Greg James, NVIDIA

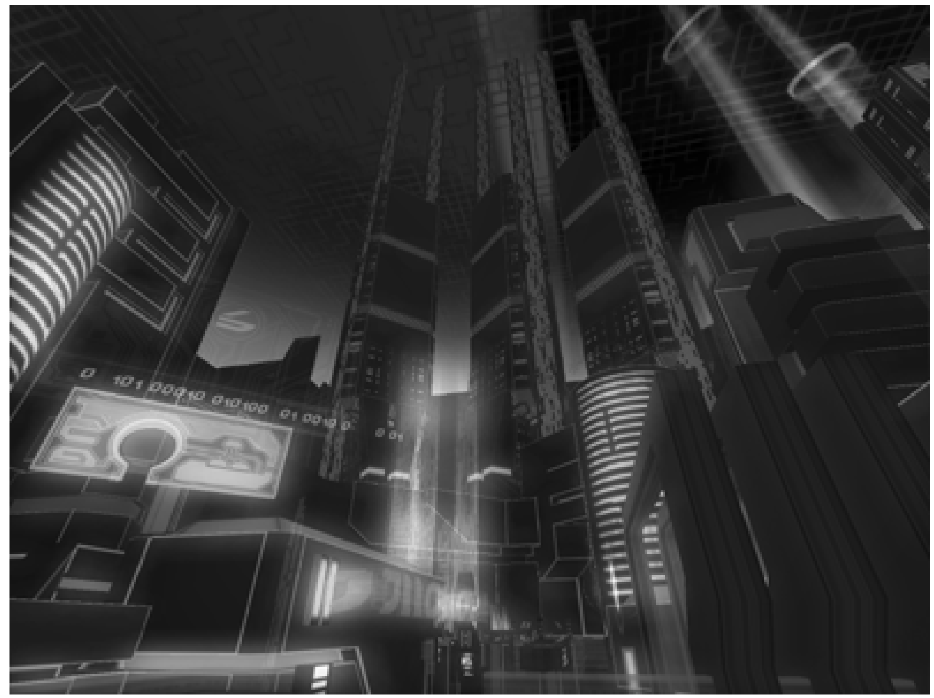
Direct3D Special Effects

- Glow effect
  - Developed for Disney/Monolith's "Tron 2.0"
- Volume fog from polygon objects
  - Used in Bandai/Dimps "UniversalCentury.net Gundam Online"

- Take away:
  - Render-to-texture is awesome!

“Tron 2.0” Glow Effect

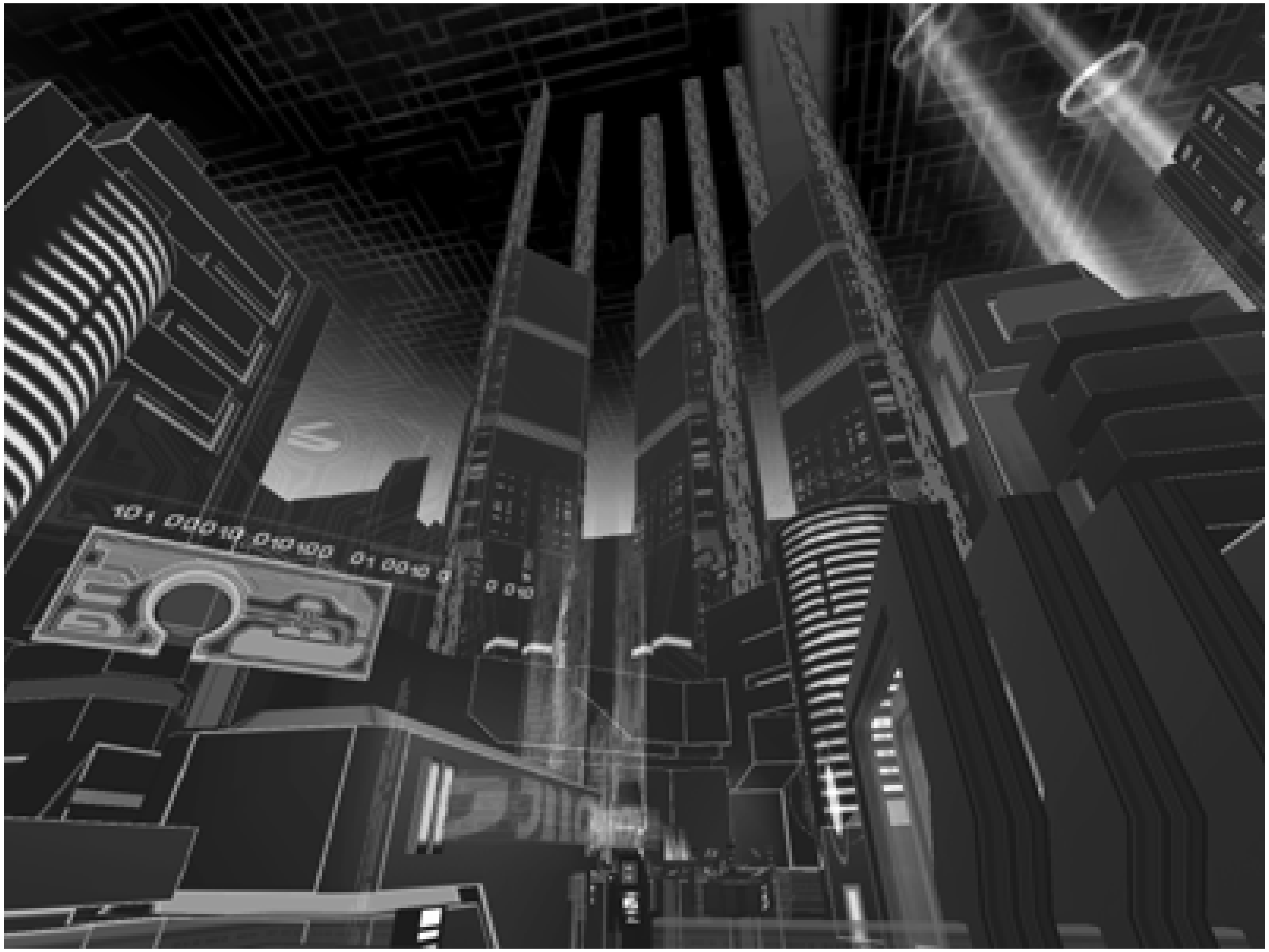
- Large glows for complex scenes
- Fast for in-game use in a FPS
- Efficient HDR effect
- Multi-colored glow
- Easy to control



