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Irradiance Volumes for Games

Natalya Tatarchuk

3D Application Research Group
ATI Research, Inc.



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Overview

- Introduction and Motivation
- Review
 - Radiance, Irradiance, Transfer
- Spherical Harmonics
 - Projection, Gradients, Evaluation
- Irradiance Volume
 - Uniform Subdivision, Adaptive Subdivision, Interpolation
- Summary



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Motivation

- Real-time and offline rendering have one important gap: the use of *global illumination* for physically based, realistic lighting
- Games use light mapping
 - Approximates global illumination on the surface
 - Only for static scenes!
 - Does not address dynamic objects that move through the scene
 - Result in beautifully rendered, globally illuminated scenes that contain unrealistic, locally lit dynamic objects
- Solution:
 - *Precomputed Irradiance Volumes* for static scenes
 - *Precomputed Radiance Transfer* for objects within those scenes



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The Irradiance Volumes

- We aim to solve as much of the global illumination calculation during preprocess time
- A 3D light map: volume of diffuse lighting samples
 - ✓ This is what we're trying to achieve



[Greger98]

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Used in *Ruby: Dangerous Curves*



- These techniques were used as a drop in replacement for diffuse lighting in the *Ruby: Dangerous Curves* demo
- At the very least, these techniques could serve as an ambient lighting solution in your games
- Before diving into the details it is necessary to have a basic familiarity with the following terms:
 - *Radiance*, *Irradiance*, and *Transfer*



Demo

Ruby2: Dangerous Curves



Agenda

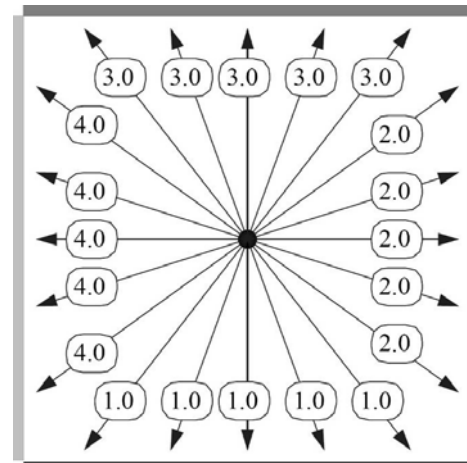
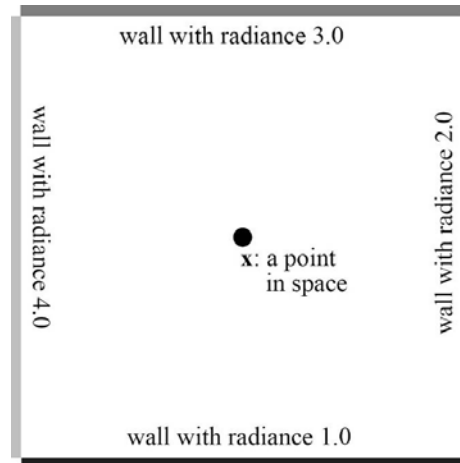
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Radiance



[Greger98]

- *Radiance* is the emitted energy per unit time in a given direction from a unit area of an emitting surface



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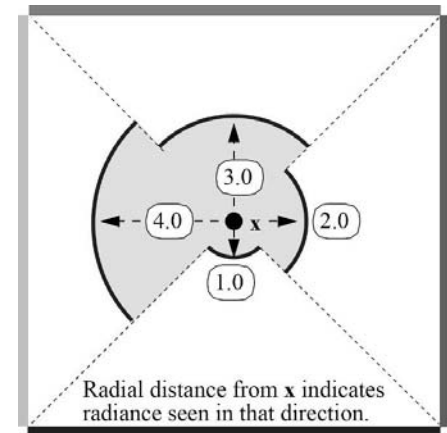
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Capturing Radiance

- Capture radiance at a point for *all directions*
 - Place a camera at that point
 - Render the surrounding scene into a cubemap
 - Scale each texel by its projected solid angle
- The cube map represents the radiance for all directions for this point
 - Known as the **radiance distribution function**
 - Not necessarily continuous (Even in simple environments)
- Every point in space has a radiance distribution function
 - Radiance is a 5D function (3 spacial dimensions and 2 directional dimensions)



[Greger98]



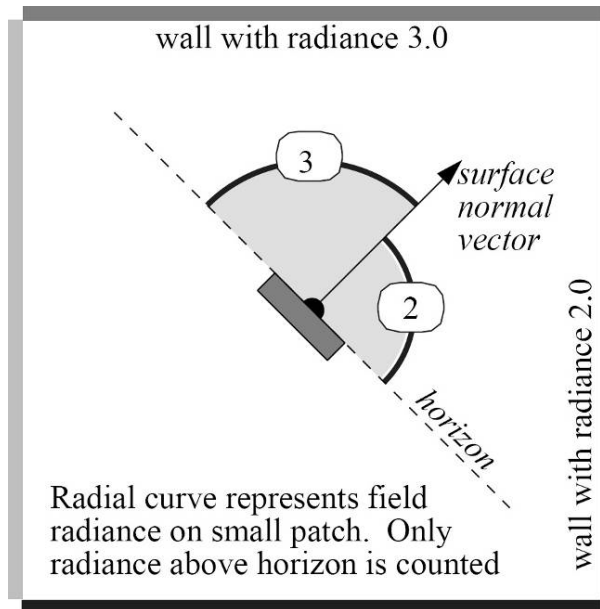
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Radiance



[Greger98]

- The radiance of a surface is a function of its BRDF and incident radiance
- The incident radiance defined on the hemisphere of incoming directions is called the *field-radiance function*

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Irradiance

- The radiance of a purely diffuse surface is defined in terms of the surface's *irradiance*
- Irradiance is an *integral* of the field-radiance function multiplied by the Lambertian cosine term over a hemisphere

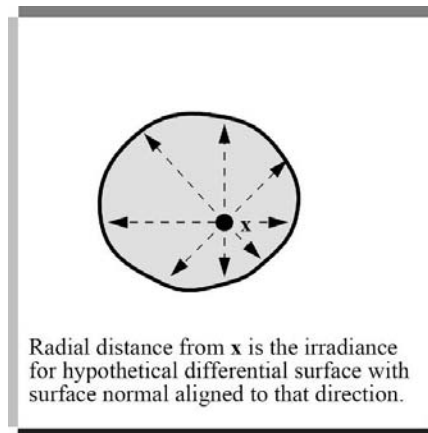
$$I(p, N_p) = \int_{\Omega} L(p, \vec{\omega}_i) (N_p \cdot \vec{\omega}_i) d\omega_i$$

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Irradiance



[Greger98]

- We could compute irradiance at a point for *all* possible orientations of a small patch:
 - For each orientation, compute a convolution of the field radiance with a cosine kernel
- The result of this convolution for all orientations would be an irradiance distribution function
- The irradiance distribution function looks like a radiance distribution function except much blurrier because of the averaging process (convolution with cosine kernel)
- The irradiance distribution function is continuous over directions



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Irradiance

- The irradiance distribution function can be computed for every point in space: irradiance is a 5D function (3 spatial dimensions and 2 directional dimensions)
- Evaluating the irradiance distribution function in the direction of a surface normal gives us irradiance at that surface location
- Computing irradiance distribution functions on demand is possible but can be costly. An obvious optimization is to precompute irradiance distribution functions for a scene at preprocess time and then use this precomputed data at runtime

