Advanced Ambient Occlusion, Shadow and Anti-Aliasing in NVIDIA GameWorks

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NVIDIA

Overview

- VXAO
- HRTS
- TXAA 3.0
- ANSEL
- HDR Display

Voxel Ambient Occlusion

- VXGI is NVIDIA's new real-time global illumination solution
  - Works by voxelizing geometry on every frame
  - Produces approximate but realistic looking diffuse and specular GI
  - Still too resource intensive to use in mainstream games
- VXAO is a special mode of operation of VXGI
  - Throw away all the lighting information, keep only occlusion
  - Works much faster
  - Integration is significantly simpler

Screen-Space AO Issues

- View dependence
  - Lack of occlusion behind foreground objects
  - Errors and unstable results near screen edges
- Locality
  - Only a small volume around a surface contributes to AO
- Blurriness
  - Computing a complete solution for every pixel would be too expensive

Why VXAO is Better Than SSAO

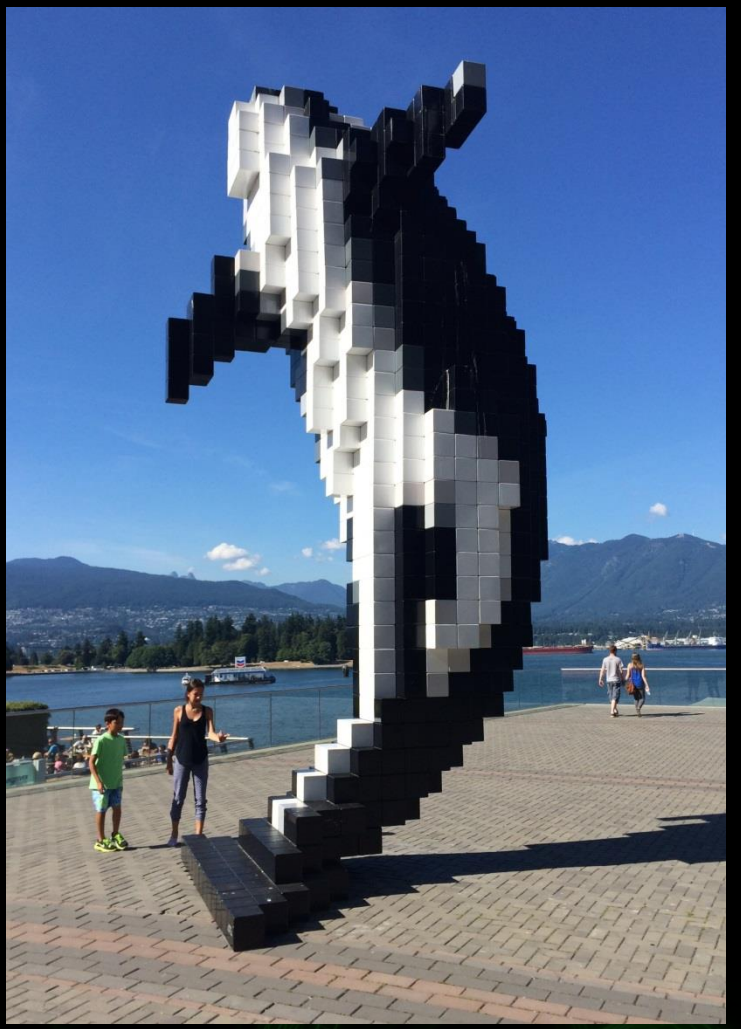
- It has none of the aforementioned issues
- World-space solution
  - An occluder can be behind something else
  - Even behind the viewer (which means less aggressive culling is required)
- Uses Voxel Cone Tracing approach
  - Occluders can be far from the surface under consideration
  - Their information will be sampled from a very coarse voxel LOD
  - Using a large AO distance has very little effect on performance

Overview of voxel cone tracing

- Transform the scene into voxels that encode opacity
  - Then downsample the opacity map
  - Opacity gives us information to compute occlusion
- Gather light by tracing cones through the opacity

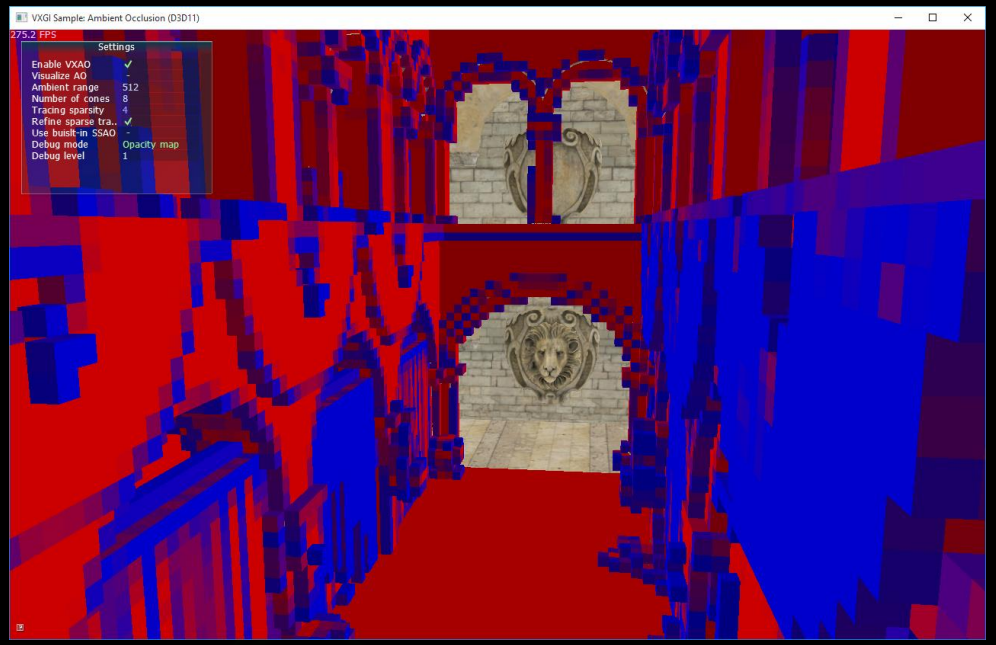
Voxelization

- The process of converting a mesh into a voxel representation
- Treat it as 3D space rasterization



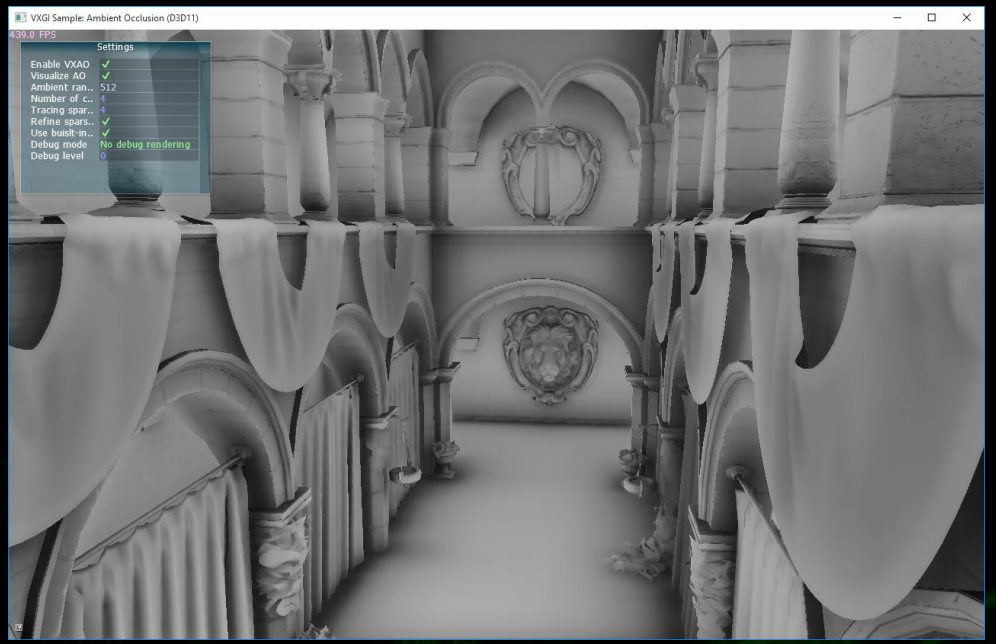
A binary voxel representation of an object with color information

In a real demo



- Voxelization

- VXAO Result



Example: HBAO+ Channel

Example: VXAO Channel

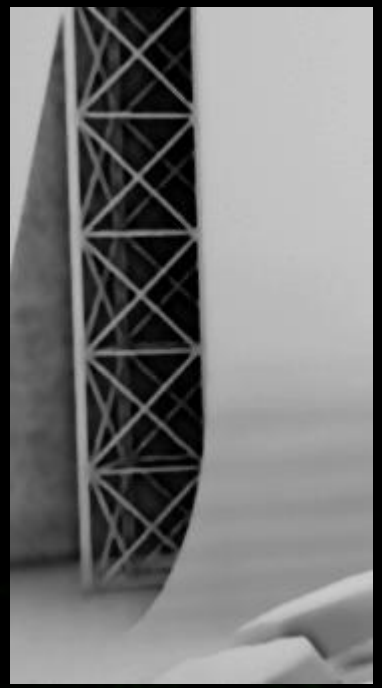
Image Quality Differences #1

HBAO+

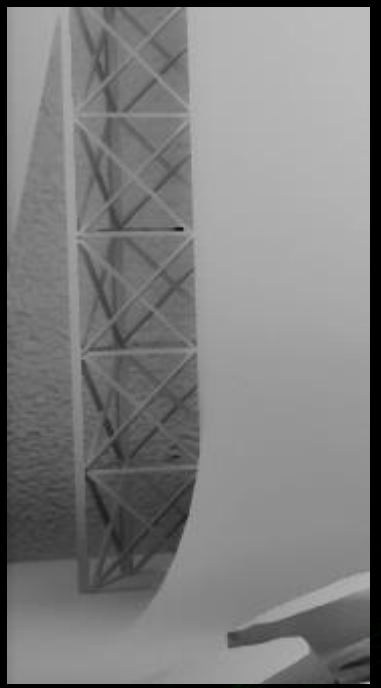
VXAO

- Ground under the tank
- Bottom part of the tracks
- Blurriness

Image Quality Differences #2



HBAO+



VXAO

HBAO+

VXAO

HBAO+ with Color

VXAO with Color

Handling Dynamic Scenes

- Voxel representation is very expensive to construct or update?
  - Wrong !
  - It takes about 1 ms to voxelize a 300K triangle scene on a GTX 980
- Most of voxel data can be preserved between frames
  - Pass a list of AABBs for geometry that has changed
  - Those regions will be cleared and updated, everything else stays

Performance on GTX 980

Pass	Time	Conditions
VXAO: Full scene voxelization	1.0 ms	300K triangles 128^3 clip-map, 5 LODs
VXAO: Voxel post-processing	1.4 ms	
VXAO: Cone tracing, Interpolation	1.6 ms	1920x1080
VXAO overall	**4.0 ms**	
HBAO+ overall	**1.2 ms**	1920x1080 Blur radius 4, normal channel supplied

HBAO+ is about 2-4x faster than VXAO on Maxwell GPUs, but loses in quality

Performance with Partial Updates

- For mostly static scenes, voxelization and post-processing cost can be significantly reduced

Voxelized geometry percentage	30%	40%	63%	83%	100%
Voxelization time, ms	0.23	0.28	0.45	0.63	1.01
Voxel post-processing time, ms	1.02	1.06	1.08	1.22	1.49
Total time relative to full voxelization	50%	54%	61%	74%	100%

