GPU TECHNOLOGY CONFERENCE

April 4-7, 2016 | Silicon Valley

HDR PROGRAMMING

Thomas J. True, July 25, 2016

PRESENTED BY

NVIDIA.

AGENDA

HDR Overview

Human Perception

Colorspaces

Tone & Gamut Mapping

ACES

HDR Display Pipeline

Best Practices

Final Thoughts

Q & A

WHAT IS HIGH DYNAMIC RANGE?

HDR is considered a combination of:

- Bright display: 750 cm/m^2 minimum, 1000-10,000 cd/m^2 highlights
- Deep blacks: Contrast of 50k:1 or better
- 4K or higher resolution
- Wide color gamut

What's a nit?

A measure of light emitted per unit area.

1 nit (nt) = 1 candela / m^2

BENEFITS OF HDR

Improved Visuals

Richer colors

Realistic highlights

More contrast and detail in shadows

Reduces / Eliminates clipping and compression issues

HDR isn’t simply about making brighter images

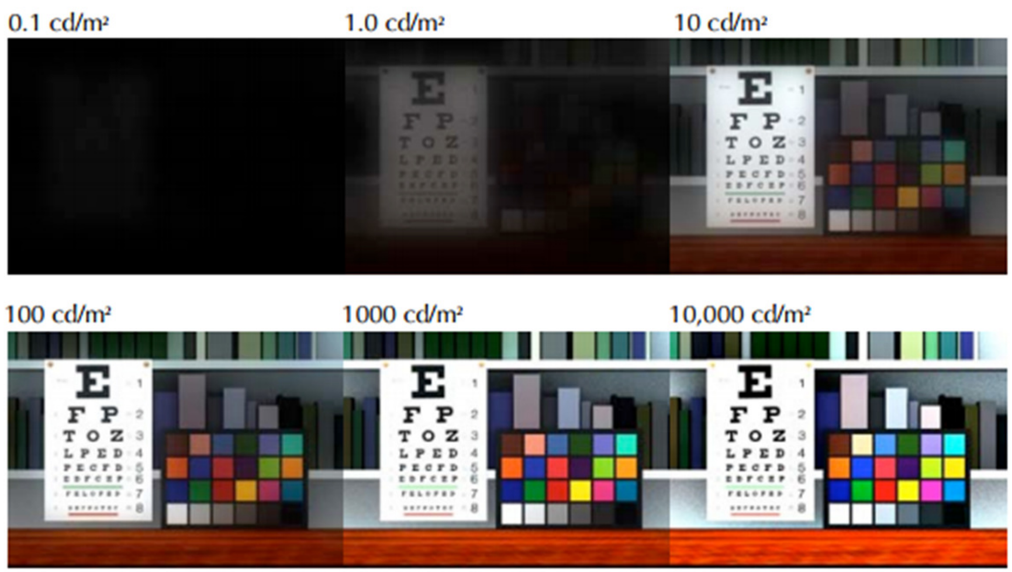
HUNT EFFECT

Increasing the Luminance Increases the Colorfulness

- By increasing luminance it is possible to show highly saturated colors without using highly saturated RGB color primaries
- Note: you can easily see the effect but CIE xy values stay the same

STEPHEN EFFECT

Increased Spatial Resolution



More visual acuity with increased luminance. Simple experiment – look at book page indoors and then walk with a book into sunlight

HOW HDR IS DELIVERED TODAY

High-end professional color grading displays

- Dolby Pulsar (4000 nits), Dolby Maui, SONY X300 (1000 nit OLED)

UHD TVs

- LG, SONY, Samsung… (1000 nits, high contrast, UHD-10, Dolby Vision, etc)

Rec. 2020 UHDTV wide color gamut

SMPTE ST-2084 Dolby Perceptual Quantizer (PQ) Electro-Optical Transfer Function (EOTF)

SMPTE ST-2094 Dynamic metadata specification

REAL WORLD VISIBLE LUMINANCE RANGE

Range of 10^17 Luminance Levels

$7.0 * 10^{10}$ cd/m^2	Lightning flash
$3.2 * 10^{9}$ cd/m^2	Sun (zenith)
$4.3 * 10^{5}$ cd/m^2	Sun (horizon)
$1.2 * 10^{5}$ cd/m^2	60W incandescent light bulb
$3.0 * 10^{4}$ cd/m^2	White paper in noon sunlight
$1.3 * 10^{4}$ cd/m^2	Clear sky (horizon)
$4.2 * 10^{3}$ cd/m^2	Full moon
$3.6 * 10^{3}$ cd/m^2	White paper in daylight shade
$1.3 * 10^{2}$ cd/m^2	White paper under office light
$1.0 * 10^{2}$ cd/m^2	White of computer monitor or TV
$1.0 * 10^{2}$ cd/m^2	Wax candle flame
$1.0 * 10^{2}$ cd/m^2	Clear sky, twilight
$2.4 * 10^{-1}$ cd/m^2	Brightest star (Sirius)
$1.3 * 10^{-3}$ cd/m^2	Absolute threshold (single flash)
$4.0 * 10^{-4}$ cd/m^2	Starless night sky
$7.5 * 10^{-7}$ cd/m^2	Absolute threshold (steady light)