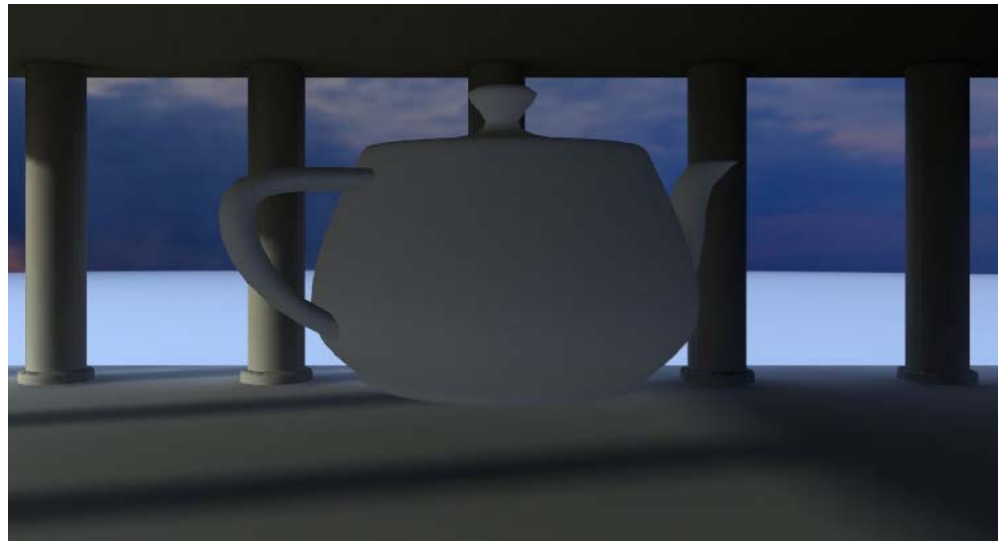
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Rendering with Irradiance

- The Irradiance Distribution Function at a point can be stored using a “Diffuse Cube Map”
- The cube map is indexed with an object’s surface normal



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Efficient Storage of Irradiance

- We need an irradiance distribution function for objects moving in the scene
- Capture the lighting environment at many points in the scene
 - At preprocess time
 - Then we'll have a volume of irradiance distribution functions
- But! We're still left with the cost of storing tons of cubemaps
 - For all the points in the scene
 - And the bandwidth overhead of indexing these maps at render time
- Instead! Compress irradiance maps
 - Represent each as a vector of spherical harmonic coefficients
 - Reduces both storage and bandwidth costs

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Spherical Harmonics

- Infinite series of spherical functions
- Can be used as basis functions
 - Stores a frequency space approximation of an environment map
- Use Microsoft DirectX SDK for spherical harmonics computations
 - Includes functions for projecting a cubemap into a representative set of spherical harmonic coefficients
 - Also functions for scaling and rotating spherical harmonics – important if your object is moving
- For code snippets that will help you write your own spherical harmonic helper functions, see Robin Green's *Spherical Harmonic Lighting: The Gritty Details*



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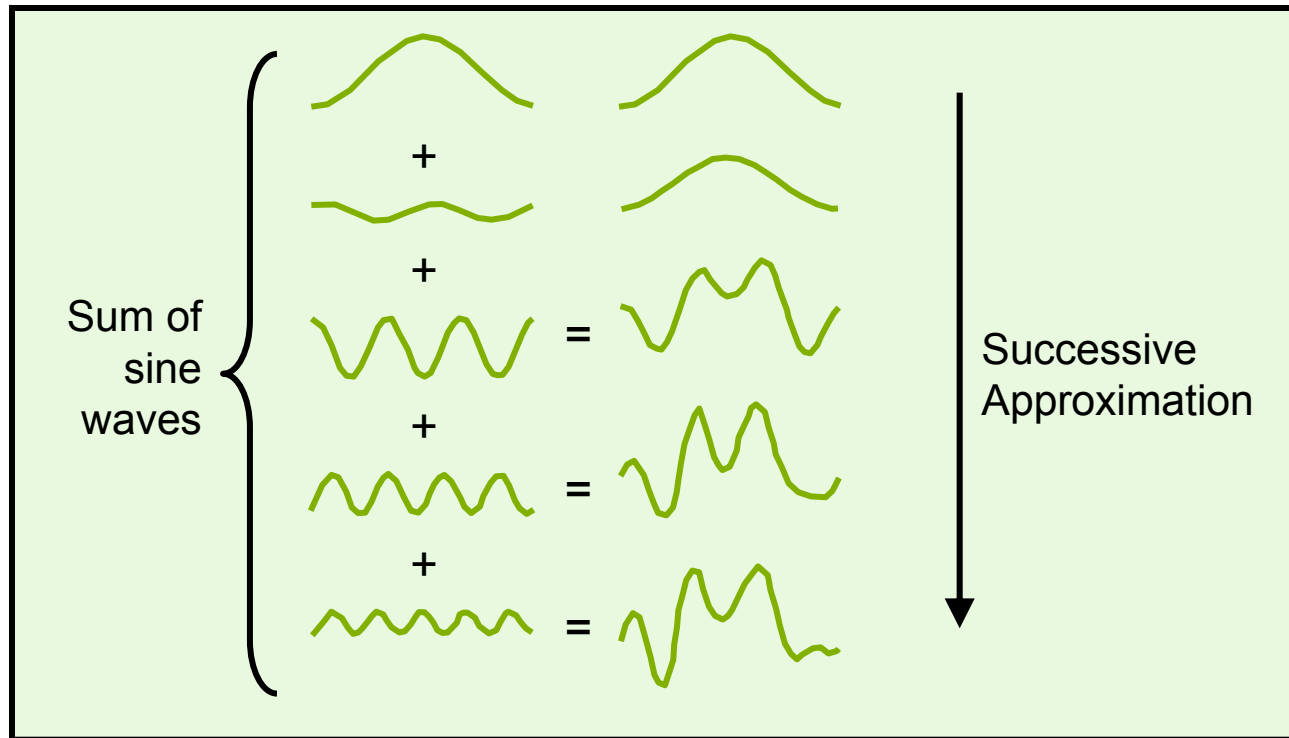
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Fourier Theory



- Recall that it is possible to represent any 1D signal as a sum of appropriately scaled and shifted sine waves
- Spherical harmonics are the same idea on a sphere!