In 100% case, some large floor and wall triangles add significant contribution.
Actual numbers strongly depend on the specific scene (Sponza Atrium in this case)

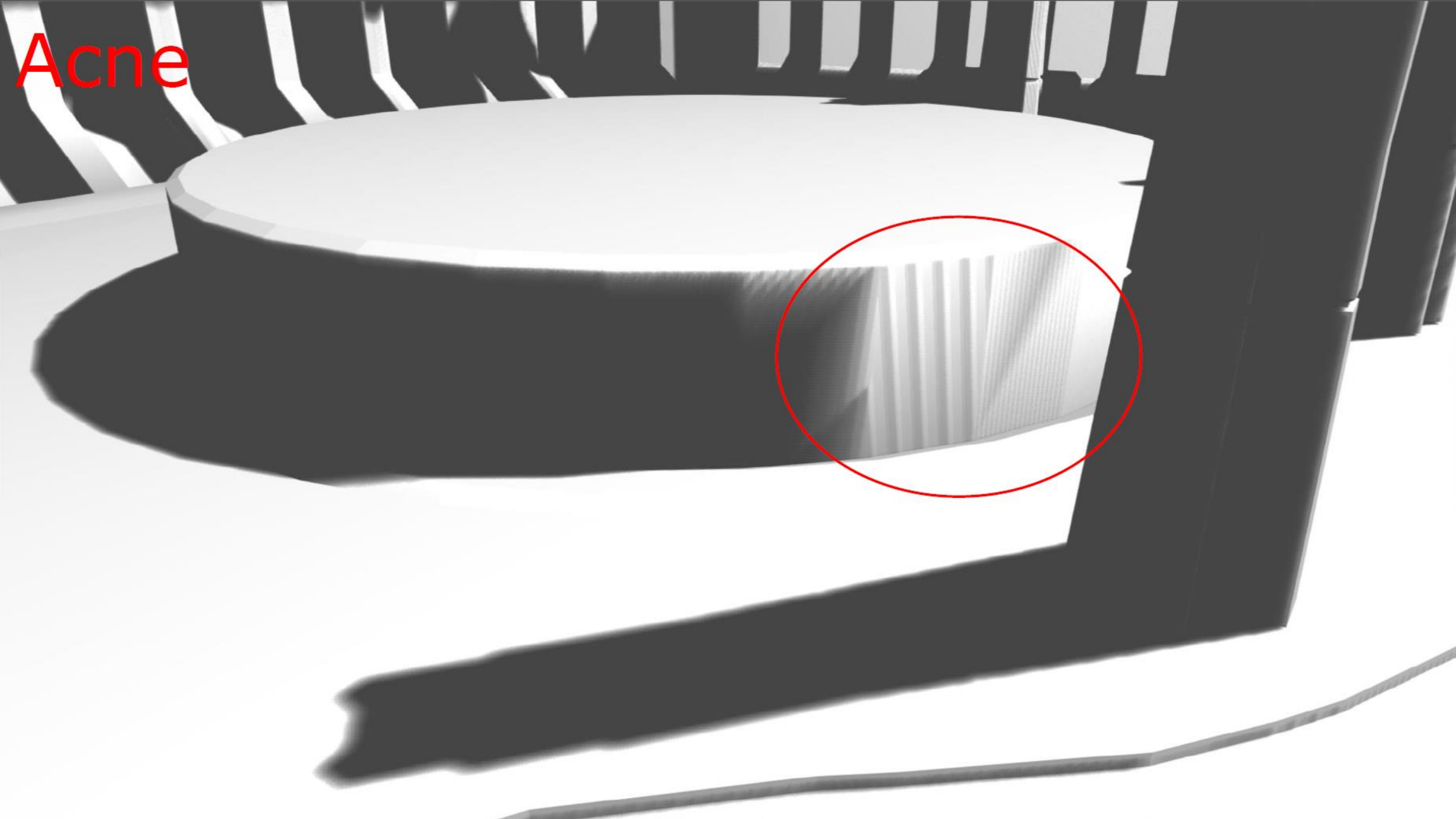
Hybrid Ray-Traced Shadows

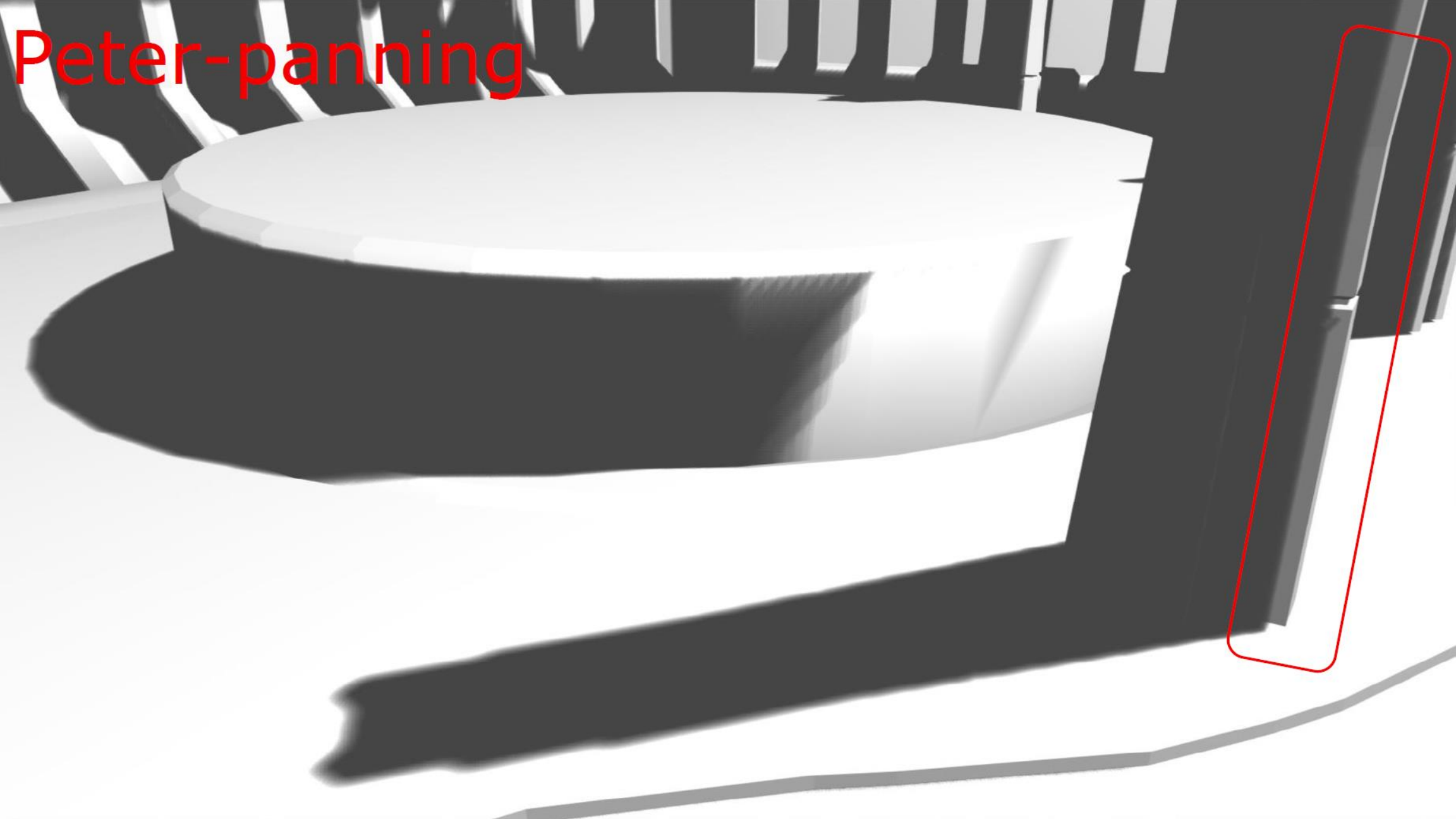
- Combine ray tracing with traditional shadow map algorithm
- Benefits
  - Razor sharp anti-alised hard shadows
  - Super soft shadows
  - HRTS will blend between the two result automatically

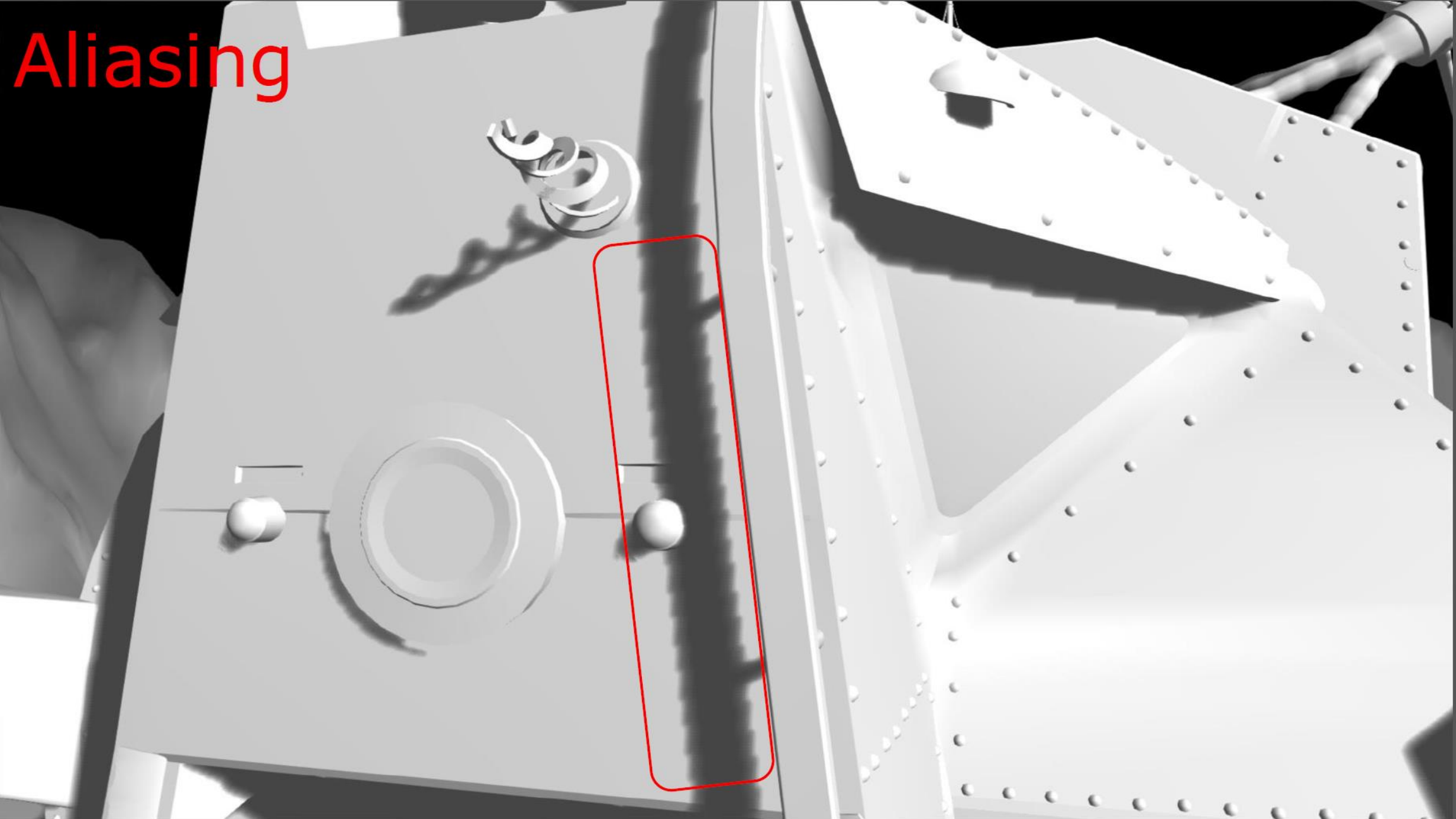
Issues in Shadow Map

- Acne
- Peter-panning
- Aliasing

- Endless tuning to alleviate the above...


