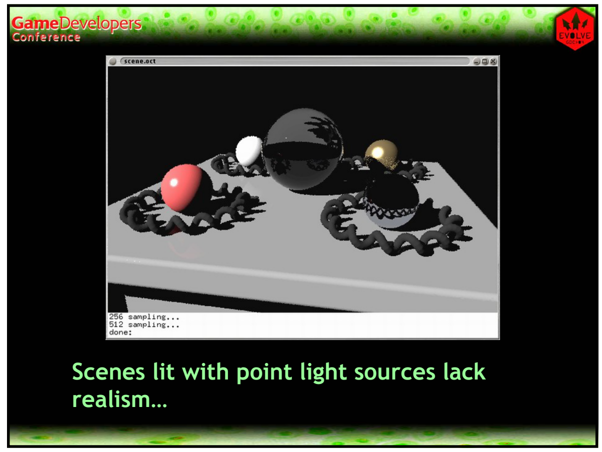
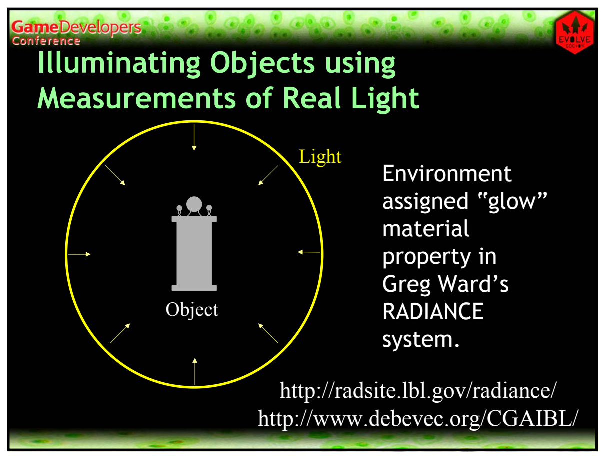
<< RETURN

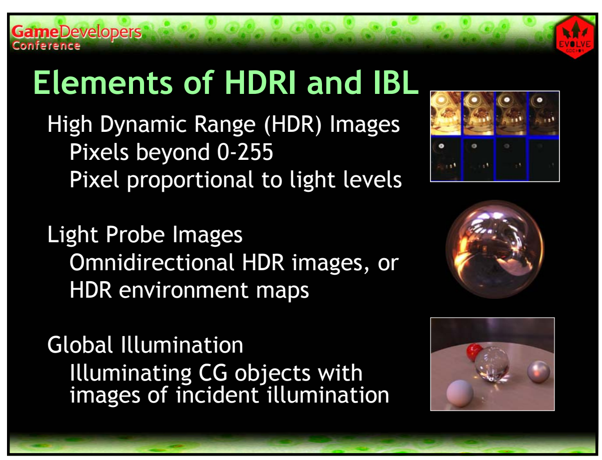

GameDevelopers Conference
EVOLVE
High Dynamic Range Lighting
Paul Debevec
University of Southern California
Institute for Creative Technologies
March 24, 2004
5:30 - 6:30 pm
www.debevec.org/IBL2004/
USC

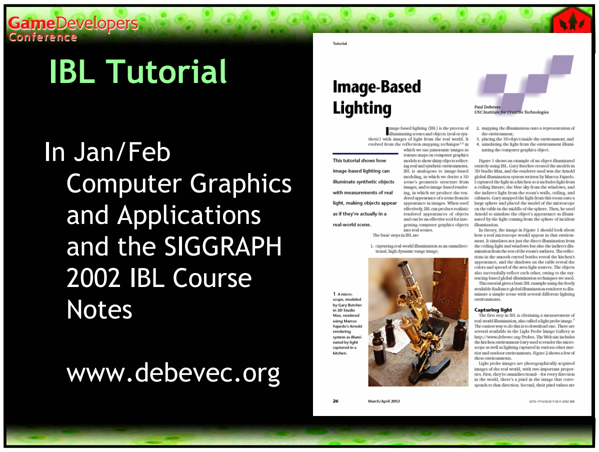

GameDevelopers Conference
Scenes lit with point light sources lack realism...

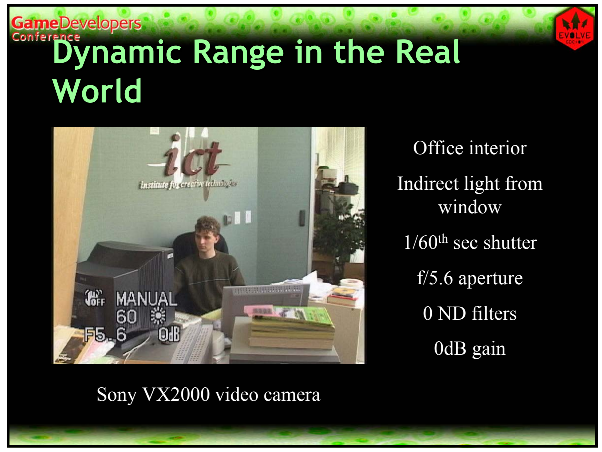

Real-World HDR Lighting Environments
Funston Beach
Eucalyptus Grove
Uffizi Gallery
Grace Cathedral
Lighting Environments from the Light Probe Image Gallery:
http://www.debevec.org/Probes/

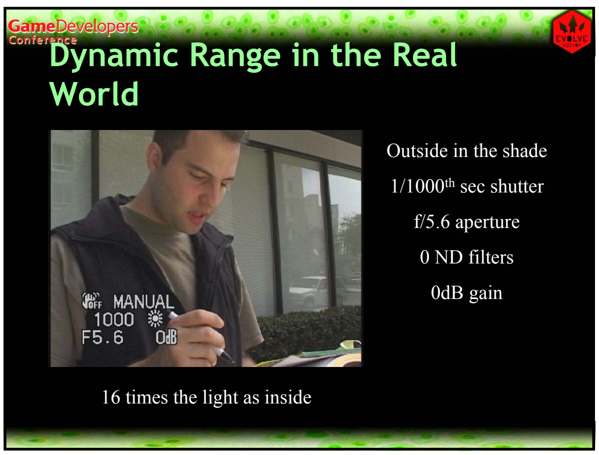

GameDevelopers Conference
Illuminating Objects using Measurements of Real Light
Light
Object
Environment assigned "glow" material property in Greg Ward's RADIANCE system.
http://radsite.lbl.gov/radiance/
http://www.debevec.org/CGAIBL/

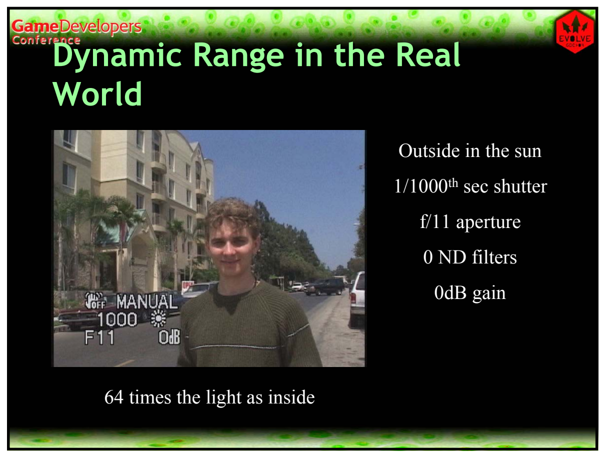

Lighting with real illumination environments yields greater realism

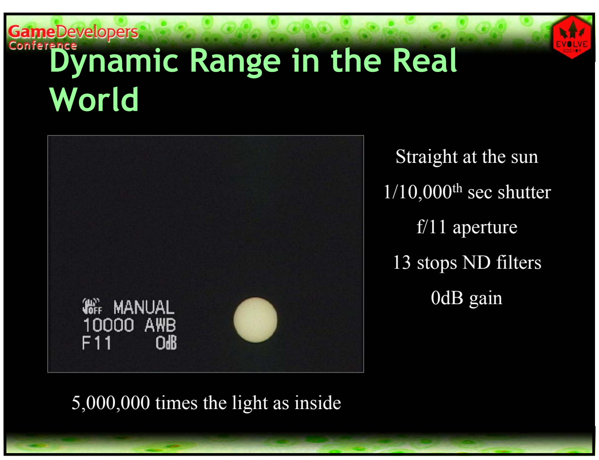

GameDevelopers Conference
Elements of HDRI and IBL
High Dynamic Range (HDR) Images
Pixels beyond 0-255
Pixel proportional to light levels
Light Probe Images
Omnidirectional HDR images, or
HDR environment maps
Global Illumination
Illuminating CG objects with
images of incident illumination

