Advanced Geometrically Correct Shadows for Modern Game Engines

Jon Story, 16 March 2016
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

 gabeworks.nvidia.com
Problems with Shadows?
Aliasing due to insufficient shadow map texels
Filter interference from overlapping blockers

Detachment due to z-bias factor
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

Screen Space List Nodes

Light Space List Head

Fixed memory footprint!

* [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

Depth → Irregular Z-Buffer → List Head

[PS] → List Nodes
Pipeline Stage: Frustum Tracing

List Head

Frustum Trace
[GS + PS]

List Nodes

Depth

Hard Shadow

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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

Depth → Heat Map → [CS] → Heat Map
Pipeline Stage: Dynamic Reprojection

Heat Map → Dynamic Reprojection [CS] → Projection Matrix Buffer
Pipeline Stage: Irregular Z-Buffer

- Projection Matrix Buffer
- Depth
- Irregular Z-Buffer
- List Head 0
- List Head 1
- List Nodes

[PS]
Pipeline Stage: Frustum Tracing

- List Head 0
- List Head 1
- List Nodes
- Depth
- Projection Matrix Buffer

Frustum Trace: [GS + PS]

Hard Shadow

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Full screen pass counts number of screen pixels mapped to a given light space texel. Visualized here as a heat map! 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 rasterized
- 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
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
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
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]
Pipeline Stage: HFTS

1. Hard Shadow
2. Depth
3. Shadow Map
4. HFTS [PS]
5. Final Image
Detachment

Too soft

Quality: PCSS
Quality: HFTS
The image shows a settings screen with options for various graphics settings. The highlighted setting is "Shadow Quality" set to High. The text on the screen includes:

- "Too soft"
- "Detachment"
- "Too hard"
- "Quality: High"
Detachment

Quality: High
Detachment

Quality: PCSS
Quality: HFTS
Detachment

Aliasing

Too soft

Quality: PCSS
Detachment

Aliasing

Too soft

Quality: PCSS
Performance
GTX Titan X
Resolution: 1920x1080

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GFSDK Shadow Lib v3.0
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• 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

• “Frustum-Traced Raster Shadows: Revisiting Irregular Z-Buffers” - i3D 2015
  Chris Wyman, Aaron Lefohn, Rama Hoetzlein

• “Hybrid Ray Traced Shadows” - GDC 2015
  Jon Story

• “Sub-Pixel Shadow Mapping” - ACM i3D 2014
  Pascal Lecocq, Jean-Eudes Marvie, Gael Sourimant, Pascal Gautron

• “GPU Gems 2: Conservative Rasterization”
  Jon Hasselgren, Tomas Akenine-Möller, Lennart Ohlsson
Questions?

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