Acne


Peter-panning

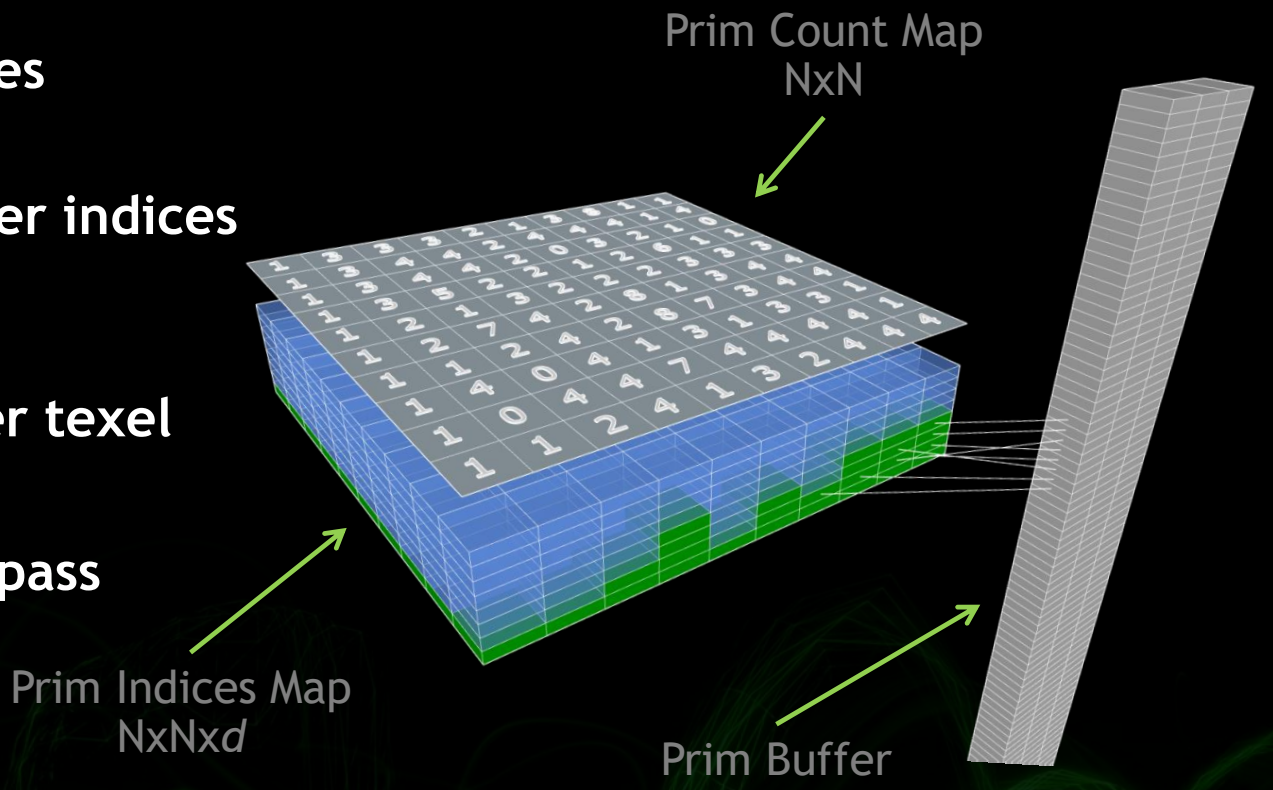

Aliasing

Traditional Spatial Hierarchy

- Typical solutions
  - KD-Tree
  - Bounding Volume Hierarchy
  - Uniform Grid
- Not practical
  - Reconstructing or updating is expensive
  - Tree traversal is inherently slow

Ray Traced Shadow Map Construction

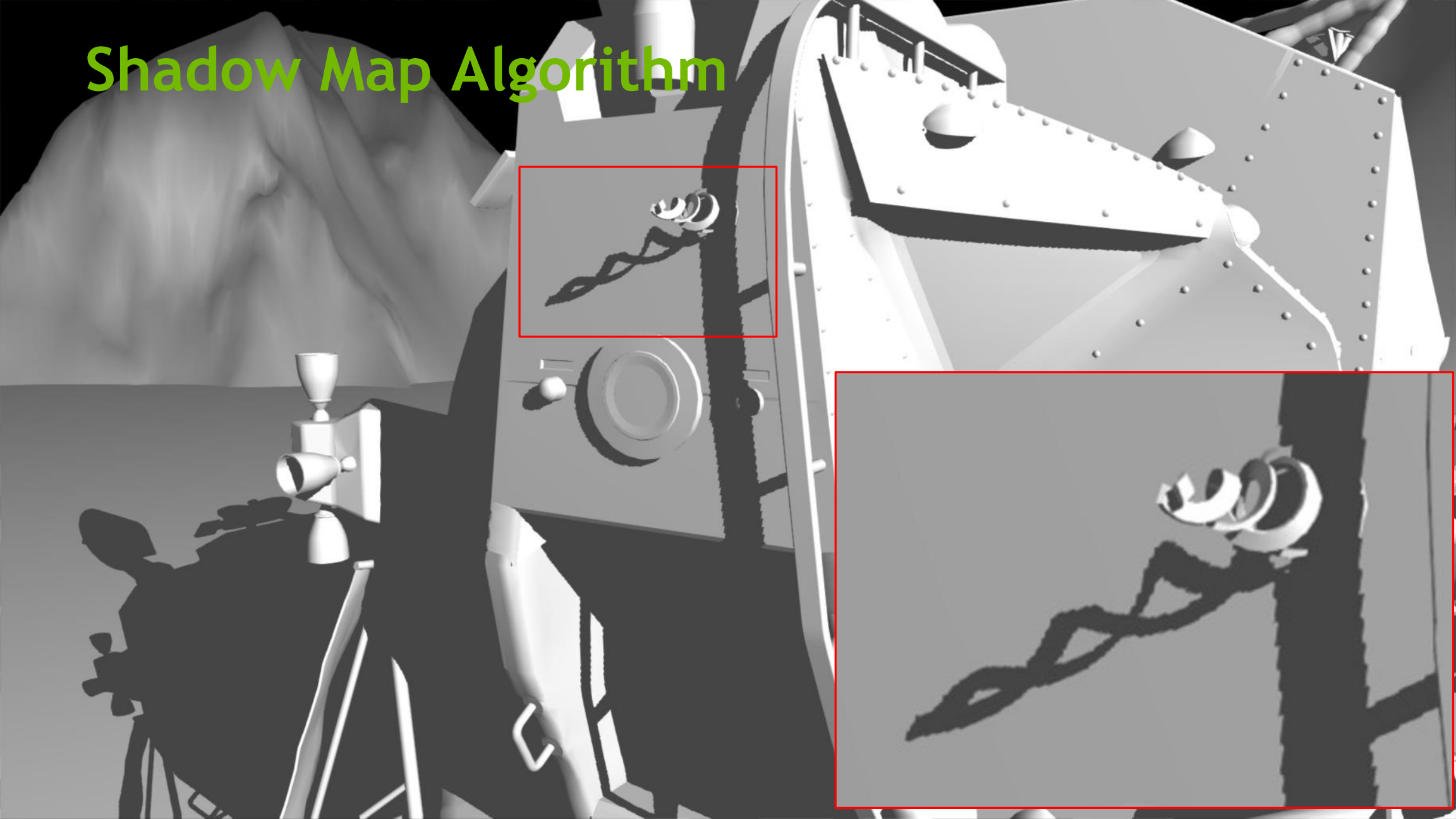
- Prim Buffer – Triangle vertices
- Prim Indices Map – Prim buffer indices of triangles
- Prim Count Map – # of tris per texel
- Raytrace triangles in a later pass



Conservative Rasterization

- Hardware Support
  - DX12
  - NVAPI
- Software Implementation
  - http://http.developer.nvidia.com/GPUGems2/gpugems2_chapter42.html

Shadow Map Algorithm



Hybrid Ray Traced Shadow

Hybrid Approach

- Combine ray-traced shadow with conventional soft shadows
- Use an advanced filtering technique such as PCSS
- Use blocker distance to compute a lerp factor
- As blocker distance approaches 0, ray-traced result is prevalent