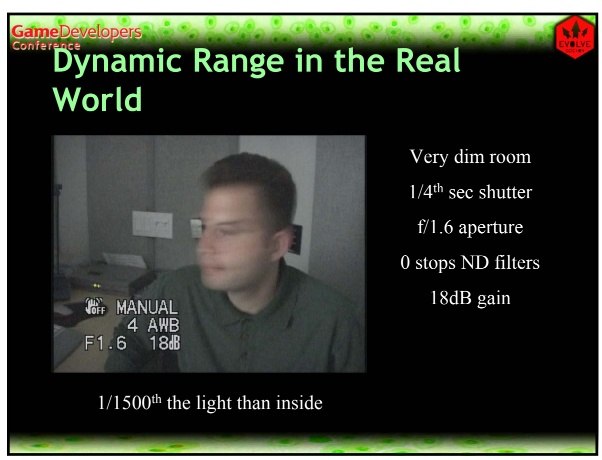

GameDevelopers Conference
IBL Tutorial
In Jan/Feb Computer Graphics and Applications and the SIGGRAPH 2002 IBL Course Notes
www.debevec.org
Image-Based Lighting

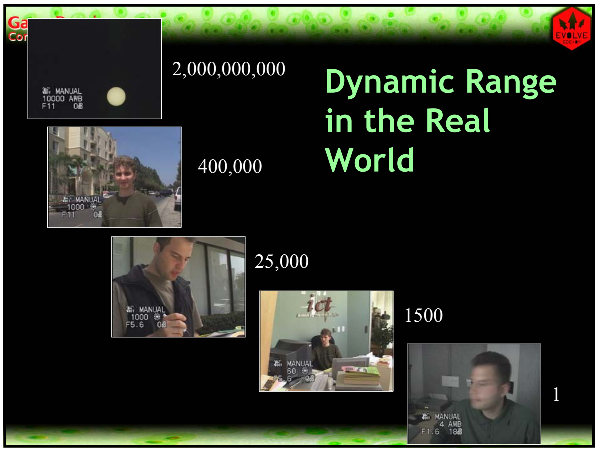

GameDevelopers Conference
Dynamic Range in the Real World
MANUAL
60
F5.6 0dB
Office interior
Indirect light from window
1/60th sec shutter
f/5.6 aperture
0 ND filters
0dB gain
Sony VX2000 video camera

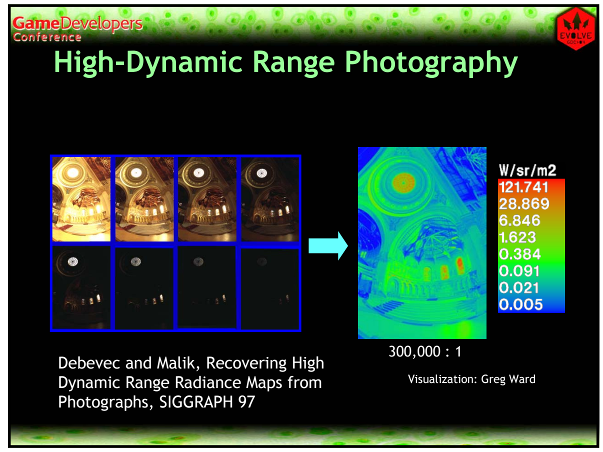

GameDevelopers Conference
Dynamic Range in the Real World
MANUAL
1000
F5.6 0dB
Outside in the shade
1/1000th sec shutter
f/5.6 aperture
0 ND filters
0dB gain
16 times the light as inside

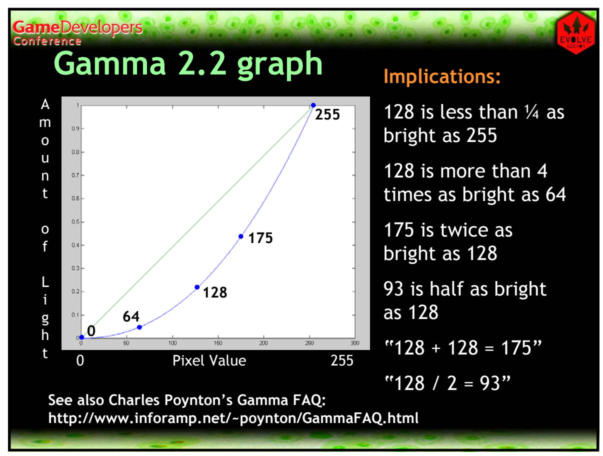

GameDevelopers Conference
Dynamic Range in the Real World
MANUAL
1000
F11 0dB
Outside in the sun
1/1000th sec shutter
f/11 aperture
0 ND filters
0dB gain
64 times the light as inside


GameDevelopers Conference
Dynamic Range in the Real World
MANUAL
10000 AWB
F11 0dB
Straight at the sun
1/10,000th sec shutter
f/11 aperture
13 stops ND filters
0dB gain
5,000,000 times the light as inside


GameDevelopers Conference
Dynamic Range in the Real World
MANUAL
4 AWB
F1.6 18dB
Very dim room
1/4th sec shutter
f/1.6 aperture
0 stops ND filters
18dB gain
1/1500th the light than inside





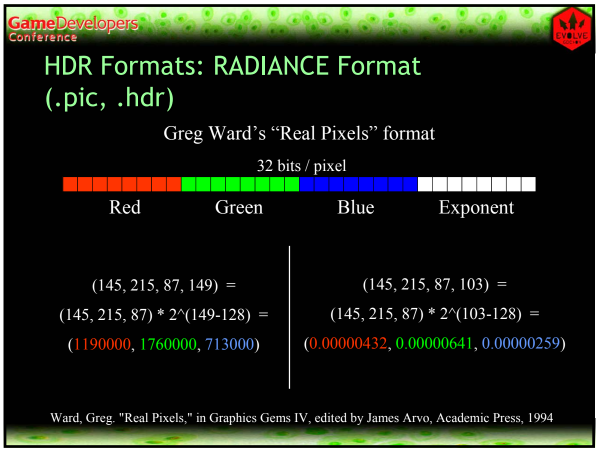


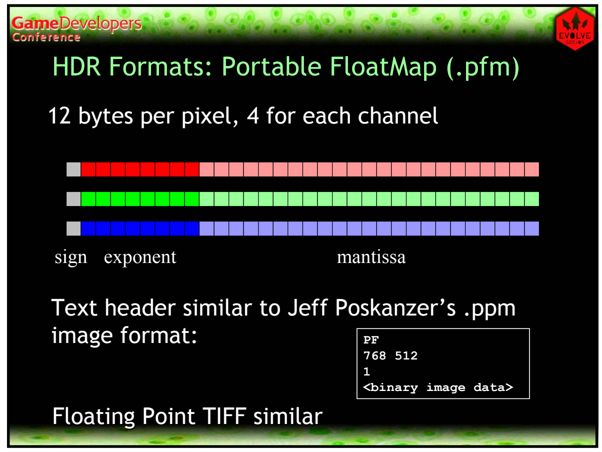
DirectX 9 HDR Data Formats

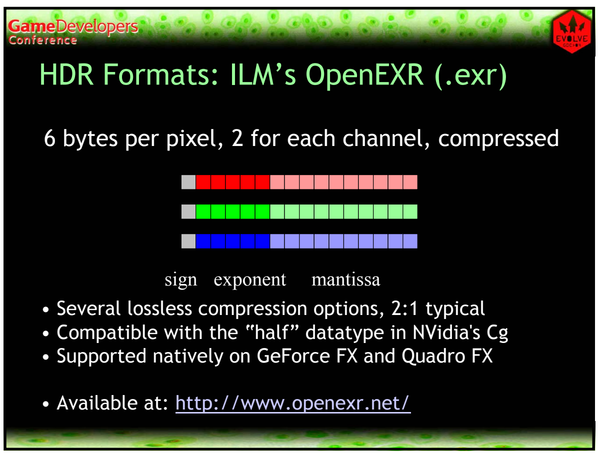
32-bit floating point textures
- D3DFMT_A32B32G32R32F / D3DFMT_R32F
- IEEE compatible