“Tron2.0” courtesy of Monolith & Disney Interactive

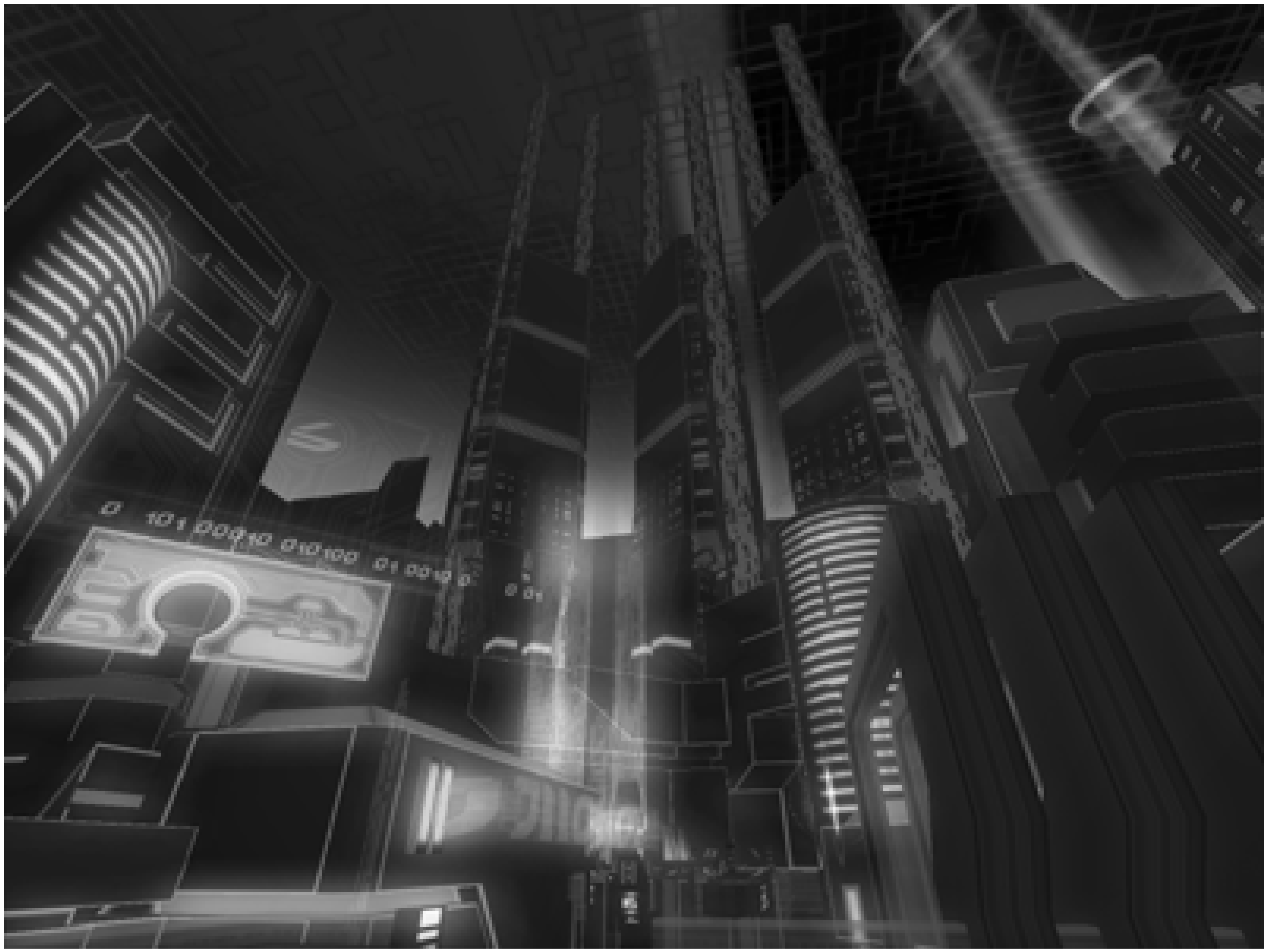
No Glow

“Tron2.0” courtesy of Monolith & Disney Interactive



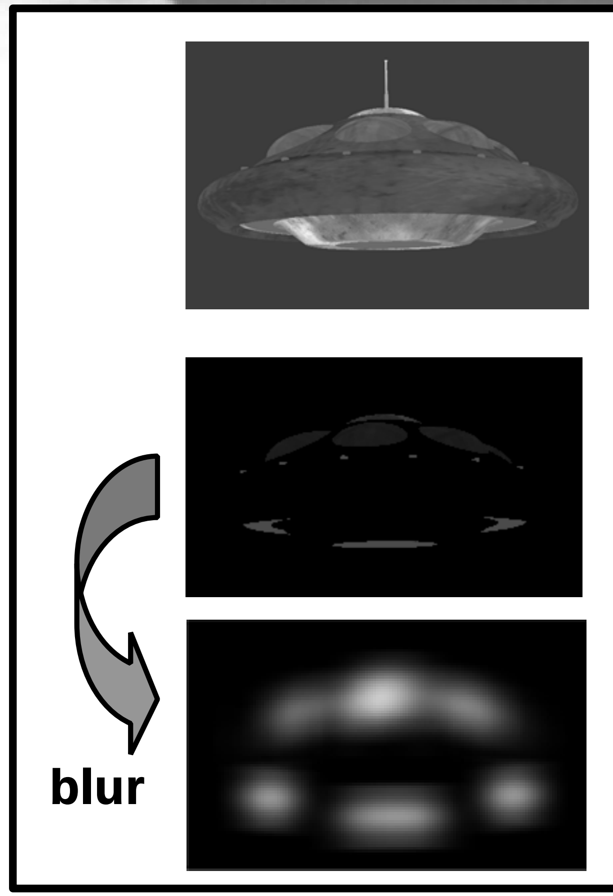
Glow

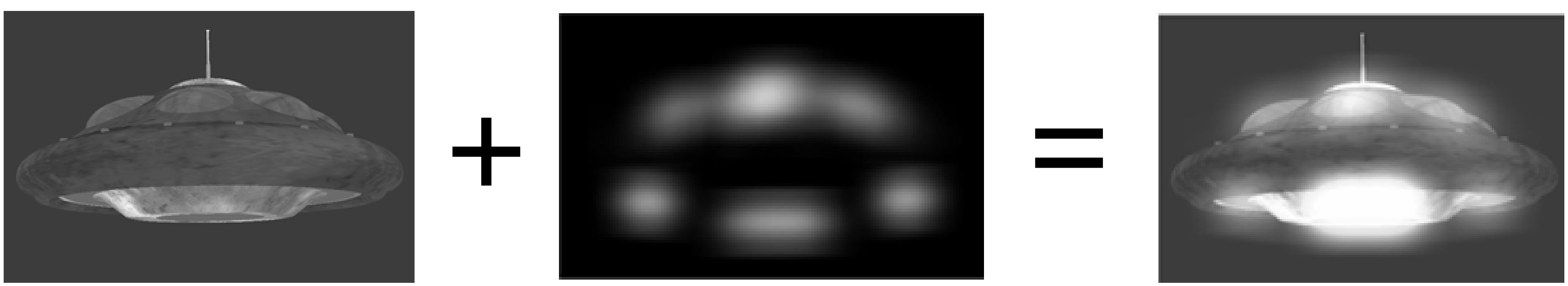
“Tron2.0” courtesy of Monolith & Disney Interactive



How It Works

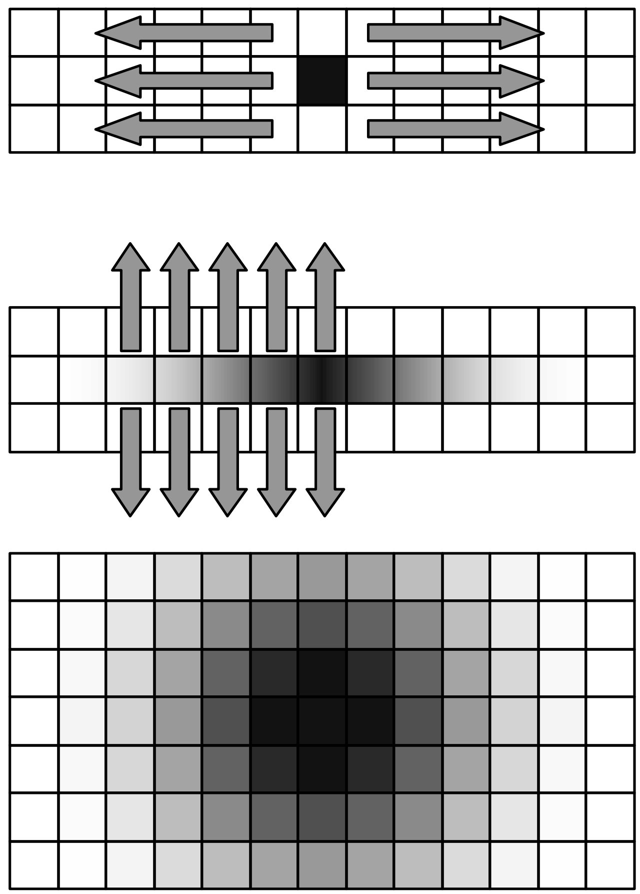
- **Start with ordinary model**
  - Render to backbuffer
- **Render parts that are the sources of glow**
  - Render to offscreen texture
- **Blur the texture**
- **Add blur to the scene**





Efficient Blur

- **Blur, then blur the blur**

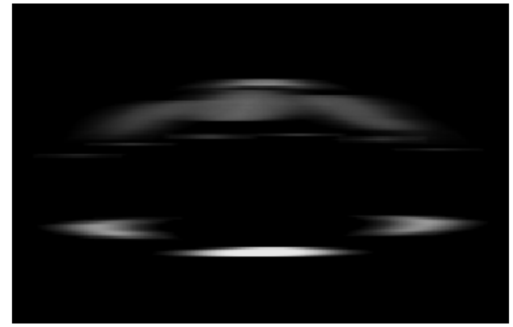


Blur the source horizontally

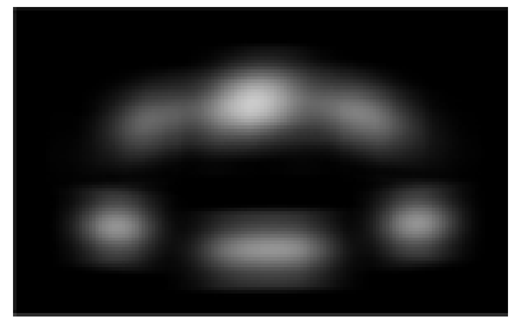
Blur the blur verticaly

Result

Source



Horizontal Blur

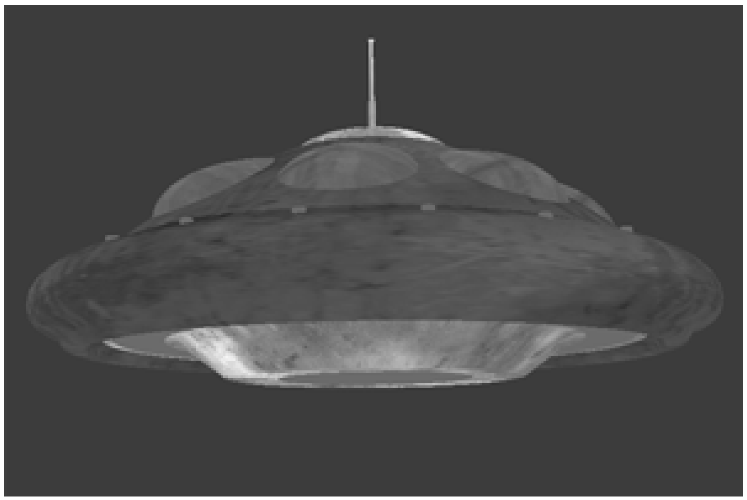


Vertical Blur

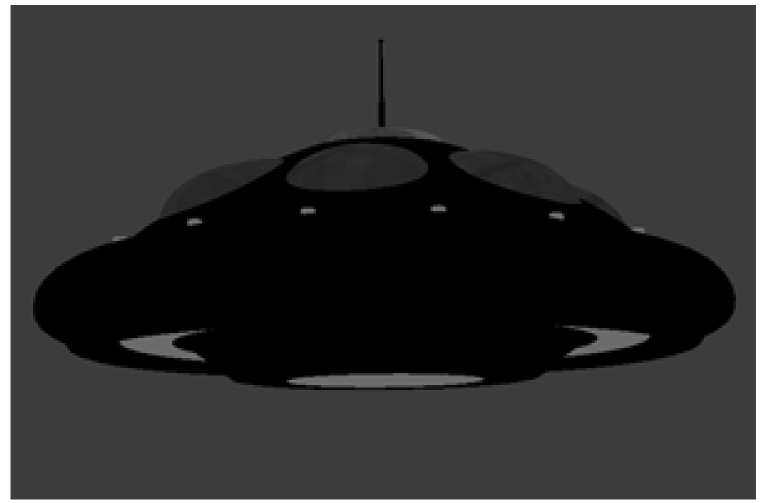
General Approach

- No CPU pixel processing!
  - No texture locks or CPU readbacks
  - Render to GPU video memory textures
- Minimize render target changes
- Fill rate bound
  - Minimize fill cost
  - Low resolution glow processing
  - Magnify glow texture to cover the full screen
- Full scene gets blurred at once
  - Could break it up for finer control