REAL WORLD VISIBLE LUMINANCE RANGE

Human Visual Response

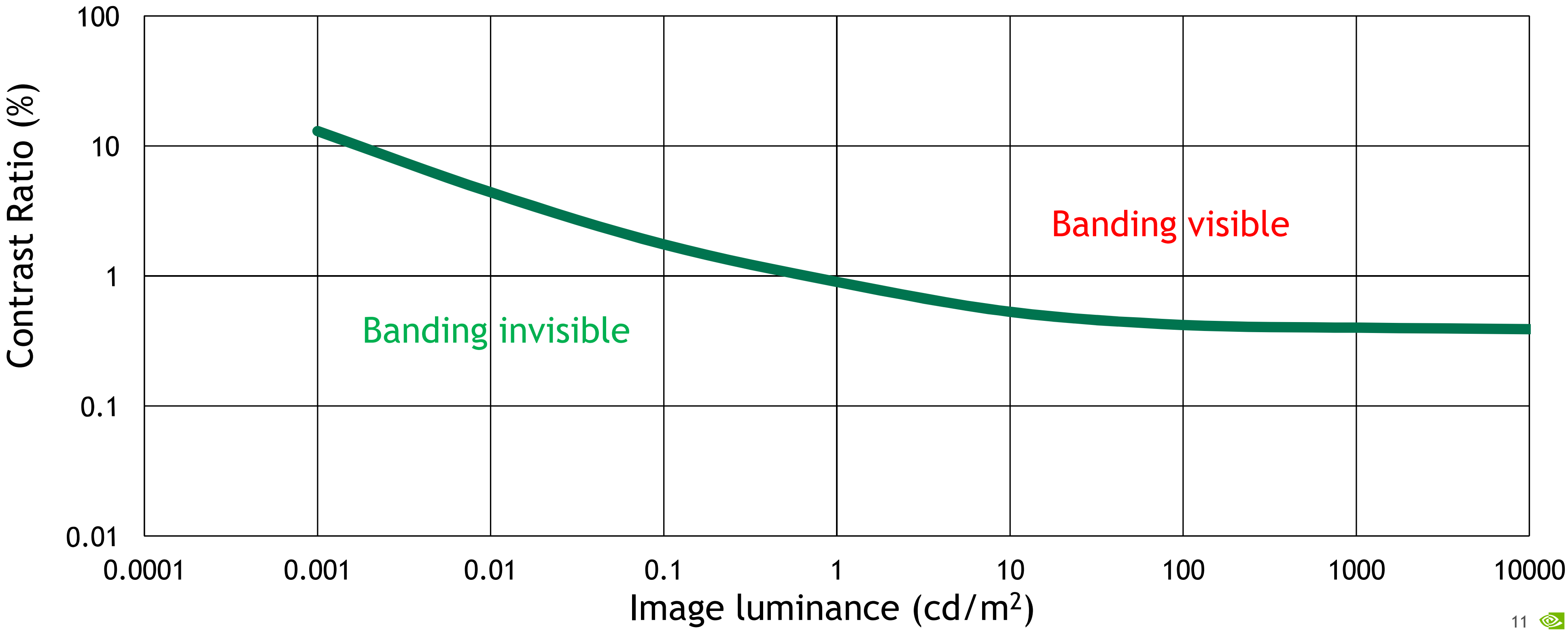
- Limited to 10^5 – 10^6 with a 95% contrast ratio of ~10000:1 (18 stops)
- Example: Full Moonlight – Can see details on the moon surface while simultaneously seeing details in the illuminated ground surface. (4200 cd/m2 to 0.012 cd/m2)
- Dark Adaptation
  - Slow, can take up to 30 minutes to see in the dark
- Light Adaptation
  - Fast, less that a second to a minute to adapt to bright light
- HDR displays should have a larger 10^7 dynamic range

COLOR PRECISION

How do we avoid banding?

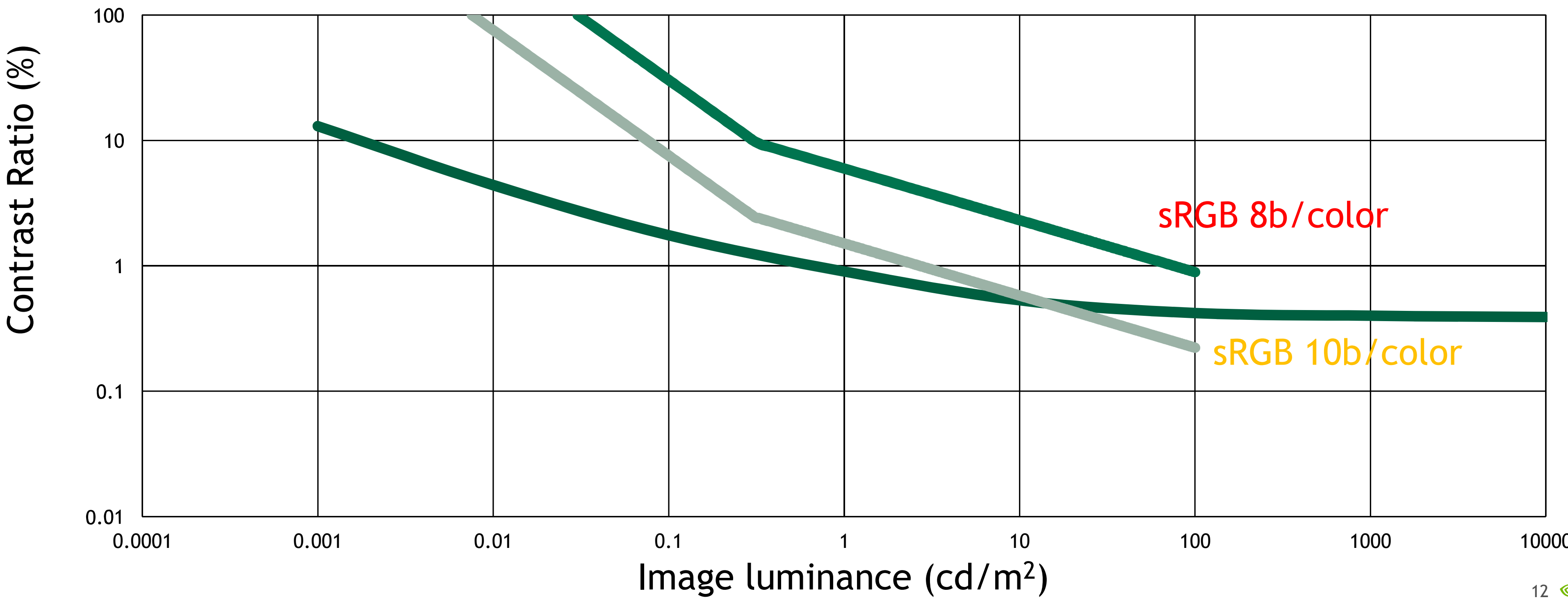
HUMAN PERCEPTION

Visibility of banding [Barten 1999]



