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Filtering Cubemaps

Angular Extent Filtering and Edge Seam Fixup Methods

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Introduction

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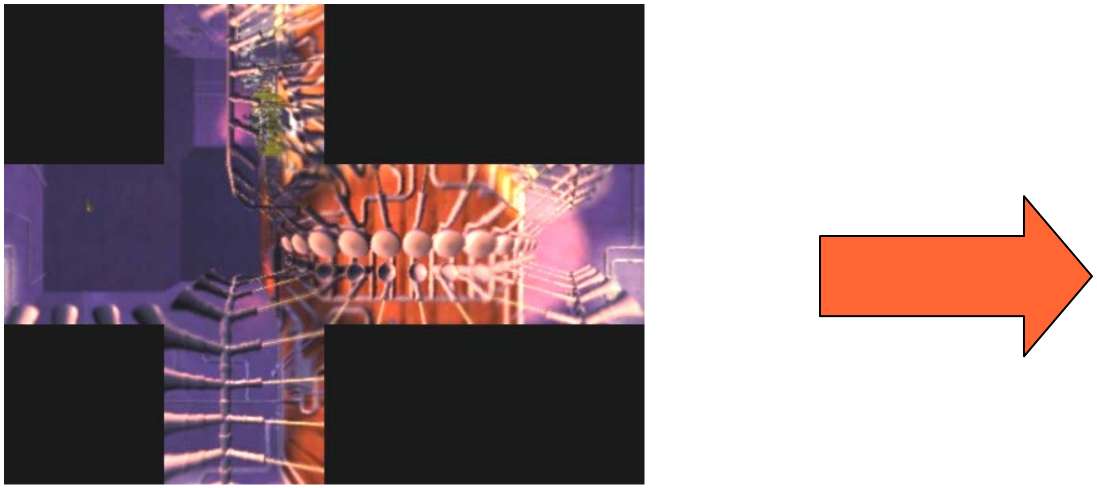

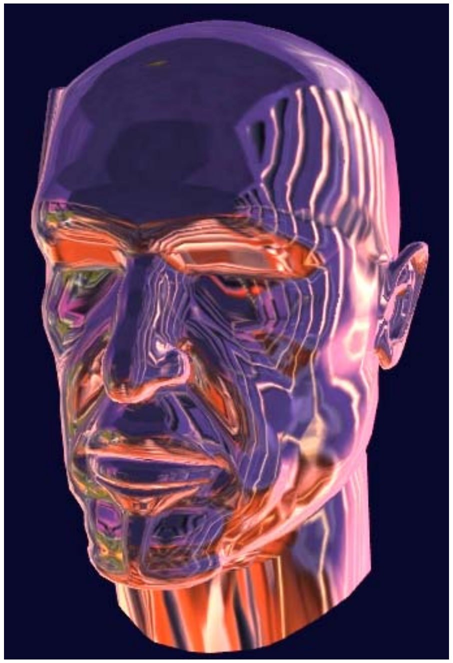

- Hardware cube mapping is ubiquitous.
  – Straightforward hardware implementation, fast!
  – (Unnormalized) direction vector used directly to fetch from texture.
    - Fewer ALU ops than other environment map parameterizations.
  – Single texture fetch for any environment map direction.
  – Solid angle subtended by texels doesn't vary as much as it does in other single fetch parameterizations such as spherical maps, lat-long maps, or angular maps.

Motivation

- However, two main issues remain troublesome for cube map users.
  - Virtually no current graphics hardware provides bi/tri linear filtering across cube faces directly.
    - Visible cubemap face edge seams in many cases. (miplevels)
    - Complaints about this from quite a few people.
    - Expensive to do correctly in hardware. Per-face texture borders are another possibility but are rarely supported.
  - Current approaches treat each cube face as a flat 2D texture for filtering.
    - It would be useful to take into account the varying solid angle of cube map texels across a face.

Overview

- The techniques described in this sketch **Angular Extent Filtering** and **Edge Seam Fixup** attempt to address these issues.
- These methods are used for preprocessing and mipchain generation for existing static cubemaps.