Specify Glow Sources



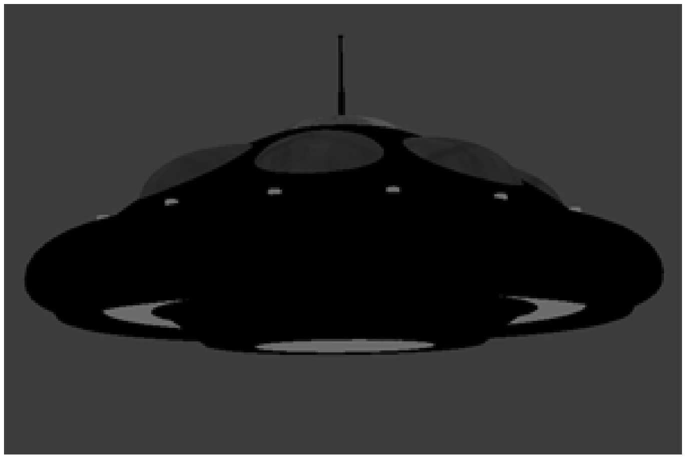
Model with diffuse texture, t0.rgba



t0.a * t0.rgb = glow source

- Start with ordinary model
- Designate areas as 'glow sources'
  - texture Alpha * texture RGB = glow source color
  - or create separate glow geometry

Render Glow Sources to Texture

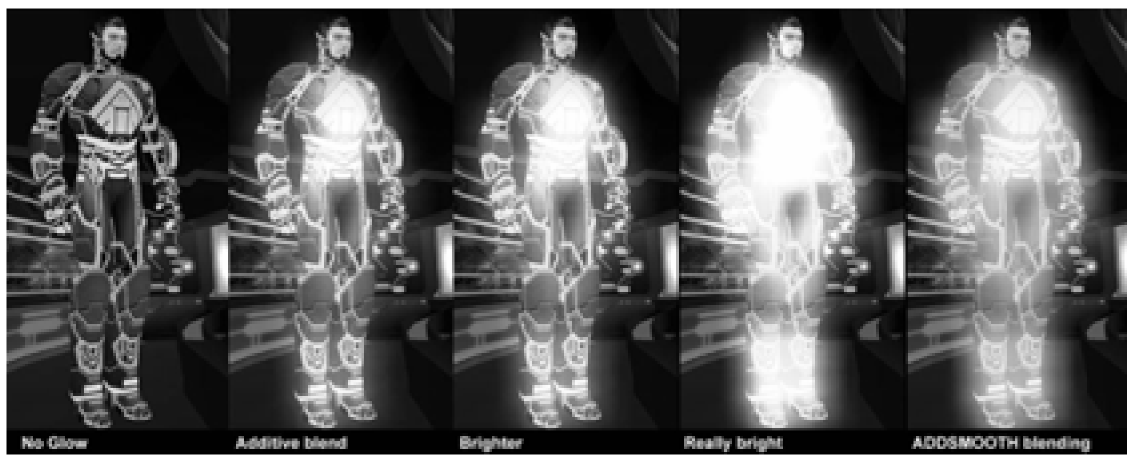


Texture render target

- **Texture render target can be lower resolution than final display**
  - **Glows are low frequency, smooth**
  - **Can be rendered at low resolution**
  - **The lower the resolution, the more aliased the sources**
    - **You can miss glow sources**
    - **Glow may shimmer and flicker**

Low Texture Resolution

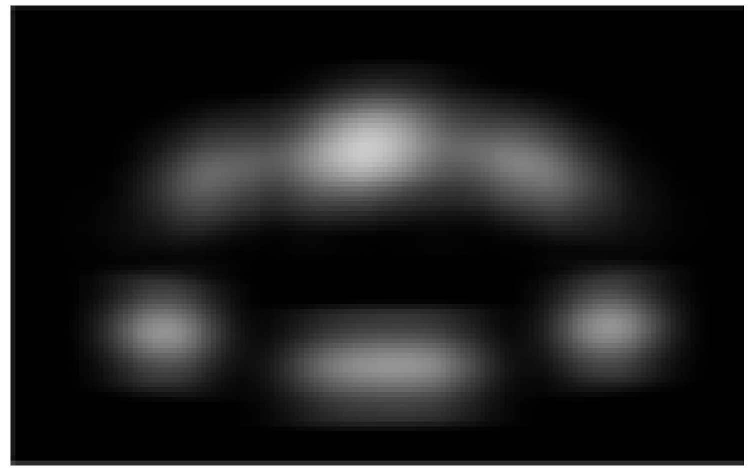
- Improve performance and size of glows
- Each glow texel can cover 2, 3, 4 etc. screen pixels
  - Example: Blur a 40x40 texel area
  - Becomes a 160x160 screen pixel glow



Assets courtesy of Monolith & Disney Interactive

Blur to Create Glow Texture

Rendered Texture

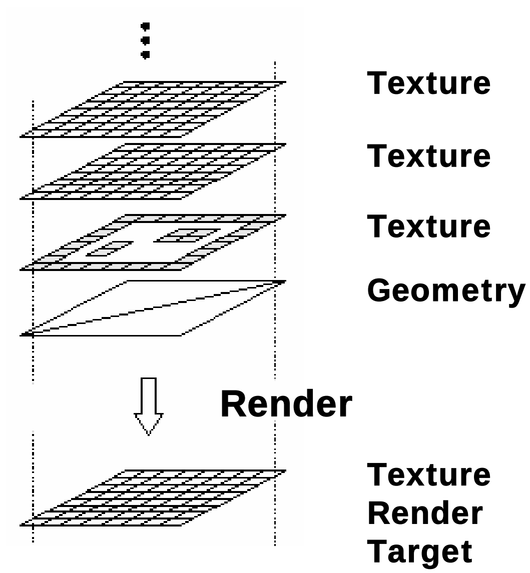


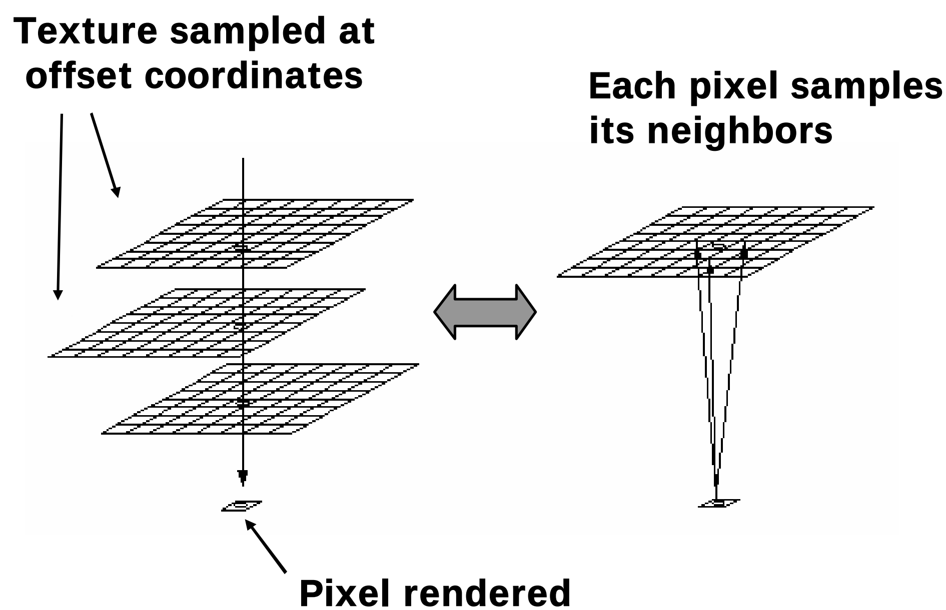
Texture render target

- **GPU render-to-texture**
- **Pixel samples from many neighbors**
  - **Details: “Game Programming Gems 2” article**
    “Operations for HW-Accelerated Procedural Texture Animation”