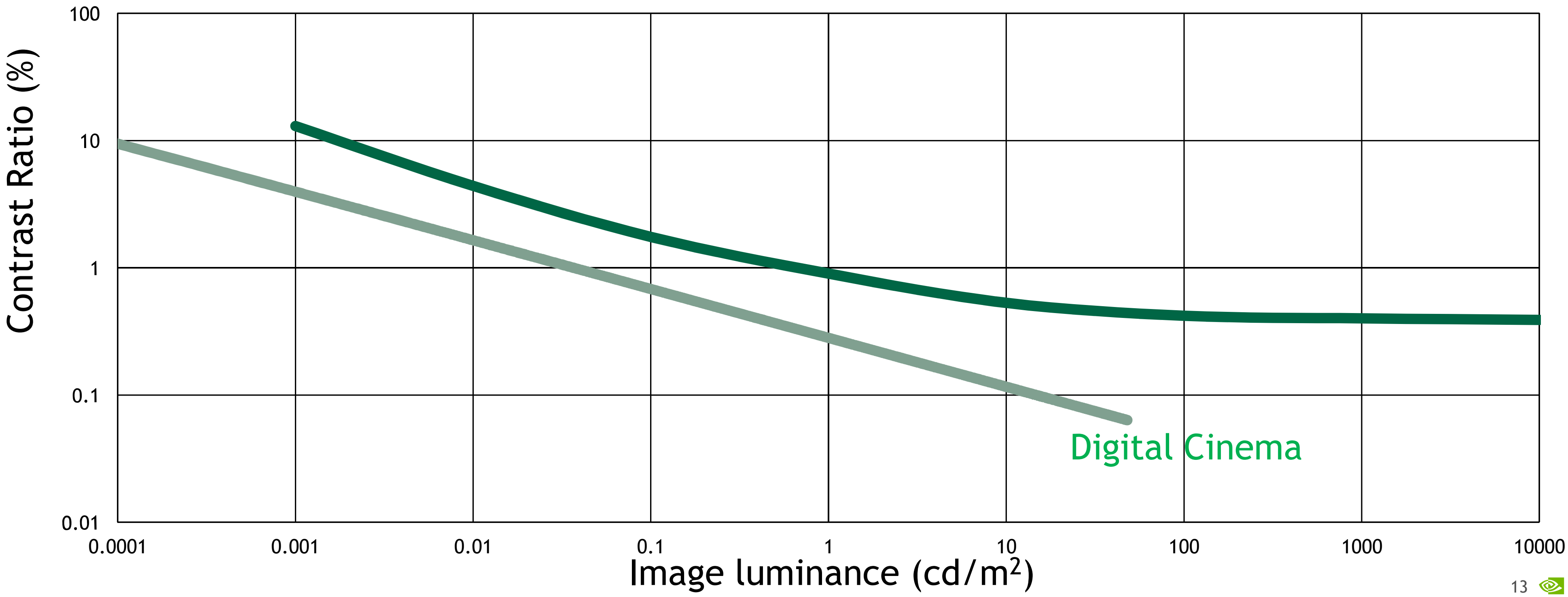
COLOR PRECISION

sRGB



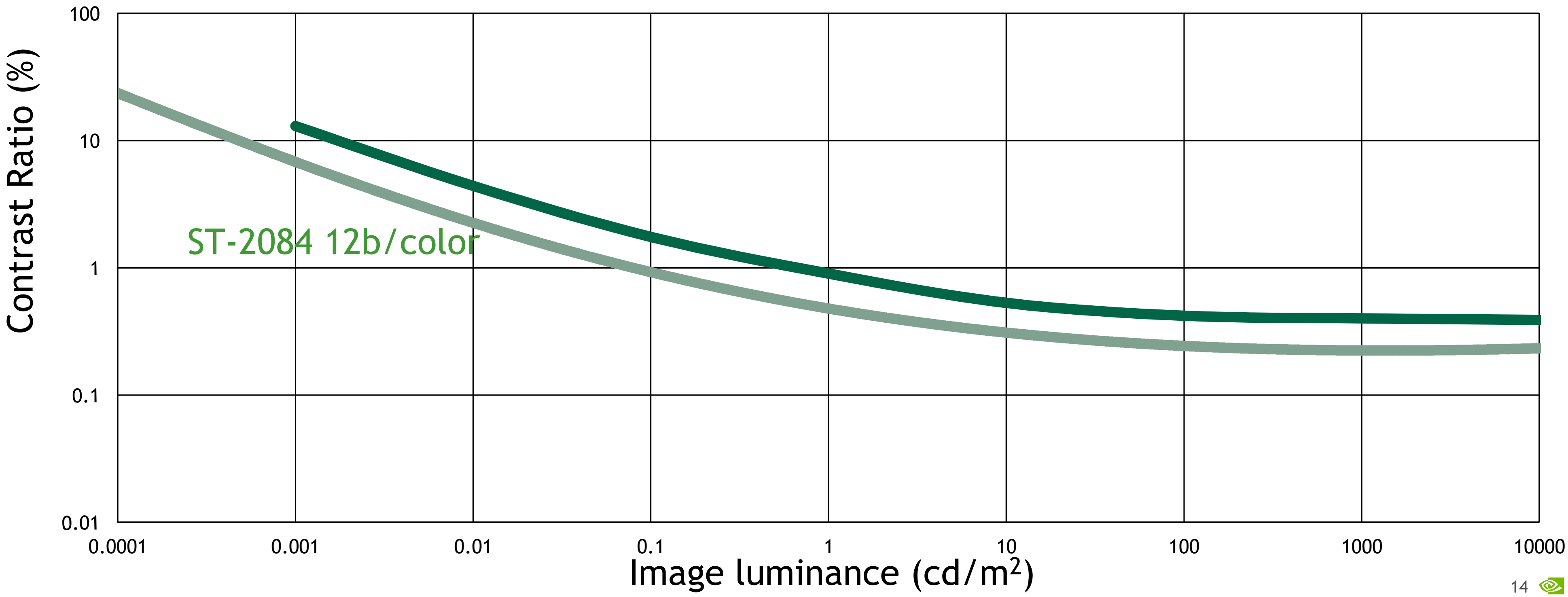
COLOR PRECISION

Digital Cinema - 12bit, gamma 2.6, full white = 48 cd/m^2



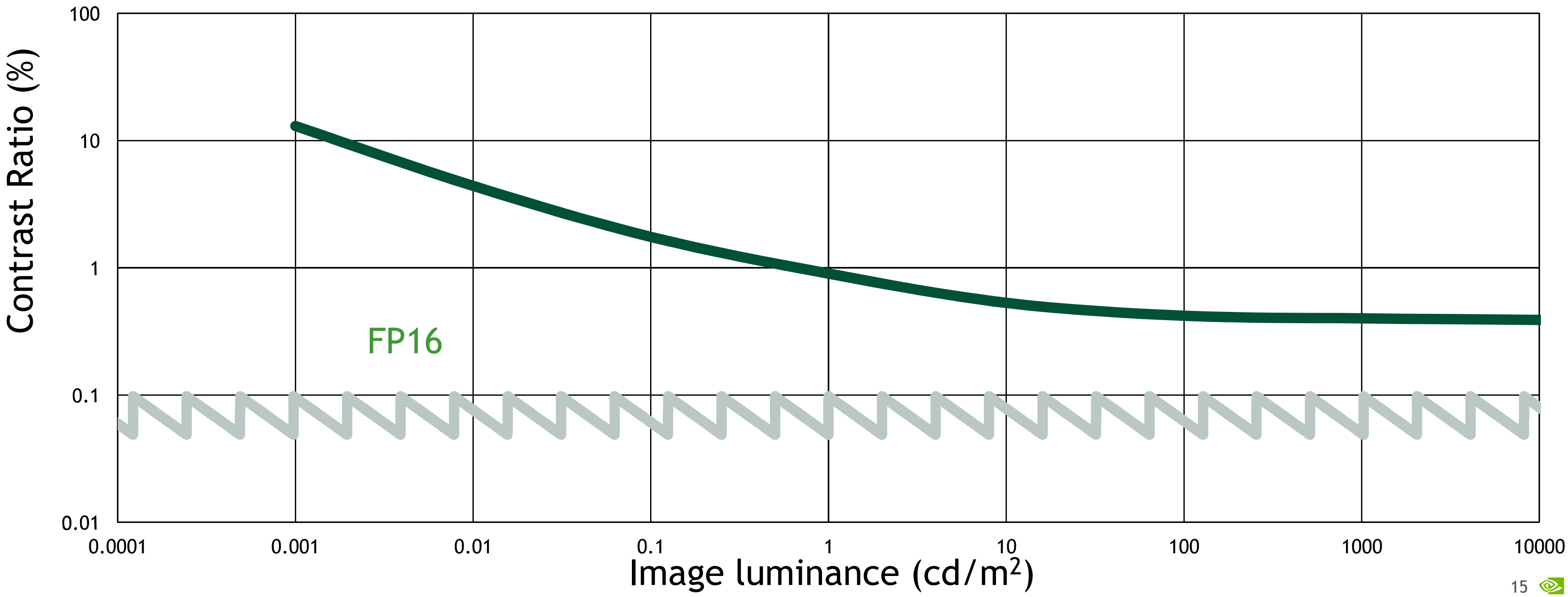
COLOR PRECISION

SMPTE ST-2084 - A new 12-bit HDR Transmission Standard



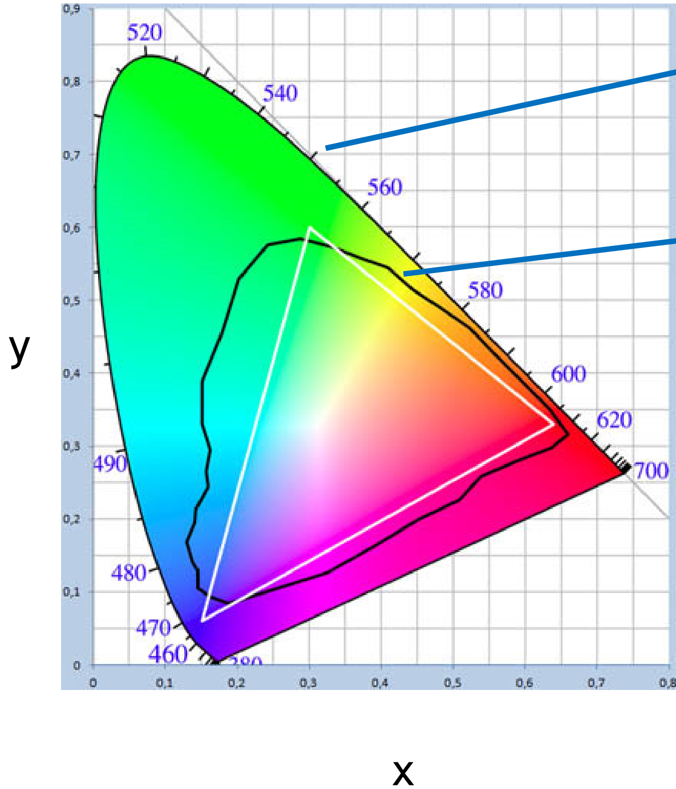
COLOR PRECISION

FP16 - For GPU Rendering



REAL WORLD VISIBLE COLORS

Pointer's Gamut of Naturally Occurring Colors

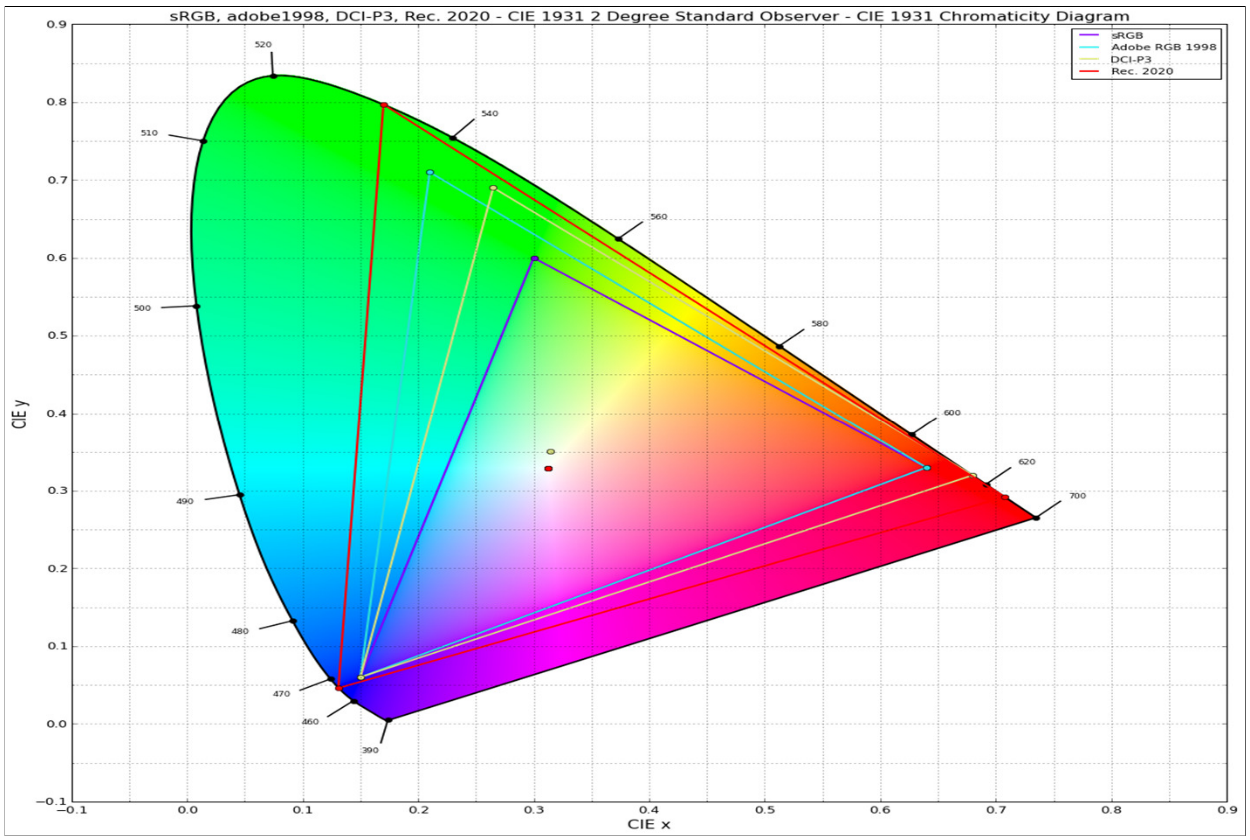


The CIE 1931 chart defines a coordinate system for all possible colors that the human eye can see

[Pointer 1980] the colors of 'real world' objects

COLORSPACES

Comparison of Common Colorspaces



Rec 2020
- UHDTV Standard
- 60% of visible colors
- 99% of Pointer’s Gamut

