Advanced Geometrically Correct Shadows for Modern Game Engines

Jon Story, 16 March 2016

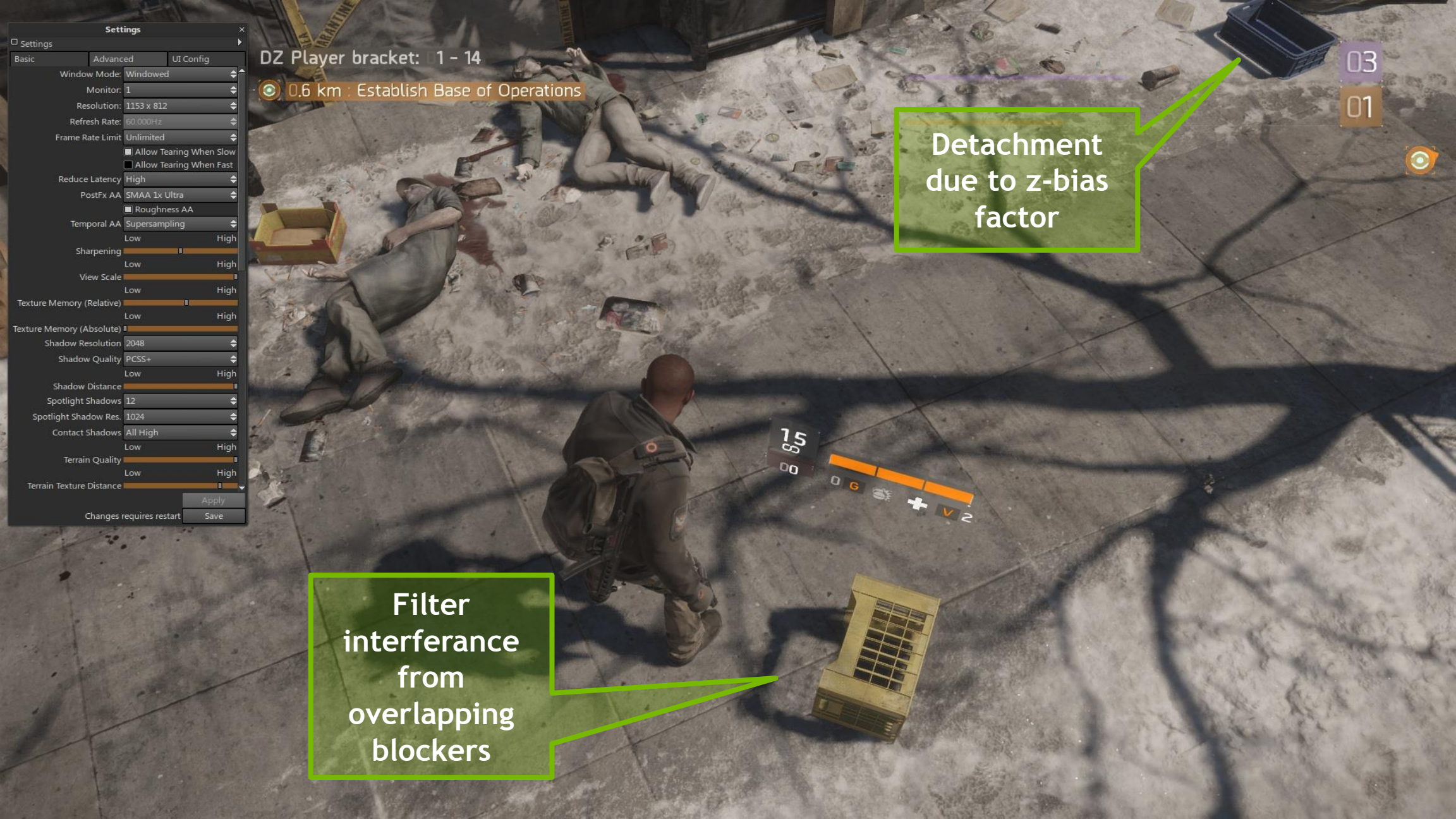
NVIDIA

Agenda

- Problems with Shadows?
- Frustum Tracing
- Irregular Z-Buffer
- Dynamic Reprojection
- Conservative Rasterization
- Anti-Aliasing
- Hybrid Frustum Traced Shadows
- Comparison Screenshots
- Performance
- GFSDK Shadow Lib v3.0

Problems with Shadows?


Settings
Settings
Basic
Advanced
UI Config
Window Mode: Windowed
Monitor: 1
Resolution: 1153 x 812
Refresh Rate: 60.000Hz
Frame Rate Limit Unlimited
Allow Tearing When Slow
Allow Tearing When Fast
Reduce Latency High
PostFx AA SMAA 1x Ultra
Roughness AA
Temporal AA Supersampling
Low High
Sharpening
Low High
View Scale
Low High
Texture Memory (Relative)
Low High
Texture Memory (Absolute)
Shadow Resolution 2048
Shadow Quality High
Low High
Shadow Distance
Spotlight Shadows 12
Spotlight Shadow Res. 1024
Contact Shadows All High
Low High
Terrain Quality
Low High
Terrain Texture Distance
Apply
Changes requires restart
Save
0.4 km : Establish Base of Operations
01
32
344
Aliasing due to insufficient shadow map texels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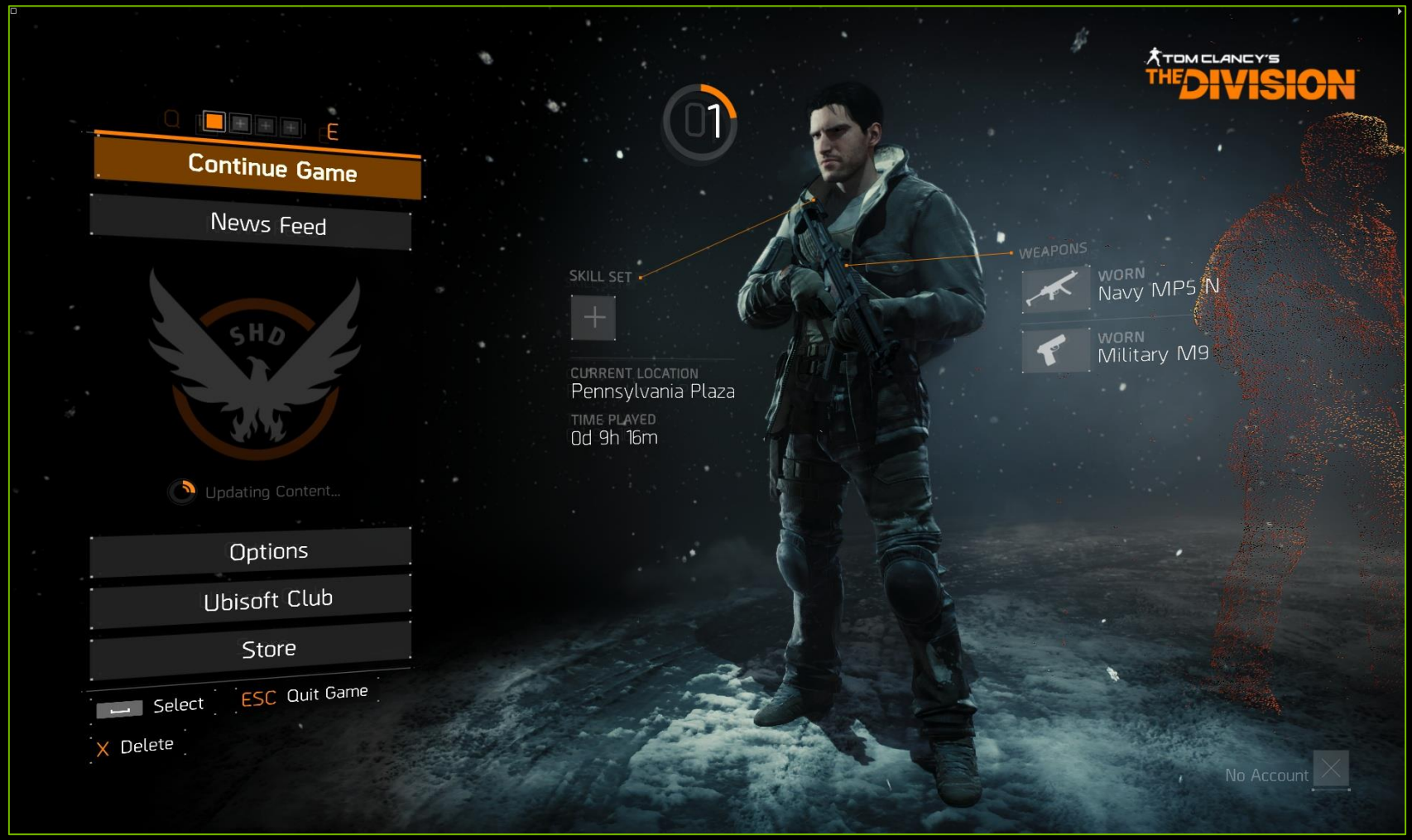
0.6 km : Establish Base of Operations
03
01
Detachment due to z-bias factor
Filter interferance from overlapping blockers


Are these shadows realistic?