How To Blur

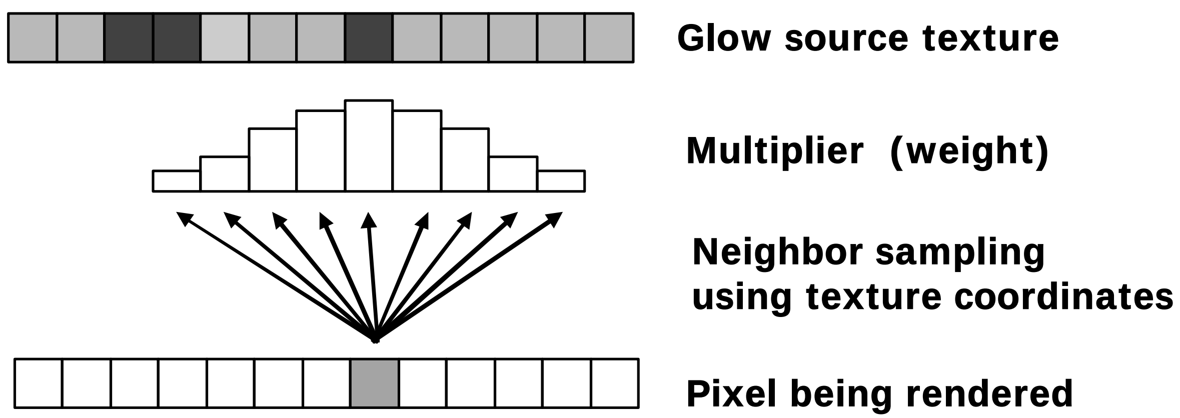
- Neighbor sampling with vertex and pixel shaders
- Simple geometry with several texture coordinates
- Each tex coord samples a pixel’s neighbor





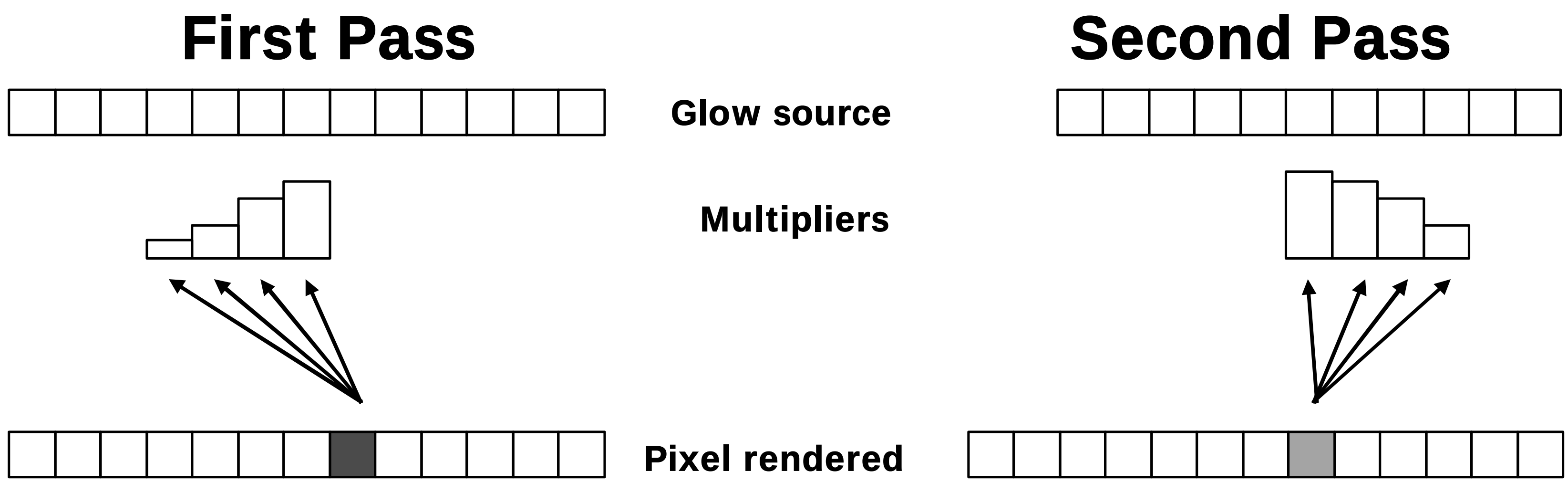
How to Blur in One Axis

- **D3D9**
  - Use 1 bound texture, sampled N times
  - Each sample multiplied by blur profile weight
  - Single pass



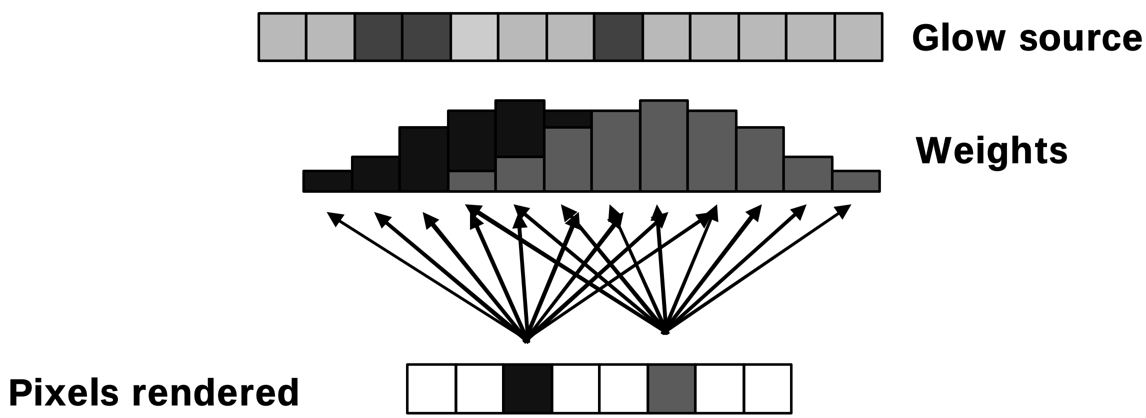
How to Blur With D3D8 HW

- **D3D8**
  - Multiple additive passes to build up N samples
  - Bind source to 4 tex units, each sampled once
  - 4 samples per pass, point or bilinear sampled



Neighbor Sampling

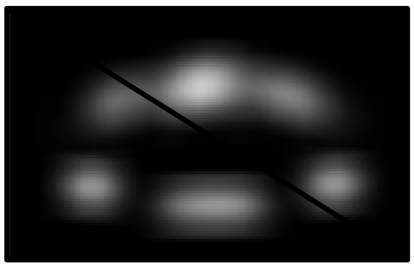
- Each pixel samples the same pattern of neighbors
- One D3D9 pass blurs all pixels horizontally
- One more pass blurs all pixels vertically



Blurring

- You might hear 'separable Gaussian'
- We can use any blur profiles
  - More than just Gaussian
- Separating into BlurV(BlurH(x)) restricts the 2D blur shapes
  - Good shapes still possible
  - Watch for square features

Add Glow to Scene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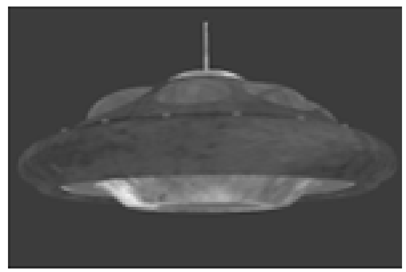
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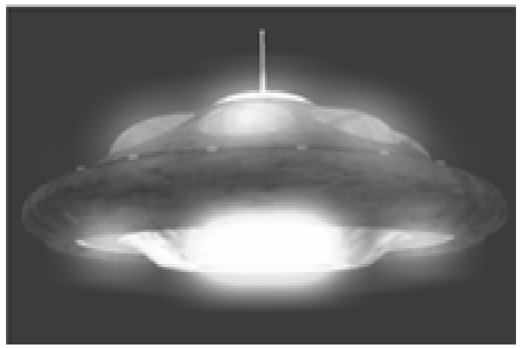