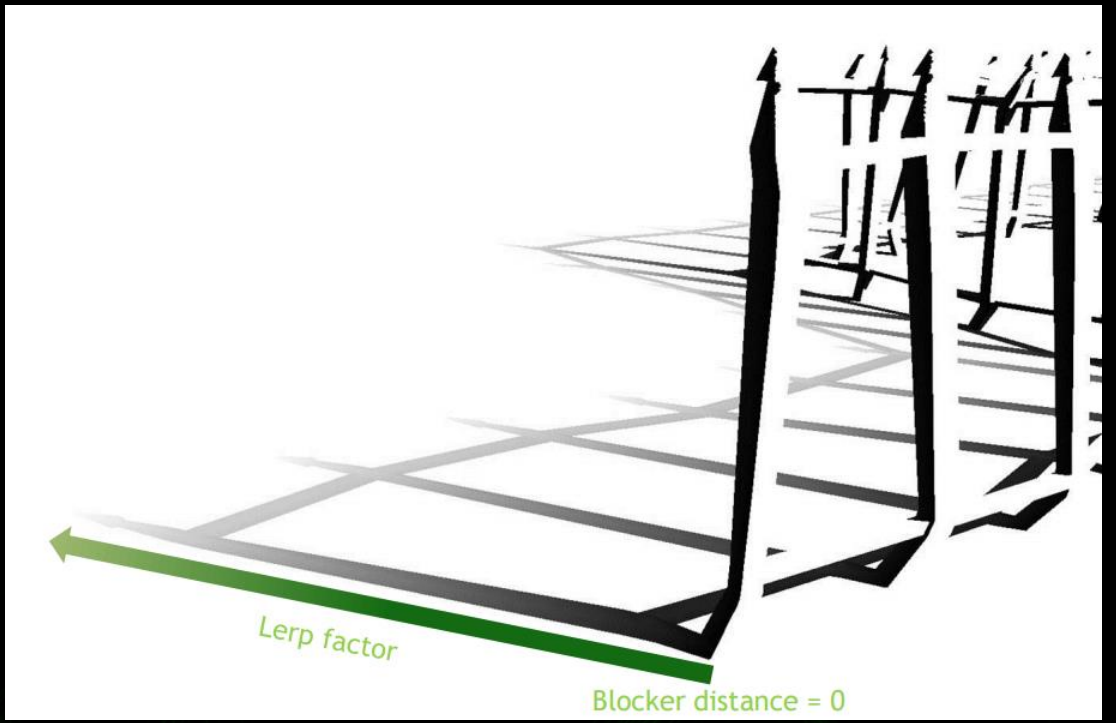
Lerp Factor Visualization

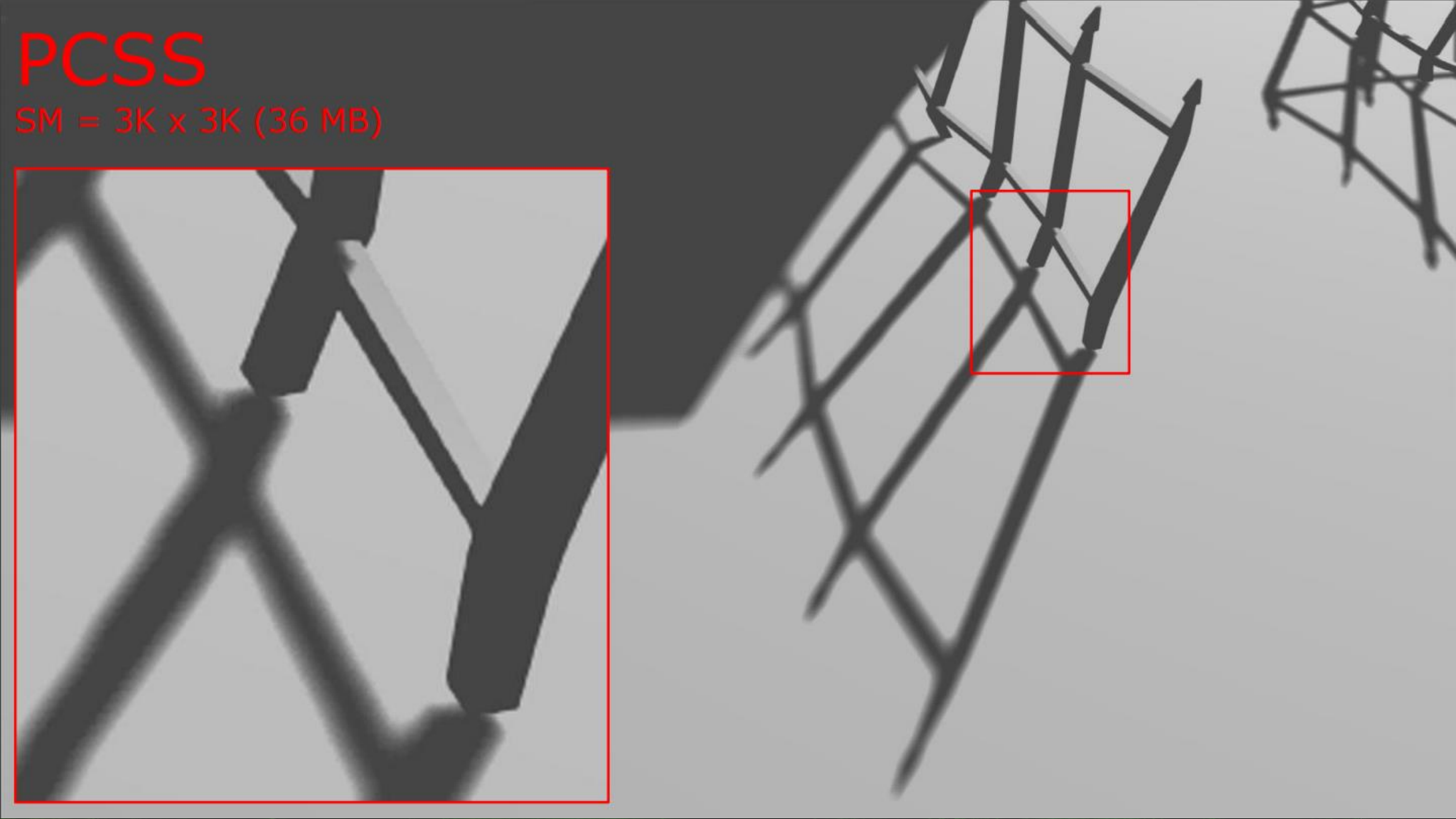
- L = saturate(BD / WSS * PHS)

- L: Lerp factor
- BD: Blocker distance (from ray origin)
- WSS: World space scale - chosen based upon model
- PHS: Desired percentage of hard shadow

- FS = lerp(RTS, PCSS, L)

- FS: Final shadow result
- RTS: Ray traced shadow result (0 or 1)
  PCSS: PCSS+ shadow result (0 to 1)




PCSS
SM = 3K x 3K (36 MB)

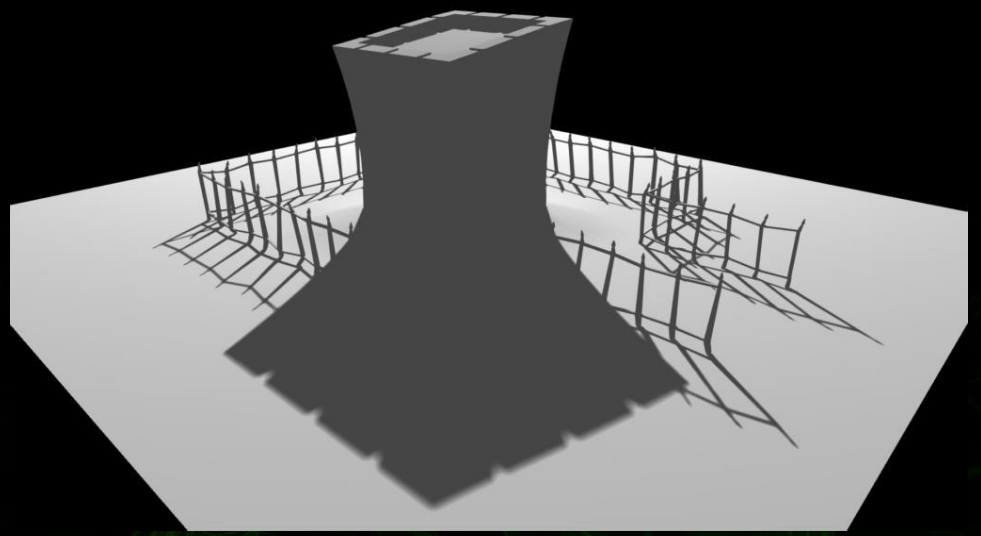
Hybrid Ray Traced + PCSS

SM = 3K x 3K (36 MB)

PM = 1K x 1K x 32 (128 MB)

Performance

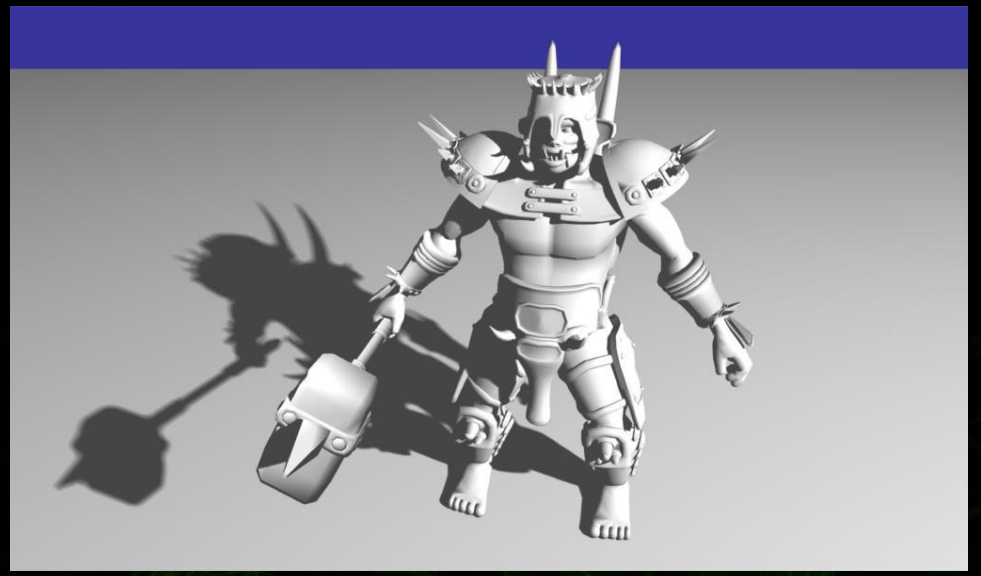
- Prims: ~10K
- Shadow Map: 3K x 3K (36 MB)
- Primitive Map: 1K x 1K x 32 (128 MB)
- Primitive Buffer: ~360K
- Shadow Buffer: 1920 x 1080



	GTX 980
Primitive Map + HW CR	0.4
Primitive Map + SW CR	0.5
Ray Trace	0.4
PCSS	1.3
PCSS + Ray Trace	1.8

Performance

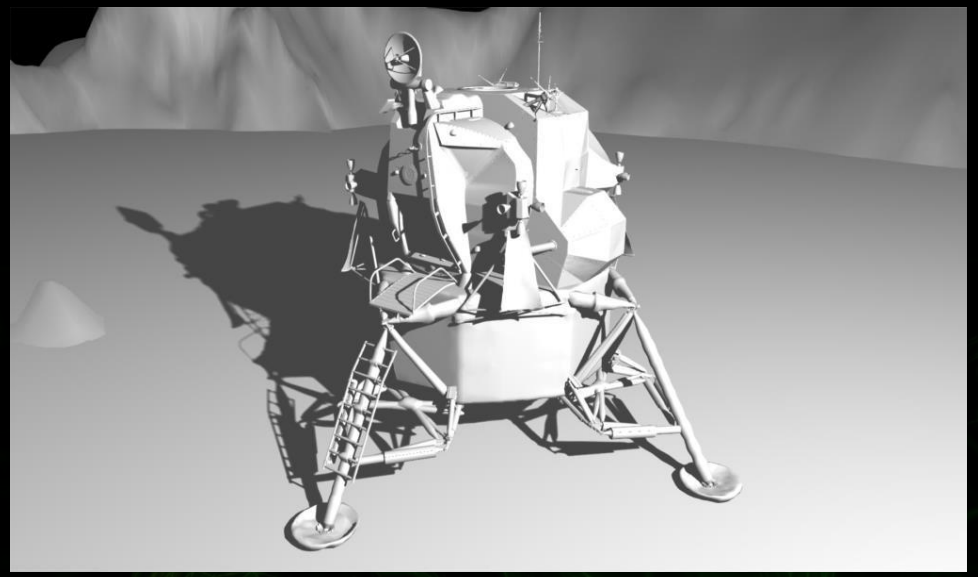
- Prims: ~65K
- Shadow Map: 3K x 3K (36 MB)
- Primitive Map: 1K x 1K x 64 (256 MB)
- Primitive Buffer: ~2.2 MB
- Shadow Buffer: 1920 x 1080



	GTX 980
Primitive Map + HW CR	0.5
Primitive Map + SW CR	0.7
Ray Trace	0.7
PCSS	1.3
PCSS + Ray Trace	2.8

Performance

- Prims: ~240K
- Shadow Map: 3K x 3K (36 MB)
- Primitive Map: 1K x 1K x 64 (256 MB)
- Primitive Buffer: ~8.2 MB
- Shadow Buffer: 1920 x 1080