Hybrid Frustum Traced
Shadows
(HFTS)

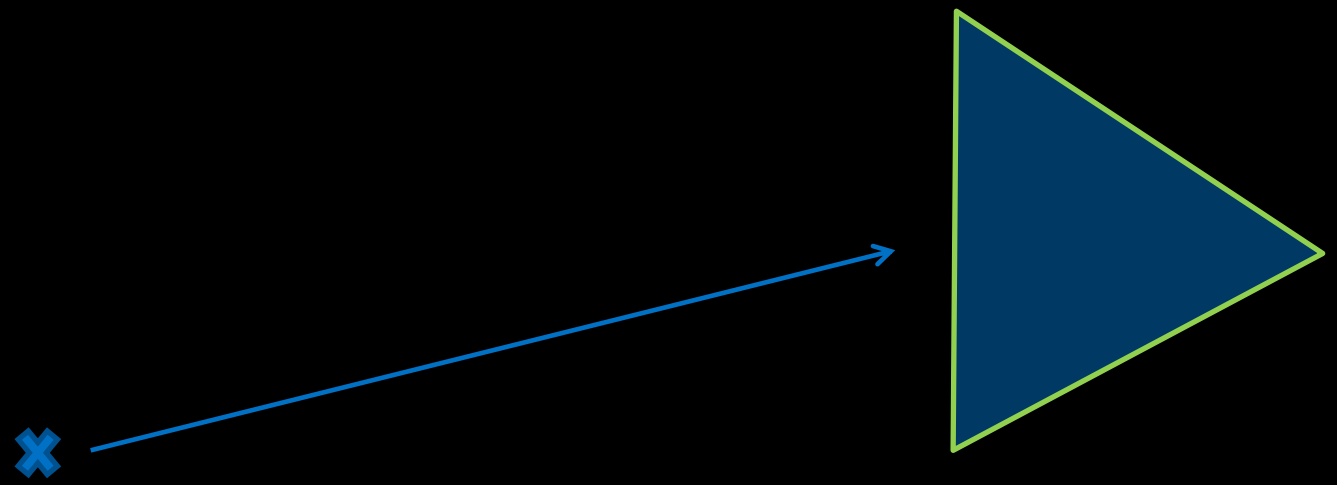
Demo: Tom Clancy‘s The Division



Frustum Tracing

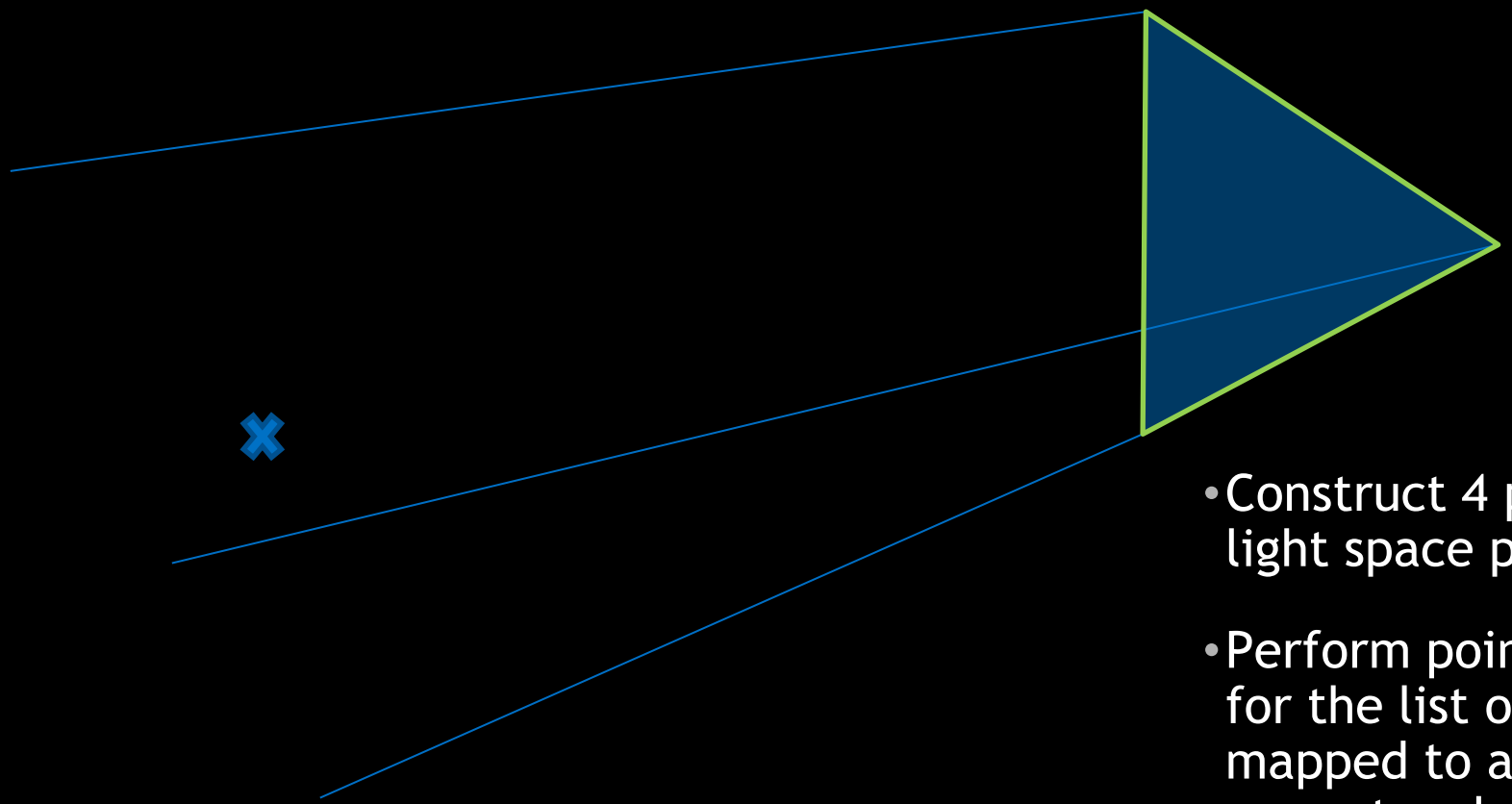
What‘s the difference between ray tracing and frustum tracing?

Ray Tracing



- Store primitives in some structure
- Perform ray triangle intersection test for all appropriate triangles

Frustum Tracing



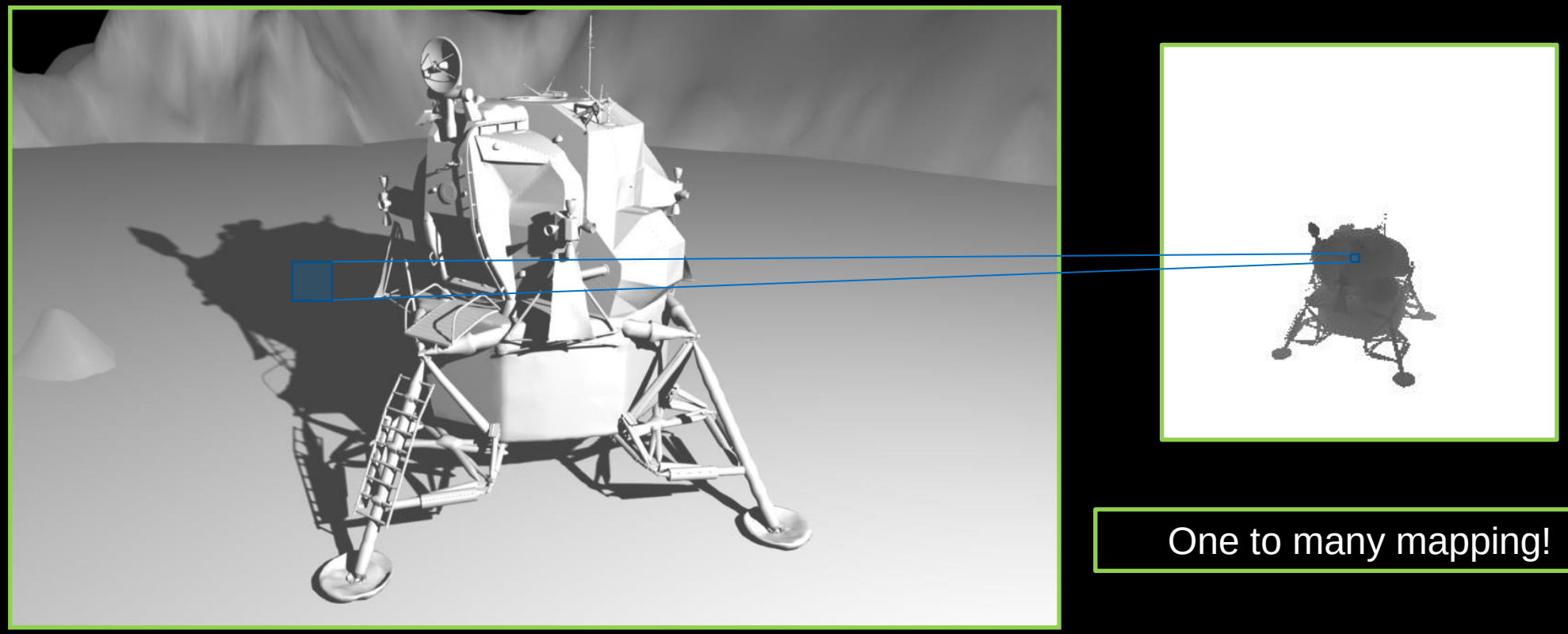
- Construct 4 planes for each light space primitive
- Perform point-in-frustum test for the list of screen pixels mapped to a given light space texel

* [Chris Wyman - i3D 2015]