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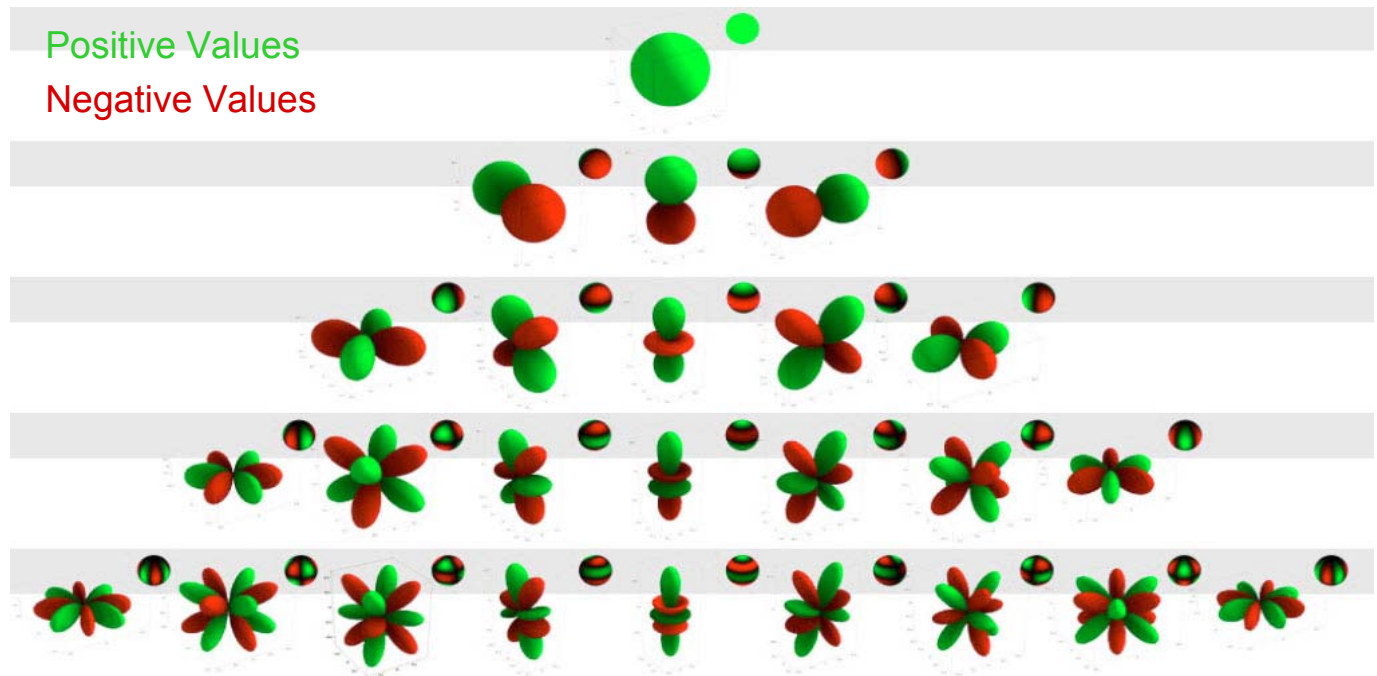
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Spherical Harmonic Basis

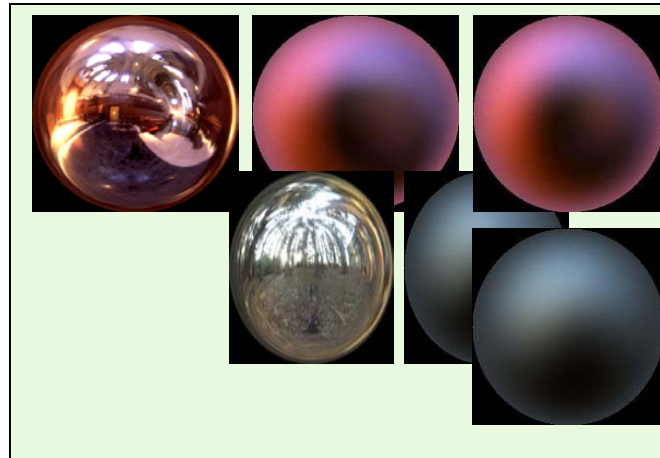


From [Green]

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Spherical Projection: Storage and Computation



[Ramamoorthi]

Original Environment Map Filtered Environment Map SH Representation

- Projecting an environment map into 3rd order spherical harmonics effectively gives you the irradiance distribution function [Ramamoorthi]
- Projection into 3rd order SH is not only a storage win but a preprocessing win too since SH projection is much faster than convolving an environment map with a cosine kernel for all possible normal orientations

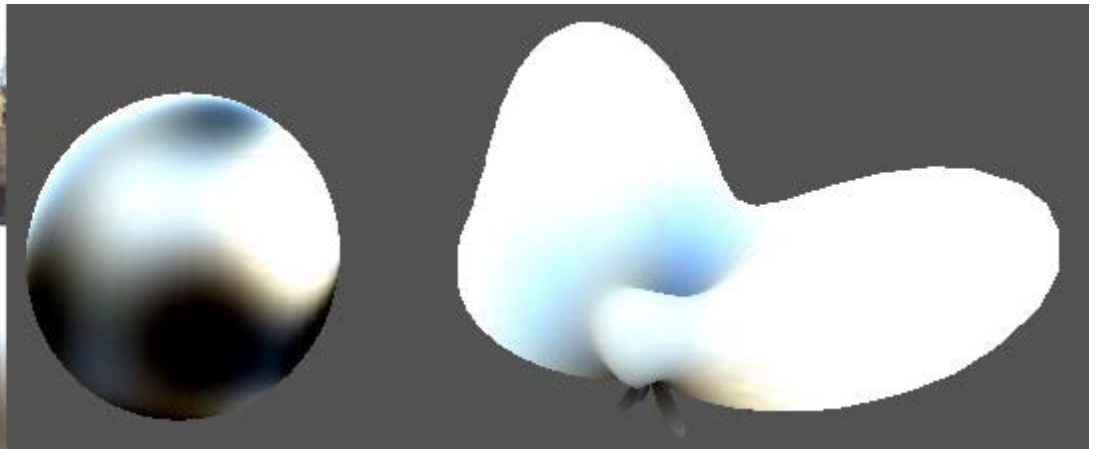
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Spherical Harmonics

- Once an environment map has been projected into spherical harmonics, the coefficients can be used to evaluate the original map in a given direction
- Storing these coefficients VS constants allows us to compute irradiance per-vertex rather than having to sample a cubemap per-pixel



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SH Evaluation With Normal

```
float4 cAr; // first 4 red irradiance coefficients  
float4 cAg; // first 4 green irradiance coefficients  
float4 cAb; // first 4 blue irradiance coefficients  
float4 cBr; // second 4 red irradiance coefficients  
float4 cBg; // second 4 green irradiance coefficients  
float4 cBb; // second 4 blue irradiance coefficients  
float4 cC; // last 1 irradiance coefficient for red, blue and green
```

```
float3 x1, x2, x3;
```

```
// Linear + constant polynomial terms
```

```
x1.r = dot(cAr, vNormal);  
x1.g = dot(cAg, vNormal);  
x1.b = dot(cAb, vNormal);
```

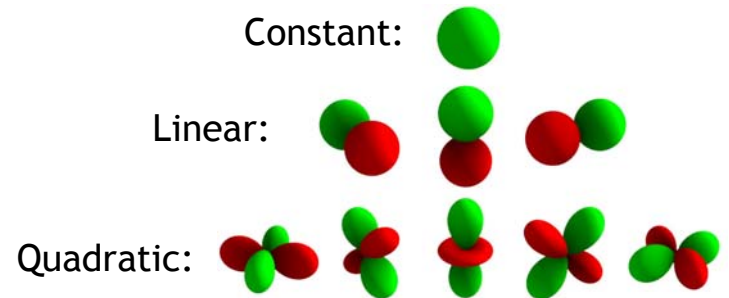
```
// 4 of the quadratic polynomials
```

```
float4 vB = vNormal.x*yz * vNormal.yz*x;  
x2.r = dot(cBr, vB);  
x2.g = dot(cBg, vB);  
x2.b = dot(cBb, vB);
```

```
// Final quadratic polynomial
```

```
float vC = vNormal.x*vNormal.x - vNormal.y*vNormal.y;  
x3 = cC.rgb * vC;
```