DCI-P3
- Digital cinema projectors

AdobeRGB (1998)
- Includes printable colors
- Same red and blue
- Purer green

scRGB (Vista)
- [-0.5, 7.5]
- (1,1,1) matches sRGB white

sRGB (1996)
- Designed around CRT
- Same primaries as Rec. 709
- 33% of visible colors
- 70% of Pointer’s Gamut

COLORSPACES

Impact on Rendering

Same colors can be represented in the different spaces, but…

- Modulus operations will yield different results based on the color primaries used
  - Material * Light is color space dependent
  - Purple in one color space will be brown in another
  - Issue is orthogonality of primaries in the other color space
- Rendering always implies a set of primaries
  - Important to keep colorspace consistent through development
  - Transform final result to different colorspace primaries

COLORSPACES

Challenges with Color Primaries

Primaries in a color space are not orthogonal when transformed into another color space. This changes the results of modulation.

SCENE LINEAR VS OUTPUT LINEAR COLOR

Scene Referred (Scene Linear)

- Linear colors as they represent light in the scene
- Photons striking the virtual film

Output Referred (Output Linear or Display Referred)

- Linear colors as they are represented by the display
- Photos emitted by the display
- May have an EOTF applied.

TONE MAPPING

Conversion from Scene Referred to Output Referred

Compresses or clips the color data into the output range

Compresses shadows and high lights

Enhances mid-tone contrast

Irreversible, data is lost

TONE MAPPING

Why Tone Map for HDR?