Irregular Z-Buffer

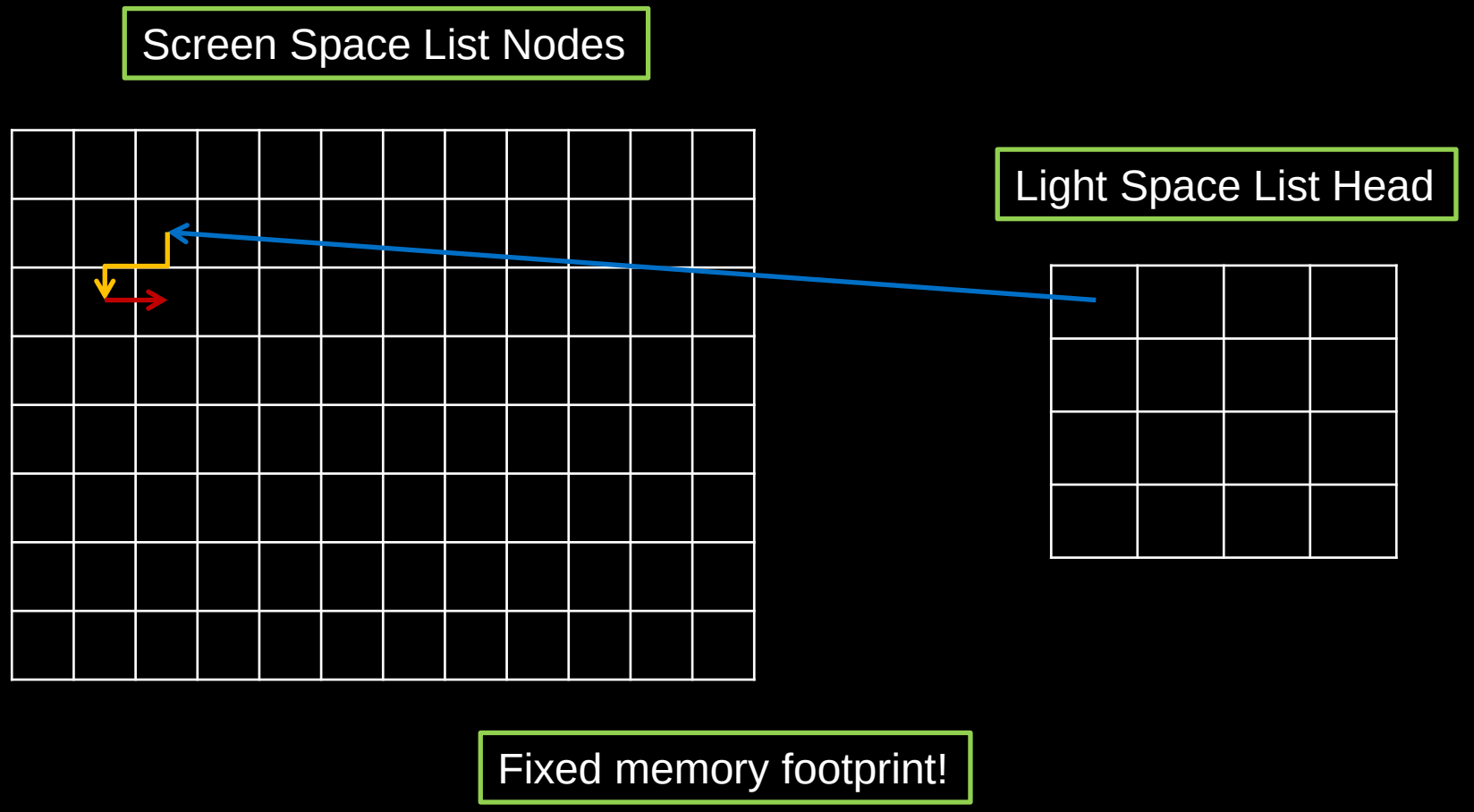
Irregular Z-Buffer

- Mapping light space to screen space...



One to many mapping!

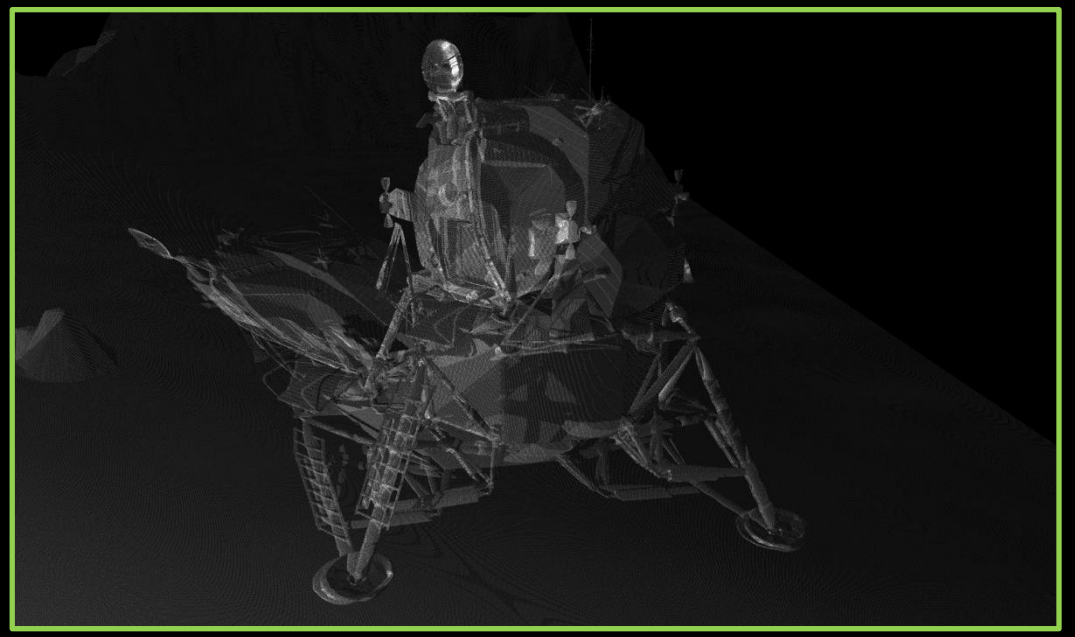
Constructing the Irregular Z-Buffer



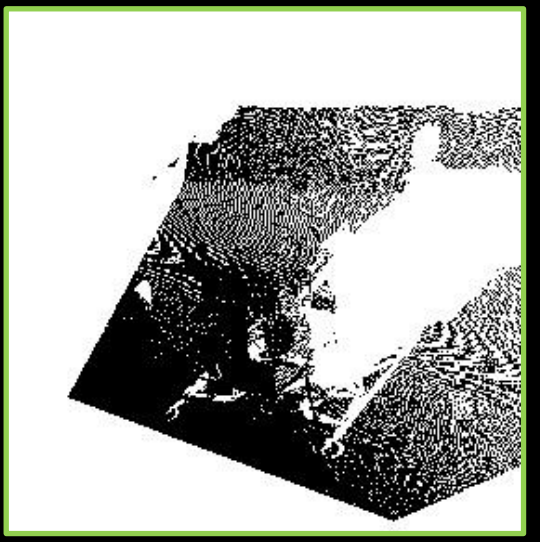
* [Chris Wyman - i3D 2015]

Visualizing the Irregular Z-Buffer

List length that each screen pixel is a member of

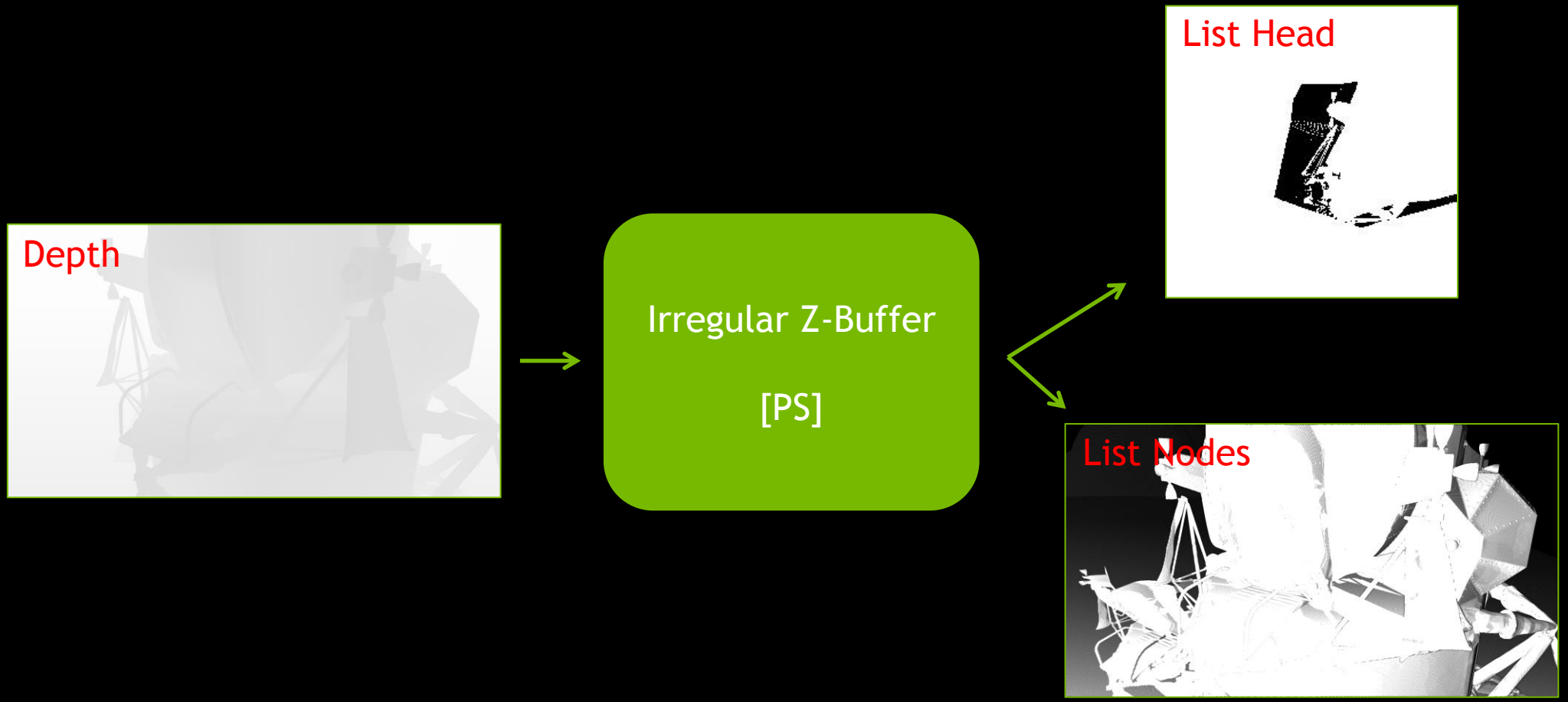


List head pointer

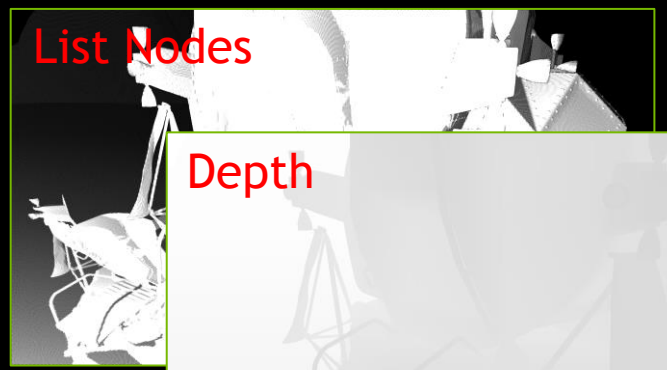


* [Chris Wyman - i3D 2015]

Pipeline Stage: Irregular Z-Buffer

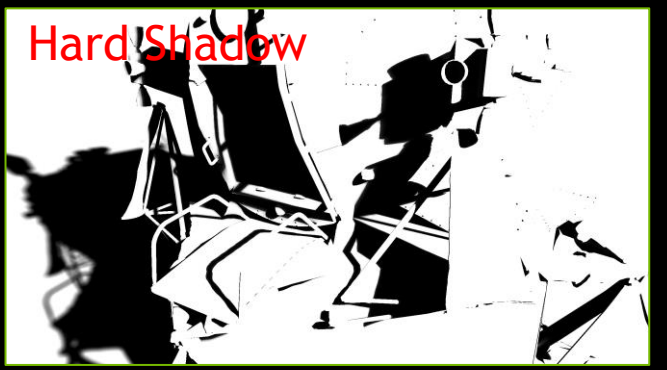


Pipeline Stage: Frustum Tracing



Frustum Trace

[GS + PS]