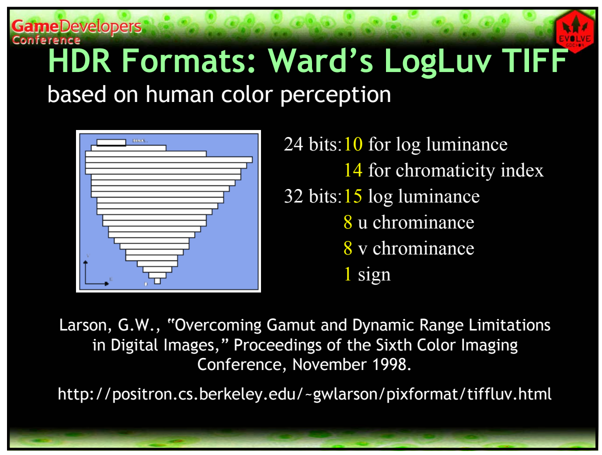
16-bit floating point textures
- D3DFMT_A16B16G16R16F
- saves memory bandwidth
- often sufficient dynamic range and precision

HDR Image File Formats

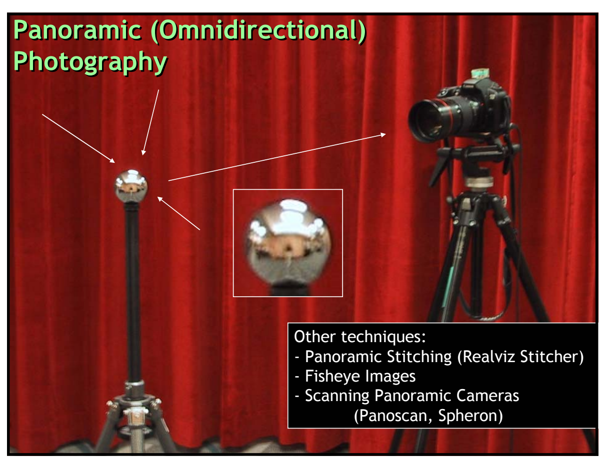

GameDevelopers Conference
HDR Formats: RADIANCE Format (.pic, .hdr)
Greg Ward's "Real Pixels" format
32 bits / pixel
Red Green Blue Exponent
(145, 215, 87, 149) =
(145, 215, 87) * 2^(149-128) =
(1190000, 1760000, 713000)
(145, 215, 87, 103) =
(145, 215, 87) * 2^(103-128) =
(0.00000432, 0.00000641, 0.00000259)
Ward, Greg. "Real Pixels," in Graphics Gems IV, edited by James Arvo, Academic Press, 1994

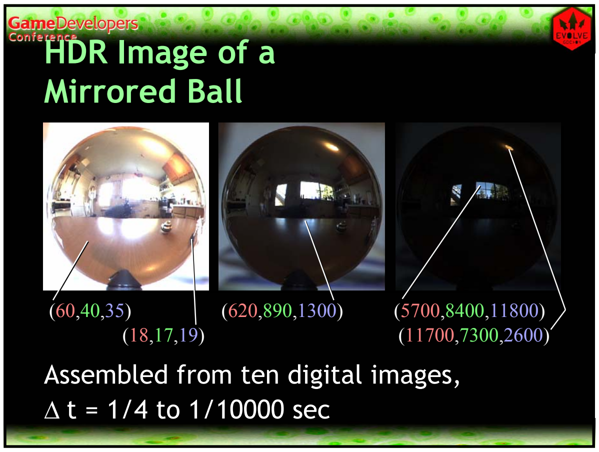

GameDevelopers Conference
HDR Formats: Portable FloatMap (.pfm)
12 bytes per pixel, 4 for each channel
sign exponent mantissa
Text header similar to Jeff Poskanzer's .ppm image format:
PF
768 512
1
<binary image data>
Floating Point TIFF similar

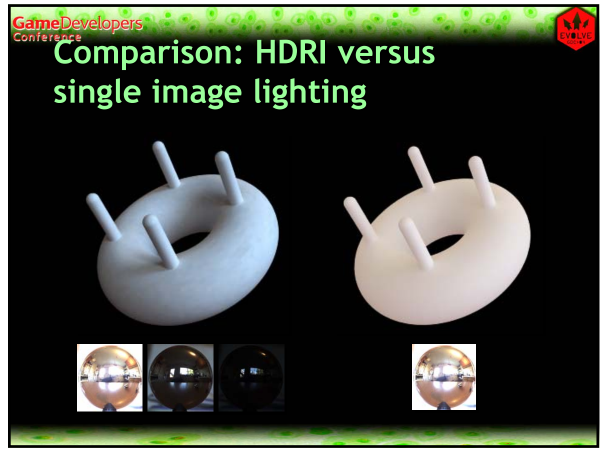

GameDevelopers Conference
HDR Formats: ILM's OpenEXR (.exr)
6 bytes per pixel, 2 for each channel, compressed
sign exponent mantissa
• Several lossless compression options, 2:1 typical
• Compatible with the "half" datatype in NVidia's Cg
• Supported natively on GeForce FX and Quadro FX
• Available at: http://www.openexr.net/


GameDevelopers Conference
HDR Formats: Ward's LogLuv TIFF
based on human color perception
24 bits: 10 for log luminance
14 for chromaticity index
32 bits: 15 log luminance
8 u chrominance
8 v chrominance
1 sign
Larson, G.W., "Overcoming Gamut and Dynamic Range Limitations in Digital Images," Proceedings of the Sixth Color Imaging Conference, November 1998.
http://positron.cs.berkeley.edu/~gwlarson/pixformat/tiffluv.html

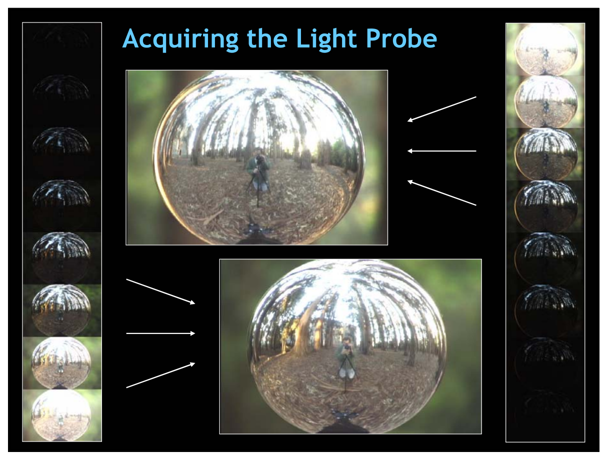

GameDevelopers Conference
EVOLVE
Light Probe Images:
Capturing Real-World Illumination

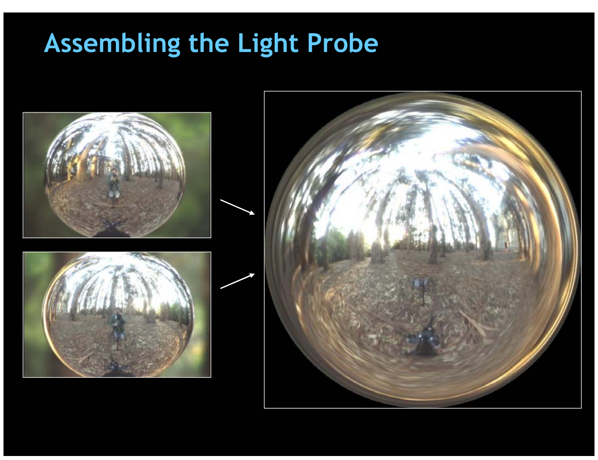

Panoramic (Omnidirectional) Photography
Other techniques:
- Panoramic Stitching (Realviz Stitcher)
- Fisheye Images
- Scanning Panoramic Cameras
(Panoscan, Spheron)


GameDevelopers Conference
HDR Image of a Mirrored Ball
(60,40,35)
(18,17,19)
(620,890,1300)
(5700,8400,11800)
(11700,7300,2600)
Assembled from ten digital images,
Δ t = 1/4 to 1/10000 sec

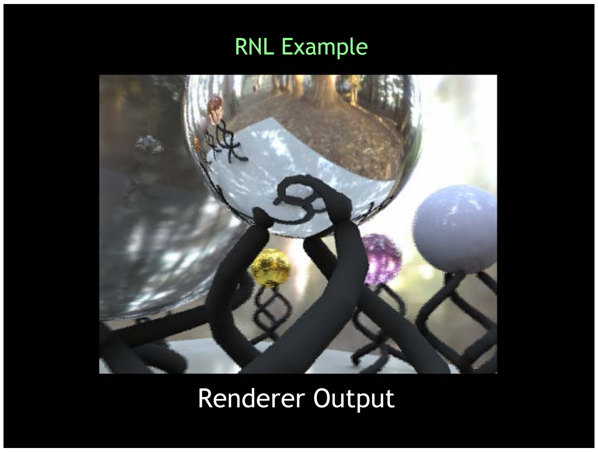

GameDevelopers Conference
Comparison: HDRI versus single image lighting


GameDevelopers Conference
Image-Based Lighting: Illuminating Synthetic Objects with Real Light
Rendering with Natural Light, SIGGRAPH 98