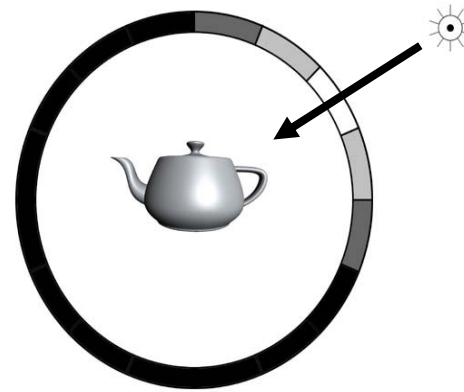
```
Output.Diffuse.rgb = x1 + x2 + x3;
```



[Shader Code From DirectX SDK]



One Irradiance Sample: A Point in Space

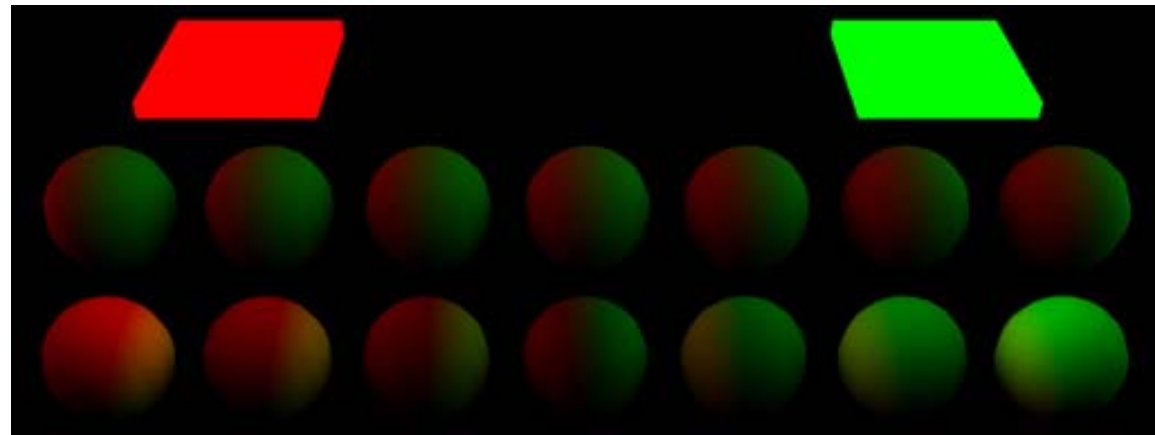


- Irradiance samples only store irradiance for a single point in space
- This really only works well if the lighting environment is infinitely distant (just like a cubic environment map)
- This error can be very noticeable when the lighting environment isn't truly distant



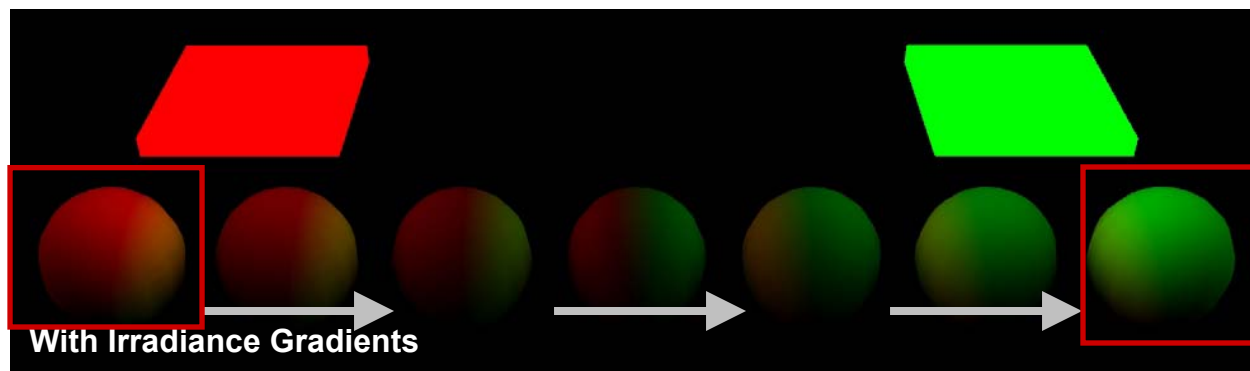
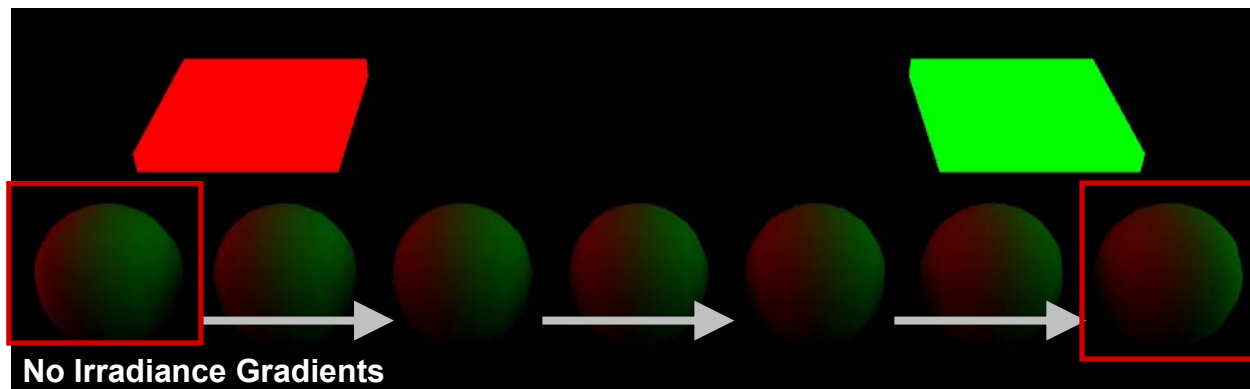
Spherical Harmonic Irradiance Gradients

- If an irradiance sample is used to shade the surface of an object, the potential error increases the further we move away from the point at which the irradiance sample was generated
- Irradiance gradients allow us to store the rate at which irradiance changes with respect to translations about the sample





Irradiance Gradients



If irradiance varies greatly near a sample point, can store irradiance gradients along with each irradiance sample. [Ward 92][Annen04]

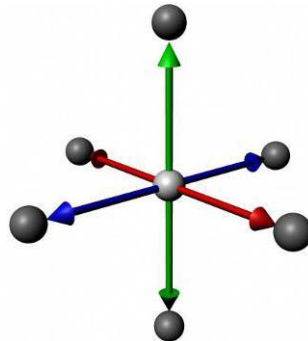
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Spherical Harmonic Irradiance Gradients

- Translational gradients for spherical harmonic irradiance samples may be computed in a number of ways [Annen]...
- One simple way to find the gradients is to use central differencing to estimate the partial derivatives of the spherical harmonic irradiance coefficients
- Project 6 additional irradiance functions into spherical harmonics and perform central differencing on each of the coefficients