Angular Extent Filtering (AEF)

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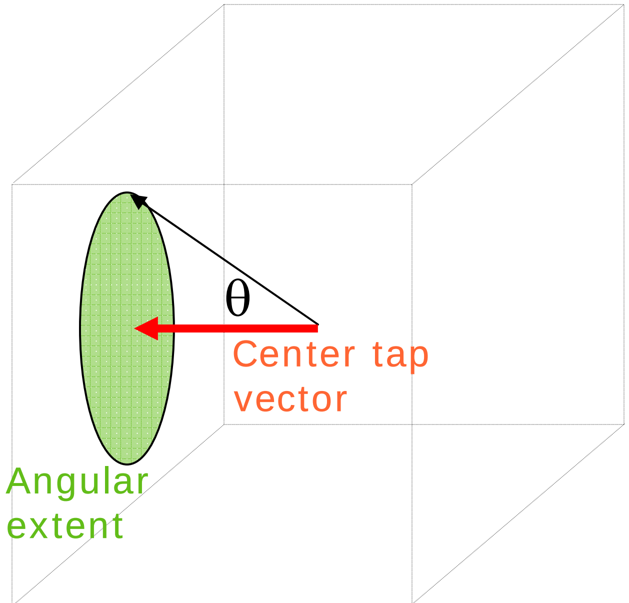
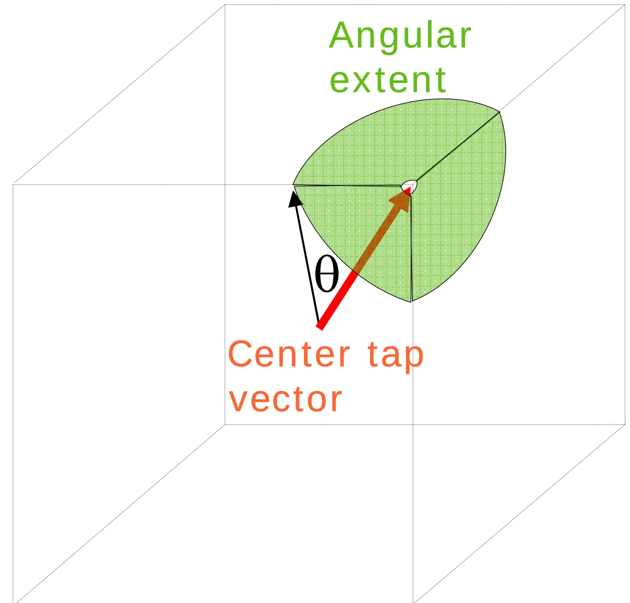


Filtering within Face



Filtering across faces

- Angular extent filtering processes all taps within a given angle of the 3D center tap vector.
  - Filter extent is not texel size dependent, rather filter extent has constant solid angle, (e.g. constant area when projected onto the unit sphere).
    - Filter may (and should) encompass a different number of texels for different center tap vectors.
  - This allows for filtering kernels that span across cube face edges.

Efficient angular extent filtering

- Precompute solid angle and direction vector lookup cubemap.
- For each output texel:
  - Determine bounding box regions for angular extent in each face on input cubemap.
  - Process all texels within each bounding box region.
    - Filter weights: lookup table indexed using dot product between tap vector and center tap vector.
    - Weight each texel using solid angle and weights of chosen filter function.

Advantages

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+ Every texel within angular extent is processed exactly once.
  - Very important for HDR imagery: Single very bright texels can significantly influence the filtered result.
+ Filter is circularly symmetric on the surface of the sphere.
  - Filter shape is independent of direction vector in spherical space.
  - The idea is applicable to other parameterizations as well,
  - The precomputed solid angle and direction vector map is only dependent on the resolution and the parameterization. Can be performed prior to filtering.