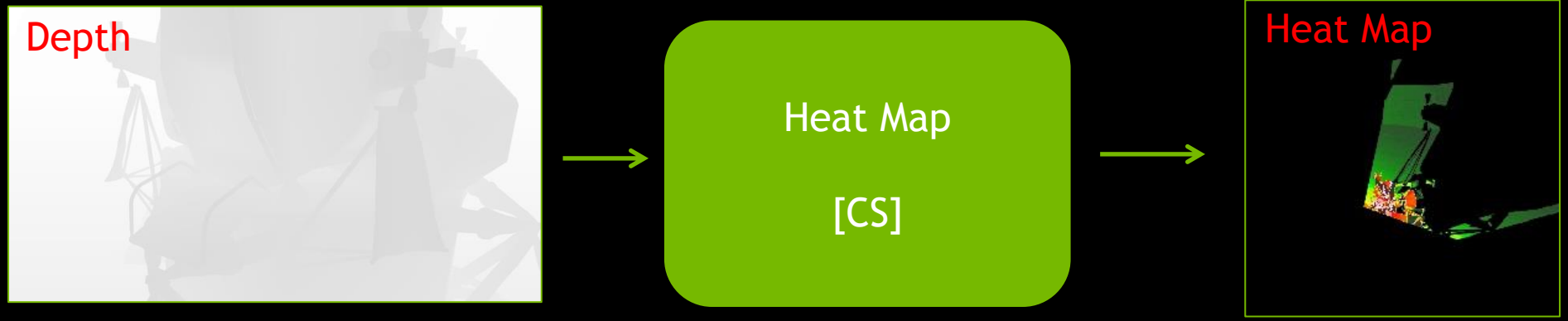


Dynamic Reprojection

Very long lists?

- A major problem with the irregular z-buffer approach
  - Causes very low occupancy
- A single light texel can map to a very large area of the screen
- SDSM can certainly be used to help alleviate this, but:
  - Requires a CPU read back
  - Frustum / occlusion culling needs to be done at render time
  - Stability issues
- A more targeted approach would be to directly detect long lists
  - Dynamically reproject those problem areas

Pipeline Stage: Heat Map



Pipeline Stage: Dynamic Reprojection

Pipeline Stage: Irregular Z-Buffer

Projection Matrix Buffer

Depth

Irregular Z-Buffer

[PS]

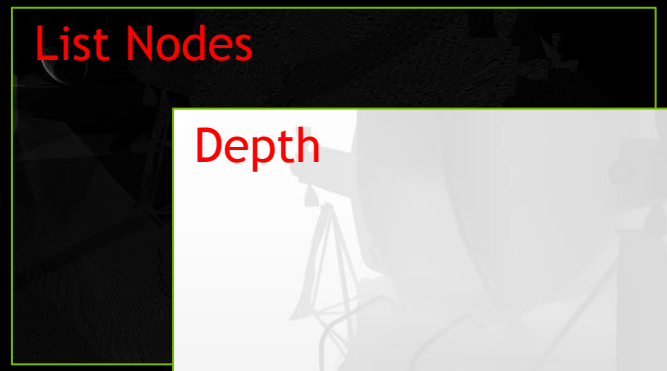
List Head 0

List Head 1

List Nodes

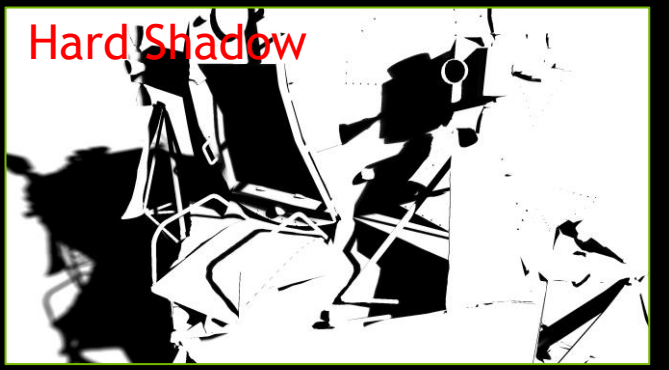
Pipeline Stage: Frustum Tracing

Projection Matrix Buffer



Frustum Trace

[GS + PS]




Full screen pass counts number of screen pixels mapped to a given light space texel
Visualized here as a heat map!
Reprojected area that contains long lists
Reprojected area of non zero list length - chops out all redundant area in light space

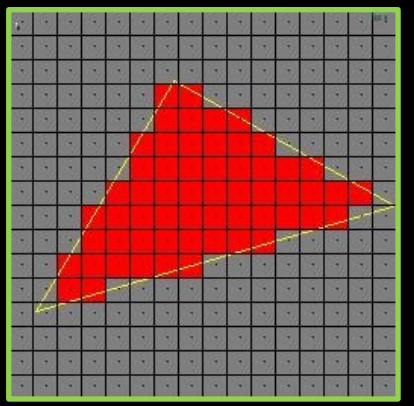
Benefits of Dynamic Reprojection

- Improves existing light space mapping for frustum tracing
  - Could be used to improve standard shadow maps?
- Reprojection is computed on the GPU
  - No CPU read back is required
  - Easy to integrate with existing cascades
- Reprojection only occurs when long lists are detected
- Drastically improves baseline performance of frustum tracing

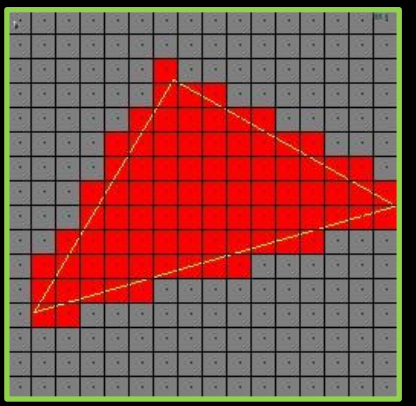
Conservative Rasterization

Requires Conservative Rasterization

- Ensures that every pixel touched by a primitive is rasterizered
- Enabled in DirectX 12 and in DirectX 11 at FEATURE_LEVEL_11_3
  - D3D11_RASTERIZER_DESC2
  - D3D12_RASTERIZER_DESC
- Also through NvAPI – it works on Windows 7 and above!
- Supported by Maxwell and above



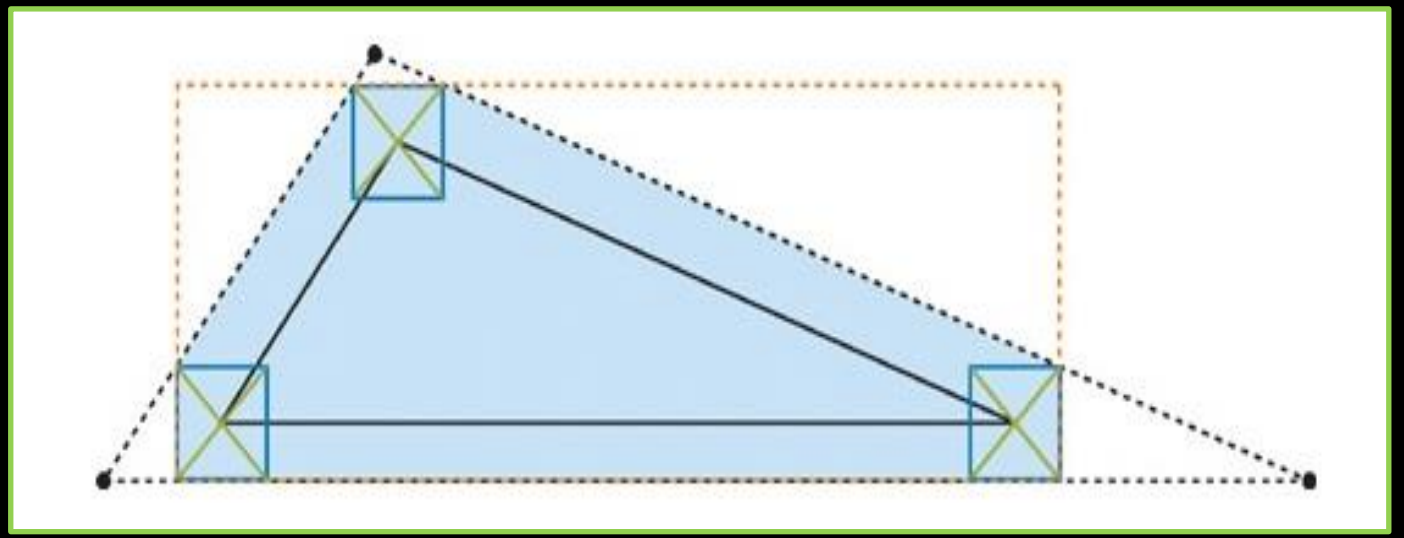
Off



On

Software Conservative Rasterization

- Use the GS to dilate a triangle in clip space
- Generate AABB to clip the triangle in the PS
- See GPU Gems 2 - Chapter 42