HDR displays still limited (1000 nit max)

Real world luminance is much higher

- Sun over 1000x more luminous
- 100w bulb over 10x more luminous

Permits differentiation of luminance levels

No one true tone mapper, choice depends on the desired aesthetics

HDR adds complexities that could be ignored in LDR

TONE MAPPING

Linear

Scale and clip to [0,1]

Same general problems as in LDR

- Hard clip at the limit of the capabilities of the display
- Sun and light bulb likely to have same luminance on screen

Scene may look dull

Needs to account for the larger luminance range when scaling / clipping

- Otherwise, scene will just get brighter

TONE MAPPING

Reinhard

Classic x/(x+1)

No concept of output brightness

- In HDR, images just get a lot brighter

Example: 0.18 will change from 12-45 nits to 150+ nits

- 0.18 is often considered the color of asphalt after exposure
- Result is a bright road

Limited control

TONE MAPPING

Drago

Algorithmic operator(similar to Reinhard)

Compressed range using an adaptive log scale

Provides argument for display output luminance

Better adapts to display brightness

TONE MAPPING

Filmic

S-curve in logarithmic space

Enhances mid-tones

Compresses shadows and highlight

Approximates the behavior of traditional film

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GAMUT MAPPING

Mapping of Unrepresentable Colors to Representable Colors

Stretching or compressing one color space to fit within another.

Remapping of the chromaticity values

Many different methods to remap the color space (clip, soft clip, scale, etc)

All methods have non-trivial caveats (hue shifts, memory colors, etc)

ACES

Academy Color Encoding System

Standard for digital post-production

Driven by the Academy of Motion Pictures

Provides framework for end-to-end processing and preservation of data

Defines reference transforms as part of the framework

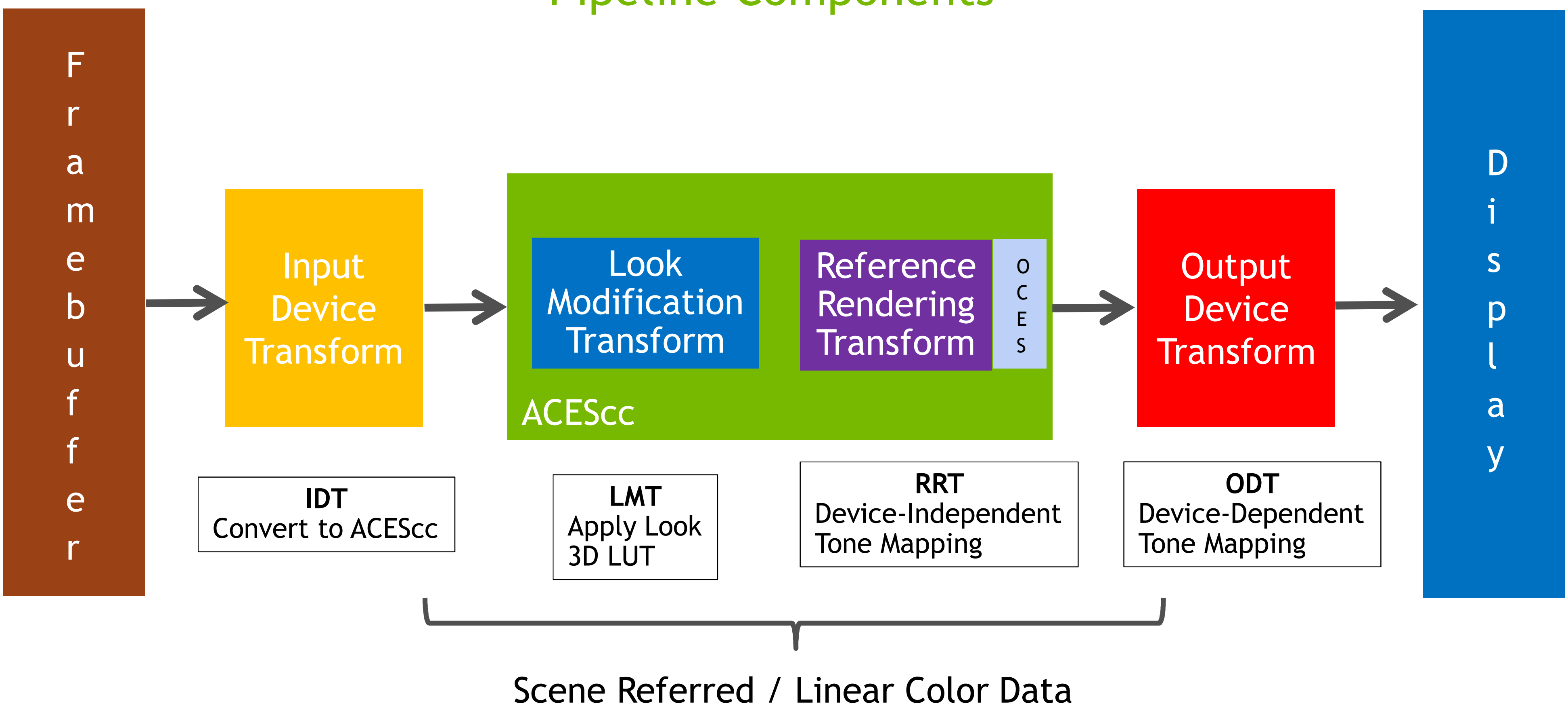
- Tone mapping for different classes of displays

Open-source and available on GitHub

- Reference is written in Color Transform Language

ACES

Pipeline Components



ACES

Tone Mapper

Tone mapper is a filmic sigmoid-style-curve

Defined by segmented quadratic spline in reference implementation

- Two splines joined at middle gray

Operates per-channel in a wide color space

- Results in natural desaturation at the shoulder

Input middle gray is set at 0.18

ACES

Parameterized ACES

Parameterized ODT developed by NVIDIA

Allows adaptation of the reference transforms to a wider set of uses

- Alter output middle gray level
- Alter input and output range of tone mapper
- Saturation adjustment
- Contrast adjustment