Angular Filter Types

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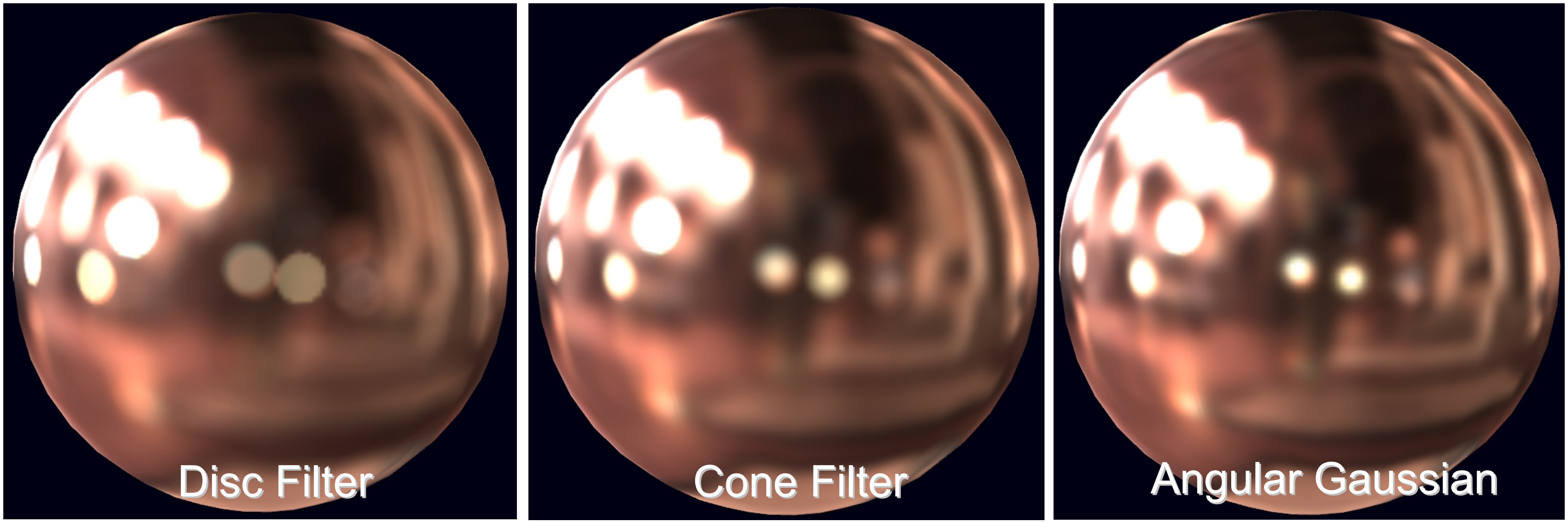

Examples of angular extent filtering:

- Disc Filter: All taps within a specified angle of the center tap weighted equally.
- Cone Filter: Linear falloff based on angle between tap and center tap.
- Angular Gaussian Filter: Gaussian falloff based on angle between tap and center tap.
  - 3 standard deviations within specified extent angle.

Edge Fixup (EF)

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- In addition to angular extent filtering, texels are averaged across edges, and corners after filtering.
  - Obscure seam artifacts from the HW not being able to filter across edges.
- To obscure the effects of the averaging, the averaging amount is blended into texels within a fixup region of the edge.
  - Two techniques to do this Pull Fixup and Smooth Fixup.

Edge Fixup: (Pull Fixup)