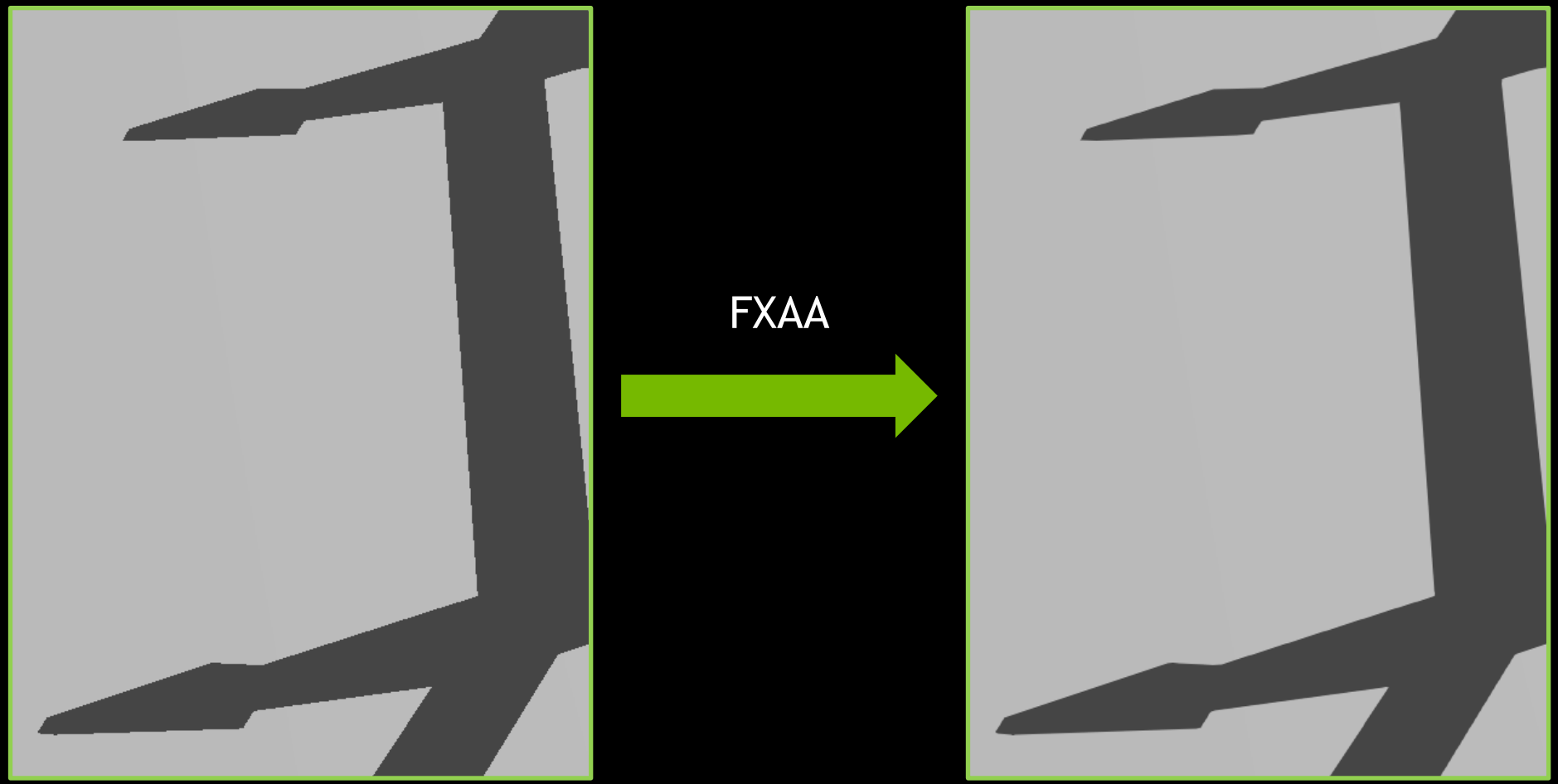


Anti-Aliasing

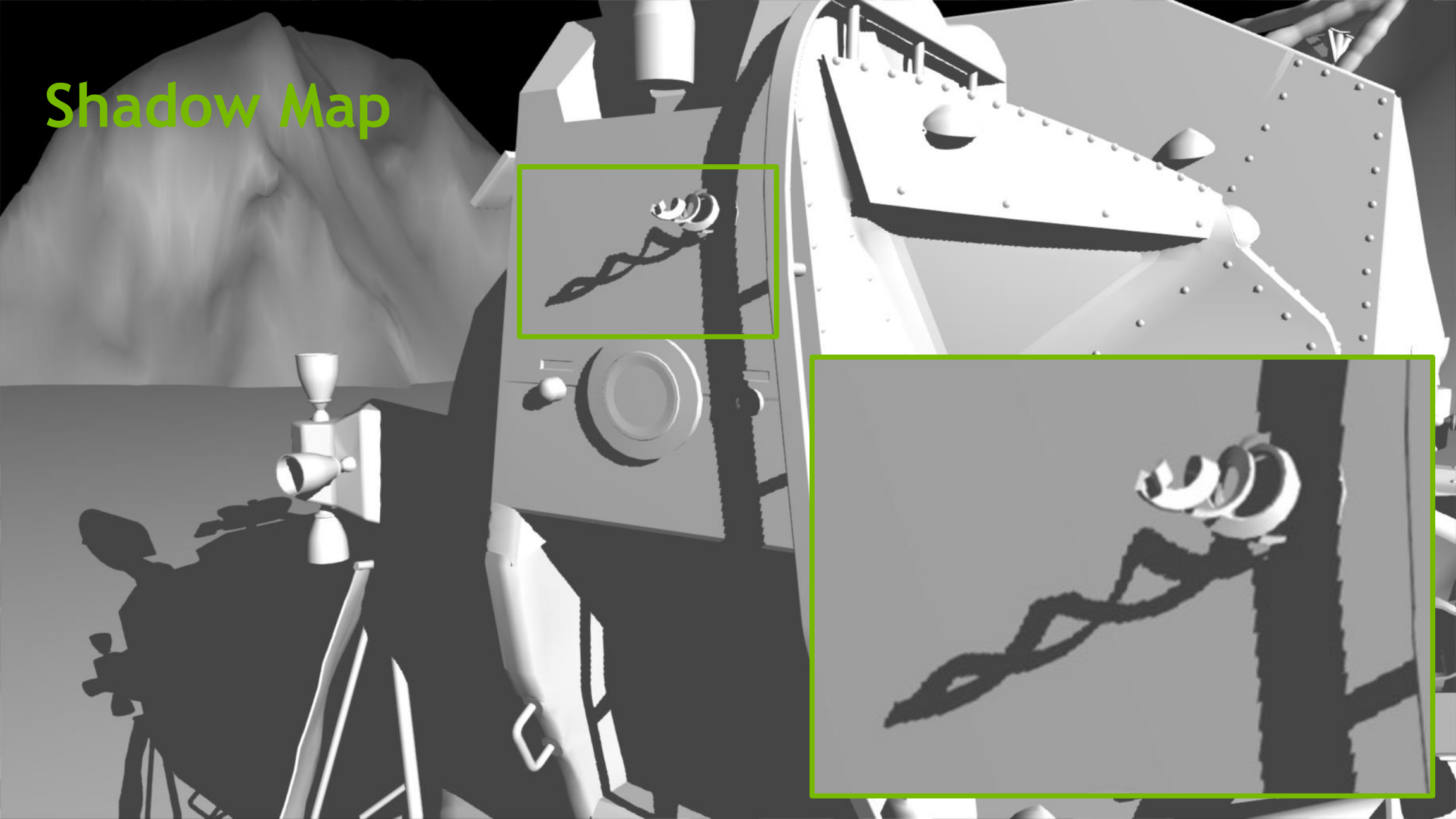
Anti-Aliasing?

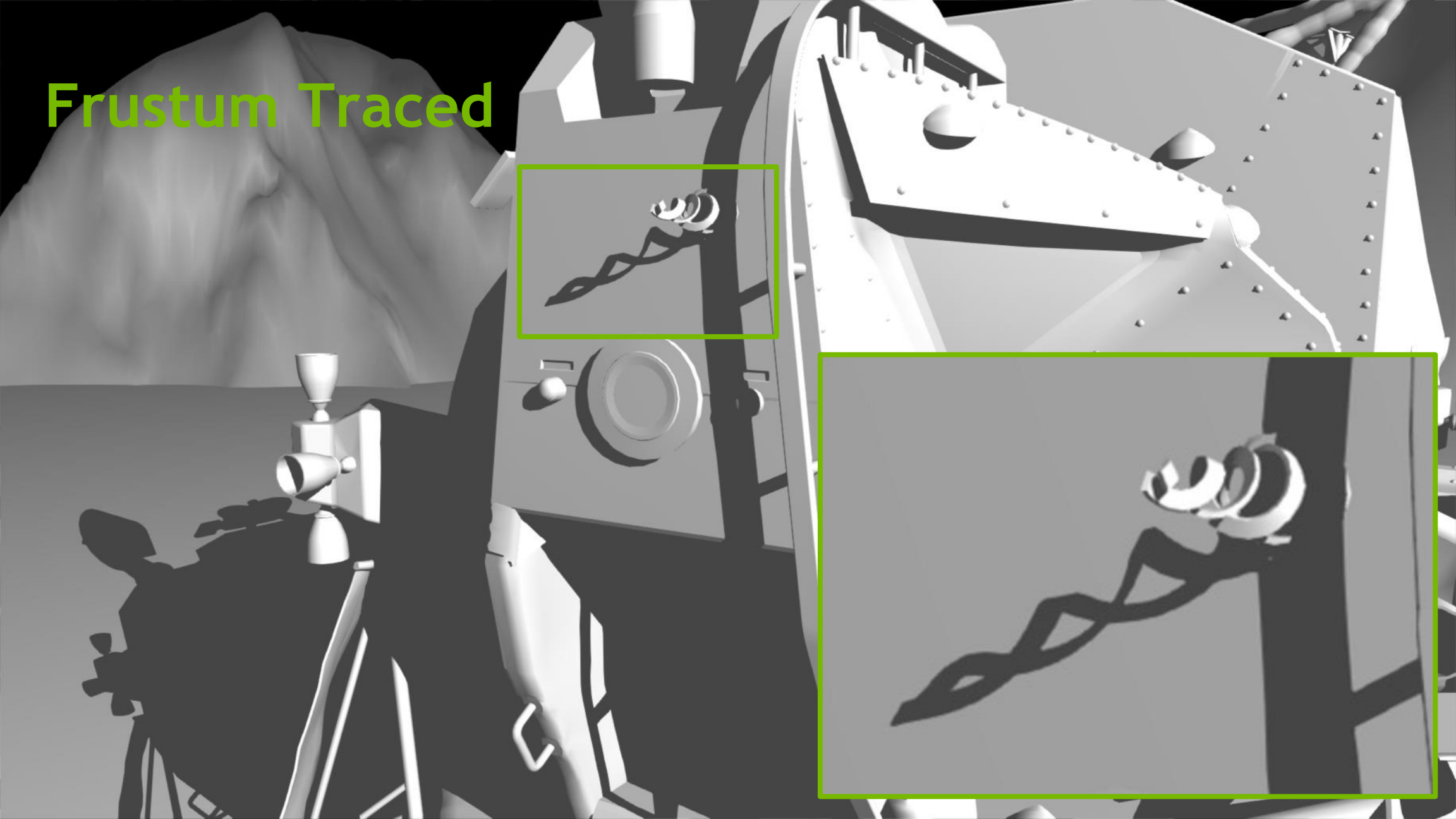
- Perform sub-pixel accurate frustum tests?
  - Perfectly possible to achieve
  - Yields really stable results
  - But comes at an additional cost
- Simple trick – apply a screen space AA technique
  - FXAA
  - Great results
  - Very cheap
  - Possibly free – if you already use screen space AA