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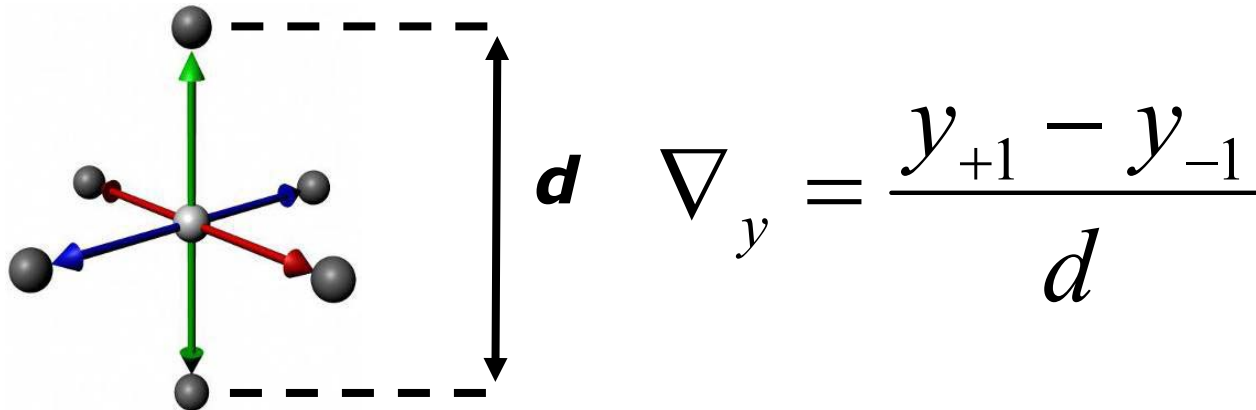
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Central Differencing



- Subtract the coefficients for samples taken at a small offset in the +Y and -Y directions
- Divide by distance between the samples
- This gives you an estimate of the partial derivative with respect to y for each coefficient
- Do this for the other two axes as well...
- You now have a 3D gradient vector for each spherical harmonic coefficient



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First-Order Taylor Expansion

- At render time, the gradient may be used to extrapolate a new irradiance function
- Compute world space vector from the location at which the sample was generated to the point being rendered
- This vector is then dotted with the gradient vector and added to the original sample to extrapolate a new irradiance function

$$I'_i = I_i + (\nabla I_i \cdot d)$$

- l'_i is the i th spherical harmonic coefficient of the extrapolated irradiance function, l_i is the i th spherical harmonic coefficient of the stored irradiance sample, ∇I_i is the irradiance gradient for the i th irradiance coefficient and d is a non-unit vector from the original sample location to the point being rendered

$$\nabla I_i$$

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```
// Compute vector from original irradiance sample position to the position that is being
// shaded
float3 vSampleOffset = (vPos - vIrradianceSamplePosWS);

// Arrays for the extrapolated 4th order (16 coefficients per color channel) spherical
// harmonic irradiance
float4 vIrradNewRed[4]; float4 vIrradNewGreen[4]; float4 vIrradNewBlue[4];

// Extrapolate new irradiance for 4th order spherical harmonic irradiance sample
for ( int index = 0; index < 4; index++ )
{
    vIrradNewRed[index] = float4( dot(vSampleOffset, vIrradianceGradientRedOS[index*4 + 0]),
                                  dot(vSampleOffset, vIrradianceGradientRedOS[index*4 + 1]),
                                  dot(vSampleOffset, vIrradianceGradientRedOS[index*4 + 2]),
                                  dot(vSampleOffset, vIrradianceGradientRedOS[index*4 + 3])
                                );

    vIrradNewGreen[index] = float4( dot(vSampleOffset, vIrradianceGradientGreenOS[index*4 +
    0]),
                                    dot(vSampleOffset, vIrradianceGradientGreenOS[index*4 +
    1]),
                                    dot(vSampleOffset, vIrradianceGradientGreenOS[index*4 +
    2]),
                                    dot(vSampleOffset, vIrradianceGradientGreenOS[index*4 +
    3]) );

    vIrradNewBlue[index] = float4( dot(vSampleOffset, vIrradianceGradientBlueOS[index*4 +
    0]),
                                    dot(vSampleOffset, vIrradianceGradientBlueOS[index*4 +
    1]),
                                    dot(vSampleOffset, vIrradianceGradientBlueOS[index*4 +
    2]),
                                    dot(vSampleOffset, vIrradianceGradientBlueOS[index*4 +
    3]) );