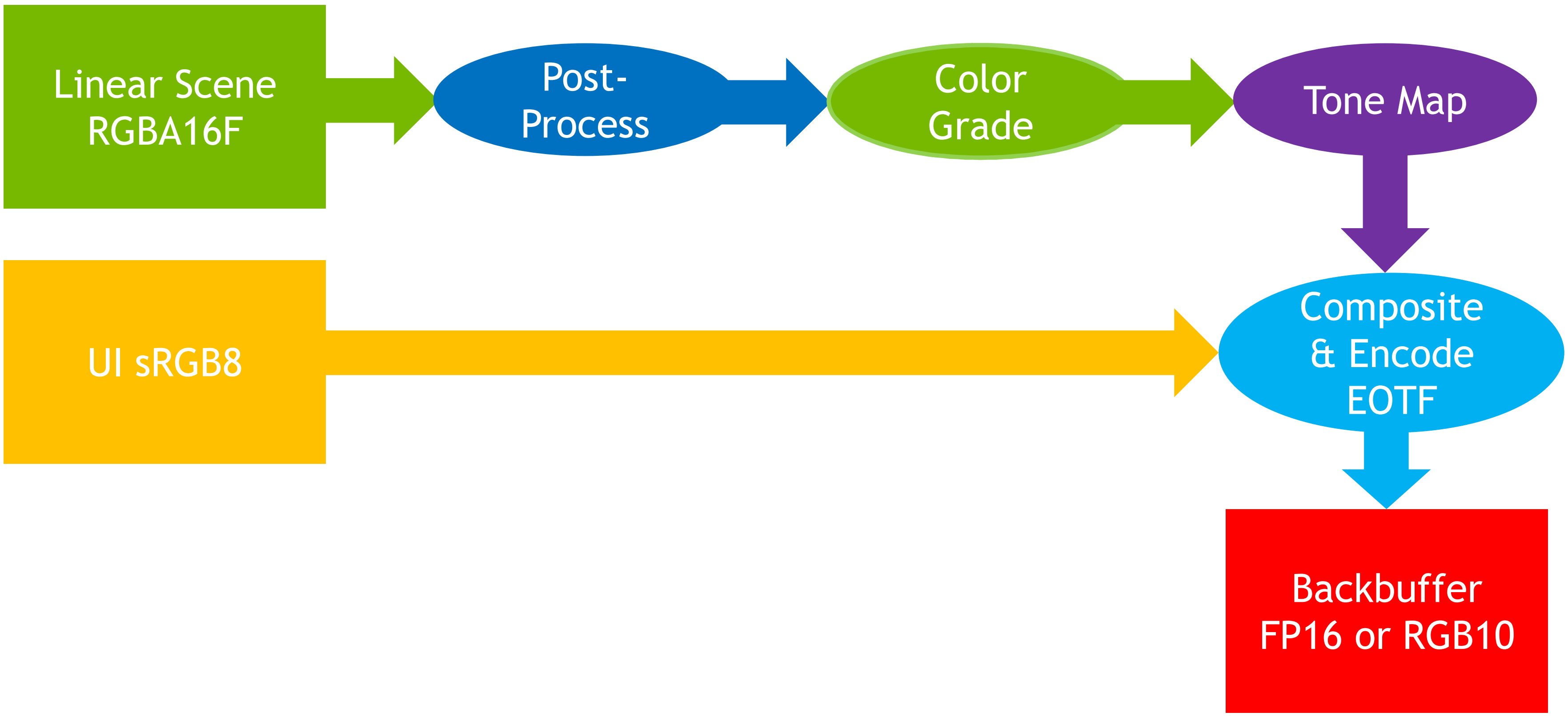
HDR DISPLAY PIPELINE

Practical Path to Utilizing Current UHD Displays

1) Create content with sRGB primaries as done today for LDR.
2) Render high-quality HDR using physically-based shading.
3) Post process in the scene referred space
4) Apply color grading to the rendered scene referred image
5) Tone map with a filmic ACES-derived tonemapper
6) Keep backbuffer in FP16 scRGB
7) Composite 8-bit sRGB referenced UI as normal

HDR DISPLAY PIPELINE

Logical Pipeline for HDR Output



DISPLAYING HDR ON WINDOWS

Quick Start Guide

Create backbuffer as R16G16B16A16_FLOAT/FP16 - Ensures enough color precision

DirectX: Create **DXGI_FORMAT_R16G16B16A16_FLOAT** swap chain

OpenGL: Specify `WGL_PIXEL_TYPE_ARB = ` **`WGL_TYPE_RGBA_FLOAT_ARB`**
with color depth 16 (`WGL_RED_BITS_ARB = ` **`16,`**
`WGL_GREEN_BITS_ARB = ` **`16,`** `WGL_BLUE_BITS_ARB = ` **`16`**)

Make window fullscreen exclusive - Prevents OS compositor from destroying data

Query HDR capability from NVAPI

Call NVAPI to send HDR metadata and enable HDR

Output linear tonemapped scene to FP16 scRGB backbuffer in scRGB colorspace

DISPLAYING HDR ON WINDOWS

Use NVAPI to Enumerate GPUs and Connected Displays

```
// Enumerate GPUs and connected displays

NvPhysicalGpuHandle *nvGPUHandle = (NvPhysicalGpuHandle *)calloc(NVAPI_MAX_PHYSICAL_GPUS,
                                                                  sizeof(NvPhysicalGpuHandle));;
NvU32 nvGPUCount;
NvU32 *nvConnectedDisplayIdCount = (NvU32 *)calloc(NVAPI_MAX_DISPLAYS, sizeof(NvU32));

NV_GPU_DISPLAYIDS **nvConnectedDisplayIds =
                                 (NV_GPU_DISPLAYIDS **)calloc(NVAPI_MAX_PHYSICAL_GPUS,
                                                               sizeof(NV_GPU_DISPLAYIDS));

if (EnumerateGPUsAndDisplays(nvGPUHandle, &nvGPUCount, nvConnectedDisplayIds,
                             nvConnectedDisplayIdCount) != NVAPI_OK)
{
    MessageBox(NULL, TEXT("GPU and Display Enumeration Failed."), applicationTitle,
               MB_OK | MB_ICONINFORMATION);
     return 0;
}
```

