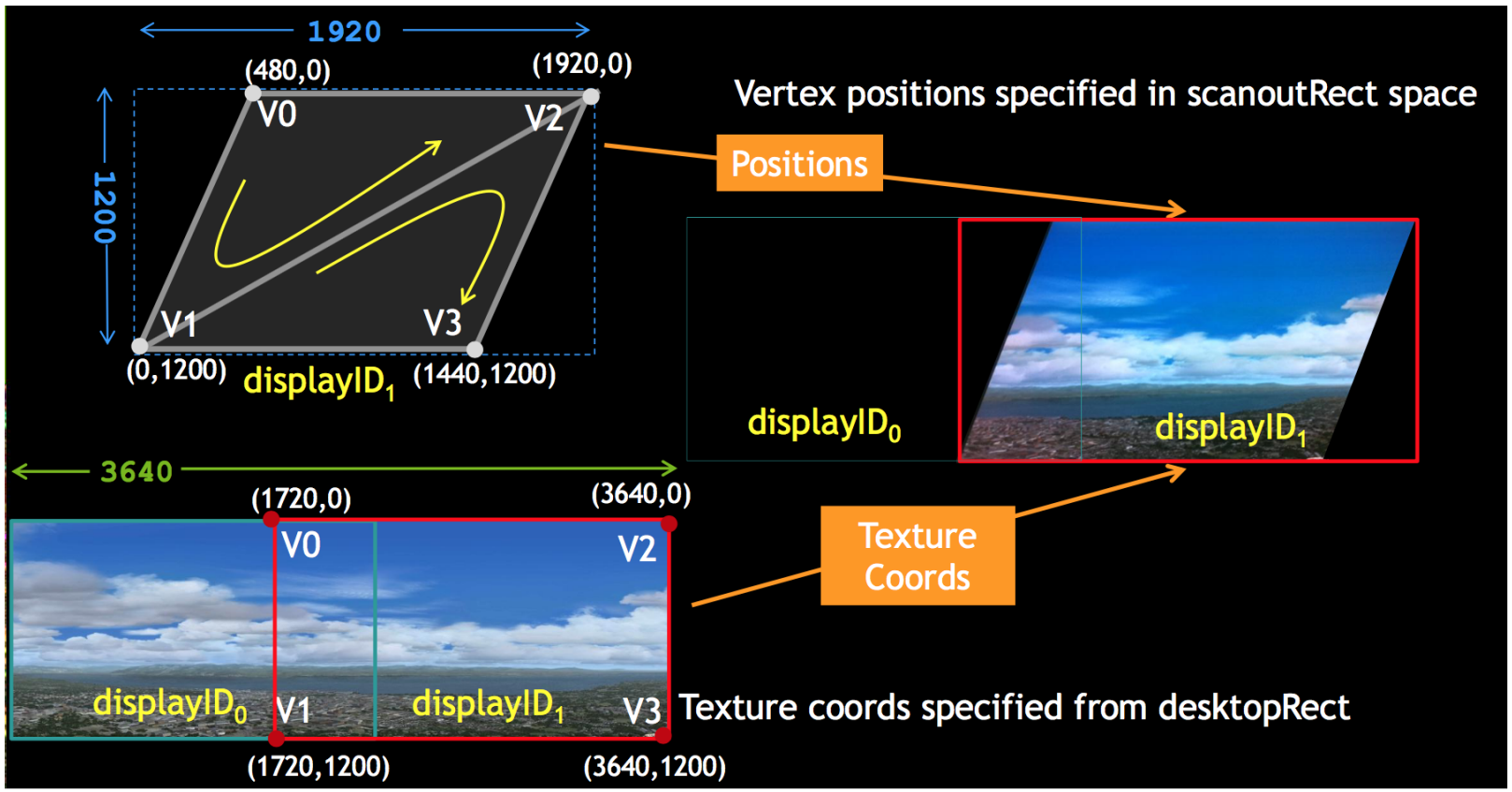
LINUX SIMILAR CO-ORDS

You use NVCNTRL to query layout

- Xscreen size
  - NV_CTRL_STRING_SCREEN_RECTANGLE
- Display Size and coordinates
  - NV_CTRL_BINARY_DATA_DISPLAYS_ENABLED_ON_XSCREEN

```
// Get resolution of the Xcreen

ret = XNVCTRLQueryStringAttribute(
        dpy,
        screen,
        0,
        NV_CTRL_STRING_SCREEN_RECTANGLE,
        &str);

ret = XNVCTRLQueryTargetBinaryData
        (dpy,
        NV_CTRL_TARGET_TYPE_X_SCREEN,
        screen, // target_id
        0, // display_mask
        NV_CTRL_BINARY_DATA_DISPLAYS_ENABLED
_ON_XSCREEN,
        (unsigned char **)&pDisplayData,
        &len);
```