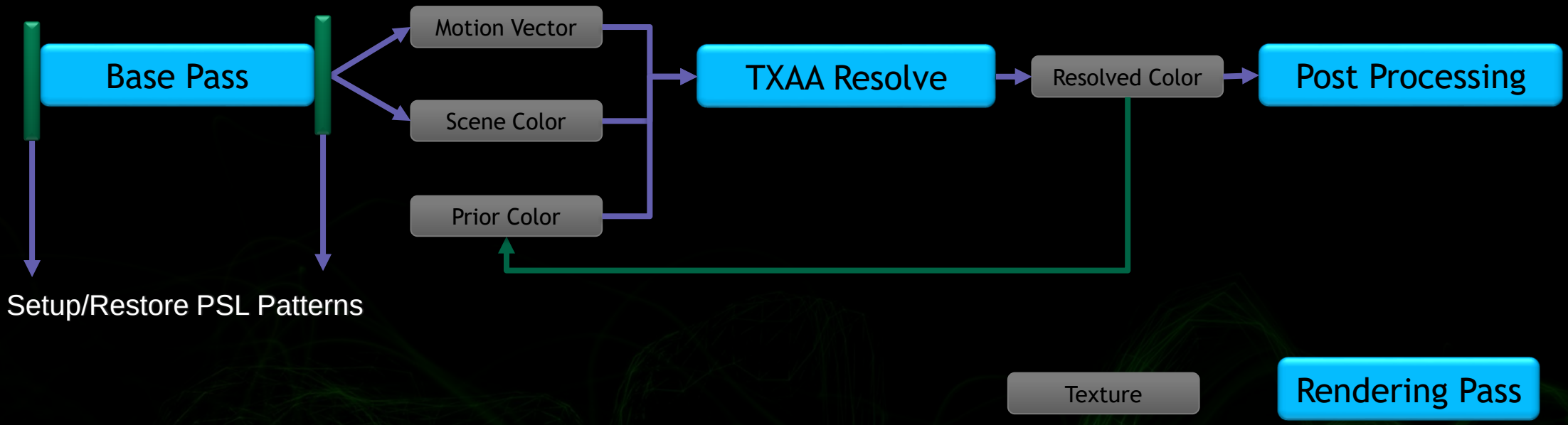
	GTX 980
Primitive Map + HW CR	3.4
Primitive Map + SW CR	4.1
Ray Trace	1.0
PCSS	1.3
PCSS + Ray Trace	3.4

Next Generation TXAA

- Time varying sample locations (PSL)
- Simpler filtering
  - No Gaussian Blur anymore, no over blurred image
  - Faster
- All MSAA mode
  - 8x MSAA mode supported
  - 1x MSAA or NonAA mode supported

TXAA 3.0 core algorithm

- TXAA 3.0 = [MSAA] + Temporal AA + MFAA

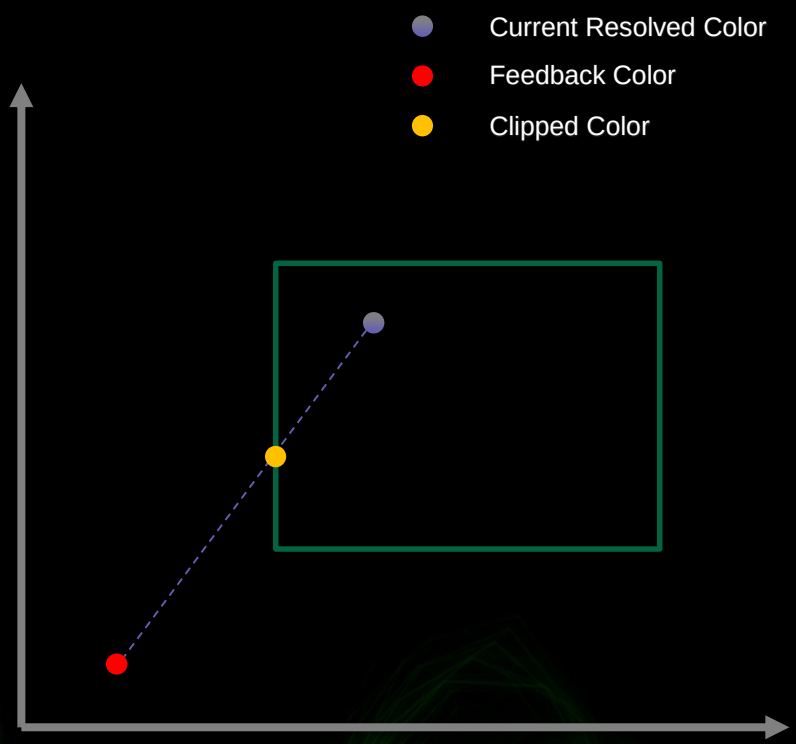


Exponential Sum

- The math formula
  - $TXAA_n = \alpha MSAA_n + (1-\alpha)TXAA_{n-1}$
- A little mathematic background:
  - $MSAA_n = MSAA_{n-k}$
    - *True for static image, k is the number of patterns used*
  - $TXAA_n = \frac{\alpha}{1-(1-\alpha)^k}\Sigma_{t=0}^{k-1}(1-\alpha)^t MSAA_{n-t}$
  - $\lim_{\alpha \to 0}\left(\frac{\alpha}{1-(1-\alpha)^k}\Sigma_{t=0}^{k-1}(1-\alpha)^t MSAA_{n-t}\right) = \frac{1}{k}\Sigma_{t=0}^{k-1} MSAA_{n-t}$
    - *Ideal result, at least for static image*
- Unfortunately, there are issues:
  - α will never be zero
  - The formula doesn't work if α depends on $MSAA_n$
  - The first equation may be false for dynamic scene

Color Clipping

- To get rid of ghost issue
- An AABB in YCgCo space is constructed by neighbor pixels
  - Min = min(c , n , s , w , e)
  - Max = max(c , n , s , w , e)
- Feedback color is clipped against the AABB



A simple demonstration in 2D space, in TXAA it works similarly in YCgCo space

Programmable Sample Location

- Enable graphics programmer to set up customized sample locations for each sample
- Enhance AA quality at minimal extra overhead

- Quality of AA algorithm depends on the number of sample patterns available, 4 or 8 samples patterns work fine

Disable PSL if Necessary

- Shadow map generation pass
- Reflection map
- UI Rendering
- Post-Processing

TXAA 3.0 Integration

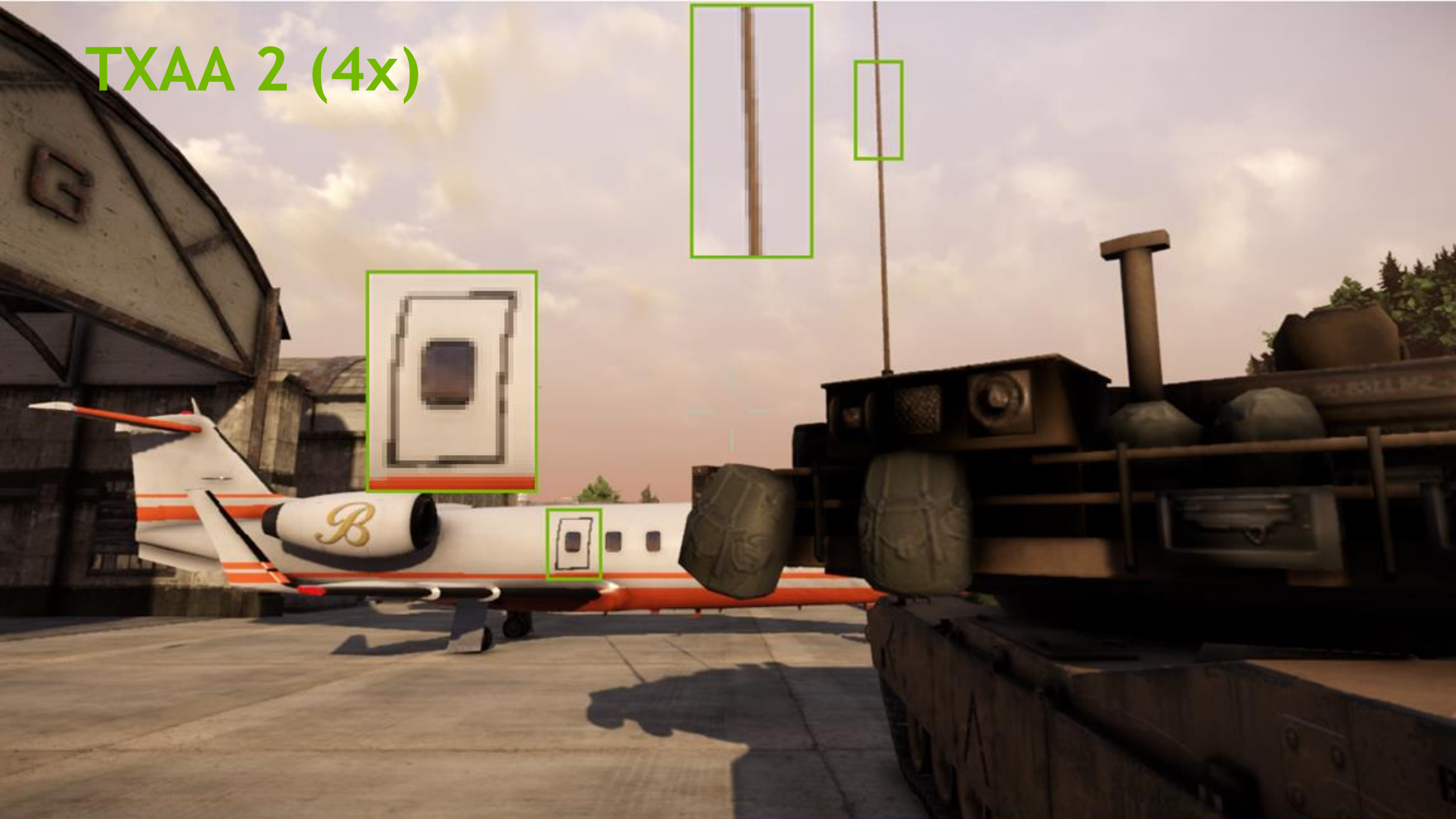
- Easy to integrate, only three interfaces:
  - GFSDK_TXAA_DX11_InitializeContext(&txaaContext, device)
    - Initialize TXAA 3.0 context, it will fail on devices prior to Kepler
  - GFSDK_TXAA_DX11_ResolveFromMotionVectors(&resolveParameters, &motion)
    - Perform TXAA 3.0 resolve pass
  - GFSDK_TXAA_DX11_ReleaseContext(&txaaContext)
    - Release TXAA 3.0 context