Anti-Aliasing



Shadow Map



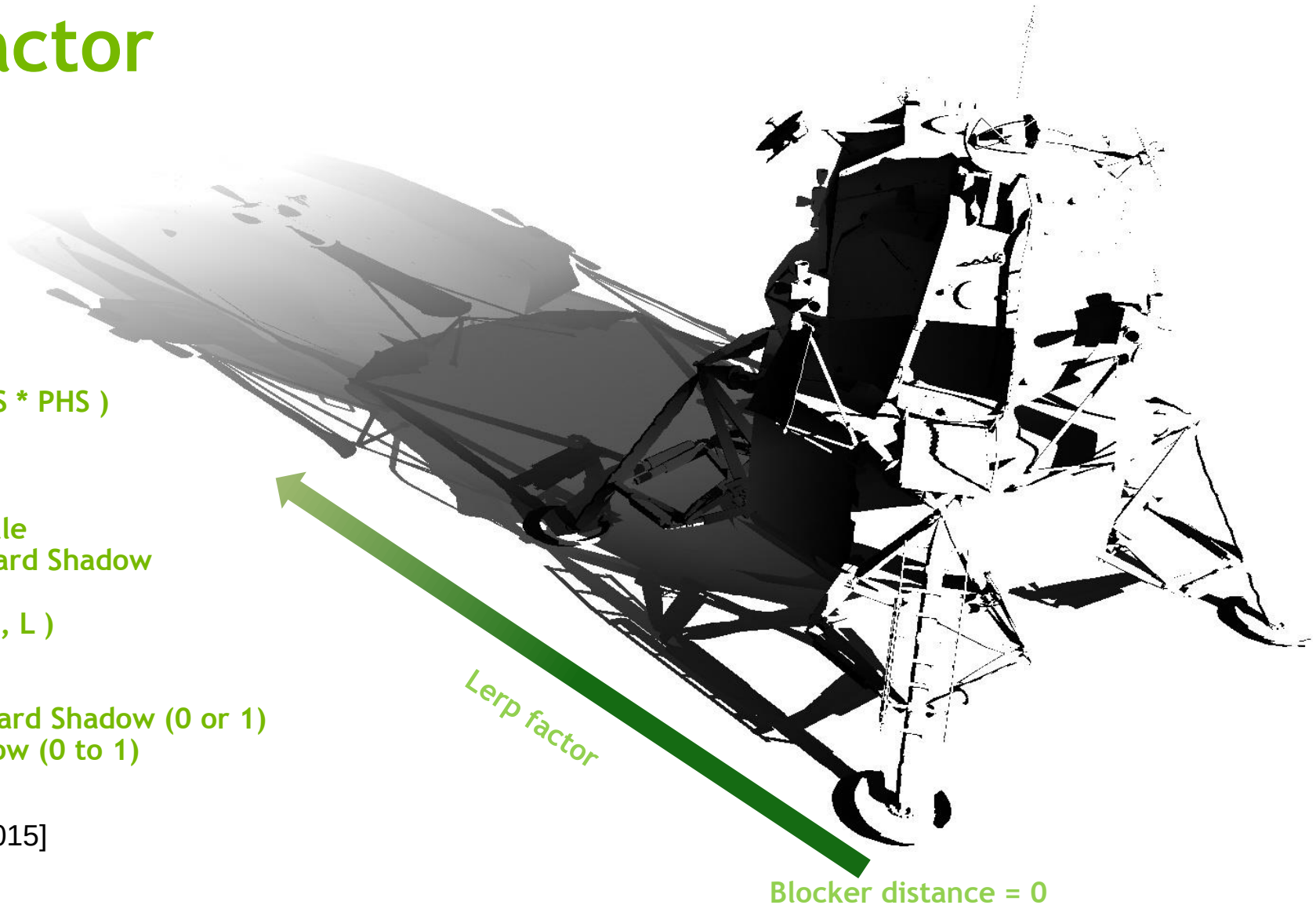

Frustum Traced

Hybrid Frustum Traced Shadows (HFTS)

Hybrid Approach

- Combine frustum traced shadow with PCSS
- Blocker distance can be used as an interpolation factor
- As blocker distance approaches zero, frustum traced result is prevalent
- Only first cascade has frustum tracing applied

Lerp factor



L = saturate(BD / WSS * PHS)

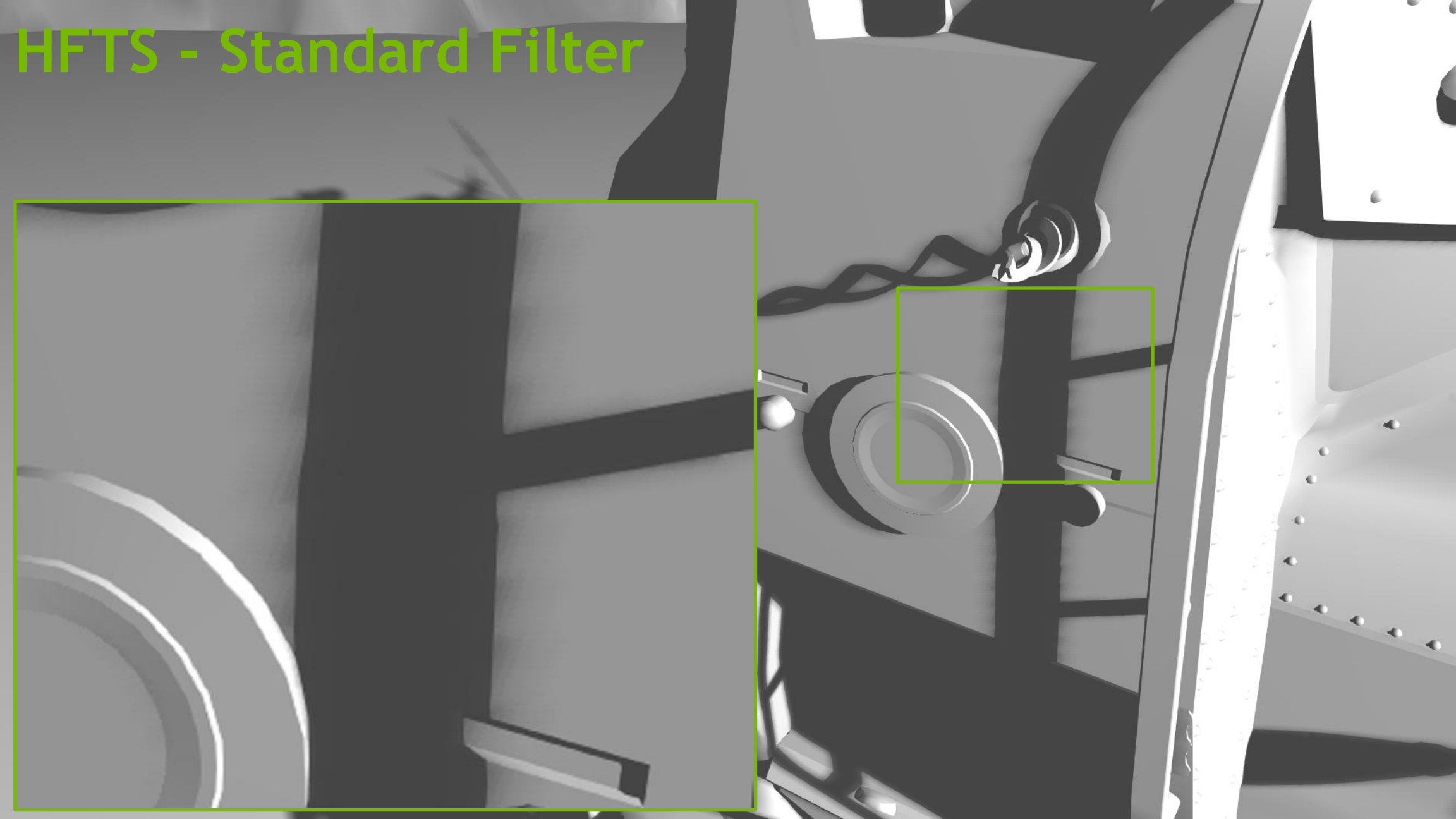
L: Lerp factor
BD: Blocker Distance
WSS: World Space Scale
PHS: Percentage of Hard Shadow

HFTS = lerp(FT, PCSS, L)

HFTS: Hybrid Shadow
FT: Frustum Traced Hard Shadow (0 or 1)
PCSS: PCSS Soft Shadow (0 to 1)

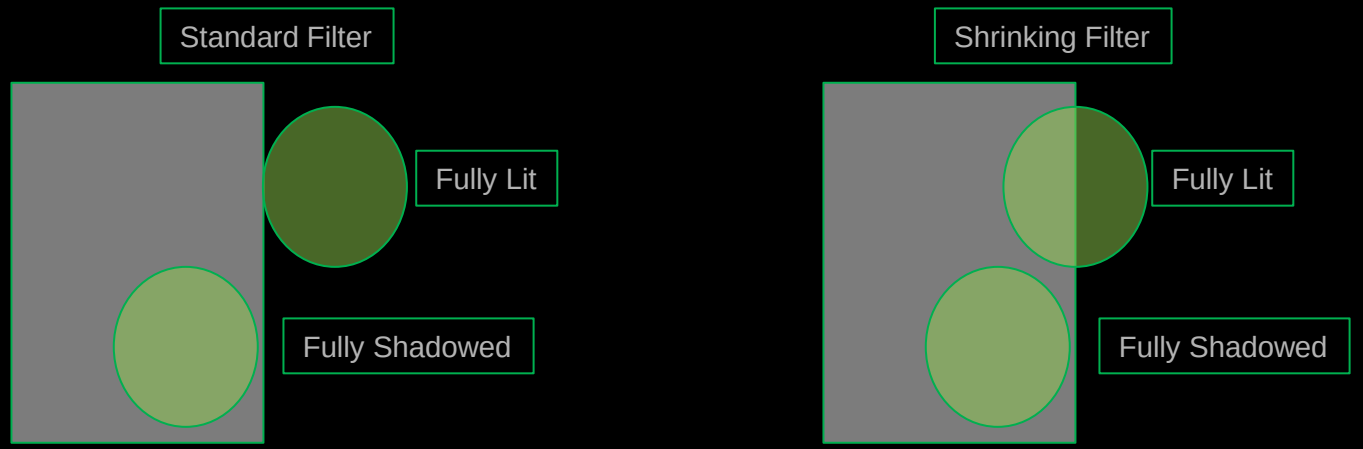
* [Jon Story – GDC 2015]