Acquiring the Light Probe

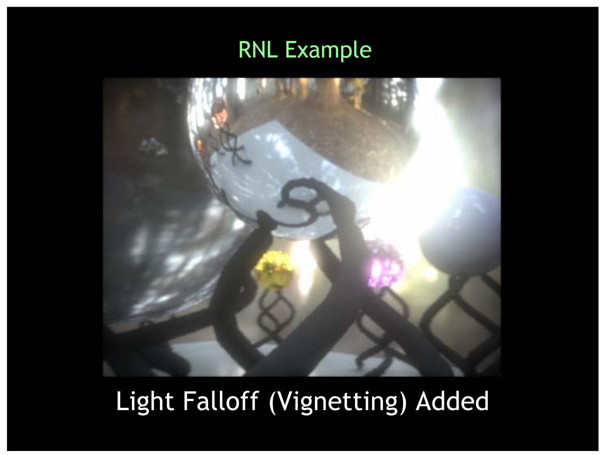

Assembling the Light Probe

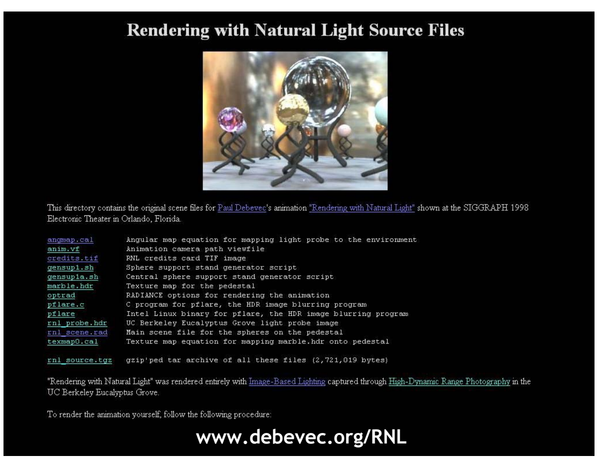

RNL Environment mapped onto interior of large cube


RNL Example
Renderer Output

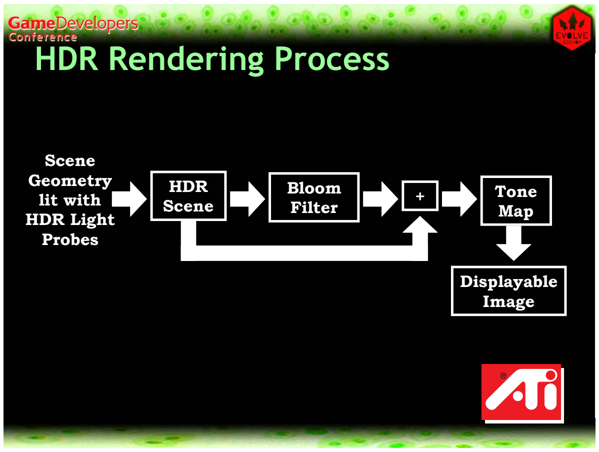

RNL Example
Defocus & Glare Added

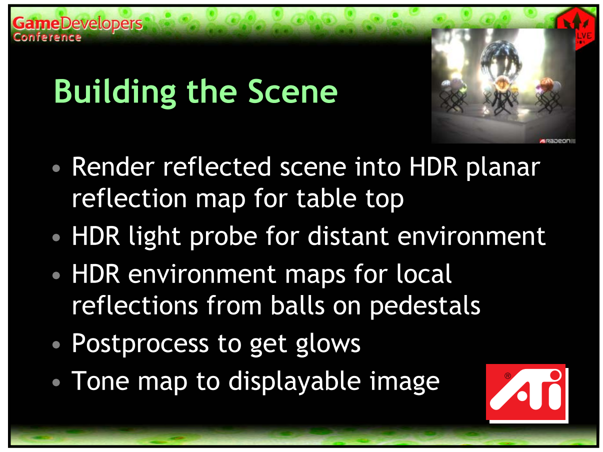

RNL Example
Soft Focus Added

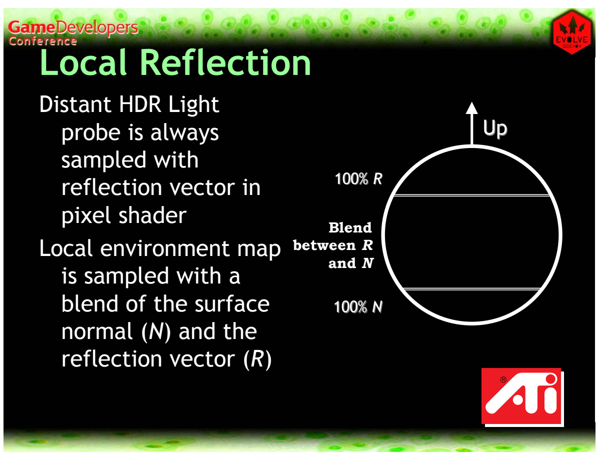

RNL Example
Light Falloff (Vignetting) Added

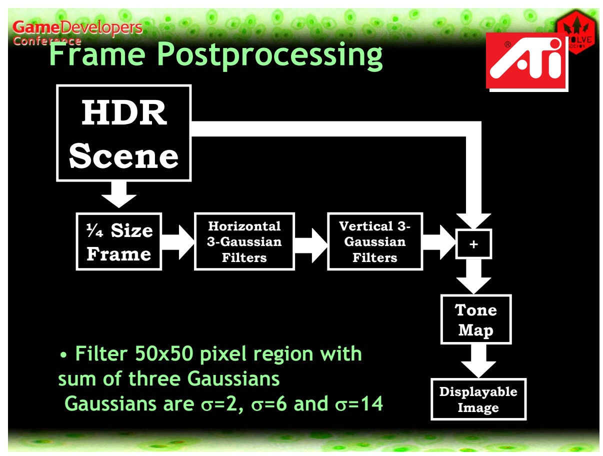

Rendering with Natural Light Source Files
This directory contains the original scene files for Paul Debevec's animation "Rendering with Natural Light" shown at the SIGGRAPH 1998 Electronic Theater in Orlando, Florida.
angmap.cal Angular map equation for mapping light probe to the environment
anim.vf Animation camera path viewfile
credits.tif RNL credits card TIF image
gensup1.sh Sphere support stand generator script
gensup1a.sh Central sphere support stand generator script
marble.hdr Texture map for the pedestal
optrad RADIANCE options for rendering the animation
pflare.c C program for pflare, the HDR image blurring program
pflare Intel Linux binary for pflare, the HDR image blurring program
rnl_probe.hdr UC Berkeley Eucalyptus Grove light probe image
rnl_scene.rad Main scene file for the spheres on the pedestal
texmap0.cal Texture map equation for mapping marble.hdr onto pedestal
rnl_source.tgz gzip'ped tar archive of all these files (2,721,019 bytes)
"Rendering with Natural Light" was rendered entirely with Image-Based Lighting captured through High-Dynamic Range Photography in the UC Berkeley Eucalyptus Grove.
To render the animation yourself, follow the following procedure:
www.debevec.org/RNL

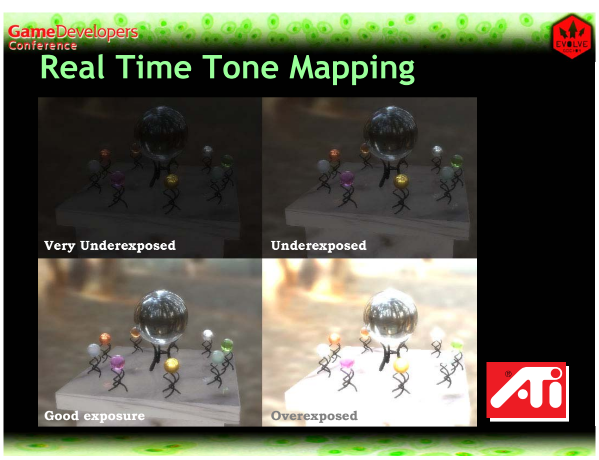

GameDevelopers Conference
Real-Time RNL
Jason Mitchell, John Isidoro, Alex Vlachos
Rendered in Real Time on ATI RADEON™ 9700


GameDevelopers Conference
HDR Rendering Process
Scene Geometry lit with HDR Light Probes
HDR Scene
Bloom Filter
+
Tone Map
Displayable Image