WARP EXAMPLE



WARPING DATA STRUCTURE

Windows

NV_SCANOUT_WARPING_DATA

VertexFormat : strip or triangle list

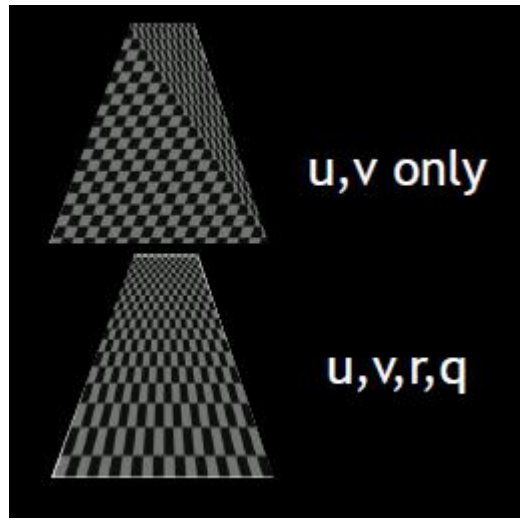
Vertices: number of vertices

x,y : mesh coordinates per-display rectangle

- `scanInfo.targetViewPortRect`

u,v : texture coordinates in desktop space

r,q : perspective mapping to simulate 3D warp



textureRect

Pass in **`scanInfo.sourceDesktopRect`**

WARPING CODE

Windows

To Enable WARP

```
          float vertices[numVerts*6] ={x0,y0,u0,v0,r,q, x1,y1,u1,v1,r,q, ...}; NV_SCANOUT_WARPING_DATA
warpingData;
          warpingData.version = NV_SCANOUT_WARPING_DATA_VER;
          warpingData.numVertices = numVerts;
          warpingData.vertexFormat = NV_GPU_WARPING_VERTICE_FORMAT_TRIANGLESTRIP_XYUVRQ;
          warpingData.vertices = vertices;
          warpingData.textureRect = osRect;
          int sticky = 0; // output - Reserved field for future use
          int maxNumVertices = 0; // output - returns the #pixels at scanout
          // This call does the warp
          NvAPI_Error error = NvAPI_GPU_SetScanoutWarping(displayId, &warpingData, &maxNumVertices,
&sticky);
```

To Disable Warp

```
          warpingData.numVertices = 0;
          warpingData.vertices = NULL;
          NvAPI_GPU_SetScanoutWarping(displayId,...);
```