- Apply glow using two triangles covering the screen
- Additive blend

Performance Concerns

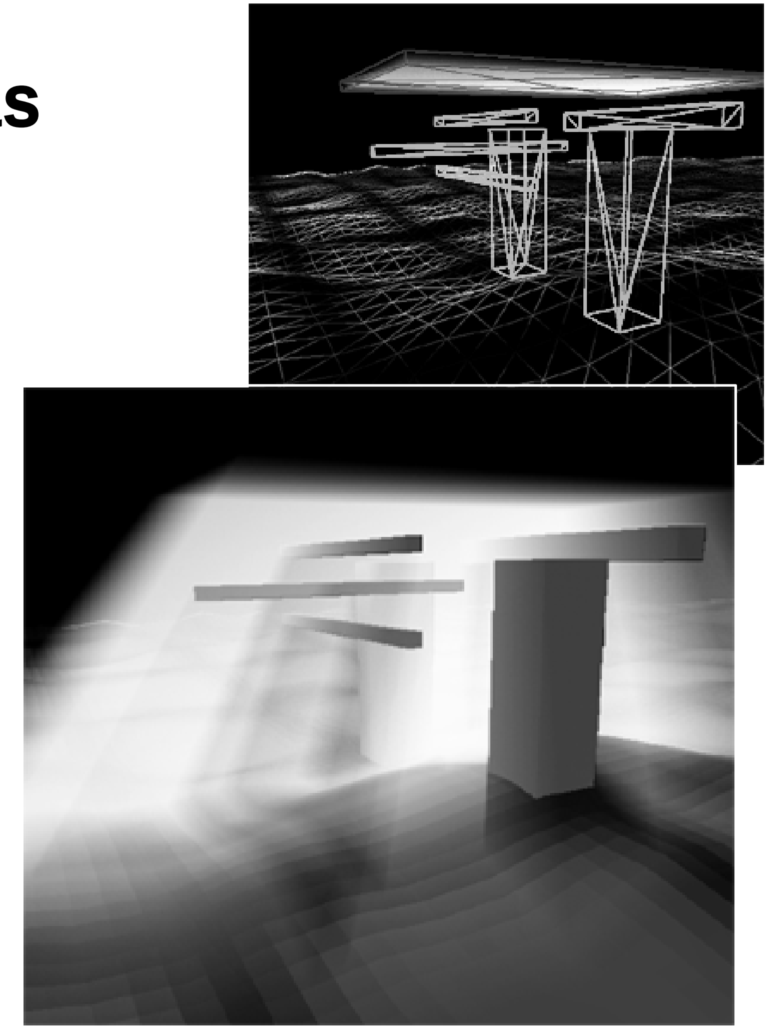
- **Limited by:**
- **Number of DrawPrimitive calls needed to render glow sources**
  - **Batch rendering of glow sources as much as possible**
  - **Call Draw..Primitive() as little as possible**
- **Texture render target resolution**
  - **Use pow2 textures or non-pow2? 256x256 or 300x200?**
  - **Test each**
- **Blur convolution size**
  - **Perf of NxN separable blur is O(N), not O(N^2)** ☺

Many Uses for Glow Technique

- Key to making things look bright
  - Subtle glow has dramatic effect
  - Reflections: water, shiny objects
  - Atmospheric: neon lights, smoke haze
- More than just glow!
  - Blur, depth of field, light scattering
- Remember, it doesn’t require HDR assets or floating point textures!
  - Great for D3D8 hardware
  - Greater with D3D9 hardware

Volume Fog from Polygon Hulls

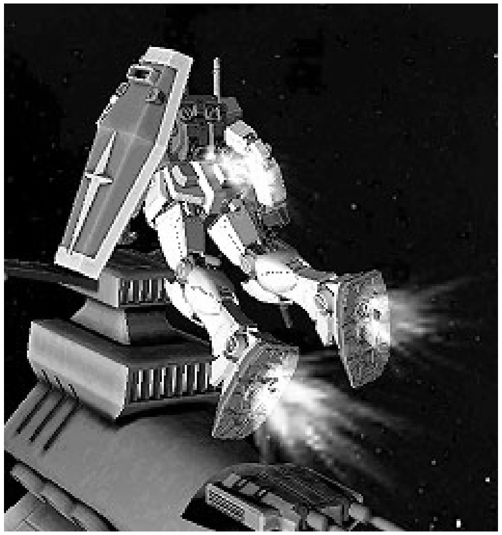
- Polygon hulls rendered as thick volumes
- True volumetric effect
- Very easy to author
- Animate volume objects
- Positive and negative volumes
- Fast, efficient occlusion & intersection
- ps_2_0, ps.1.3 fallbacks



Practical Effect

- Used in Bandai / Dimps "UniversalCentury.net Gundam Online"
  - Engine thrust

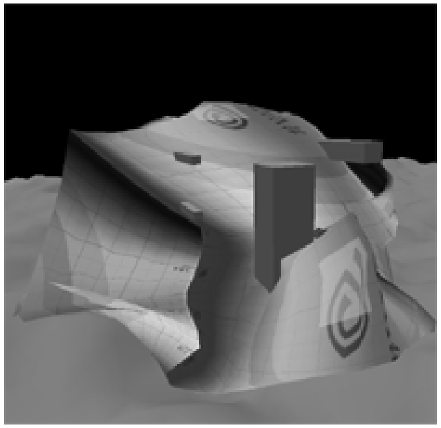
Concept art

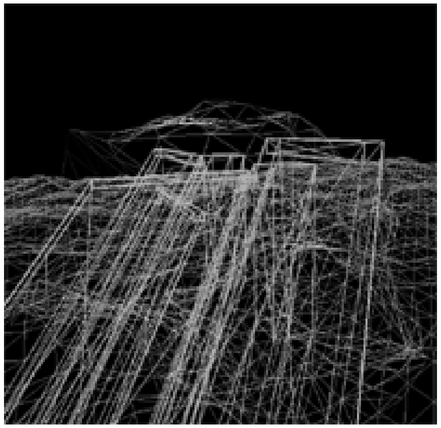


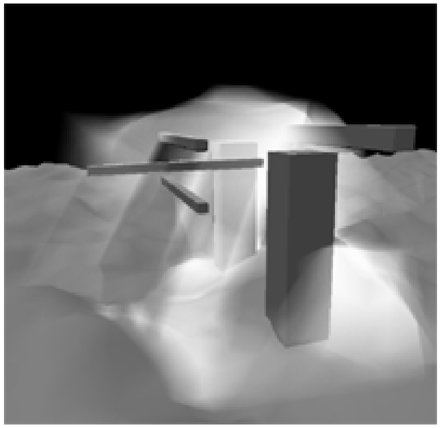
In-game

Volume Objects

- Ordinary polygon hulls
  - Use existing objects.   Closed hulls
  - No new per-object vertex or pixel data
  - Just a scale value for thickness-to-color and 3 small shared textures
  - Can use stencil shadow volume geometry







Demo

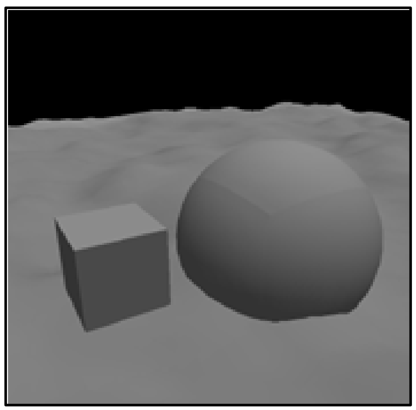
The Technique

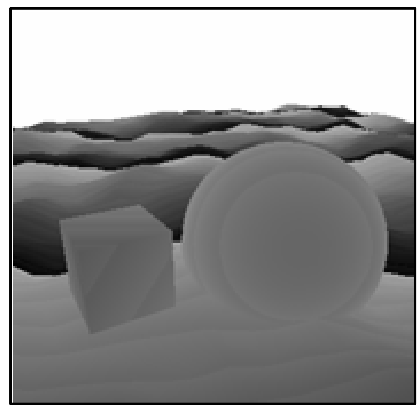
- Inspired by Microsoft's "Volume Fog" DXSDK demo
- Improves the approach
  - Higher precision: 12, 15, 18, 21-bit depth
  - Precision vs. depth complexity tradeoff
  - High precision decode & depth compare
  - Dithering
  - No banding, even with deep view frustum
  - Simple, complete intersection handling for any shapes

The Technique

- Render to offscreen textures
- Instead of rendering object “color,” render the object depth at each pixel
  - Encode depth as RGB color

Objects





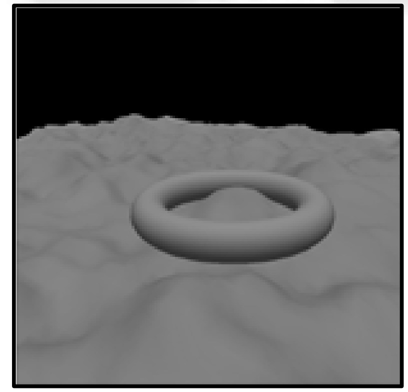
RGB-encoded depth

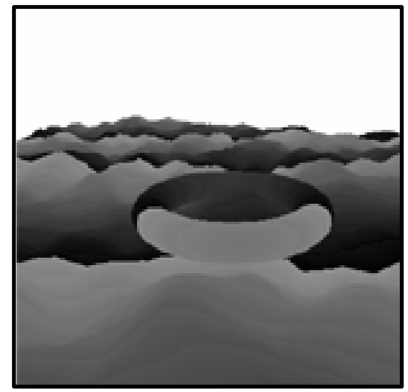
- Depths used to calculate thickness through objects at each pixel

Before all the Details...

Here's how simple it is!

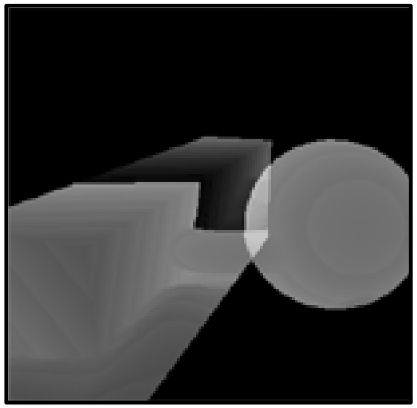
1. **Render solid objects to backbuffer**
   – Ordinary rendering
2. **Render depth of solid objects that might intersect the fog volumes**
   – To ARGB8 texture, "S"
   – RGB-encoded depth. High precision!
3. **Render fog volume backfaces**
   – To ARGB8 texture, "B"
   – Additive blend to sum depths
   – Sample texture "S" for intersection



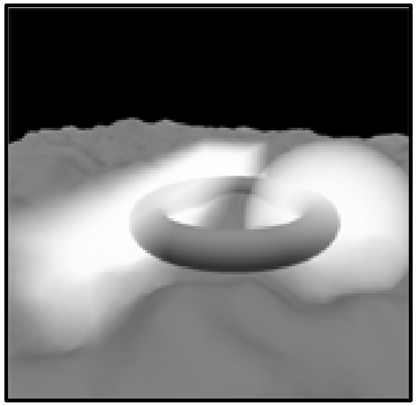


Simplicity...