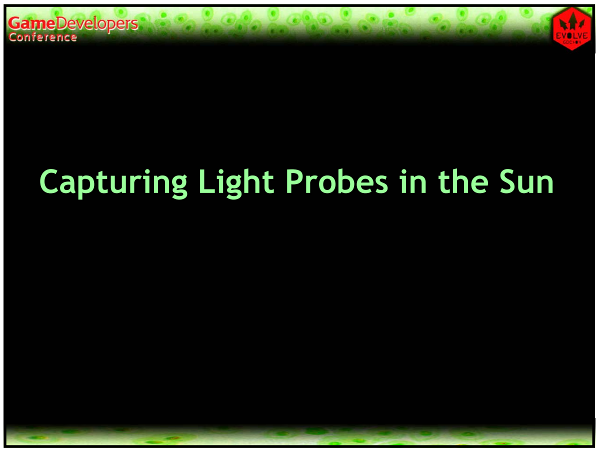

GameDevelopers Conference
Building the Scene
• Render reflected scene into HDR planar reflection map for table top
• HDR light probe for distant environment
• HDR environment maps for local reflections from balls on pedestals
• Postprocess to get glows
• Tone map to displayable image

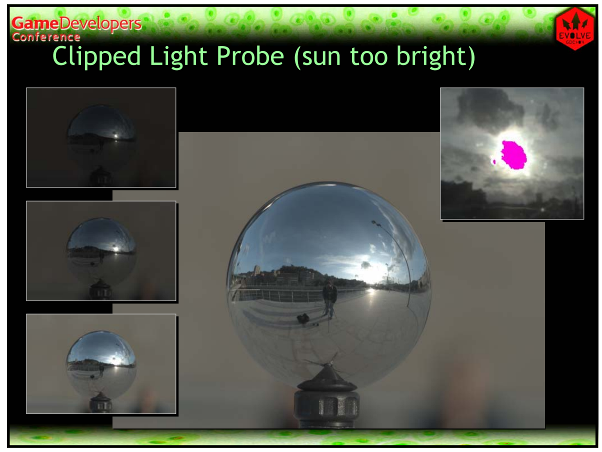

GameDevelopers Conference
Local Reflection
Distant HDR Light probe is always sampled with reflection vector in pixel shader
Local environment map is sampled with a blend of the surface normal (N) and the reflection vector (R)
Up
100% R
Blend between R and N
100% N

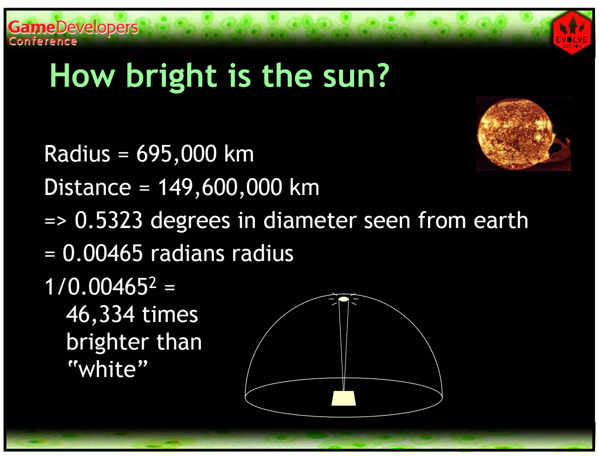

GameDevelopers Conference
Frame Postprocessing
HDR Scene
¼ Size Frame
Horizontal 3-Gaussian Filters
Vertical 3-Gaussian Filters
+
Tone Map
Displayable Image
• Filter 50x50 pixel region with sum of three Gaussians
Gaussians are σ=2, σ=6 and σ=14

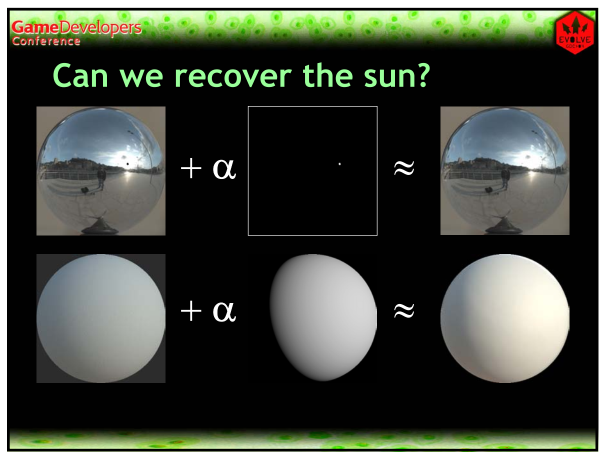

GameDevelopers Conference
Real Time Tone Mapping
Very Underexposed
Underexposed
Good exposure
Overexposed


GameDevelopers Conference
Masaki Kawase DirectX 9 Demo
http://www.daionet.gr.jp/~masa/

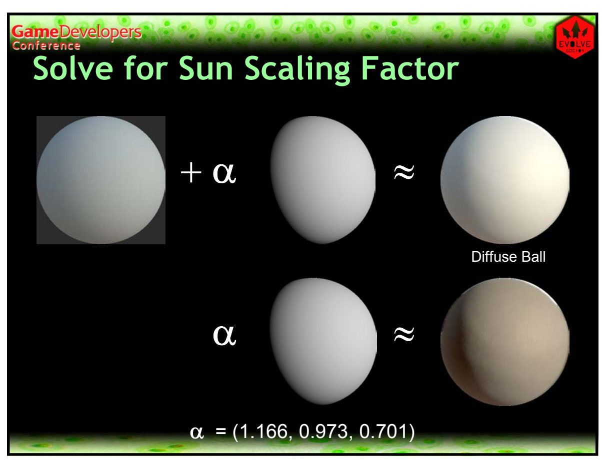

GameDevelopers Conference
Capturing Light Probes in the Sun

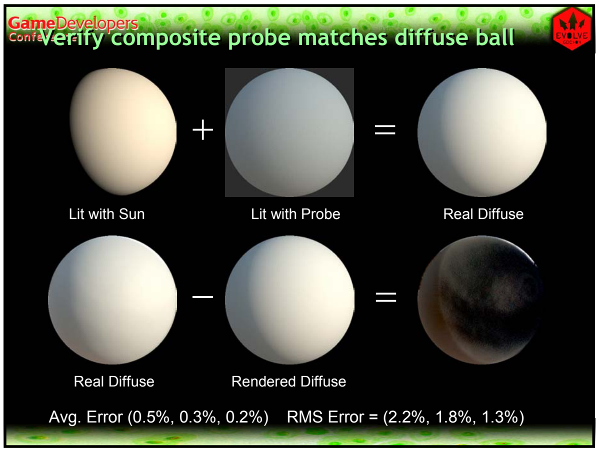

GameDevelopers Conference
Clipped Light Probe (sun too bright)


GameDevelopers Conference
How bright is the sun?
Radius = 695,000 km
Distance = 149,600,000 km
=> 0.5323 degrees in diameter seen from earth
= 0.00465 radians radius
1/0.00465² =
46,334 times
brighter than
"white"


GameDevelopers Conference
Can we recover the sun?
+ α
≈
+ α
≈

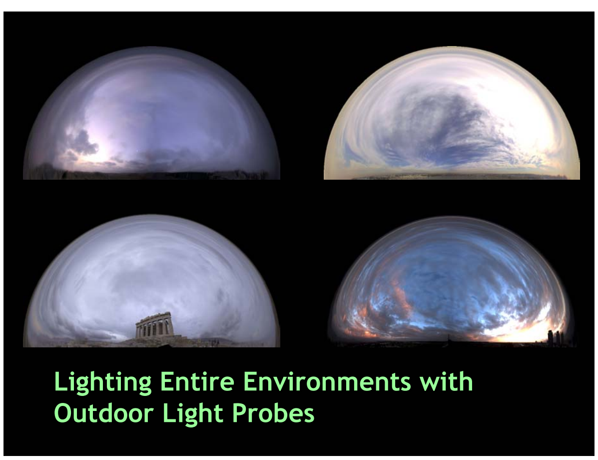

GameDevelopers Conference
Shoot Diffuse Sphere

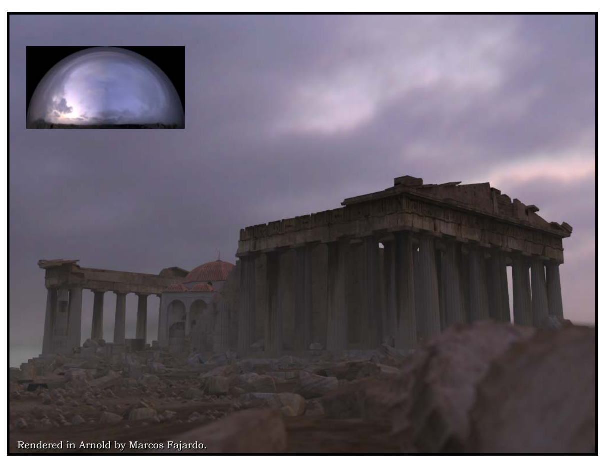

GameDevelopers Conference
Solve for Sun Scaling Factor
+ α
≈
Diffuse Ball
α
≈
α = (1.166, 0.973, 0.701)