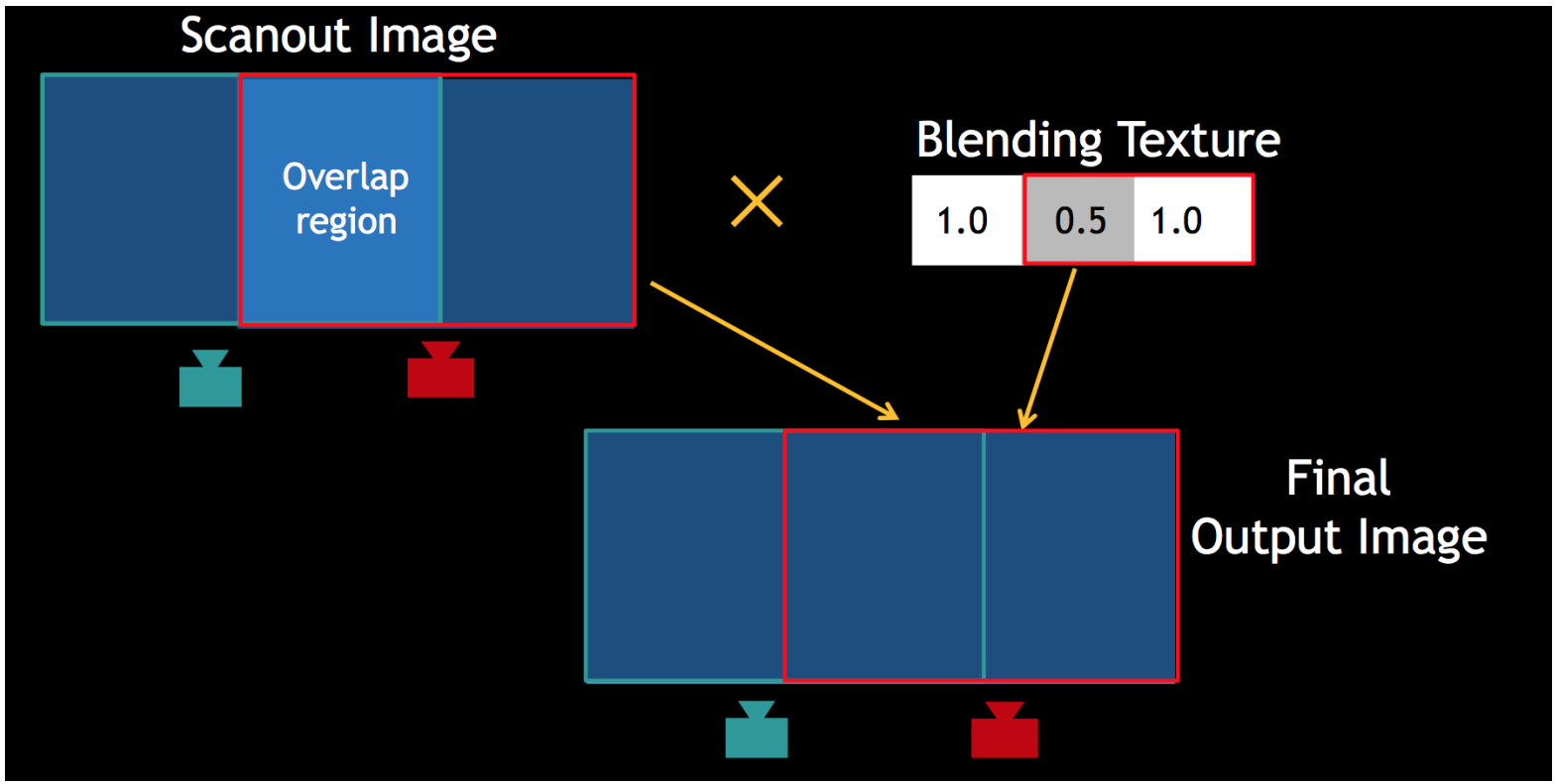
WARPING CODE

On Linux

All co-ordinates are normalized – 0.0f to 1.0f

```
// Prime the random number generator, since the helper functions need it.

srand(time(NULL));


// Apply our transformed warp data to the chosen display.

XNVCTRLSetScanoutWarping(xDpy, screenId, dpyId,
      NV_CTRL_WARP_DATA_TYPE_MESH_TRIANGLES_XYUVRQ,
                  6, // 6 vertices for two triangles
                                (float *)warpData);
```

BLENDING EXAMPLE



BLEND/INTENSITY ADJUSTMENT

NV_SCANOUT_INTENSITY_DATA

- width, height
  - Dimensions of blending texture
  - Normally same dimensions as scanout rectangle
  - If larger than scanout size, driver dynamically downsamples using box filter
- blendingTexture
  - float[width*height*3], RGB with same storage layout as OpenGL
  - Set to NULL for no adjustments
- offsetTexture
  - Same dimensions as blendingTexture
- offsetTexChannels
  - Number of components in the offsetTexture, 1 or 3

SAMPLE CODE

Windows

```
NV_SCANOUT_INTENSITY_DATA intensityData;
// simple 1x2 config, overlap region is modulated by 0.5
float intensityTexture[6] = {0.5f, 0.5f, 0.5f, 1.0f, 1.0f, 1.0f} ;
// overlapped region doesn't require an offset
float offsetTexture[6] = {0.0f, 0.0f, 0.0f, 0.1f, 0.1f, 0.1f} ;
intensityData.version = NV_SCANOUT_INTENSITY_DATA_VER;
intensityData.width = 2;
intensityData.height = 1;
intensityData.blendingTexture = intensityTexture;
 intensityData.offsetTexture = offsetTexture;
 intensityData.offsetTexChannels =3
 int sticky = 0; // output - Reserved field for future use
// This call does the intensity map
NvAPI_Status error = NvAPI_GPU_SetScanoutIntensity(displayId, &intensityData,
&sticky);
```