    vIrradNewRed[index] = vIrradNewRed[index] + vIrradianceSampleRed[index];
    vIrradNewGreen[index] = vIrradNewGreen[index] + vIrradianceSampleGreen[index];
    vIrradNewBlue[index] = vIrradNewBlue[index] + vIrradianceSampleBlue[index];
}
}
```



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What About Self Occlusion or Bounced Lighting?

- Gradients improve the usefulness of each sample but we still haven't solved all our problems...
- One limitation of irradiance mapping is that it doesn't account for an object's self occlusion or for bounced lighting from the object itself
- This additional light transport complexity can be accounted for by generating pre-computed radiance transfer (PRT) functions for points on the object's surface



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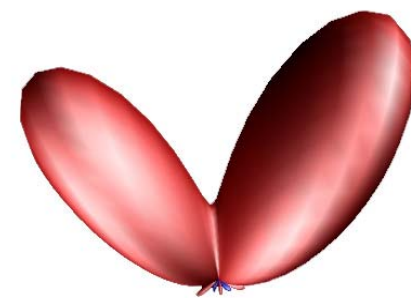
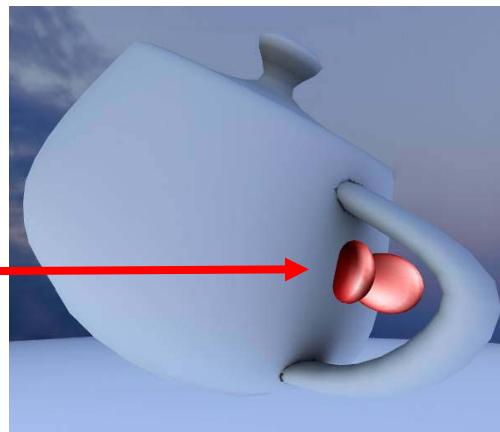
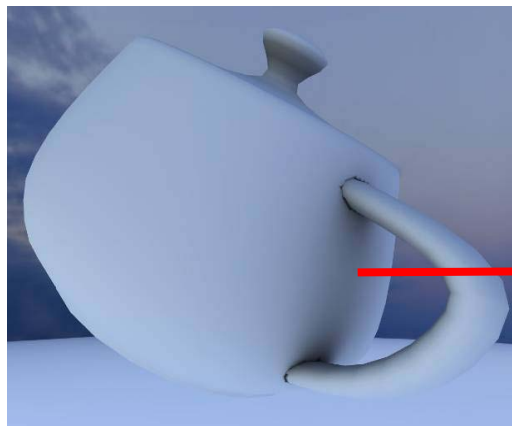
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Precomputed Radiance Transfer

- Radiance Transfer maps incident radiance to reflected radiance
- PRT require incident *radiance*, we're dealing with *irradiance*?!
 - If you project an environment map into 3rd order SH and evaluate with a surface normal then the SH data represents irradiance
 - If you project an environment map into SH and integrate the product of the environment and transfer functions then the SH data represents low-frequency incident radiance (where “low-frequency” is relative to the order of the SH projection)
 - As long as we're assuming low-frequency, the data is the same... the difference is semantic
- If stored as SH, the integral of (Incident Radiance * Transfer) reduces to a dot product of two vectors (the vectors contain SH coefficients for incident radiance and transfer)



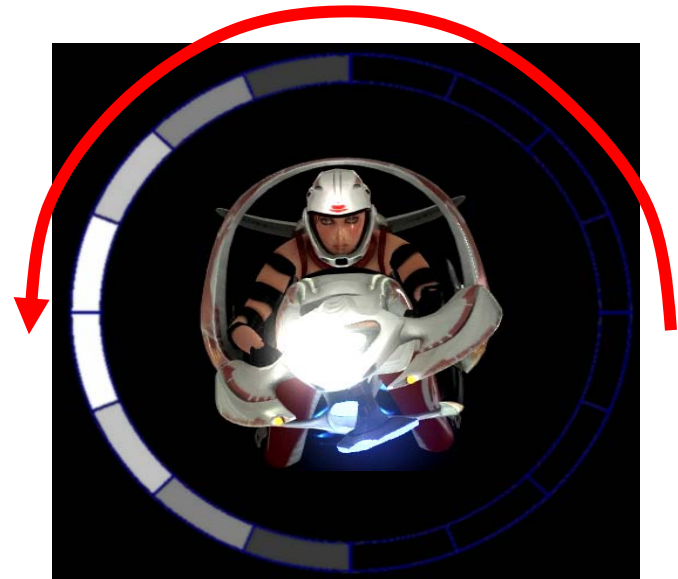
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Handling Rotation

- If using samples for irradiance distribution, the surface normal used for finding irradiance should be transformed into world space (skinned) before evaluating the SH function
- If using the samples for PRT, the transfer function can not be easily rotated on the GPU so instead rotate the lighting environment by the inverse model transform on the CPU



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Irradiance Volume: Background

- Irradiance volumes have been used by the film industry as an acceleration technique for high quality, photorealistic offline rendering
- The volumes store irradiance distribution functions for points in space by utilizing a spatial partitioning structure that serves as a cache
- Sampling the volume allows the for the global illumination of a point in space to be quickly calculated
- Spherical harmonics allow irradiance volumes to be efficiently stored and evaluated
- These volumes are compatible with precomputed radiance transfer and allow for fast, efficient and realistic rendering in real time applications such as games

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The Irradiance Volume



From [Greger]

- A grid of irradiance samples is taken throughout the scene
- At render time, the volume is queried and near-by irradiance samples are interpolated to estimate the global illumination at a point in the scene



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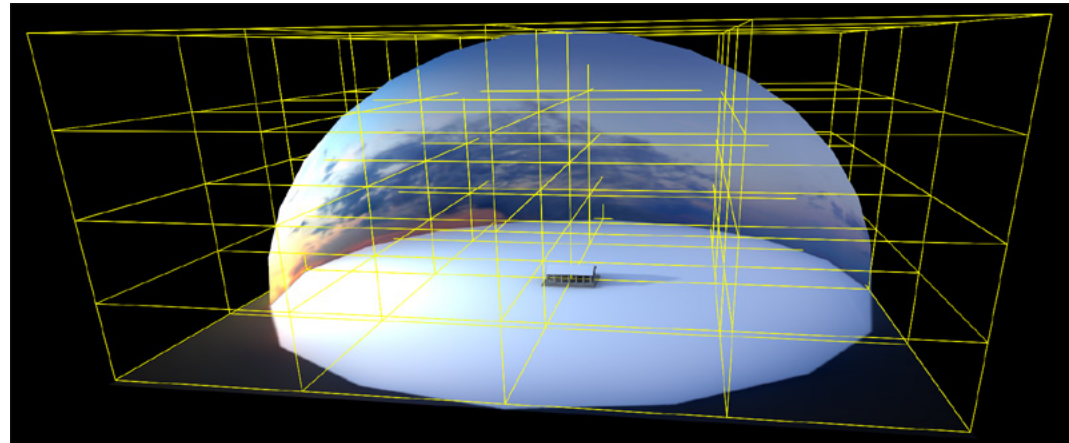
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Uniform Volume Subdivision



- Subdividing a scene into evenly spaced voxels is one way to generate and store irradiance samples
- Irradiance samples should be computed for each of the eight corners of all the voxels
- A uniform grid is easy to implement but quickly becomes unwieldy for large, complex scenes that require many levels of subdivision



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Adaptive Volume Subdivision



- Choosing an adaptive subdivision scheme such as an octree will allow you to only subdivide the volume where subdivision is beneficial
 - For a given scene, some areas will have slowly changing irradiance and can be subdivided coarsely
 - Areas with quickly changing irradiance will need to be subdivided more finely



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Demo

*Irradiance Volumes with
Irradiance Gradients
Computed Using Adaptive
Subdivision*



Adaptive Octree Subdivision

- Knowing which areas of your scene need further subdivision is a challenging problem
- For example, a character standing just inside a house will appear shadowed on a sunny day but if the character moves over the threshold of the door and into the sunlight they should appear much brighter; irradiance can change very quickly
- We need a way to find areas of rapidly changing irradiance so that these areas can be more finely subdivided

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Adaptive Subdivision

- Since irradiance sampling is done as a preprocess, one option is to use a brute force method that starts by super-sampling irradiance using a highly subdivided uniform grid