HFTS - Standard Filter



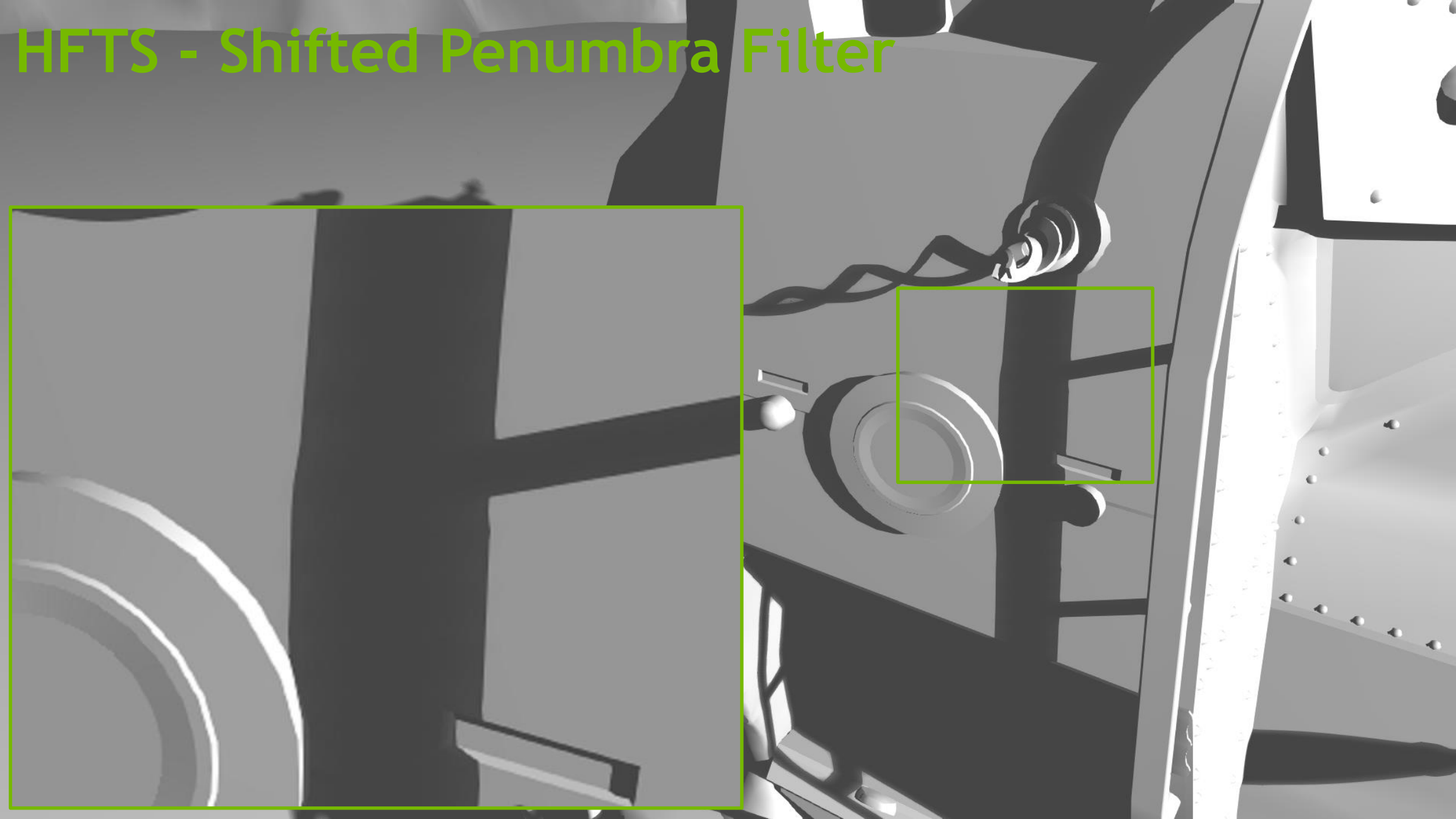
Needs a Shifted Penumbra Filter

- Shadow map result would not be contained within the frustum traced result
- Would lead to ugly artifacts during interpolation



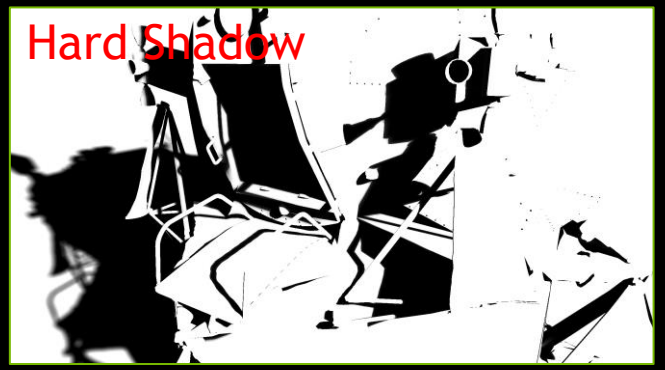
* [Jon Story – GDC 2015]

HFTS - Shifted Penumbra Filter



HFTS

Pipeline Stage: HFTS



HFTS

[PS]

Comparison Screenshots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Frame Rate Limit Unlimited
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Roughness AA
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View Scale
Low High
Texture Memory (Relative)
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Texture Memory (Absolute)
Shadow Quality High
Shadow Distance
Spotlight Shadows 12
Spotlight Shadow Res. 1024
Contact Shadows All High
Low High
Terrain Quality
Low High
Terrain Texture Distance
Apply
Changes requires restart
Save
0.4 km : Establish Base of Operations
Quality: High
Too soft
Too hard
Detachment


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Too soft
Detachment
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Quality: High


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44 m : Signal for JTF assistance
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Contact Shadows All High
Low High
Terrain Quality
Low High
Terrain Texture Distance
Apply
Changes requires restart
Save
0.4 km : Establish Base of Operations
Quality: High 01
Detachment
Aliasing
Too soft
32
344
1
G
V
2