4. **Render fog volume front faces**
   – To ARGB8 texture, “F”
   – Additive blend to sum depths
   – Sample texture “S” for intersections



5. **Render quad over backbuffer**
   – Samples “B” and “F”
   – Computes thickness at each pixel
   – Samples color ramp
   – Converts thickness to color
   – Blends color to the scene
   – 7 instruction ps_2_0 shader

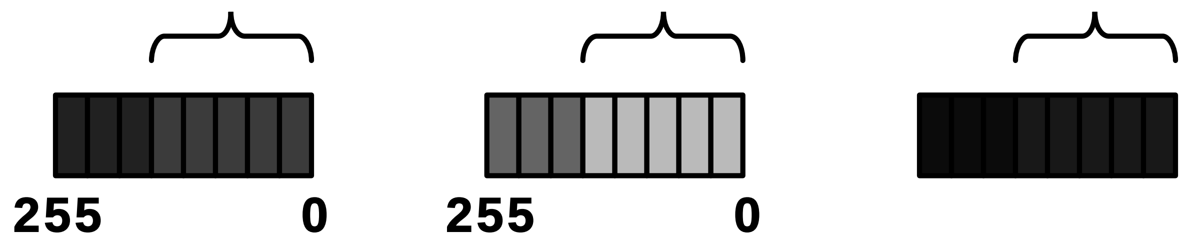


Floating Point Image Surfaces?

- Why not use those?
- Need additive blending
  - No existing HW supports float additive blending to the render target
  - Too many passes without it
- ARGB8 surfaces can do the job
  - Good for all D3D8 pixel shading hardware
  - Millions can run the effect today

RGB-Encoding of Depth

- **Use "L" low bits of each color channel**
  - ie. 5 low bits from each R, G, and B color
  - Gives 3*L bits of precision (15-bit precision)



- **(8 – L) high bits "H" for acumulation**
  - $2^{(8-L)}$ depth values can be added before overflow
  - ie. L=5 lets you add 8 values safely

RGB-Encoding of Depth

- Use “L” low bits of each color channel
  - ie. 5 low bits from each R, G, and B color
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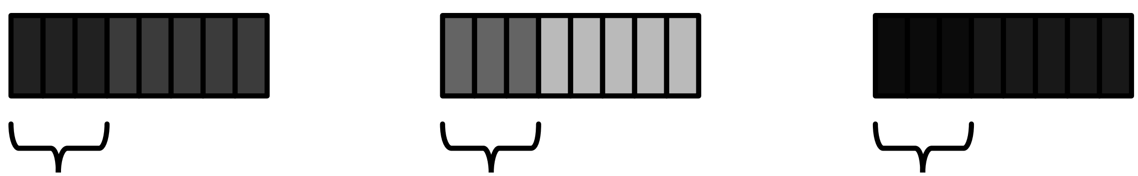
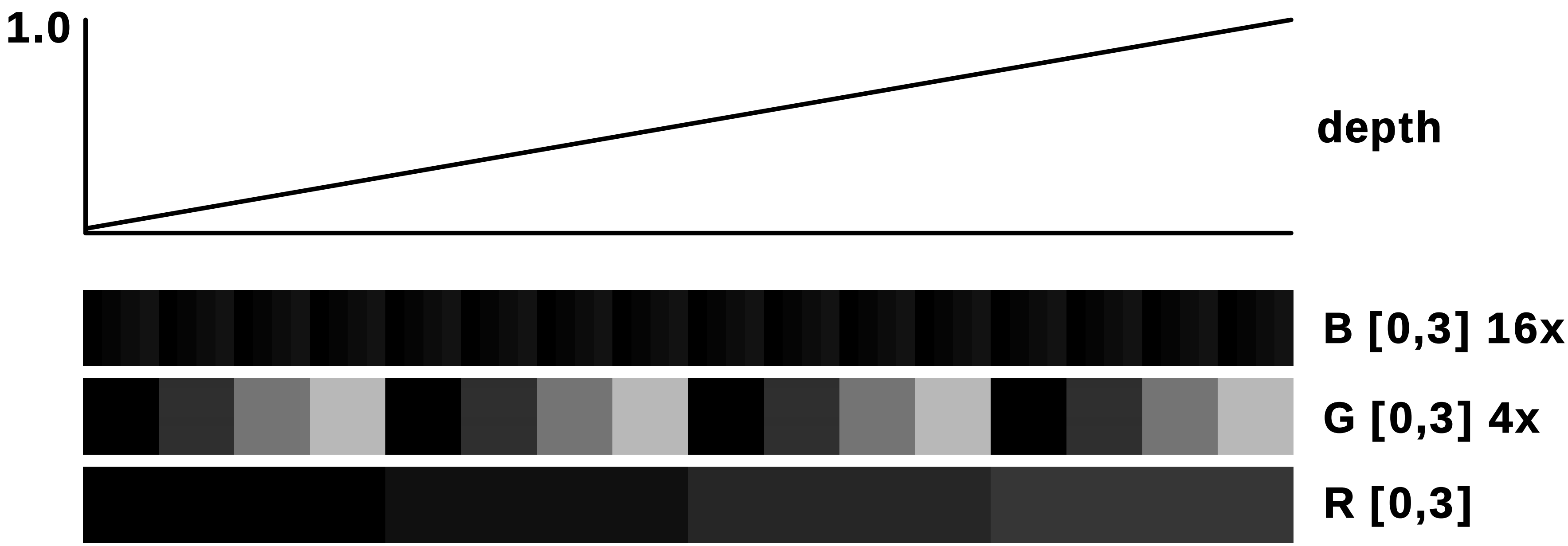


- (8 – L) high bits “H” for summing values
  - $2^{(8-L)}$ values can be added before saturation
  - ie. L=5 lets you add 8 values correctly

RGB-Encoding Diagram: L=2



- One 6-bit depth uses only [0,3] of [0,255]
- Values [4,255] used when adding depths

RGB-Encoding

- **Vertex shader computes depth from [0,1]**

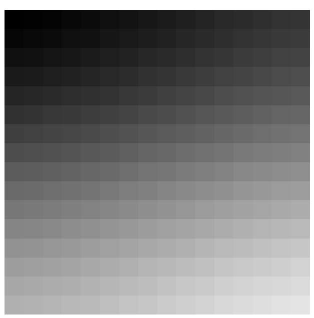
```
DP4 r1.x, V_POSITION, c[CV_WORLDVIEWPROJ_0]
DP4 r1.y, V_POSITION, c[CV_WORLDVIEWPROJ_1]
DP4 r1.z, V_POSITION, c[CV_WORLDVIEWPROJ_2]
DP4 r1.w, V_POSITION, c[CV_WORLDVIEWPROJ_3]
```

- **Vertes shader turns depth into tex coords**
  - **TexCoord.r = D * 1.0**
  - **TexCoord.g = D * 2^L** ie. G = D * 16
  - **TexCoord.b = D * 2^{2L}** ie. B = D * 256

```
MUL  r0.xyz, r1.z, c[CV_DEPTH_TO_TEX_SCALE].xyz
```