SAMPLE CODE

Linux

```
// Apply it to the display. blendAfterWarp is FALSE, so the
edges will be
 // blended in warped space.
  XNVCTRLSetScanoutIntensity(xDpy,
                             screenId,
                             nvDpyId,
                             blendPixmap,
                             False);
```

WARP 2.0

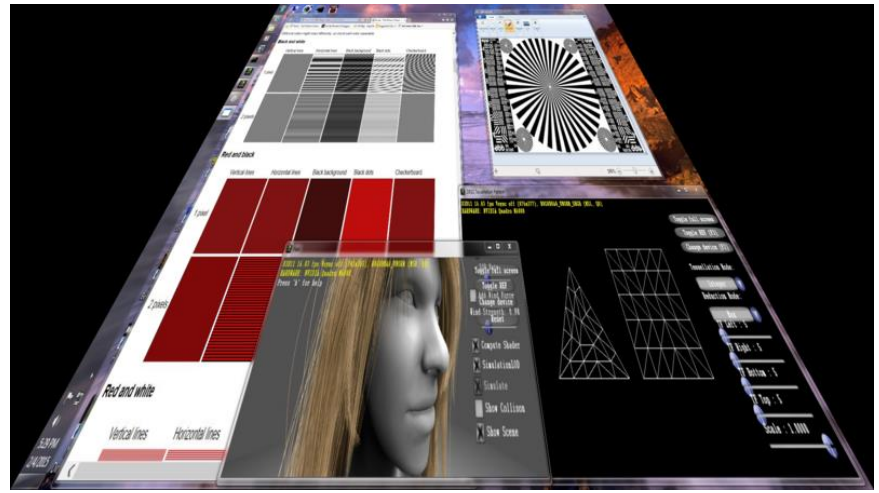
New filtering methods

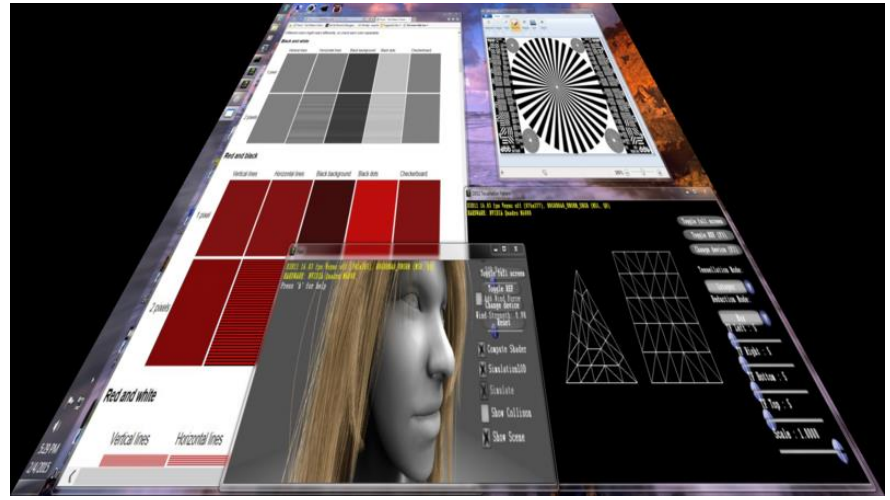
`NvAPI_GPU_SetScanoutCompositionParameter`

Selectable via NVAPI

- Bilinear
- BI-CUBIC Triangular
- BI-CUBIC Bell Shaped
- BI-CUBIC Bspline
- BI-CUBIC – Adaptive Triangular
- BI-CUBIC – Adaptive Bell Shaped
- BI-CUBIC Adaptive Bspline