Settings
Settings
Basic
Advanced
UI Config
Window Mode: Windowed
Monitor: 1
Resolution: 1153 x 812
Refresh Rate: 60.000Hz
Frame Rate Limit Unlimited
Allow Tearing When Slow
Allow Tearing When Fast
Reduce Latency High
PostFx AA SMAA 1x Ultra
Roughness AA
Temporal AA Supersampling
Low High
Sharpening
Low High
View Scale
Low High
Texture Memory (Relative)
Low High
Texture Memory (Absolute)
Shadow Quality PCSS+
Shadow Distance
Spotlight Shadows 12
Spotlight Shadow Res. 1024
Contact Shadows All High
Low High
Terrain Quality
Low High
Terrain Texture Distance
Apply
Changes requires restart
Save
0.4 km : Establish Base of Operations
Quality: PCSS 01
Detachment
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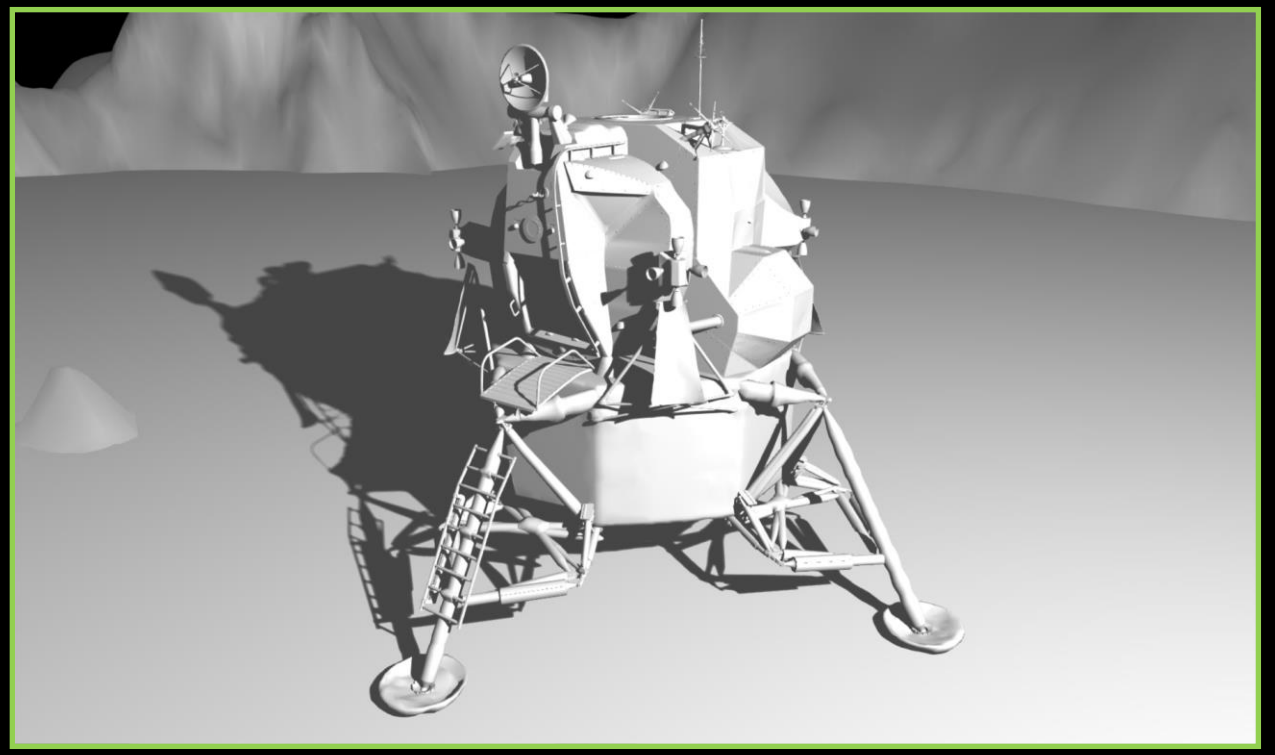
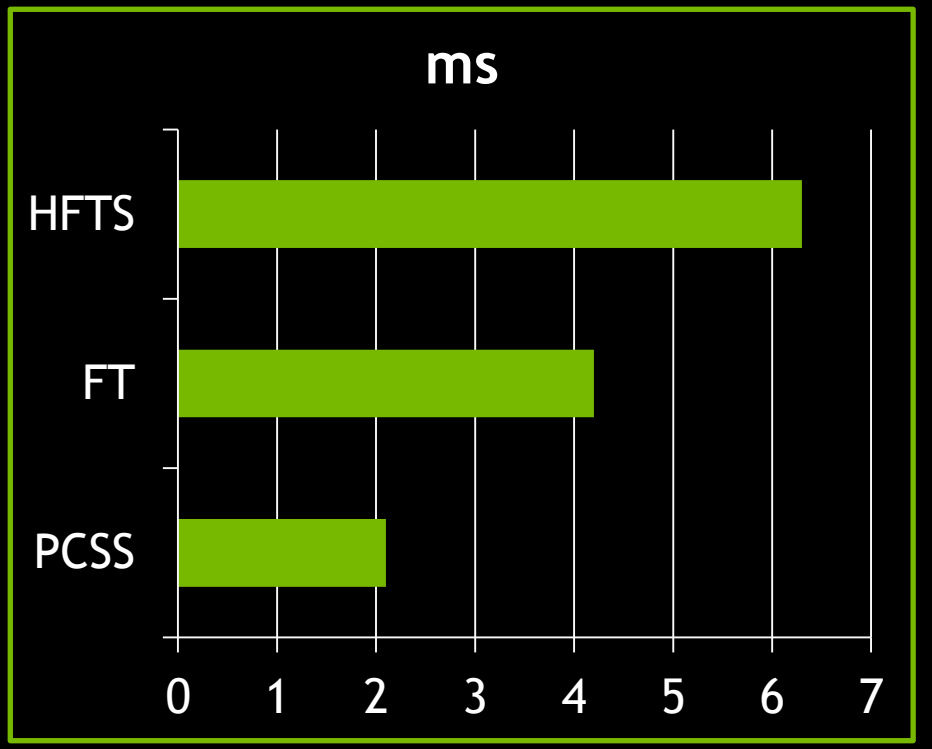
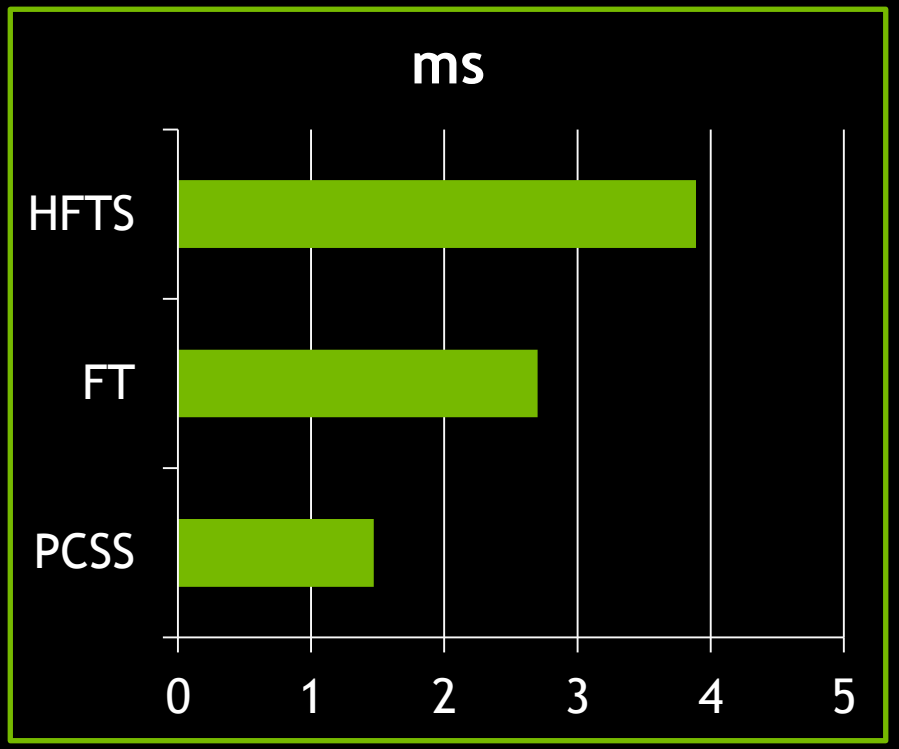
Settings
Settings
Basic
Advanced
UI Config
Window Mode: Windowed
Monitor: 1
Resolution: 1153 x 812
Refresh Rate: 60.000Hz
Frame Rate Limit Unlimited
Allow Tearing When Slow
Allow Tearing When Fast
Reduce Latency High
PostFx AA SMAA 1x Ultra
Roughness AA
Temporal AA Supersampling
Low High
Sharpening
Low High
View Scale
Low High
Texture Memory (Relative)
Low High
Texture Memory (Absolute)
Shadow Quality HFTS (NVIDIA only)
Shadow Distance
Spotlight Shadows 12
Spotlight Shadow Res. 1024
Contact Shadows All High
Low High
Terrain Quality
Low High
Terrain Texture Distance
Apply
Changes requires restart
Save
0.4 km : Establish Base of Operations
Quality: HFTS 01
32
344
1
G
V
2

Performance

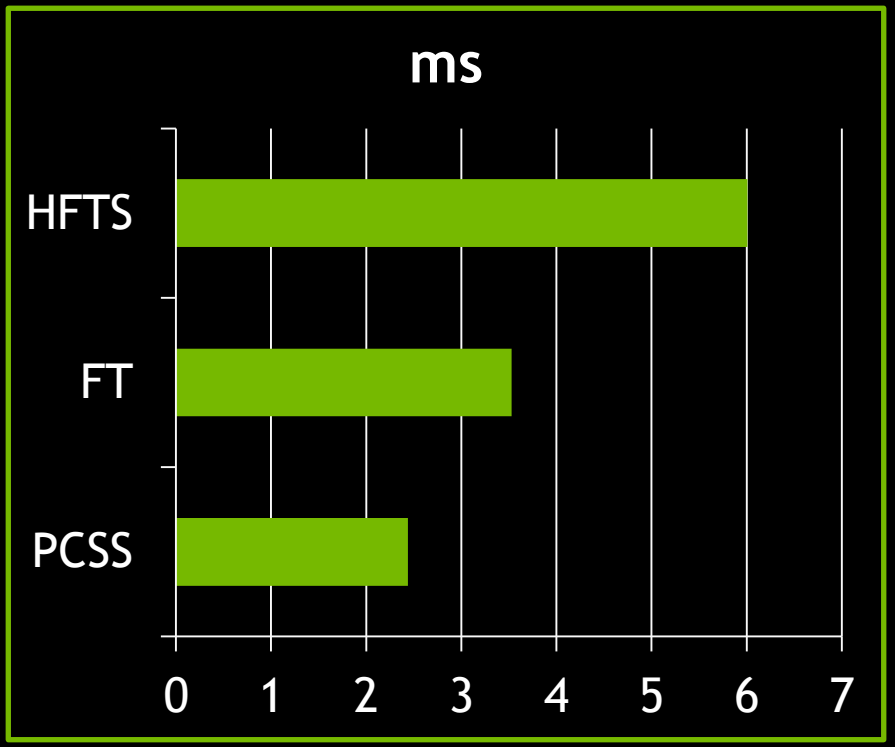




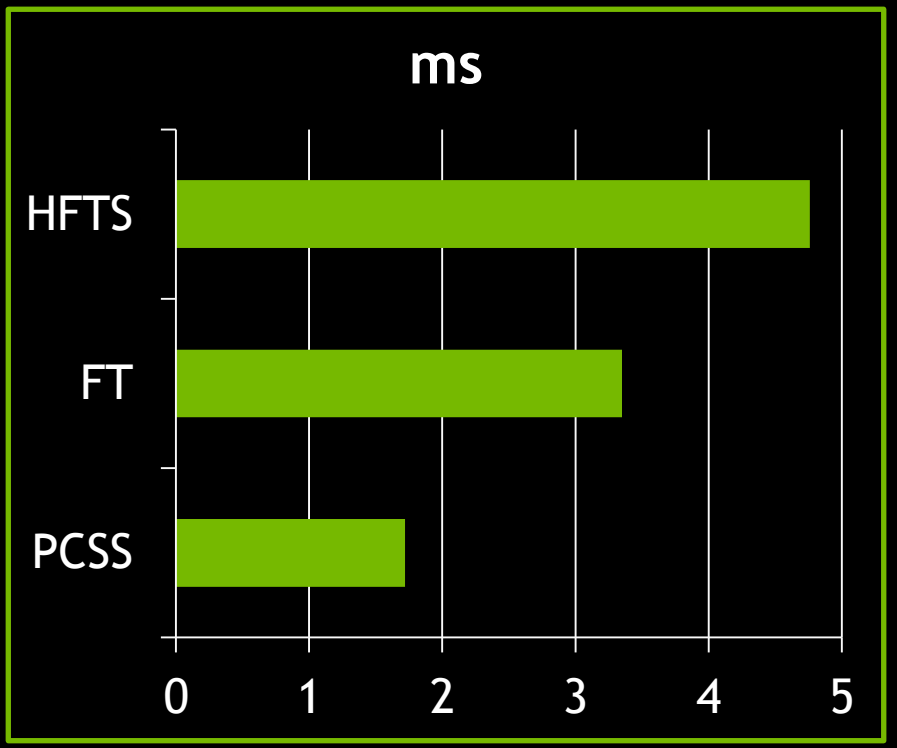
GTX Titan X
Resolution: 1920x1080



GTX Titan X
Resolution: 1920x1080



GTX Titan X
Resolution: 1920x1080



GTX Titan X
Resolution: 1920x1080

GFSDK Shadow Lib v3.0

GFSDK Shadow Lib v3.0

- Lots of shadow techniques (PCF, PCSS, RT, HRTS, FT, HFTS)
- Handles spot and directional lights with cascades
- Offers SDSM or user defined cascades
- Industry leading shadow quality
- Why not HFTS your game...?

Special Thanks

- *Anders Holmquist and team at MASSIVE*

References

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- **"Sub-Pixel Shadow Mapping" - ACM i3D 2014**
  Pascal Lecocq, Jean-Eudes Marvie, Gael Sourimant, Pascal Gautron
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  Jon Hasselgren, Tomas Akenine-Möller, Lennart Ohlsson

Questions?

jons@nvidia.com