RGB-Encoding

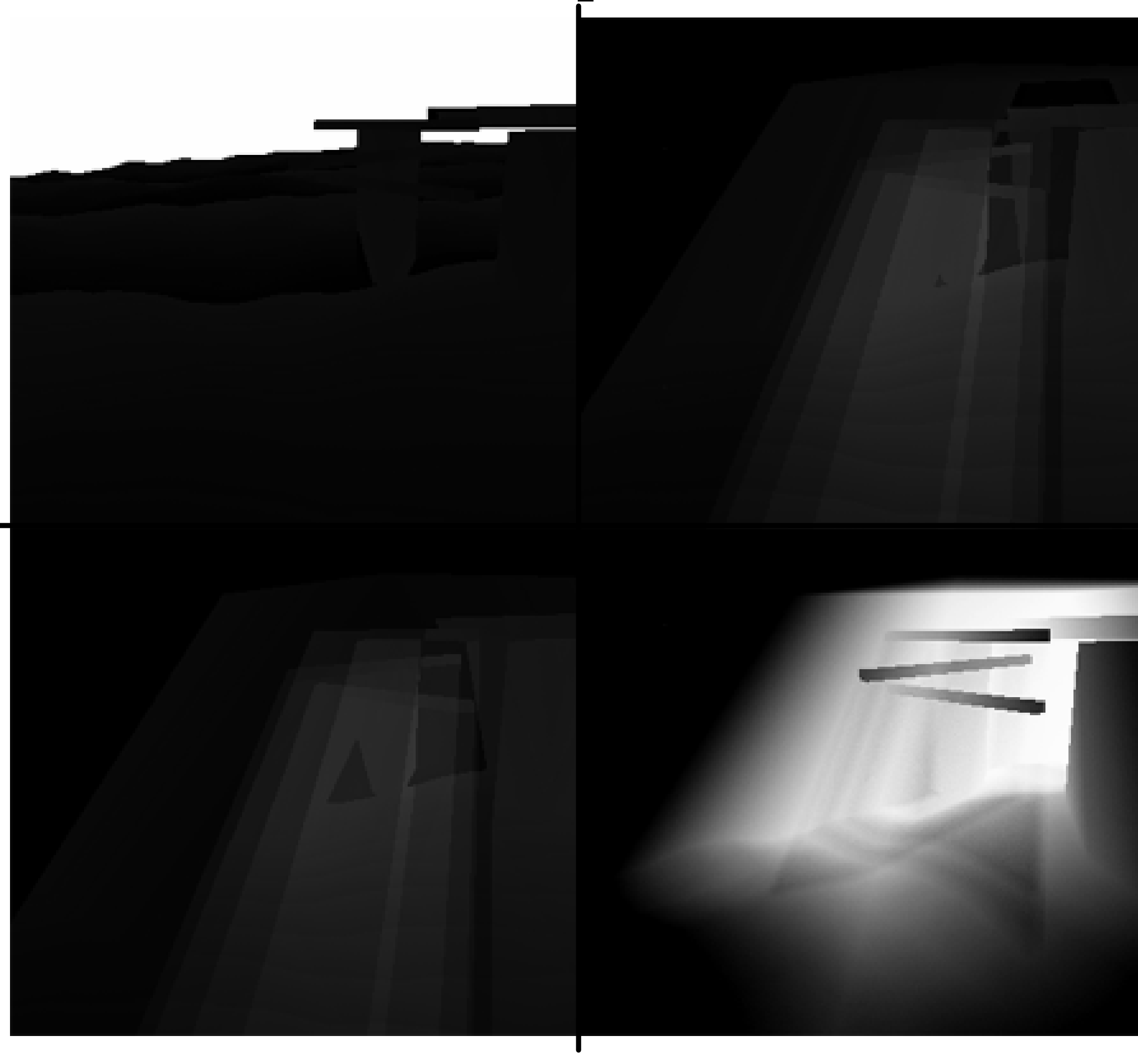
- **Texture coordinates read from small R, G, and B ramp textures**
  - resolution 2^L in the addressed axis
  - point sampled with wrapping
  - color ramp from $[0, 2^L - 1]$
- **Example: L = 4, means 16 values per axis**



RGB-Encoded Depths

Solid Object Depth

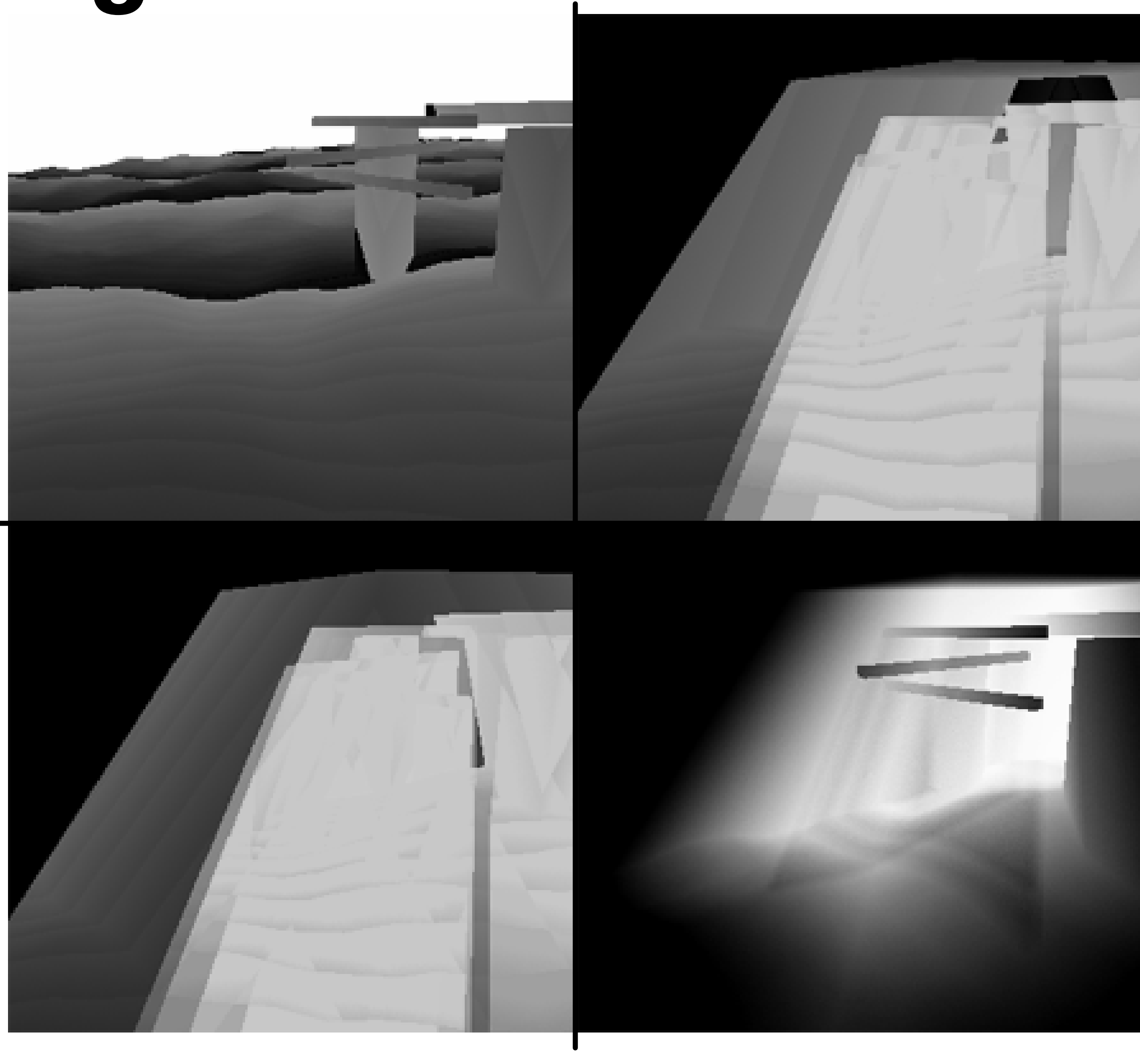
Backfaces Sum



Frontfaces Sum

Rendered Image

Overbright So You Can See Them

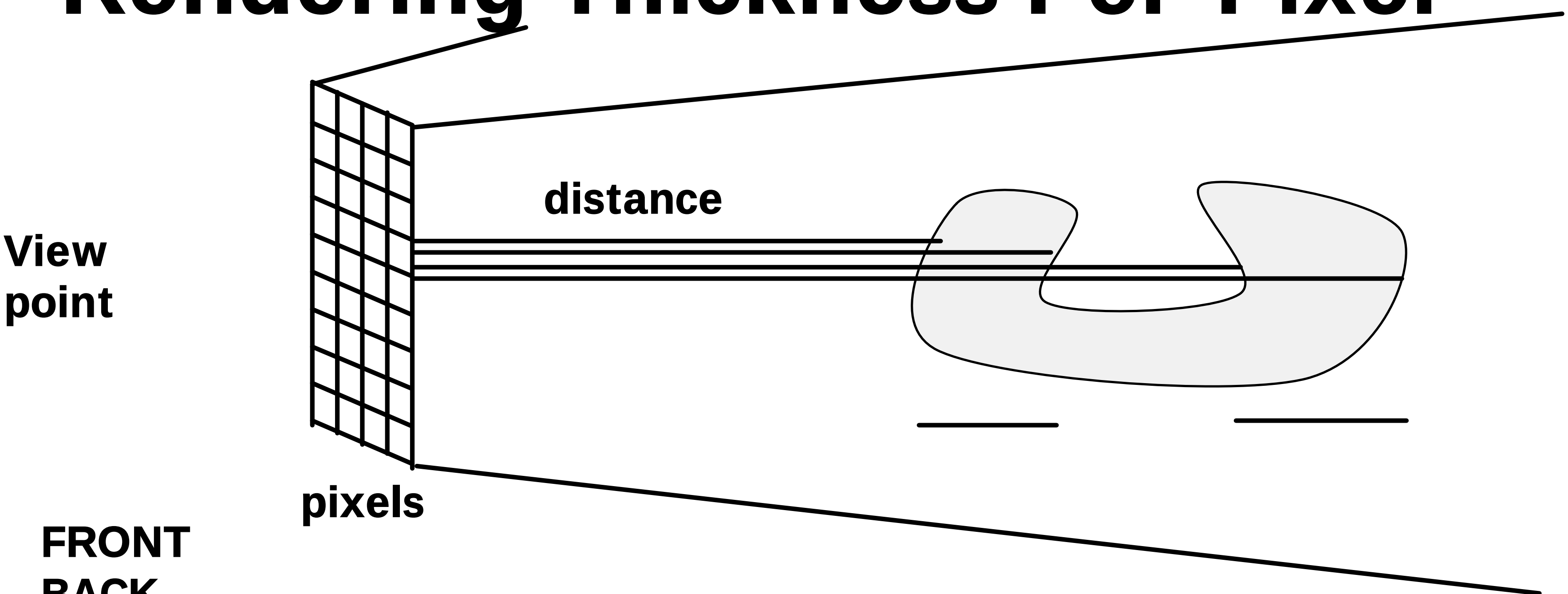


Precision vs. Number of Surfaces

L low bits	Depth Precision	# of adds
3	9-bit	32
4	12-bit	16 ☆
5	15-bit	8

- If visible fog volume depth complexity is higher than the “# of adds” limit:
  - Add a pass to carry the bits
  - Or start rendering to another surface
  - Most likely, this is never needed
- This is using RGB.   Could use RGBA