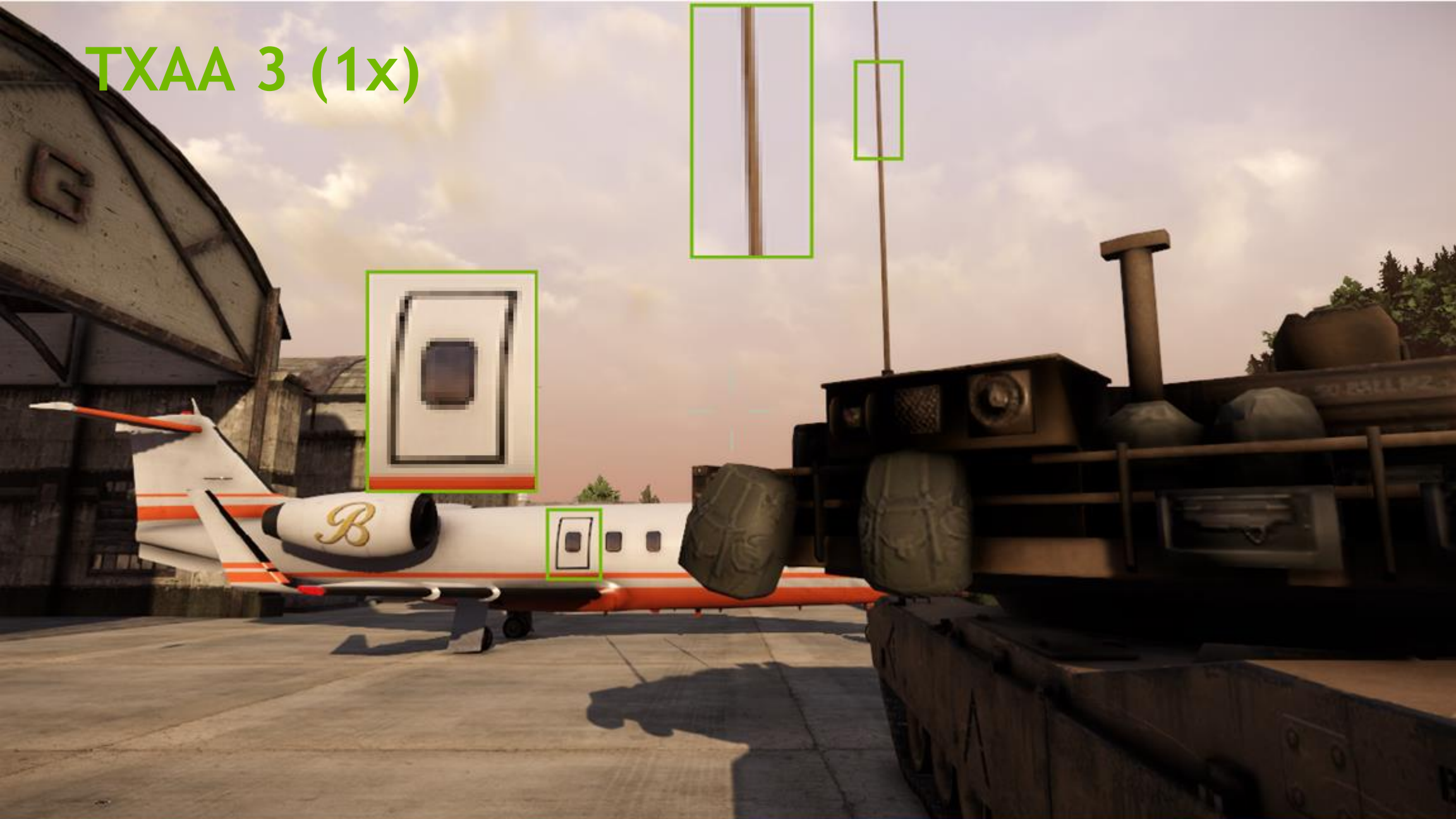
- Misc:
  - TXAA 3.0 also provides several debugging features
  - Besides the library itself, there is also an utility library providing some helper interfaces
    - Edge detection
    - Motion vector generation from depth and camera information


No AA


4x MSAA

TXAA 2 (4x)




TXAA 3 (1x)

TXAA Performance

- Comparing with other AA techniques, the overhead in TXAA can almost be neglected
- TXAA only has one draw call, relatively cheap
  - On a GTX 980, it costs less than 1ms
  - Even with 4x MSAA

Ansel

FREE CAMERA

FILTERS

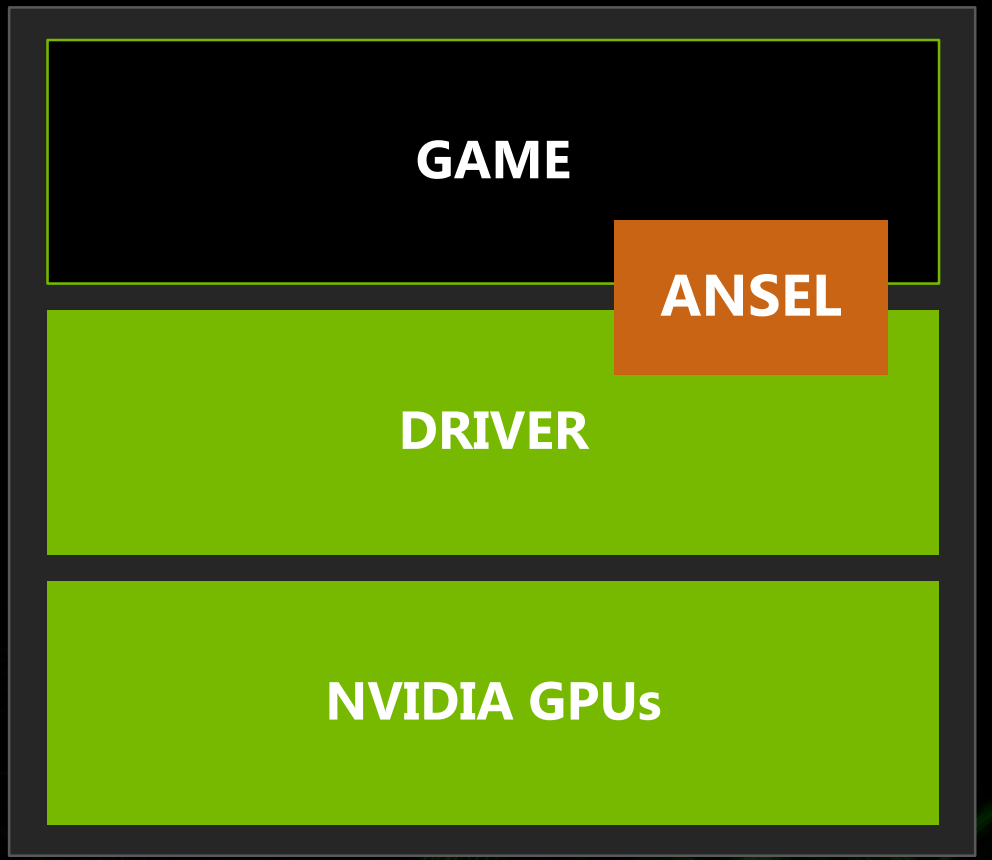
EXR

SUPER REZ

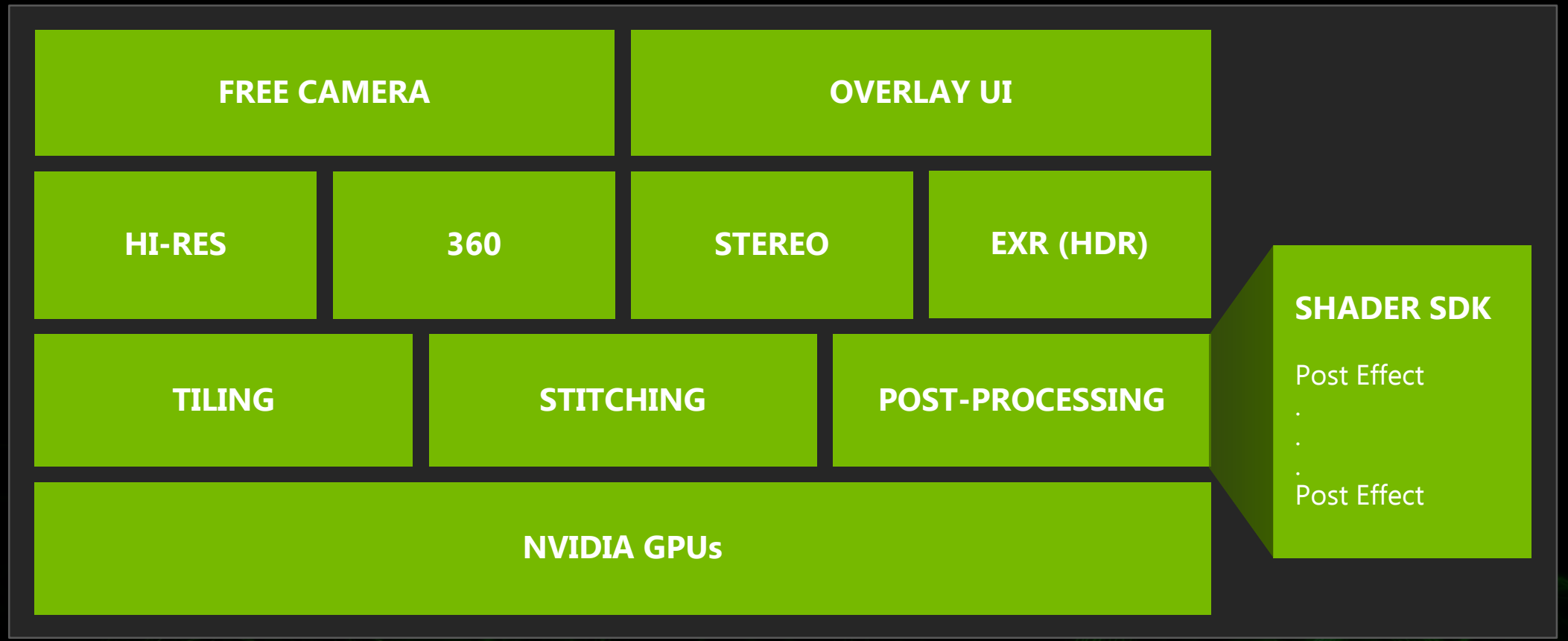
360

ANSEL Integration

- Ease of integration
- Overlay UI Controls
- Witness integration is ~40 lines of code
- Witcher 3 integration is ~150 lines of code