DISPLAYING HDR ON WINDOWS

Query HDR Capabilities of Each Display from NVAPI

```
// On each GPU, get the HDR capabilities of each active display.
NvU32 gpu = 0;
NvU32 display = 0;
while (gpu < nvGPUCount)
{
      while (display < nvConnectedDisplayIdCount[gpu])
      {
            NV_HDR_CAPABILITIES hdrCapabilities;
            if (NvAPI_Disp_GetHdrCapabilities(display, &hdrCapabilities) != NVAPI_OK)
            {
                  MessageBox(NULL, TEXT("NVAPI GetHdrCapabilities Failed."),
                             applicationTitle, MB_OK | MB_ICONINFORMATION);
                  return 0;
            }

            // If HDR is supported, break
            if (hdrCapabilities.isST2084EotfSupported)
                  break;

           display++;
    }
    gpu++
}
```

DISPLAYING HDR ON WINDOWS

Call NVAPI To Send HDR Meta Data and Enable HDR

```
// If HDR is supported, enable it
if (hdrCapabilities.isST2084EotfSupported)
{
    NV_HDR_COLOR_DATA hdrColorData = {};
    memset(&hdrColorData, 0, sizeof(hdrColorData));

    hdrColorData.version = NV_HDR_COLOR_DATA_VER;
    hdrColorData.cmd = NV_HDR_CMD_SET;
    hdrColorData.static_metadata_descriptor_id = NV_STATIC_METADATA_TYPE_1;
    hdrColorData.hdrMode = NV_HDR_MODE_UHDA;

    if(NvAPI_Disp_HdrColorControl(display, &hdrColorData) != NVAPI_OK)
    {
        MessageBox(NULL, TEXT("NVAPI HdrColorControl Failed."), applicationTitle,
                   MB_OK | MB_ICONINFORMATION);
        return 0;
    }
}
```

DISPLAYING HDR ON LINUX

DISPLAYING HDR ON LINUX

Not Possible Today Due to Lack of Infrastructure

32-bit XServer prevents color deeper than R10G10B10A2.

No infrastructure for metadata transfer

Will be discussed at XDC 2016 Conference September 21-23 in Helsinki, Finland

HDR BEST PRACTICES

Physically-Based Rendering

Makes light interactions more correct / plausible.

- Results in proper highlights, not just a hack that looks good in LDR

Creates values on a scale consistent with the real world

- [0,1] brightness level doesn't make sense in an HDR world
- Will need to make compromises (FP16 won't represent the brightest sun)

HDR BEST PRACTICES

Colorspace

Keep using sRGB primaries.

Keeps consistency with the present art pipeline

- No surprises for artists
- No gamut mapping problems on LDR displays

Will still reap the benefits of brightness and brighter saturated colors

Starting point. Plan to be more aggressive in the future.

HDR BEST PRACTICES

Gamut Remapping

Stretches rendering done with sRGB primaries to more extreme ones.

- Produces richer / more saturated colors
- May work OK for some applications, not so much for others

Will present challenges with existing artwork

- Unnatural skin tones
- Hue shifting
- Memory color

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HDR BEST PRACTICES

Luminous Effects

Make things that glow, glow at a level consistent with the light source

- Emissive level and light source should be correlated

Looks odd when a specular high light outshines a light source

HDR BEST PRACTICES

Scene Referred Post-FX

Perform operations that require linear lighting prior to tone mapping.

- Bloom
- Motion blur
- Depth of field

Operating scene-referred maintains consistency

- Same operation for HDR and LDR

HDR BEST PRACTICES

Color Grading

Ideally done in scene-referred space

- Makes operations consistent LDR/HDR
- Avoids tone mapping “fix-ups”

HDR BEST PRACTICES

Luminance-Aware Tone Mapping

Many operators designed to work within a generic [0-1] space.

- How bright is 1.0?
- Scaling to a 1000 nit display would display asphalt at 100 nits

Need an operator that understands the output luminance

- Middle gray stays at a reasonable level
- Colors only compressed where they need to be

Use ACES or Drago

HDR BEST PRACTICES

UI Compositing

UI typically authored in straight RGB

- Need to composite properly into the color space of the HDR scene

Using scRGB backbuffer provides simple solution

- Same sRGB primaries with (1, 1, 1) as the brightness level for white
- Blending just works.

HDR BEST PRACTICES

UI Blending Challenges

UI may look dimmer / duller than intended

- Due to adaptation of the eye to the brighter colors of the HDR display
- Scale up the UI luminance to conteract this

Transparent elements may suffer glow throw effects

- Example: 1000 nit highlight behind a transparent dialog with white text
- Solution: Clip / Apply simple LDR tone map to scene elements underneath

HDR SDK

HDR Display Sample Code

Simple app demonstrating ACES tone mappers + HDR display

Allows setting HDR metadata to enable HDR on UHD TVs

Offers standard ACES tone mappers + customized ACES tone mappers

Provides EXR and HDR file format loading to visualize HDR data

Offers exposure scaling and range ‘enhancement’ tools

http://developer.nvidia.com/high-dynamic-range-display-development/

OTHER NOTES

Random Stuff

HDMI 2.0a is required.

- On Quadro GPUs will need an active DP 1.2 -> HDMI 2.0a dongle.

THINGS TO COME

Support for HDR is Evolving

Native OS Support for HDR

- Will remove requirement for full-screen exclusive window
- Include support for HDR10/UDH metadata transmission replacing NVAPI functions.

GPU Hardware support

DP 1.4 metadata support

MORE INFORMATION

http://developer.nvidia.com/high-dynamic-range-display-develpment

- White Paper
- SDK

[Barten 1999] Peter G.J. Barten, ‘Contrast Sensitivity of the Human Eye and its Effects on Image Quality’

[Pointer 1980] M.R. Pointer, ‘the Gamut of Real Surface Colors’

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Q & A

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