GameDevelopers
Verify composite probe matches diffuse ball
+
=
Lit with Sun
Lit with Probe
Real Diffuse
−
=
Real Diffuse
Rendered Diffuse
Avg. Error (0.5%, 0.3%, 0.2%) RMS Error = (2.2%, 1.8%, 1.3%)


Background plate

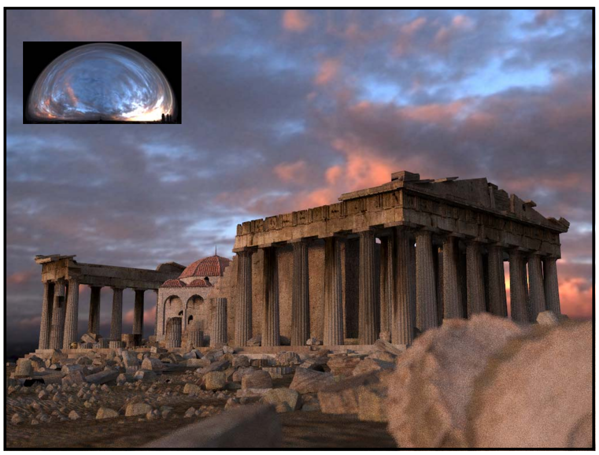

Synthetic objects added


Lighting Entire Environments with
Outdoor Light Probes


Rendered in Arnold by Marcos Fajardo.

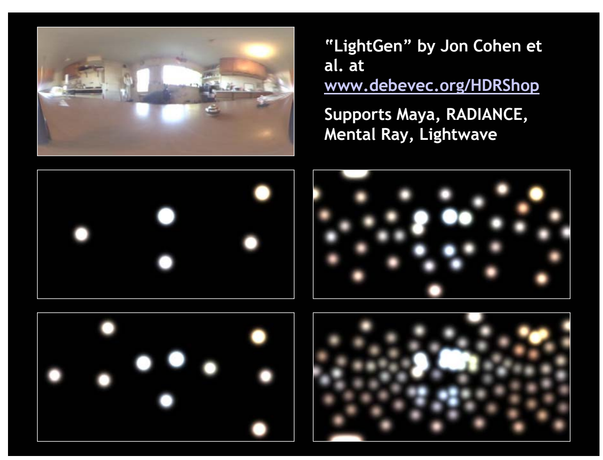

Rendered in Arnold by Marcos Fajardo.

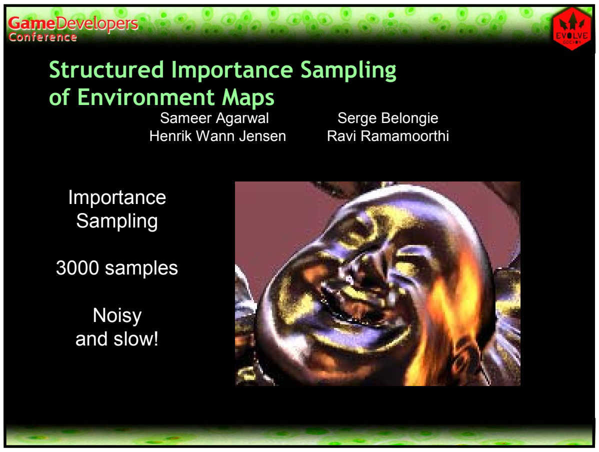

Rendered in Arnold by Marcos Fajardo.

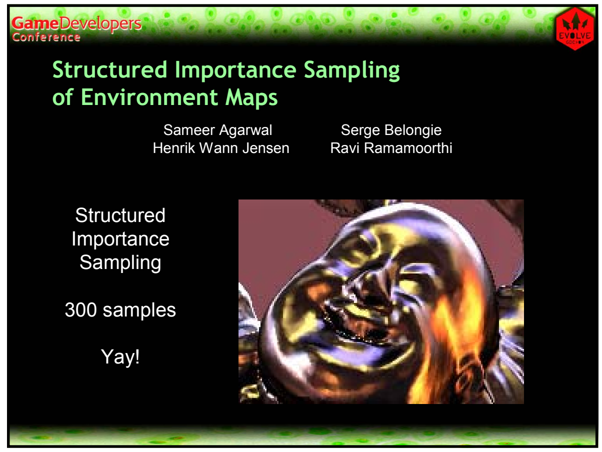



GameDevelopers
Conference
Making High Dynamic Range Lighting Efficient


GameDevelopers
Conference
Rendering Light Probes as Light Sources
1999

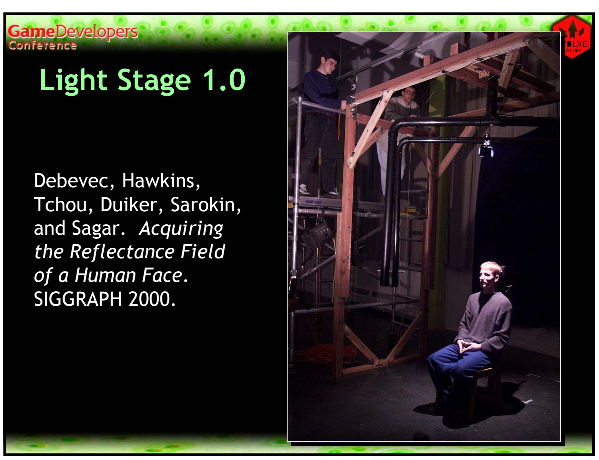

"LightGen" by Jon Cohen et al. at
www.debevec.org/HDRShop
Supports Maya, RADIANCE, Mental Ray, Lightwave

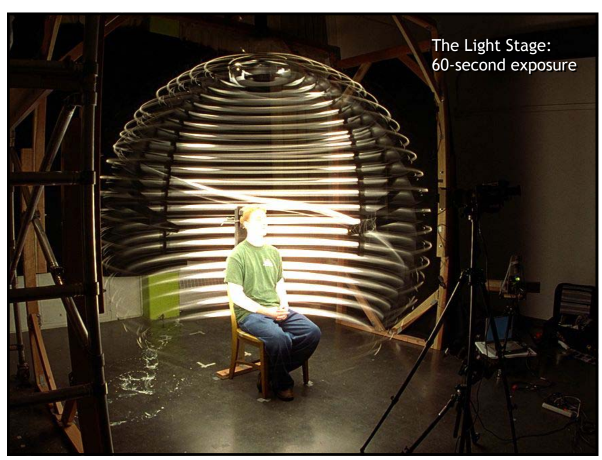

GameDevelopers Conference
Structured Importance Sampling of Environment Maps
Sameer Agarwal
Henrik Wann Jensen
Serge Belongie
Ravi Ramamoorthi
Importance Sampling
3000 samples
Noisy and slow!

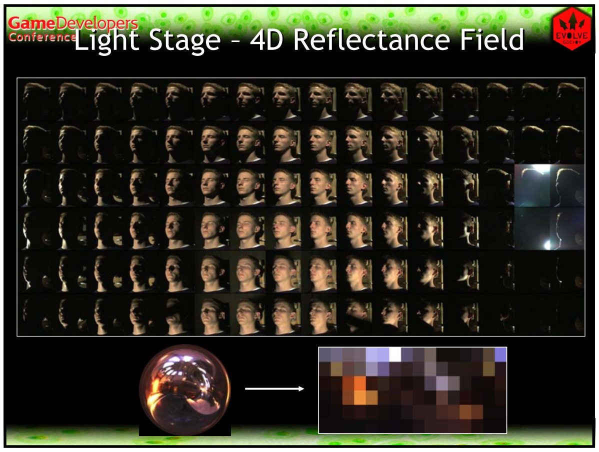

GameDevelopers Conference
Structured Importance Sampling of Environment Maps
Sameer Agarwal
Henrik Wann Jensen
Serge Belongie
Ravi Ramamoorthi
Structured Importance Sampling
300 samples
Yay!


GameDevelopers Conference
Approximating Environments


GameDevelopers
Step 1) Partition into regions of increasing brightness
Step 2) Use Hochbaum-Schmoys Algorithm to place samples in the brightest region(s)
Step 3) Repeat for the next brightest region, but make sure you consider the samples you added above first
Step 4) Repeat until you've covered the whole environment.