ANSEL Architecture

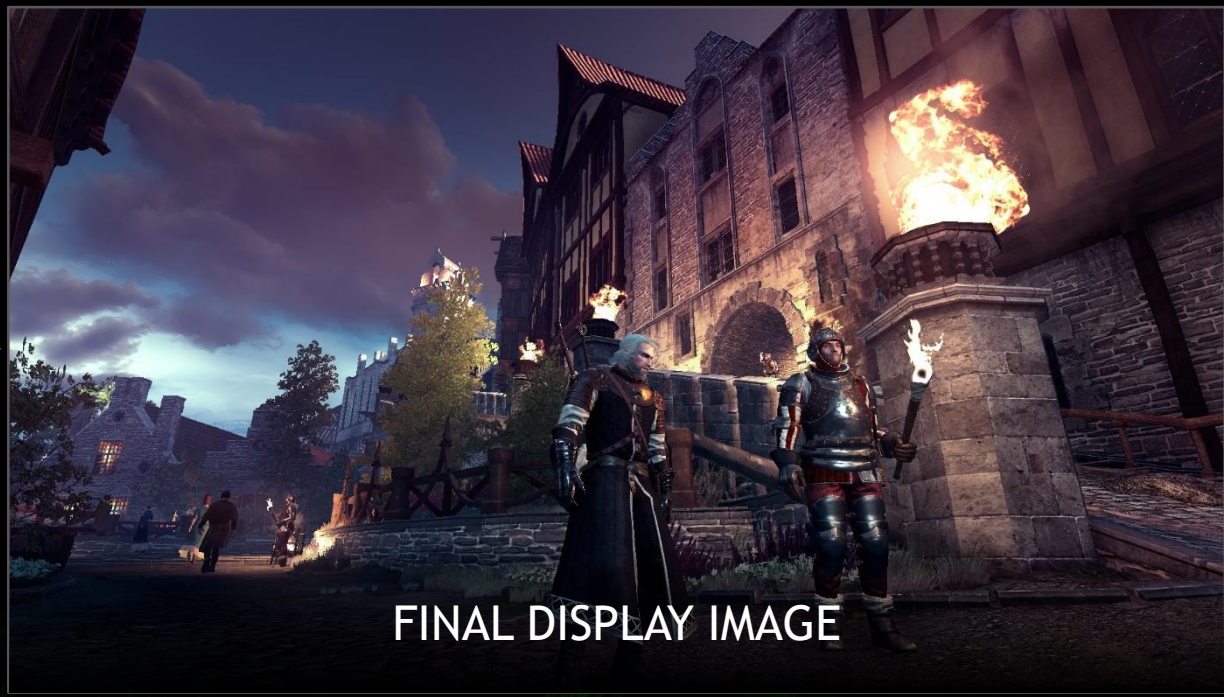


Free Camera

Super Resolution

ANSEL POST-PROCESS SHADER

GAME ENGINE → BUFFERS
COLOR BUFFER
Z BUFFER
G BUFFER
… → POST PROCESS SHADER →

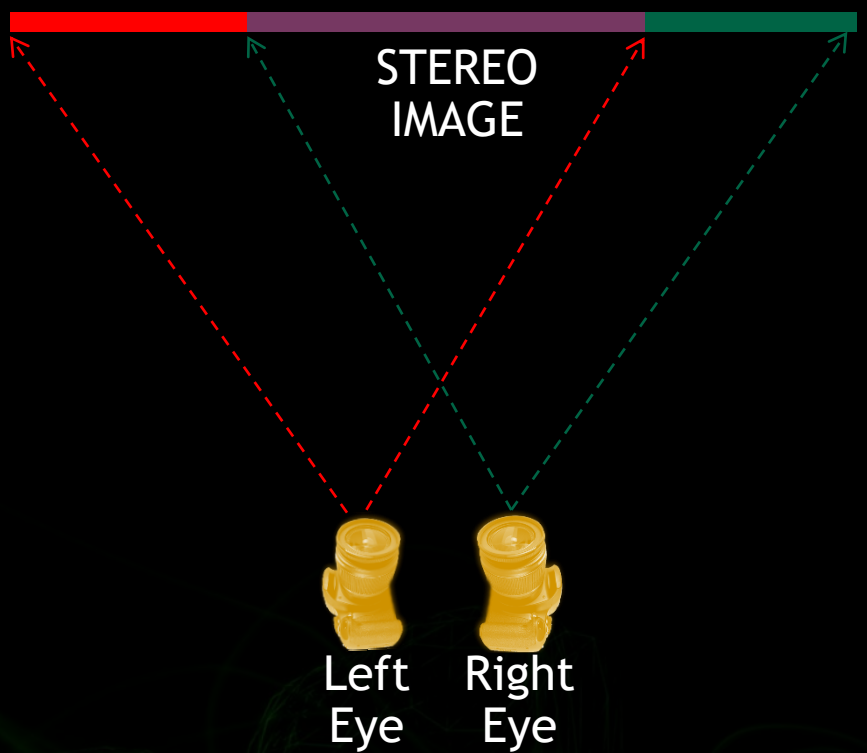


Loads of Effects!

- Color curves
- Sketch
- Color space transformation
  - Hue shift
  - Desaturation
  - Brightness
- Contrast
- Film grain
- Bloom
- Lens flares
- Anamorphic glare
- Distortion effects
  - Map distortion ("heathaze")
  - Fisheye
  - Explosion
- Color aberration
- Tonemapping schemes
  - Haarm-Peter Duiker
  - Reinhard
  - Hable (Uncharted2)
- Lens dirt
- Lightshafts
- Vignette
- Gamma correction
- Convolution filters
  - Sharpening
  - Edge detection
  - Blur
  - Hipass/lowpass
- FXAA
- Sepia tone
- Halftone
- Deband
- Denoise

360 photos

Stereo capture



Ansel Coming to games soon





Ansel Coming to games soon

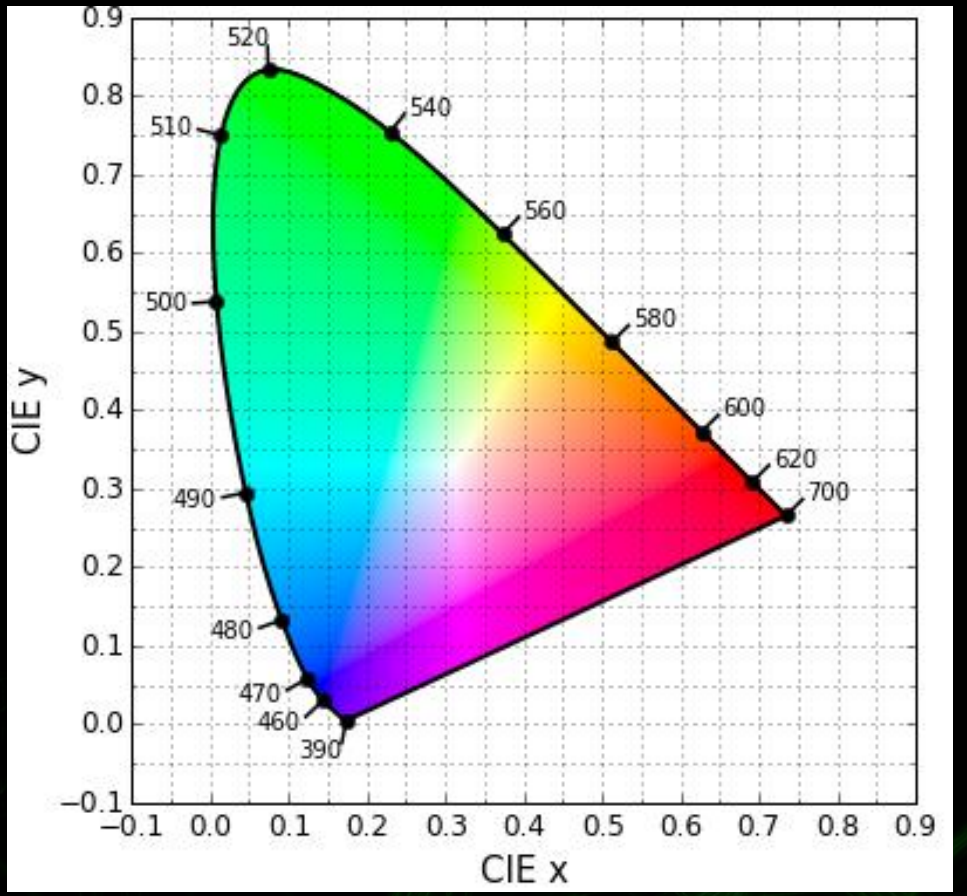
Why HDR Display

- LDR display offers much limited range of gamut
- Without HDR display
  - Highlight looks flatter, can’t be distinguished from diffuse white
  - Highlight compromise on saturation
  - Shadows get crushed toward black
- HDR Display
  - Higher luminance. (1000+nits)
  - Wider gamut.

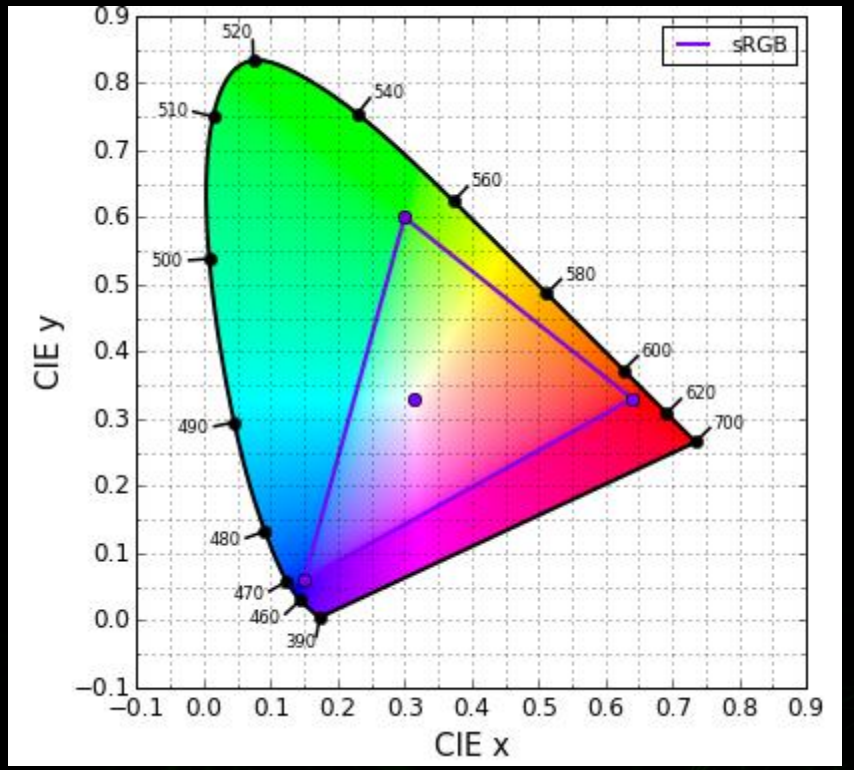
LDR Displayed Image

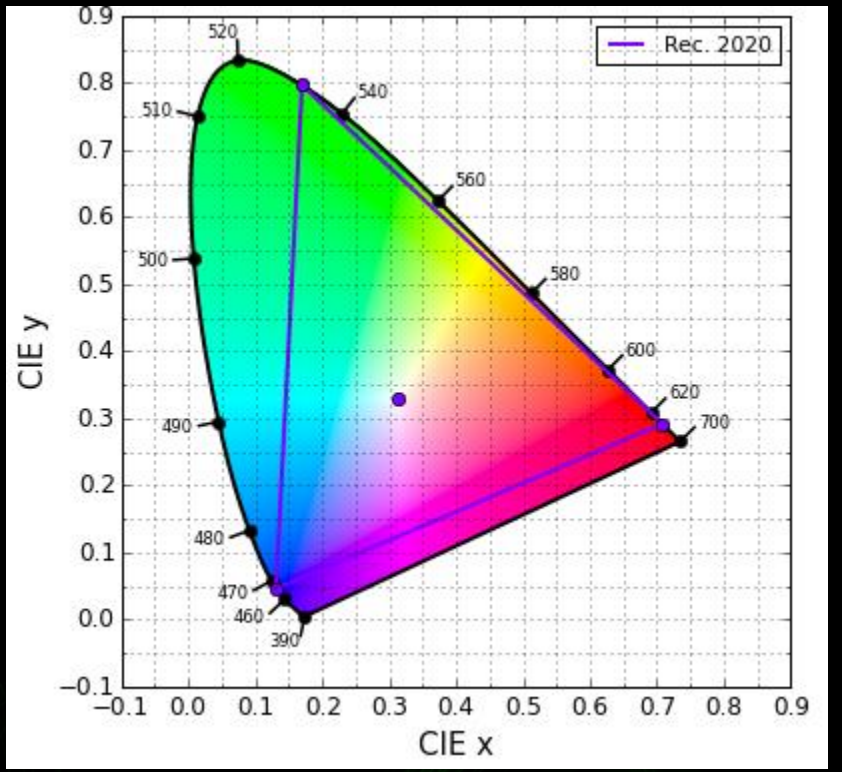
CIE Chromaticity Diagram

- It reveals the gamut that is visible to human
- Colors with the highest saturation are at the boundary
- Any interior color can be generated by interpolating different set of colors