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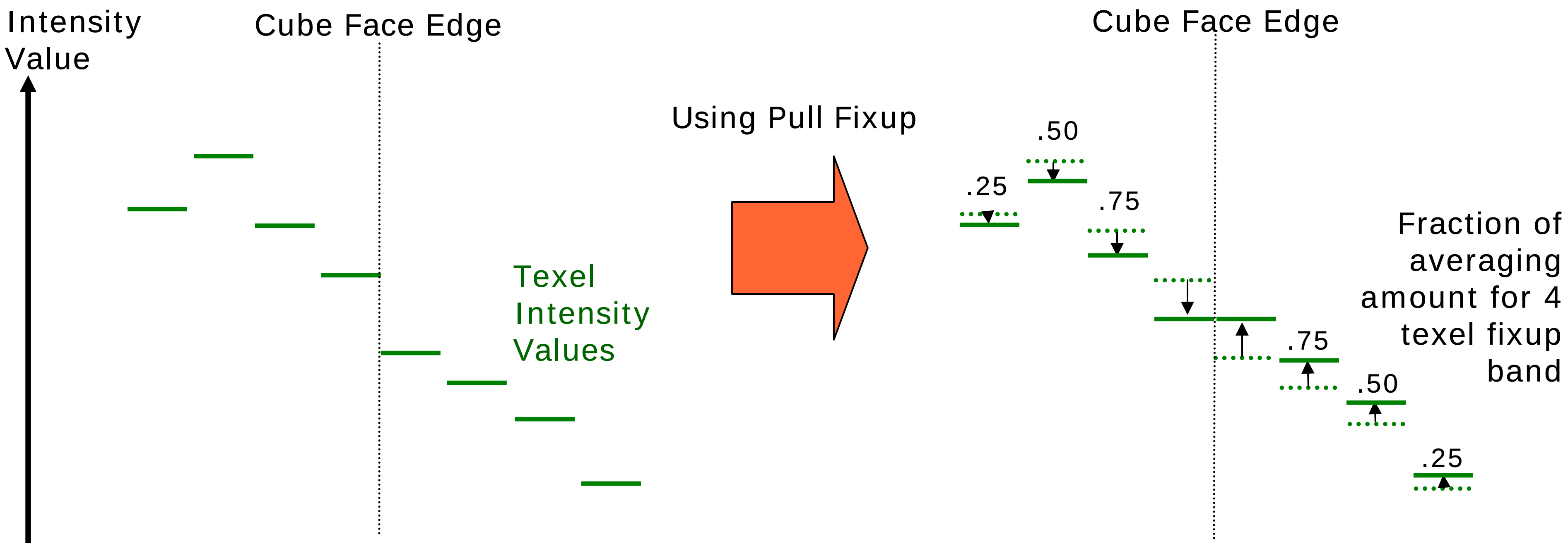

- Pull Approach: looks at the **amount of intensity change** caused by averaging edge values.
- The intensity change is propagated and faded out over the texels within a few texel lengths of the edge.
  - Fade out is either linear or cubic.
- Preserves high frequency detail, while obscuring the hard seam.

Edge Fixup: (Smooth Fixup)

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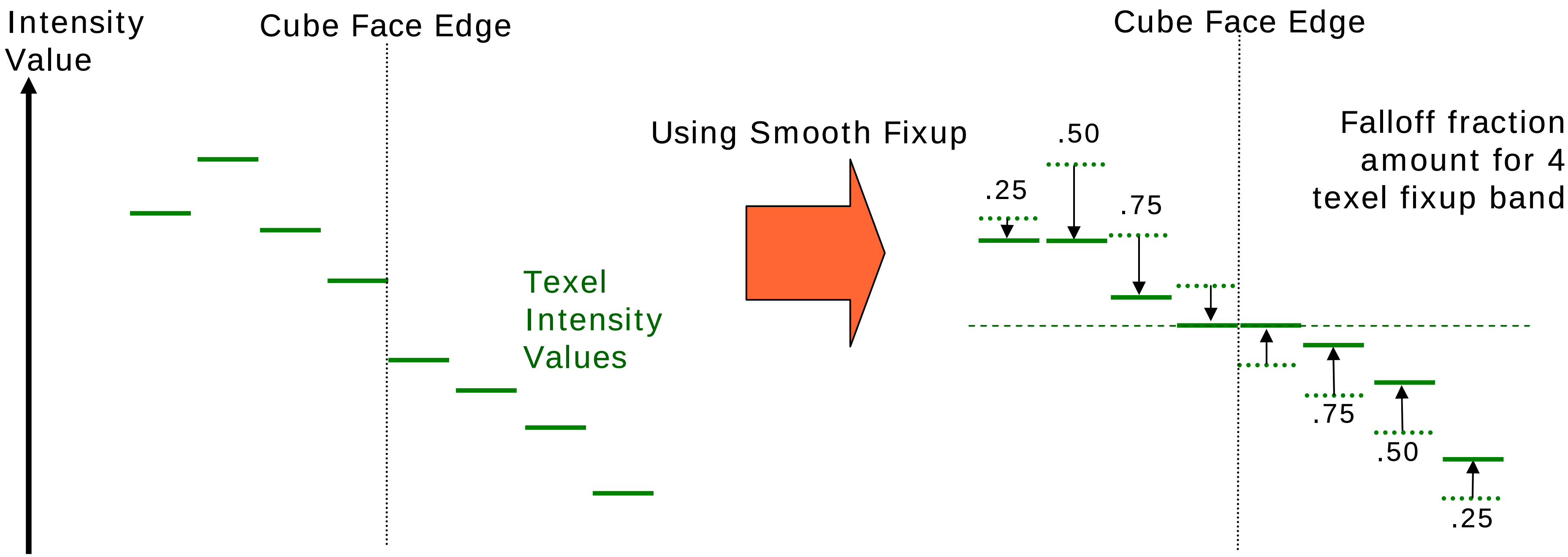

