Lighting And Material Of Halo3

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Bungie

Microsoft Research Asia

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NON FACETE NOBIS CALCITRARE VESTRVM

Talk Overview

- Introduction
- Halo3 Lighting
- Halo3 Material Model
- HDR Rendering
- Results
- Acknowledgement
- Q&A


Halo2
per pixel light map
per vertex dominant lightdir+“ambientess”
Bump maps modulates light map color.
Objects sample LM and build fake lights.
Bumps only see single directional light
Bumps disappear In shadowy area
Specular from point lights only
LDR pipeline
CAUTION

Halo3

- What do we want?
  - global illumination
  - handle variety of lighting environments
  - consistent lighting everywhere
  - render bump maps "correctly"
  - complex material under complex lighting
  - HDR

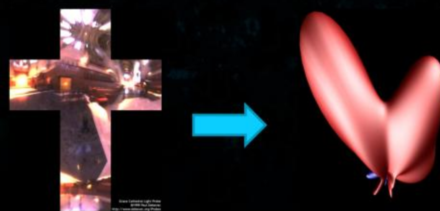
Definitions

- Radiance
  - *L(ω)*: density of light energy through a given point in a given direction.
- Irradiance
  - *I*: incident radiance integrated over the hemisphere of the surface normal with the cosine lobe.
- BRDF
  - *f(V, L)*: Bidirectional reflectance distribution function.
- Fresnel
  - *F*: Predicts ratio of reflected and transmitted light when light travels between different mediums.
  - *F0*: Reflectance at near normal incident angle.

Related Work

- Irradiance Volume [Greger98][ATI05]
- SH Irradiance Environment Map [Ramamoorthi01]
- Pre-computed Radiance Transfer [Sloan02]
- SH Light Maps [Good05]
- Sky and Atmosphere [Preetham99][Hoffman02]
- Reflectance Models [CookTorrance82][Schlick94]
- Low Frequency Glossy Material [Kautz02][Sloan03]
- Frequency Space Environment Map [Ramamoorthi02]

SH Irradiance Env Map



[Ramamoorthi00]

$$L_{lm} = \iint_{\theta,\phi} L(\theta,\phi) Y_{lm}(\theta,\phi) sin(\theta) d\theta d\phi$$

distant radiance at given direction

SH basis evaluated at given direction

diff solid angle

SH Irradiance Env Map

- Irradiance distribution as SH vector.
- <3% error with just 9 terms [Basri Jacobs 01]
- Evaluate normal to get irradiance.
- Only represent a single point in space.
- Only for infinite lighting environment.
- What about local lighting?