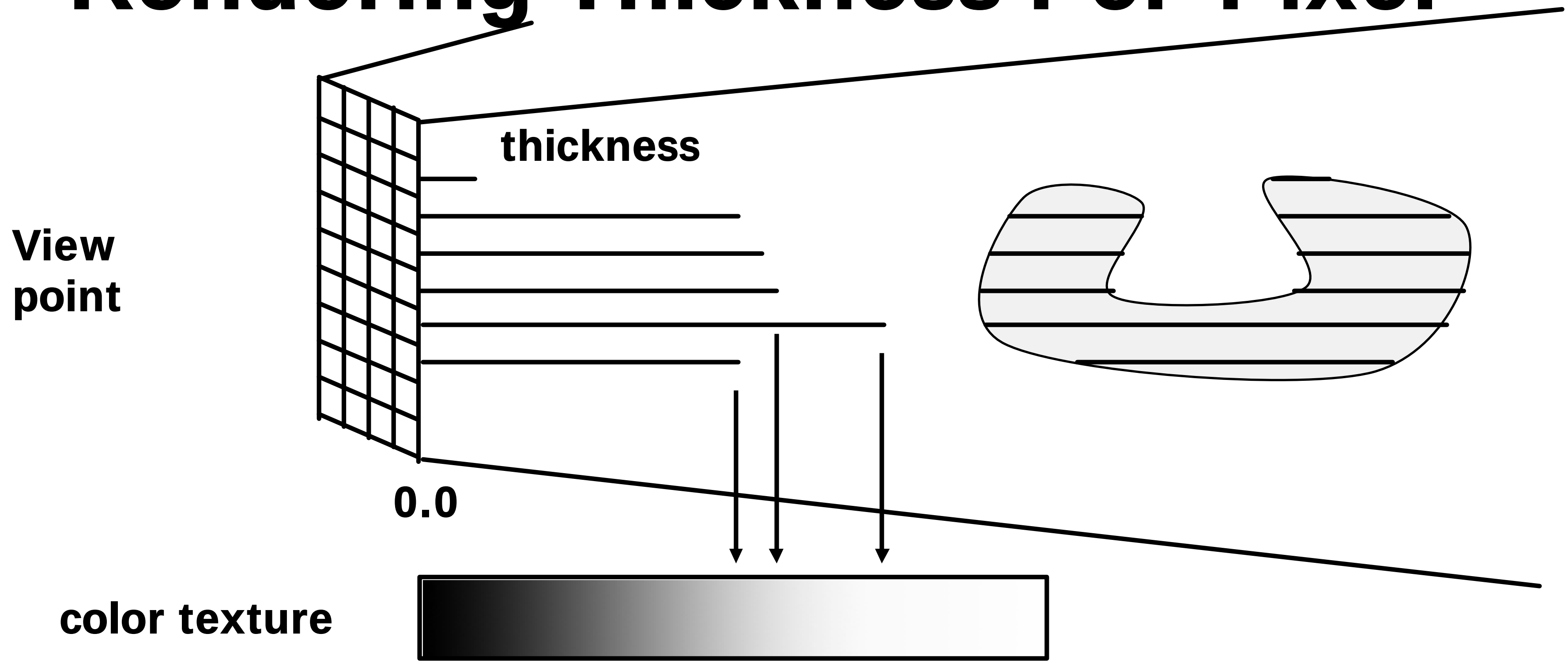
Rendering Thickness Per-Pixel



$$Thickness = \sum Back - \sum Front$$

- Sum the depths of all back faces
- Sum the depths of all front faces
- Difference of the sums is the total thickness

Rendering Thickness Per-Pixel



- Thickness * scale ➔ TexCoord.x
- Artistic or math color ramp
- Very easy to control the look

Decoding RGB-Encoded Values

- Just one dot-product !

  Decoded value =
  (D.r, D.g, D.b) DOT (1.0, 2^{-L}, 2^{-2L})

- Properly handles carried, uncarried, and negative components
- Must be done at floating point precision
  - ps.1.3 texture address ops
  - ps_2_0 shader ops

Handling Solid Objects Intersecting the Fog

- No additional passes required
- Step 2. texture "S" rendered to have nearest solid object depth
- When rendering fog volume depths:
  - No Z-buffer test. Pixels always written
- Pixel shader:
  - Compute RGB-encoded distance, "D" to pixel
  - Read "S" depth at pixel location
  - If "D" is GREATER than "S" then output "S" ELSE output "D"

D3D9 Depth Encode, Compare, and Decision Pixel Shader

```
texld    r0, t0, s0               // red+green part of depth encoding
texld    r1, t1, s1               // blue part of depth encoding
ADD      r0, r0, r1               // RGB-encoded depth of triangle's pixel
texldp   r1, t3, s3               // RGB-encoded depth from texture at s2

// Compare depth of triangle's pixel (r0) to depth from texture (r1)
// and choose the lesser value to output.

ADD      r2, r0, -r1              // RGB-encoded difference

                                  // Decode to positive or negative value
DP3      r2, r2,  CPN_RGB_TEXADDR_WEIGHTS

                                  // always choose the lesser value
CMP      r3, r2.xxxx, r1, r0      // r1 >= 0 ? : r1 : r0
MOV      oC0, r3
```

D3D8 Depth Encode, Compare, and Decision Pixel Shader

- **Numbers must saturate to [-1,1] range**

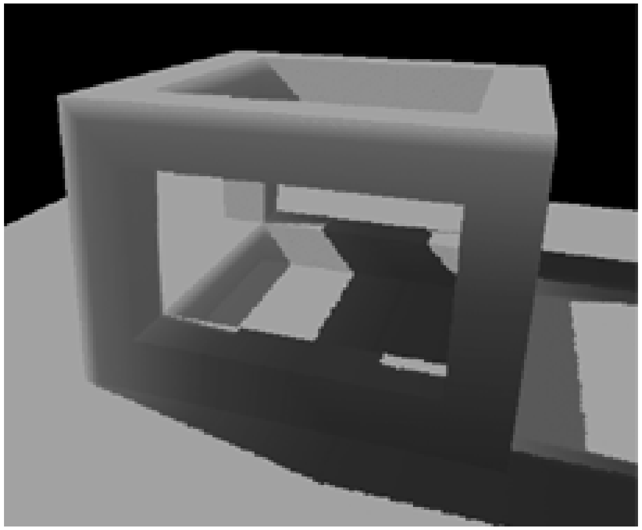
```
ps.1.3
def c7, 1.0, 0.66, 0.31, 0.0
def c6, -0.01, -0.01, -0.01, 0.0

tex t0                      // red+green ramp texture
tex t1                      // blue ramp texture
tex t3                      // depth of solid objs

add    t2,  t0, t1          // Add R + G + B to make depth value
add_x4 r1, -t3, t2          // r1 = diff * 4
add_x4 r1, r1, r1
add_x4 r1, r1, r1           // diff * 256, result is –1, 0, or 1 in each color
dp3_x4 r1, r1, c7           // weight R, G, B to make + or - value
// The sign of r1 reflects whether the value which t2 represents is greater
//  than or less than the value which t3 represents
add r1, r1, c6              // CMP performs >= 0, so subtract a small value from r1
cmp r0, r1, t3, t2          // r1.rgb >= 0 ? t3.rgb : t2.rgb
```

Further Uses : Translucency

- Color ramp based on distance light travels through an object
- Similar to shadow maps



Greg James, NVIDIA

Simon Green, NVIDIA

Further Ideas

- Attenuation from volumes
  - Simulate light scattering or absorption
  - Darken things behind the volumes
- Turbulence texture
  - RGB-encoded turbulence applied in order to add and subtract thickness
  - Enhance simple volume fog geometry
  - Animate the texture
- Animate the volume objects

Additional Materials

- NVIDIA SDK & Cg Effects Browser
- http://Developer.nvidia.com
  - SDK\DEMOS\Direct3D9\Src\cg_Glow
  - SDK\DEMOS\Direct3D8\Src\cg_Glow
  - SDK\DEMOS\Direct3D9\Src\FogPolygonVolumes
  - SDK\TOOLS\bin\release\CgBrowser\CgBrowser.exe
- Books:
  - "Real-Time Rendering" 2nd ed. ISBN 1-56881-182-9
  - "ShaderX" ISBN 1-55622-041-3
  - "Game Programming Gems" and 2 ISBN 1-58450-054-9
  - "The Cg Tutorial" ISBN 0-321-19496-9

Additional Credits

- NVIDIA DevTech & DemoTech!
- Matthias Wloka
  - Neighbor sampling & convolution
- Gary King
  - Parallel development GeForce FX OGL volume fog
- Simon Green
  - Translucency, endless supply of cool articles!
- Microsoft
- Chas Boyd & co.
  - DXSDK examples

Questions?

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