- Smooth Approach: looks at the **intensity value of the edge texel** caused by averaging edge values.
- The intensity value is averaged over the texels within a few texel lengths of the edge.
  - Fade out is either linear or cubic.
- Obscures the seam better, but loses high frequency detail.

Pull/Smooth Fixup Example

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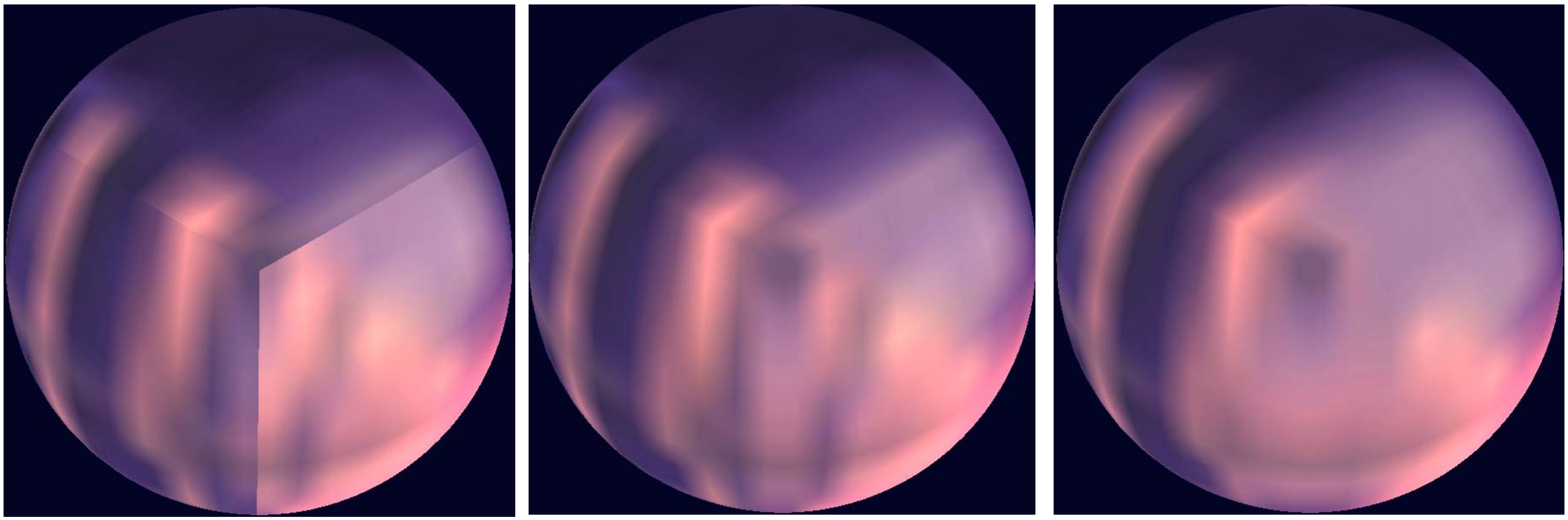
16x16 miplevel, 4 texel fixup band



No Edge Fixup | Pull Fixup | Smooth Fixup

- Pull fixup preserves high frequency detail better.
- Smooth fixup obscures the edge seam better.