- After this super-sampled volume is found, redundant voxels may be discarded by comparing irradiance samples at child nodes using some error tolerance to determine if a voxel was unnecessarily subdivided
- This brute force method isn't perfect though because it assumes you know the maximum level of subdivision or super-sampling that is needed for a given scene
- Instead, certain heuristics may be used to detect voxels that might benefit from further subdivision



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Subdivision Heuristics

- Measuring irradiance gradients and flagging voxels where the irradiance is known to change quickly with respect to translation (large gradient) is one way to test if further subdivision is necessary
- Testing gradients isn't perfect though, because this will only subdivide areas where you know that irradiance changes rapidly. There may still be areas that have small gradients but contain sub-regions with quickly changing irradiance
- Subdivide any voxels that **contain scene geometry** [Greger98]
- Find the **harmonic mean** of scene depth at a sample point to determine when subdivision is needed [Pharr04]
- The idea is that areas that contain a lot of geometry will have more rapidly changing irradiance
 - Not a bad assumption, the more geometry surrounding a sample point the more opportunities for shadows, bounced lighting, etc...
 - In the center of a room, lighting doesn't change much. As one approaches the walls things get interesting.



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Harmonic Mean of Scene Depth

- Shoot a bunch of rays out from the irradiance sample's position
- Compute the harmonic mean of distance traveled by all rays before intersection

$$HM = \frac{N}{\sum_i \frac{1}{d_i}}$$

- N is the total number of rays fired, and d_i is the distance that the i th ray traveled before intersecting scene geometry
- The harmonic mean is then used as an upper-bound for the sample's usefulness. If the neighboring irradiance samples are further away than this upper-bound, then their associated voxels should be subdivided
- The harmonic mean is chosen over the arithmetic mean (or linear average) because large depth values—due to infinite depth if no geometry exists in a given direction—would quickly bias the arithmetic mean to a large value



Using the GPU: Harmonic Mean of Scene Depth

- For each sample location, render the scene into each face of a floating point cubemap
- The scene should be drawn with a shader that outputs: $1/\text{depth}$
- Read the cubemap back into system memory and find the harmonic mean

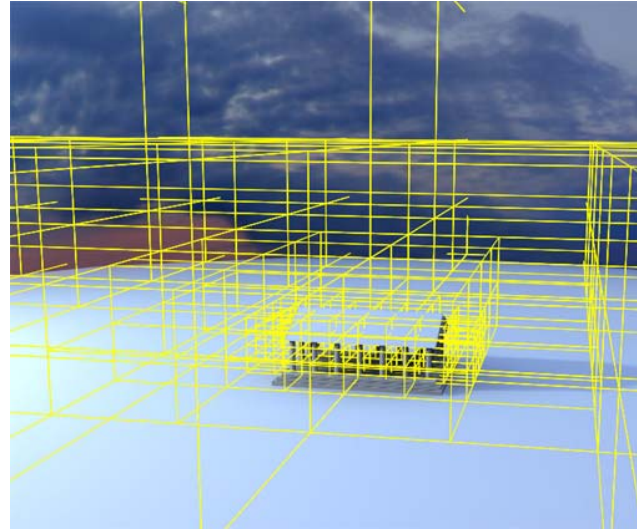


Using the GPU: Voxel Contains Scene Geometry

- If you're already reading back scene depth for the harmonic mean test, you can also use this data to determine if any scene geometry exists inside the voxel
 - Scene depth is sampled at the voxel corners, so only some of the cubemap texels should be used to test for scene intersection
- Alternatively, you could use occlusion queries:
 - Place the camera at the center of a voxel
 - Render into each face of a cubemap
 - First draw quads for each face of the voxel
 - Second draw the scene
 - If any of the scene's draw calls pass the occlusion query, a part of the scene is inside the voxel



Adaptive Subdivision



- Specify a **Min** and **Max** level of subdivision
- Allow thresholds to be specified for each subdivision heuristic
- After you've fully sampled the volume, go back and reject any redundant samples: if a voxel has been subdivided and it's children don't differ enough from the parent, these samples may be culled



Sampling the Volume

- If you're using an octree, search the tree for the voxel that contains the object's centroid
- Use the surrounding samples to determine irradiance
 - Interpolate surrounding samples (trilinear)
 - Find a weighted sum of surrounding samples (weighted by $1/\text{distance}$)

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Trilinear Interpolation



- Seven LERPs of the spherical harmonic coefficients
- Works well for uniformly subdivided volumes
- Adaptively subdivided volumes require slightly more care



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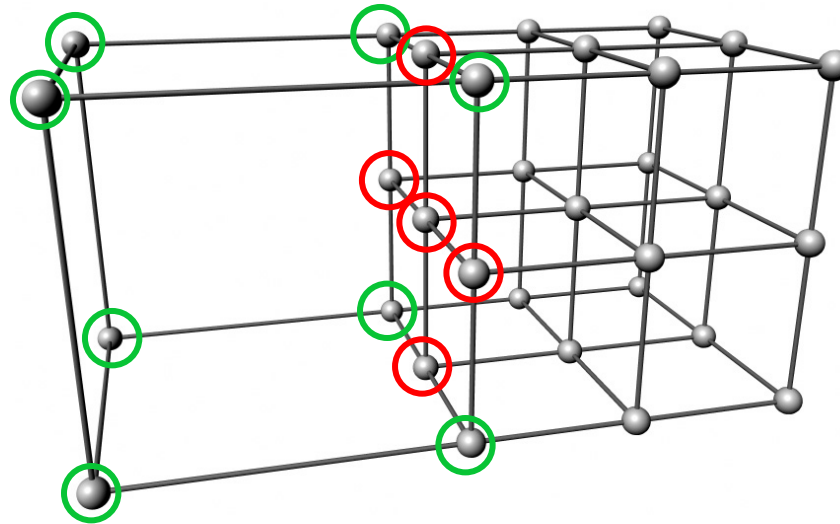
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Trilinear Interpolation



- When transitioning between voxels that have been adaptively subdivided, naïve trilinear interpolation can produce popping artifacts
- As an object moves from finely subdivided voxels to coarsely subdivided voxels, some of the sample data will suddenly be ignored



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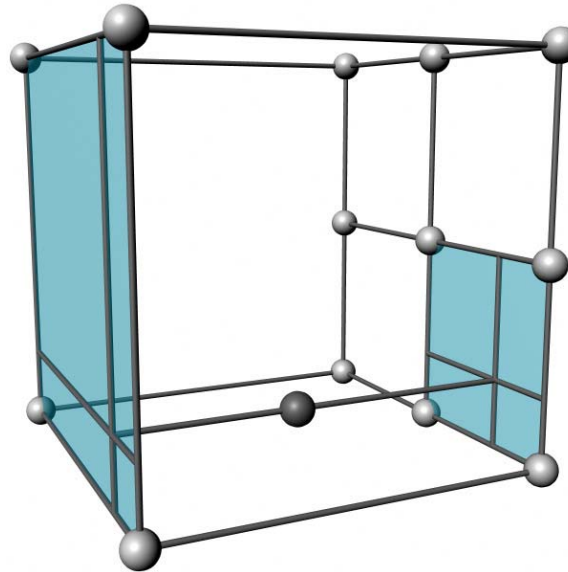
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Trilinear Interpolation



- To prevent popping, continue using samples from subdivided neighbors for interpolation
- Each octree node should store pointers to samples that lie on each face



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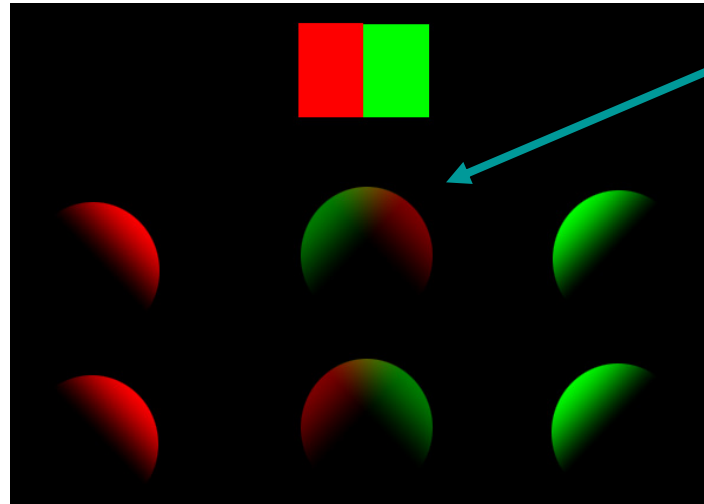
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Using Gradients for Interpolation



Linear interpolation between left and right samples