sRGB vs BT.2020/Rec.2020

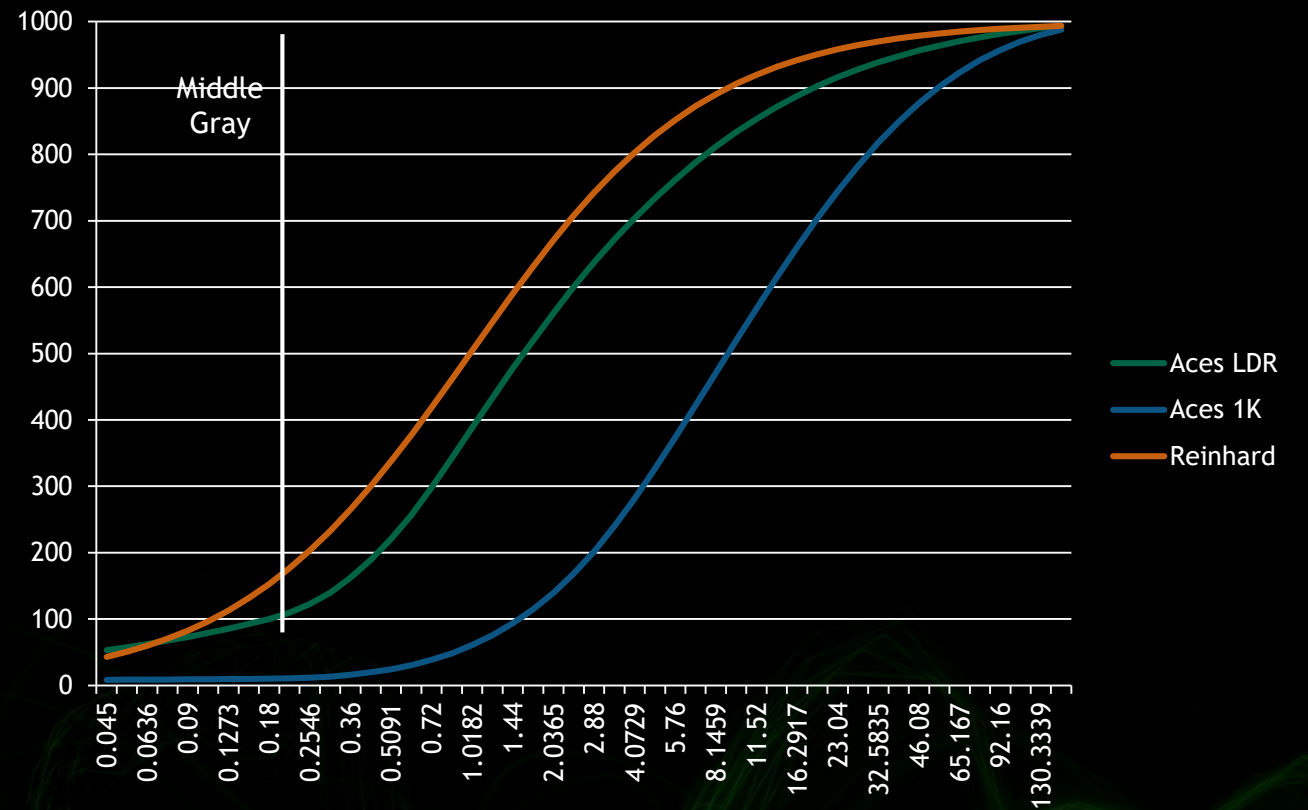




- sRGB
- BT.2020/Rec.2020

Does the old way work?

- Over compressed image
- Lose bright values
- Dim values appears shiny
  - Middle-Grey appears white



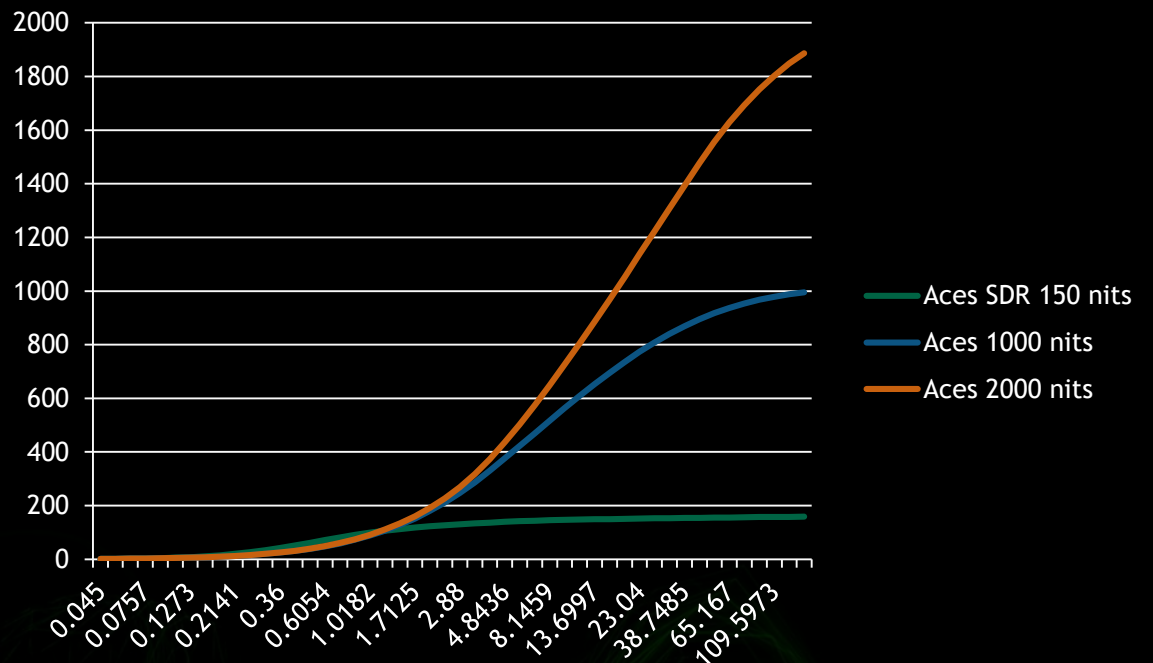
Can we drop Tonemapping?

- Since we have HDR display now, is tone mapping still necessary?
- Yes
  - The best displays come nowhere close to the range of luminance in real world
  - The first generation HDR compliant will generate 1000 nits of luminance
  - BT. 2020 only supports luminance up to 10000 nits

Condition	Luminance (cd/m^2, or nits)
Sun at horizon	600000
60-watt light bulb	120000
Clear sky	8000
Typical office	100-1000
LDR display	80-100
Cloudy moonlight	0.25

A new Tone Mapping

- Tone mapping in Academy Color Encoding System (ACES)
  - Sigmoid-style curve
  - Performs on each color channel independently
- We have already implemented the algorithm for you



UI Composition

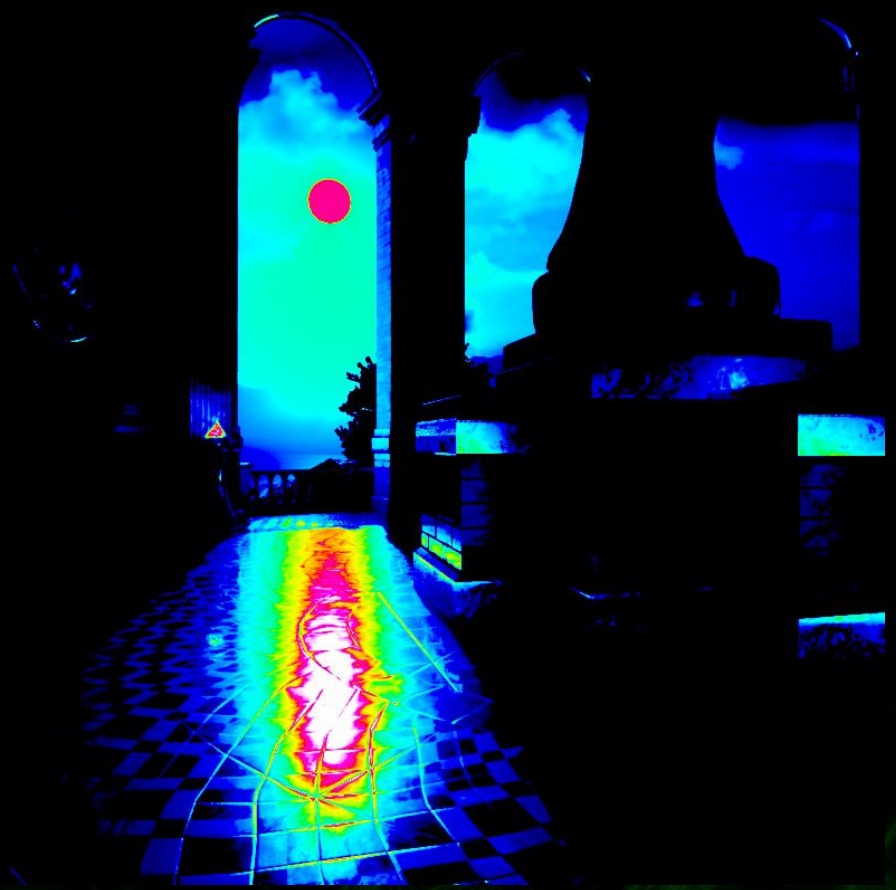
- Used to be done in sRGB space after 3D Rendering
- It works the same way on HDR display
- Hints:
  - Don’t use color with maximum luminance in UI components
  - Add a scaling factor
  - Be careful with alpha blending, use a simple tonemapper (Reinhard)

Physically Based Shading

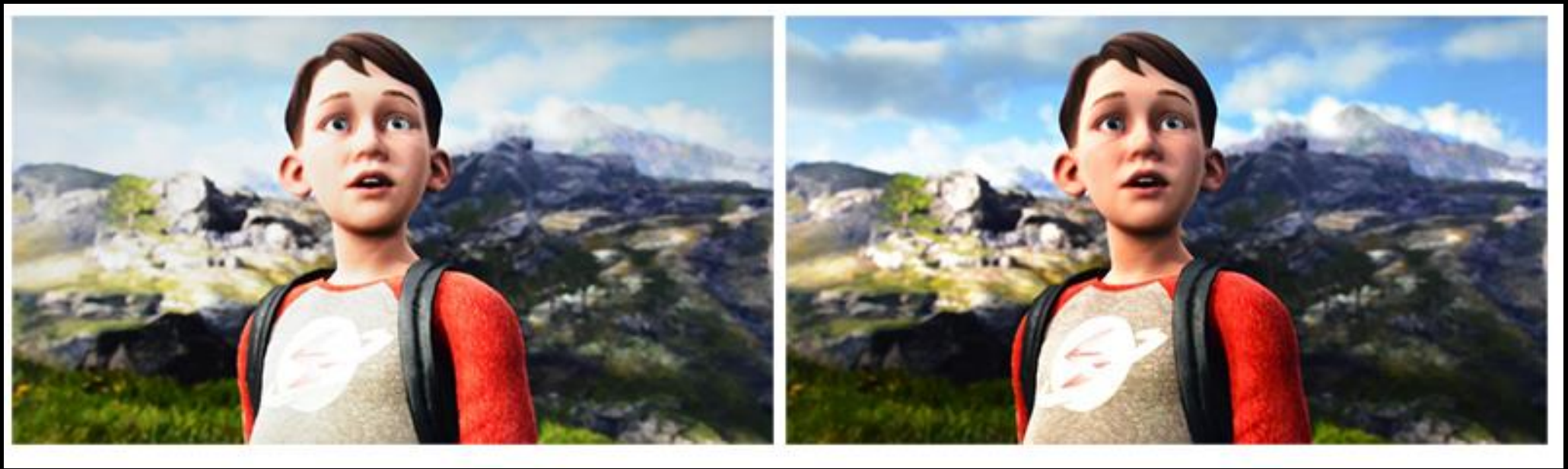
- It will generate colors with a large range of luminance

Be Careful with Light Geometry Proxy

- Light geometry proxy may be dimmer than reflected light
- It used to work fine in LDR monitor since both reach maximum brightness



LDR vs HDR



- Left : Image rendered on LDR display
- Right : Image rendered on HDR TV and captured with a real camera

Q&A

THANKS