Using DXT Block Compression with edge fixup

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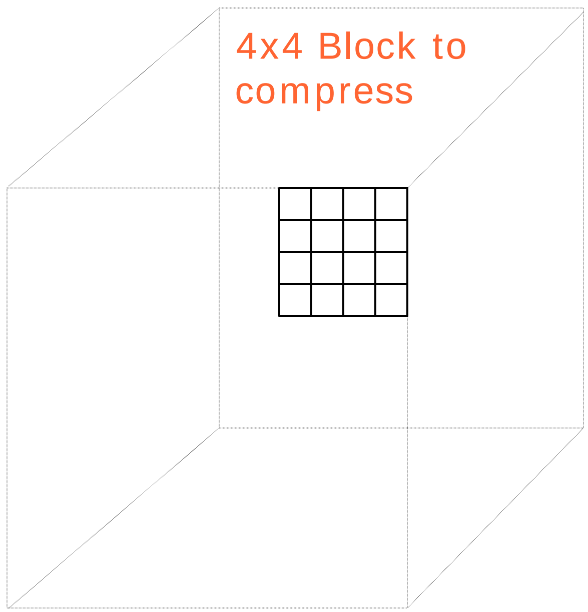

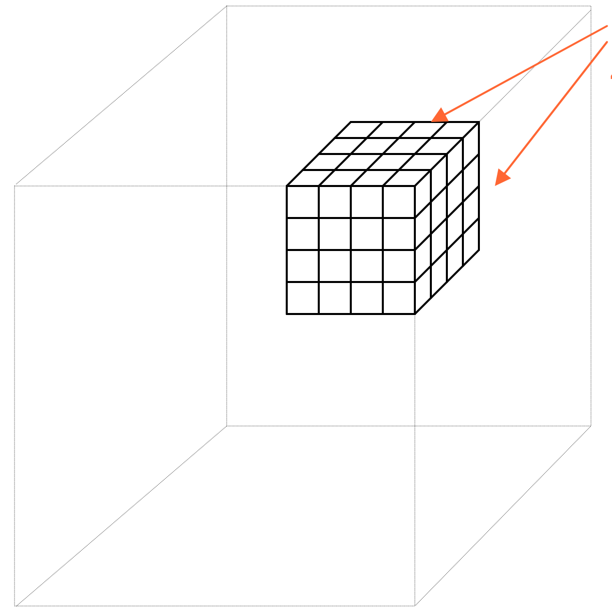

- DXT1 block compression encodes each 4x4 block of texels using two representative ramp colors and 2-bits per texel to linearly interpolate between them.
  - Each 4x4 block is independent of the others.
- To use edge fixup, estimate the ramp colors for a block using not only its own 4x4 neighborhood, but any 4x4 neighborhoods adjacent across a cubemap edge.
  - Since the ramp colors for across edge adjacent blocks are identical, the edge texel colors (post-compression) will be identical as well.

2x2 Miplevel (Standard)

- 2x2 mip-level without edge fixup and across face filtering
  - Strong edge artifacts.. 2x2 miplevel is unusable by itself .

2x2 Miplevel (AEF&EF)

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- AEF & EF allows for the 2x2 mip level to be used as a diffuse environment lighting term.

4x4 Miplevel (Standard)

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- Edge filtering artifacts make the 4x4 miplevel from standard mip filtering algorithms are only useful for mipmapping purposes.

4x4 Miplevel (AEF&EF)

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- AEF & EF makes cubemaps with a 4x4 miplevel that can also be used for rough metal shaders.