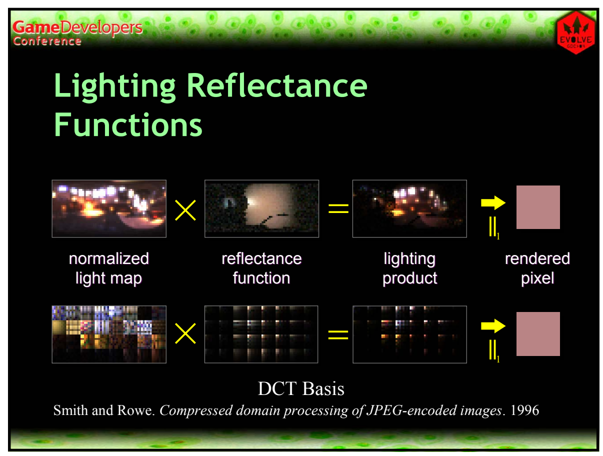

GameDevelopers Conference
Light Stage 1.0
Debevec, Hawkins, Tchou, Duiker, Sarokin, and Sagar. Acquiring the Reflectance Field of a Human Face. SIGGRAPH 2000.

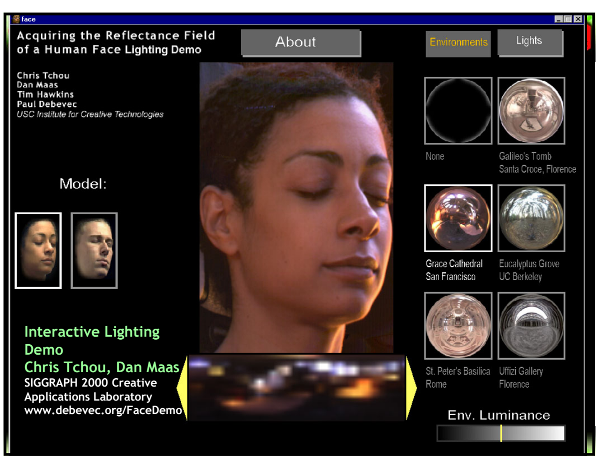

The Light Stage:
60-second exposure

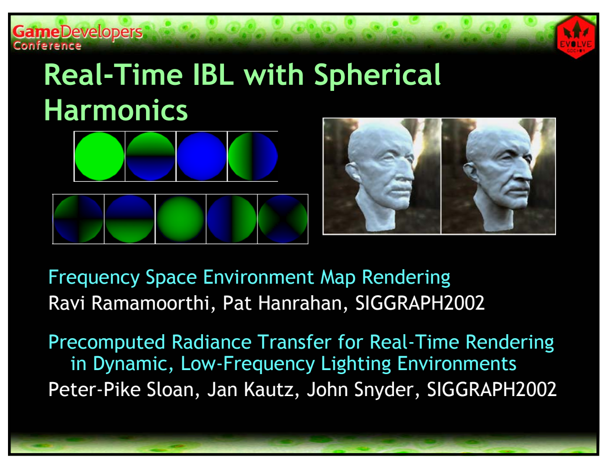

GameDevelopers Conference
Light Stage – 4D Reflectance Field

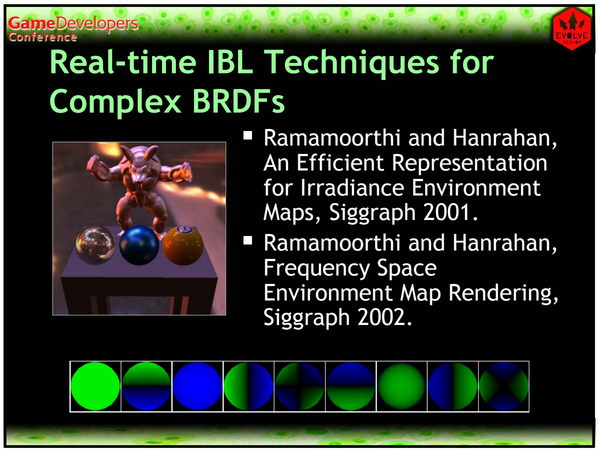

GameDevelopers Conference
Modulated Images


GameDevelopers Conference
Light Stage Results
Environments from the Light Probe Image Gallery
www.debevec.org

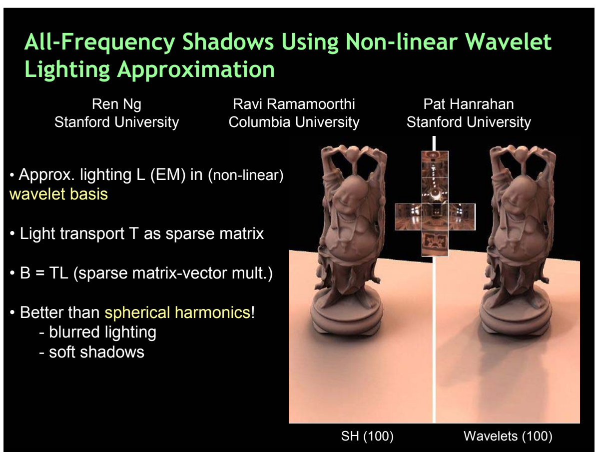

GameDevelopers Conference
Lighting Reflectance Functions
normalized light map
reflectance function
lighting product
rendered pixel
DCT Basis
Smith and Rowe. Compressed domain processing of JPEG-encoded images. 1996

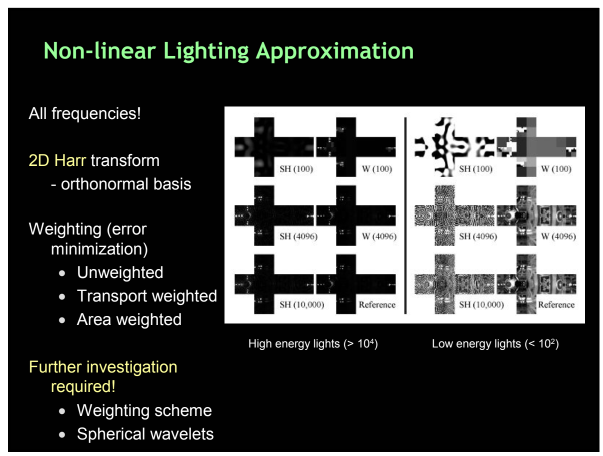

Acquiring the Reflectance Field of a Human Face Lighting Demo
About
Environments
Lights
Chris Tchou
Dan Maas
Tim Hawkins
Paul Debevec
USC Institute for Creative Technologies
Model:
None
Galileo's Tomb Santa Croce, Florence
Grace Cathedral San Francisco
Eucalyptus Grove UC Berkeley
St. Peter's Basilica Rome
Uffizi Gallery Florence
Interactive Lighting Demo
Chris Tchou, Dan Maas
SIGGRAPH 2000 Creative Applications Laboratory
www.debevec.org/FaceDemo
Env. Luminance


GameDevelopers Conference
Real-Time IBL with Spherical Harmonics
Frequency Space Environment Map Rendering
Ravi Ramamoorthi, Pat Hanrahan, SIGGRAPH2002
Precomputed Radiance Transfer for Real-Time Rendering in Dynamic, Low-Frequency Lighting Environments
Peter-Pike Sloan, Jan Kautz, John Snyder, SIGGRAPH2002


GameDevelopers Conference
Real-time IBL Techniques for Complex BRDFs
Ramamoorthi and Hanrahan, An Efficient Representation for Irradiance Environment Maps, Siggraph 2001.
Ramamoorthi and Hanrahan, Frequency Space Environment Map Rendering, Siggraph 2002.


GameDevelopers Conference
Real-time IBL Techniques
P.-P. Sloan, J. Kautz, J. Snyder, Precomputed Radiance Transfer for Real-Time Rendering in Dynamic, Low-Frequency Lighting Environments, SIGGRAPH 2002
Excellent Overview:
Robin Green, Spherical Harmonic Lighting: The Gritty Details, GDC 2003.