Bi-linear filtering – WARP 1.0





Bi-cubic triangular filtering

CONCLUSIONS

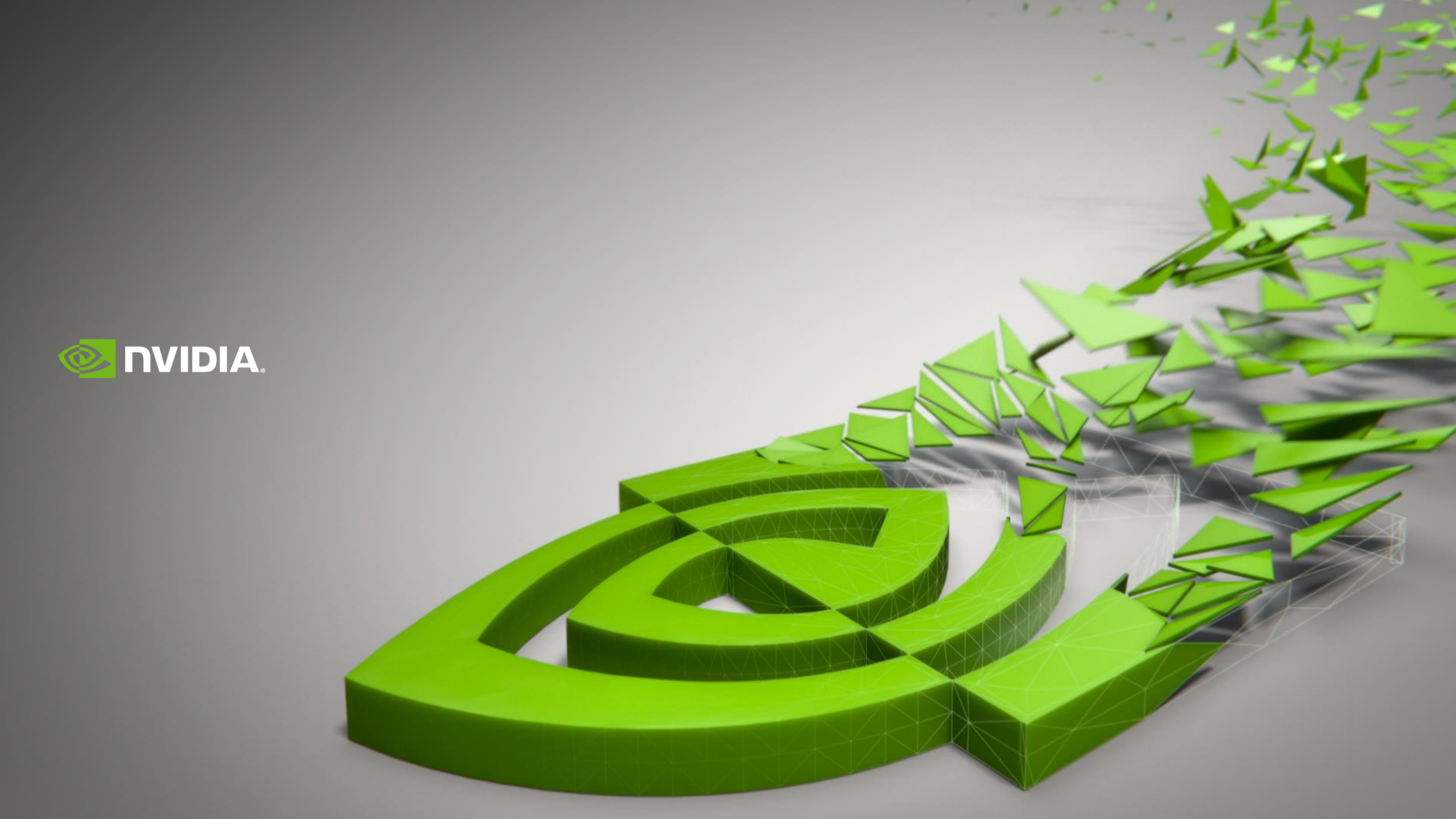
- Disabling/enabling warp is expensive
  - Requires modeset, lag in projector environments
  - However, changing the warp mesh does not require modeset
    - Eg During calibration, use identity quad with warp call to simulate no warping
- Changing warp mesh is not deterministic
  - Warp should not be changed for continuous updates
    - Eg eye tracking at 60Hz, best to do that in the app
  - OK to change it infrequently
    - Eg during calibration

NVIDIA DESIGNWORKS

https://developer.nvidia.com/warp-and-blend

-SDKs for WARP are packaged and available for online users

- Past talks
  - S5143 - Architectural Display Walls Using NVAPI – Doug Traill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