Other Miplevels (AEF&EF)

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- Different mip levels can be used to simulate different surface roughness [Ashikmin02]
  - Rougher surface → more blurry reflection
  - Use **MaxMipLevel** texture sampler state to clamp miplevel, not **texCUBEbias(…)**

Per-pixel Roughness Mapping

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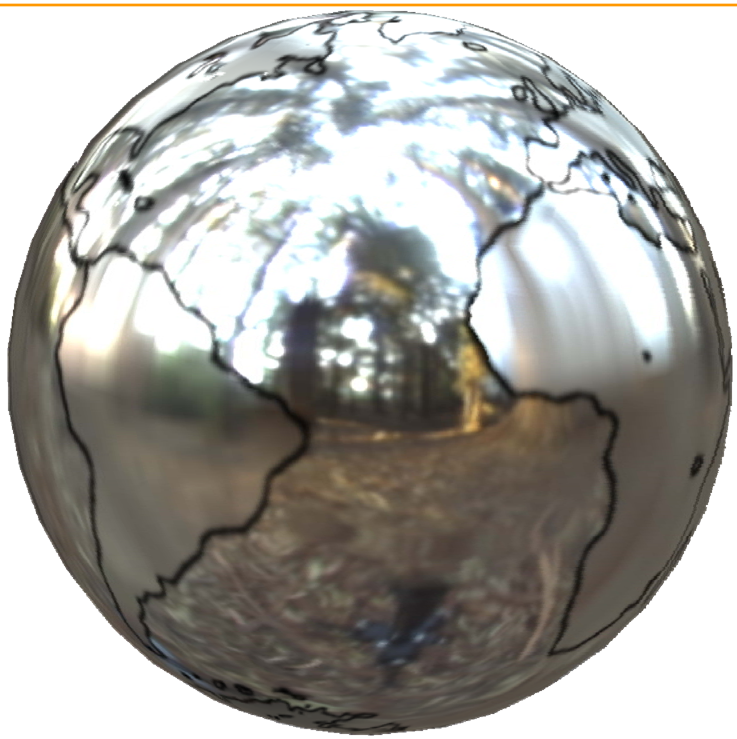

- Per-pixel roughness mapping
  - Pack miplevel index into alpha channel of each cubemap miplevel
  - Use it to determine bias amount for **texCUBEbias(…)** to implement miplevel clamping in shader
  - Or use **texCUBElod(…)** on PS 3.0

Roughness Mapping Shader

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```
float fNumMipLevels;     // number of mip-levels in cubemap
float fBlurScale = 4.0;  // scale factor for blurriness

float4 main(float2 inUV   : TEXCOORD0, float3 inNormal : TEXCOORD1,
            float3 inView : TEXCOORD2) : COLOR0
{
  // Surface roughness stored in alpha of base map
  float4 cBase = tex2D(tBase, inUV);
  float fRoughness = cBase.a;

  float3 R = reflect (normalize(inView), normalize(inNormal));

  // Each cubemap stores miplevel index in alpha (scaled by 16/255).
  // Determine mip-LOD levels from 0 to fNumMipLevels (minification)
  float fMipLevelMinification = (255.0/16.0) * texCUBE(tCube, R).a;

  // Determine mip-LOD levels from -fNumMipLevels to 0 (magnification)
  float fMipLevelMagnification = (255.0/16.0) *
         texCUBEbias(tCube, float4(R, fNumMipLevels-1.0)).a;
[…]
```

- Determine the miplevel for the current texel by fetching the cube map with different mipbias levels and using the miplevel stored in the alpha channel.

Roughness Mapping Shader


```
[…]
  float fMipLevel = 0;

  //choose between magnification and minification range
  if(fMipLevelMinification == 0) { // 0 is the largest (base) miplevel
    // the whole cubemap is being magnified, compute "logical" miplevel
    // (which is negative)
    fMipLevel = fMipLevelMagnification - (fNumMipLevels - 1.0);
  }
  else {
    // the cubemap is being minified
    fMipLevel = fMipLevelMinification;
  }