Gradients used for first-order Taylor expansion before interpolation

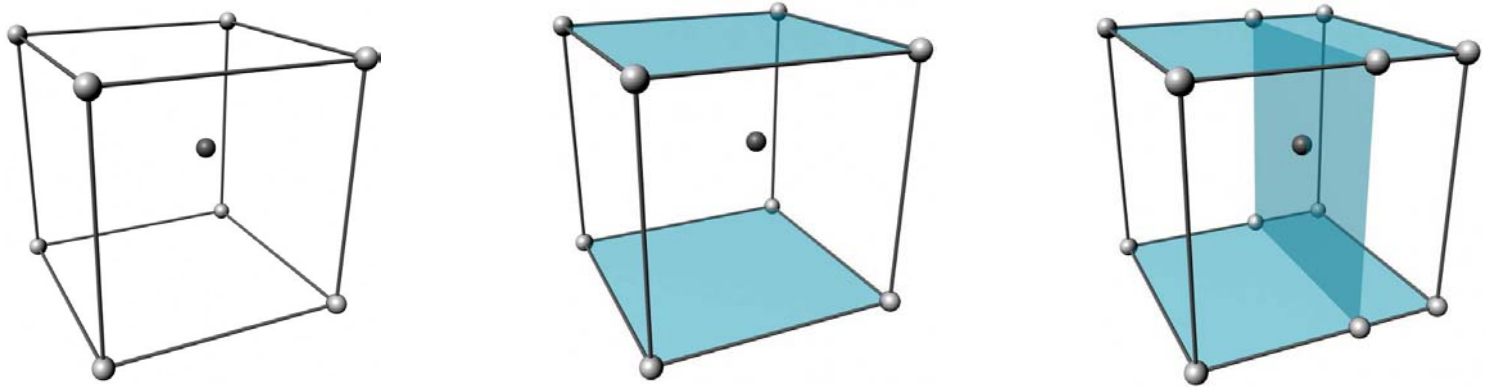
- Before using a sample for interpolation, evaluate the first-order Taylor expansion, then interpolate as usual.

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Tricubic Interpolation



Use samples and gradients to construct cubic patches for interpolation. Hermite patches are well suited for this since they only require four control points and four tangents (gradients).



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GPU Memory Requirements (Constant Store)

6th order SH approximation for R, G and B: 108 floats

6th order SH gradients for R, G, and B: 324 floats

432 floats / sample

3rd order SH approximation for R, G, and B: 27 floats

3rd order SH gradients for R, G, and B: 81 floats

108 floats / sample

Modern GPUs can typically store 1024 to 2048 floats in VS constant store

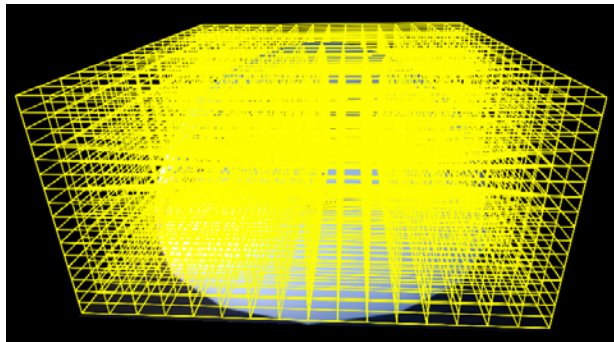


GPU Memory Requirements (Constant Store)

- If you have enough constant store available, you can send all nearby samples and their gradients to the vertex shader and do the interpolation per-vertex
- If this is too costly for you, interpolate on the CPU and send a single interpolated sample and interpolated gradient to the vertex shader
 - We did this for *Ruby: Dangerous Curves* and were very pleased with the results



System Memory Requirements

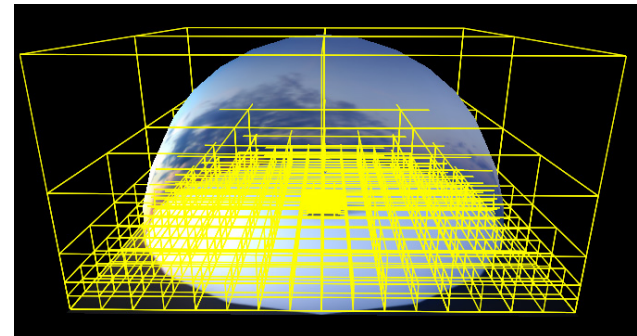


Uniform Subdivision Scene:

4913 Unique Samples

3rd Order SH + Gradients: ~2MB

6th Order SH + Gradients: ~8.2MB



Adaptive Subdivision Scene:

2301 Unique Samples

3rd Order SH + Gradients: ~970kB

6th Order SH + Gradients: ~3.8MB



Pros:

- Fast, efficient global illumination: A 3D light map for characters
- Much smaller memory cost compared to diffuse cubemaps
- Scalable: use higher/lower order SH approximations depending on needs
- Compatible with lower-end hardware

Cons:

- Doesn't handle dynamic lighting well
- Articulated characters are tricky
 - Works fine if evaluating irradiance samples with a vertex normal but PRT can be problematic
 - Instead of using Spherical Harmonic basis functions...
 - Valve uses a Cartesian basis in HalfLife2 (Ambient cube): http://www2.ati.com/developer/gdc/D3DTutorial10_Half-Life2_Shading.pdf
 - Zonal Harmonics are more GPU rotation friendly. See Microsoft's GDC 2004 talk on LDPRT



Conclusion

- A lighting technique for dynamic characters in static scenes
- Compact storage of diffuse lighting functions using Spherical Harmonics for many points in a scene
- First order derivatives are used for Taylor series expansion of the incident lighting functions to increase the accuracy of each sample
- Adaptive scheme using an octree for efficiently subdividing a scene
- Interpolation between samples



Irradiance Samples Along a Path



- We used a technique, similar to the one presented today, for diffuse lighting in *Ruby: Dangerous Curves*
- We cheated a little though, rather than storing an entire volume, we only stored samples along each character's animation spline
- Rather than parameterize the samples by position, we parameterized by time

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References

- [Greger98] *The Irradiance Volume*, Greger, G., Shirley, P., Hubbard, P., and Greenberg, D., *IEEE Computer Graphics & Applications*, 18(2):32-43, 1998.
- [Cohen93] *Radiosity and Realistic Image Synthesis*, Cohen M., Wallace, Academic Press Professional, Cambridge, 1993.
- [Arvo95] *Analytic Methods for Simulated Light Transport*, Arvo, J., PhD thesis, Yale University, December 1995.
- [Brennan02] “*Diffuse Cube Mapping*”, Brennan, C., *Direct3D ShaderX: Vertex and Pixel Shader Tips and Tricks*, Wolfgang Engel, ed., Wordware Publishing, 2002, pp. 287-289.
- [Debevec98] *Rendering Synthetic Objects into Real Scenes: Bridging Traditional and Image-Based Graphics with Global Illumination and High Dynamic Range Photography*, Debevec, P.E., SIGGRAPH 1998.
- [Ramamoorthi01] *An Efficient Representation for Irradiance Environment Maps*, Ramamoorthi, R., and Hanrahan, P., SIGGRAPH 2001, 497-500.
- [Green03] *Spherical Harmonic Lighting: The Gritty Details*, Green, R., <http://www.research.scea.com/gdc2003/spherical-harmonic-lighting.html> 2003.
- [Annen04] *Spherical Harmonic Gradients for Mid-Range Illumination*, Tomas Annen, T., Kautz, J., Durand, F., and Seidel, H.-P., Proceedings of Eurographics Symposium on Rendering, June 2004
- [Sloan02] *Precomputed Radiance Transfer for Real-Time Rendering in Dynamic, Low-Frequency Lighting Environments*, Sloan, P.-P., Kautz, J., Snyder, J., SIGGRAPH 2002.
- [Pharr04] *Physically Based Rendering*, Pharr, M., Humphreys, G., Morgan Kaufmann, San Francisco, 2004.
- See also Richard Huddy’s truly awesome material elsewhere, even if it is on other subjects like cats, chickens and performance malarkey...



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Thank you

- >Chris Oat for ideas and implementation
- >Jan Kautz and Peter-Pike Sloan for providing their input on spherical harmonic gradients
- >Paul Debevec for the light probes (from www.debevec.org)