All-Frequency Shadows Using Non-linear Wavelet Lighting Approximation
Ren Ng
Stanford University
Ravi Ramamoorthi
Columbia University
Pat Hanrahan
Stanford University
• Approx. lighting L (EM) in (non-linear) wavelet basis
• Light transport T as sparse matrix
• B = TL (sparse matrix-vector mult.)
• Better than spherical harmonics!
- blurred lighting
- soft shadows
SH (100)
Wavelets (100)

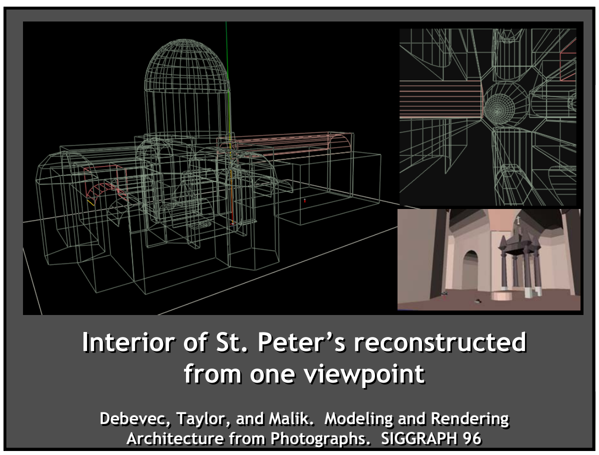

Non-linear Lighting Approximation
All frequencies!
2D Harr transform
- orthonormal basis
Weighting (error minimization)
• Unweighted
• Transport weighted
• Area weighted
Further investigation required!
• Weighting scheme
• Spherical wavelets
SH (100)
W (100)
SH (4096)
W (4096)
SH (10,000)
Reference
High energy lights (> 10⁴)
Low energy lights (< 10²)

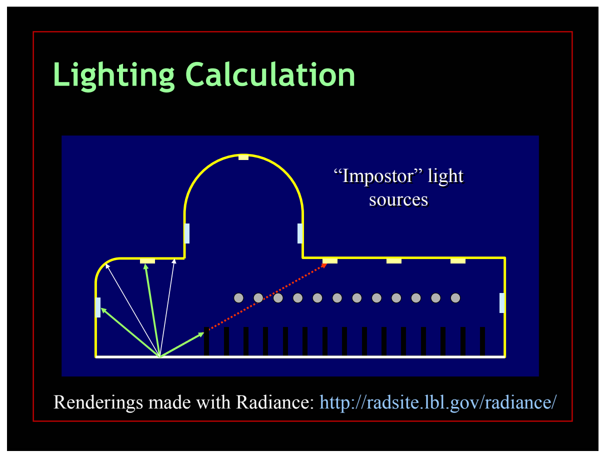

GameDevelopers Conference
Image-Relighting Comparison
Reference Image


GameDevelopers Conference
IMAGE-BASED LIGHTING IN FIAT LUX
Paul Debevec, Tim Hawkins, Westley Sarokin, H. P. Duiker, Christine Cheng, Tal Garfinkel, Jenny Huang
SIGGRAPH 99 Electronic Theater

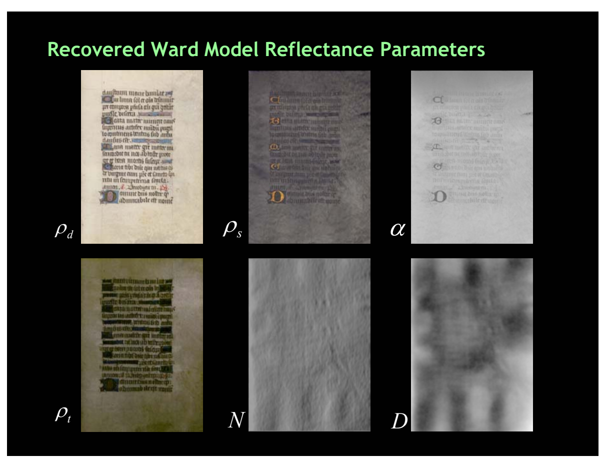

GameDevelopers Conference
Assembled Panorama


GameDevelopers Conference
Light Probe Images


Interior of St. Peter's reconstructed from one viewpoint
Debevec, Taylor, and Malik. Modeling and Rendering Architecture from Photographs. SIGGRAPH 96


Lighting Calculation
"Impostor" light sources
Renderings made with Radiance: http://radsite.lbl.gov/radiance/


GameDevelopers Conference
HDR Lighting Real-World Reflectance Properties
Gardner, Tchou, Hawkins, and Debevec SIGGRAPH 2003


Recovered Ward Model Reflectance Parameters
ρ_d
ρ_s
α
ρ_t
N
D

The Ward Model with Translucency (Single Light Source)

$$\frac{I}{\pi}\left(\rho_d\cos\theta_i+\rho_t\cos(\theta_i+\pi)+\rho_s\cdot\sqrt{\frac{\cos\theta_i}{\cos\theta_r}}\cdot\frac{\exp\left[-\tan^2\frac{\delta^2}{\alpha^2}\right]}{4\alpha^2}\right)$$

Note: all cosines are clamped to be non-negative

In terms of vectors

$$\frac{I}{\pi}\left(\rho_d(\vec{L}\cdot\vec{N})+\rho_t(\vec{L}\cdot-\vec{N})+\rho_s\sqrt{\frac{\vec{L}\cdot\vec{N}}{\vec{V}\cdot\vec{N}}}\frac{\exp\left[-\tan^2\frac{\delta^2}{\alpha^2}\right]}{4\alpha^2}\right)$$

Where:
$\delta=\cos^{-1}(\|L+V\|\cdot N)=\cos^{-1}(H\cdot N)$ = half angle

Interpolated / Constant Values

$$\frac{I}{\pi}\left(\rho_d(\vec{L}\cdot\vec{N})+\rho_t(\vec{L}\cdot-\vec{N})+\rho_s\sqrt{\frac{\vec{L}\cdot\vec{N}}{\vec{V}\cdot\vec{N}}}\frac{\exp\left[-\tan^2\frac{\delta^2}{\alpha^2}\right]}{4\alpha^2}\right)$$

I = light intensity
L = light direction vector
V = view (camera) direction vector
H = half angle vector

HDR Texture Maps

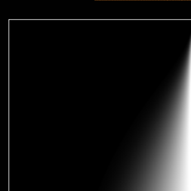
$$\frac{I}{\pi}\left(\rho_d(\vec{L}\cdot\vec{N})+\rho_t(\vec{L}\cdot-\vec{N})+\rho_s\sqrt{\frac{\vec{L}\cdot\vec{N}}{\vec{V}\cdot\vec{N}}}\frac{\exp\left[-\tan^2\frac{\delta^2}{\alpha^2}\right]}{4\alpha^2}\right)$$

ρ_d = Diffuse reflectance (RGB)
ρ_t = Translucent transmission (RGB)
ρ_s = Specular reflectance (RGB)
α = Specular roughness (A)
N = Surface normal (XYZ)

Gaussian Specular Lobe Table

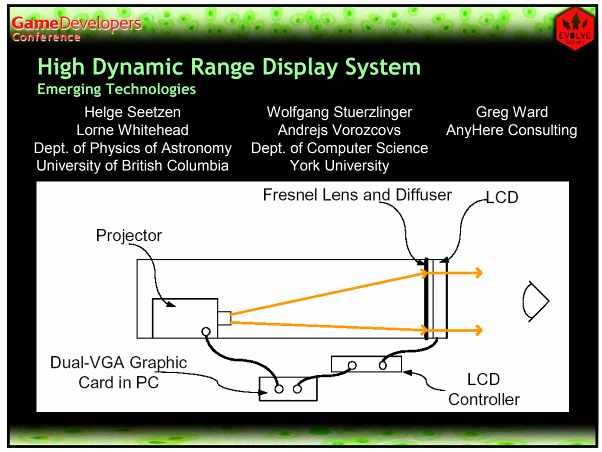
$$\frac{I}{\pi}\left(\rho_d(\vec{L}\cdot\vec{N})+\rho_t(\vec{L}\cdot-\vec{N})+\rho_s\sqrt{\frac{\vec{L}\cdot\vec{N}}{\vec{V}\cdot\vec{N}}}\frac{\exp\left[-\tan^2\frac{\delta^2}{\alpha^2}\right]}{4\alpha^2}\right)$$

Stored in a texture map indexed by
$(\alpha, H\cdot N)$



LLS Real-Time Demo…


High Dynamic Range Display System
HDR DISPLAYS


GameDevelopers Conference
High Dynamic Range Display System
Emerging Technologies
Helge Seetzen
Lorne Whitehead
Dept. of Physics of Astronomy
University of British Columbia
Wolfgang Stuerzlinger
Andrejs Vorozcovs
Dept. of Computer Science
York University
Greg Ward
AnyHere Consulting
Fresnel Lens and Diffuser
LCD
Projector
Dual-VGA Graphic
Card in PC
LCD
Controller


GameDevelopers Conference
Thanks!
Jason Mitchell, Chris Brennan, Masaki Kawase
Chris Tchou, Andrew Gardner, Tim Hawkins, H.P. Duiker, Westley Sarokin
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http://www.debevec.org/