  // compute final mip bias to clamp miplevel
  float fMipBias = max(fGlossScale * fRoughness - fMipLevel, 0.0);

  float4 cRefl = texCUBEbias(tCube, float4(R, fMipBias));

  return cBase * cRefl;
}
```

- The miplevel can be subsequently used to determine the mipbias amount needed to implement per-pixel mip-level clamping in the pixel shader.

Roughness Mapping

- Could use multiple subsequent mip-clamped fetches into cubemap for piecewise assembly of BRDF response.
  - Miplevel determination only needs to be computed once per-pixel shader invocation.

CubeMapGen Tool

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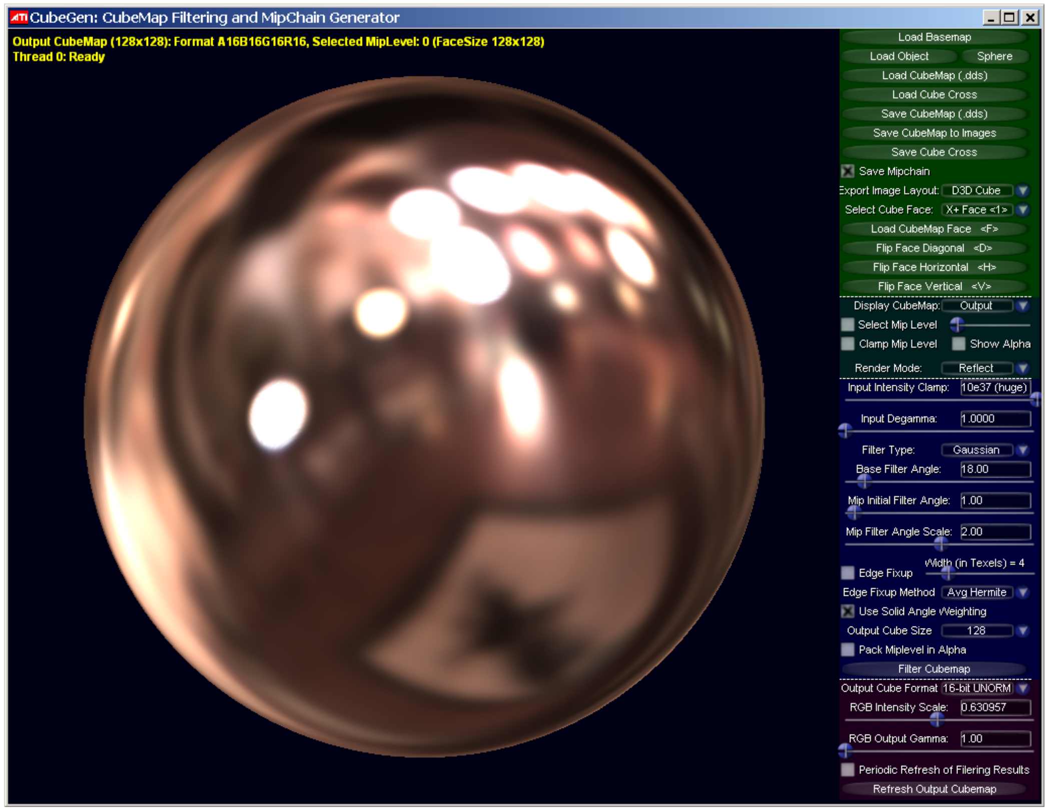

- CubeMapGen is a publicly available tool for cubemap filtering and mip-chain generation that uses angular extent filtering and edge seam fixup.
  - Available on http://www.ati.com/developer

References

- [Ashikhmin02] Ashikhmin, M. and Abhijeet, G. 2002. *Simple Blurry Reflections with Environment Maps*. In Journal of Graphics Tools, 7(4):3-8.
- [Kautz00] J. Kautz, P. P. Vázquez, W. Heidrich, and H.-P. Seidel *A Unified Approach to Prefiltered Environment Maps,* EG Rendering Workshop '00
- [Voorhies94] Voorhies, D. and Foran, J. *Reflection Vector Shading Hardware*. SIGGRAPH 1994, pp 163-166

- Some of the cubemaps used in this presentation can be found at:
  - http://www.debevec.org/Probes/
- Questions?