$$E(n) = n^t M n$$

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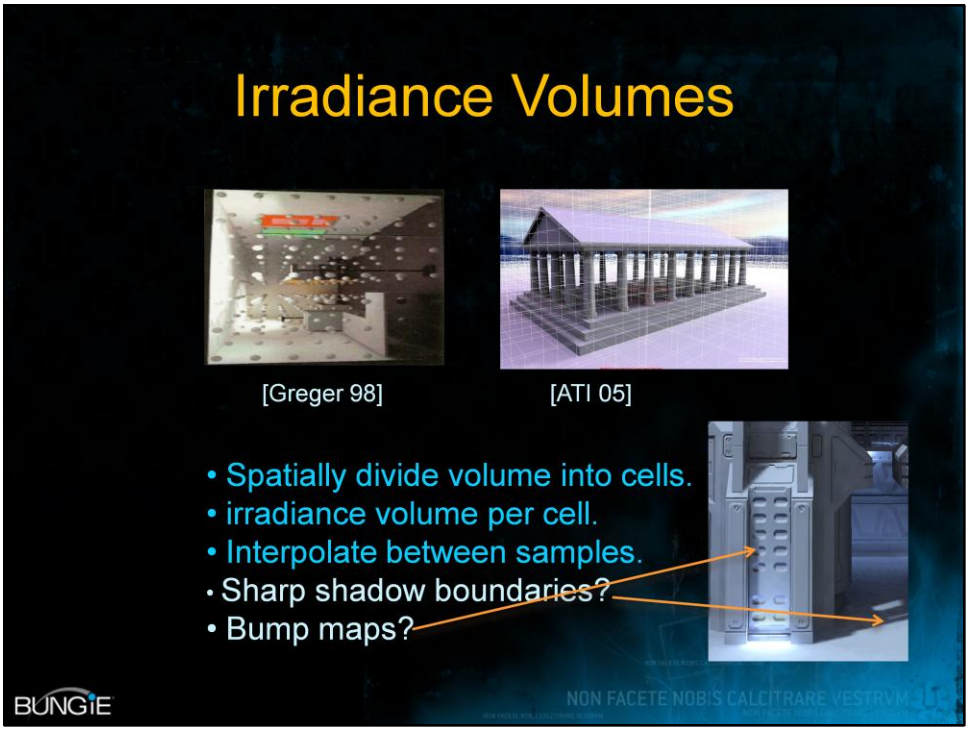
Irradiance Volumes
[Greger 98]
[ATI 05]
• Spatially divide volume into cells.
• irradiance volume per cell.
• Interpolate between samples.
• Sharp shadow boundaries?
• Bump maps?
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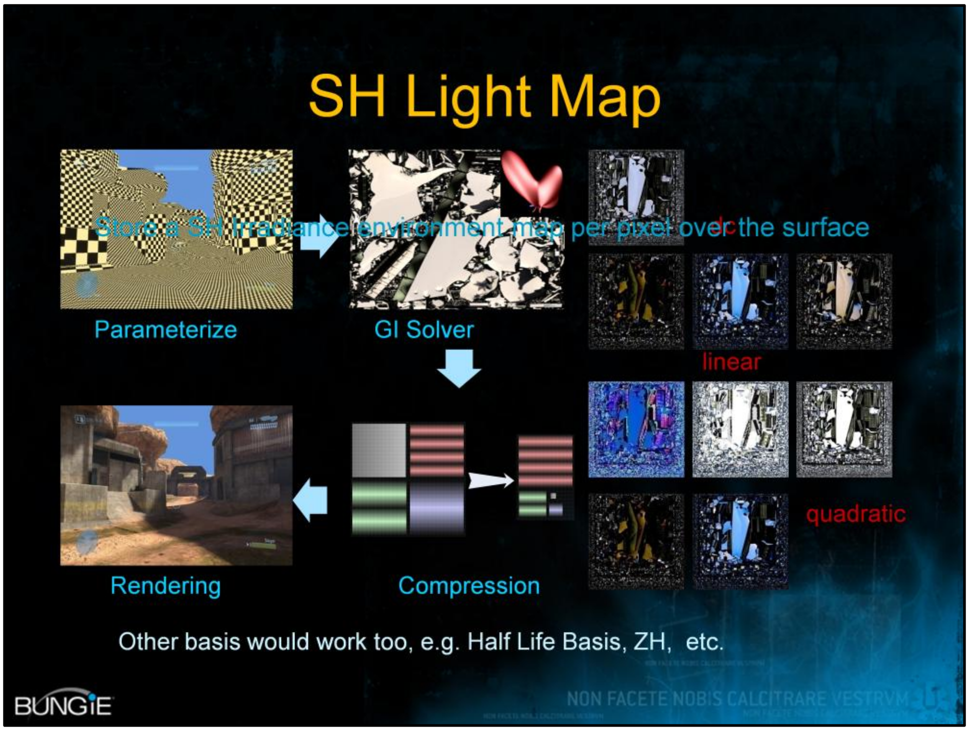
SH Light Map
Store a SH irradiance environment map per pixel over the surface
dc
Parameterize
GI Solver
linear
quadratic
Rendering
Compression
Other basis would work too, e.g. Half Life Basis, ZH, etc.
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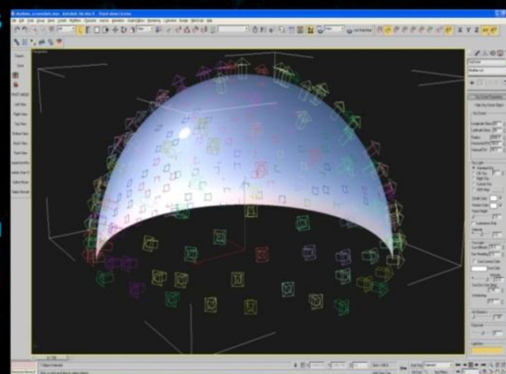
Sky and Sun

- HDR pipeline means starting with HDR light sources.
- Custom sky plugin for 3DStudio Max.
- Procedural Sky/Sun Model[Preetham99]
- CIE Sky Model
- Can also use HDR Cubemap



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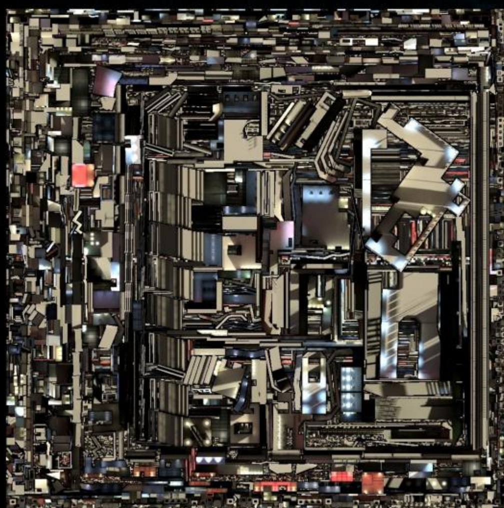
HDR Sky Example

Parameterization



- UVAtlas (DirectX SDK)
  - Minimize distortion
  - Efficient Packing
  - Input “importance”
- Halo3 improvements:
  - small charts placement.
  - long and thin charts.
- > 80% texel utilization
  - Halo2: < 50%

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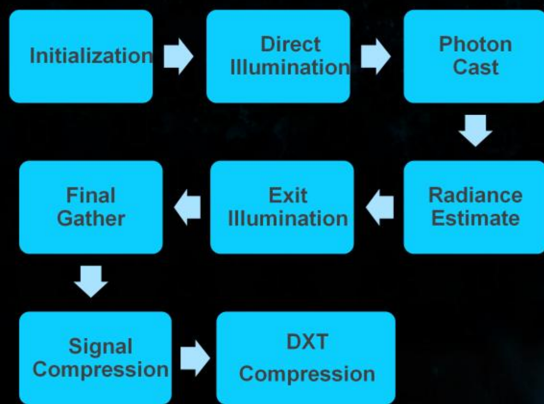
Photon Mapping Farm



256 servers; 456 Processors; 1GB memory per proc; see Luis's talk.

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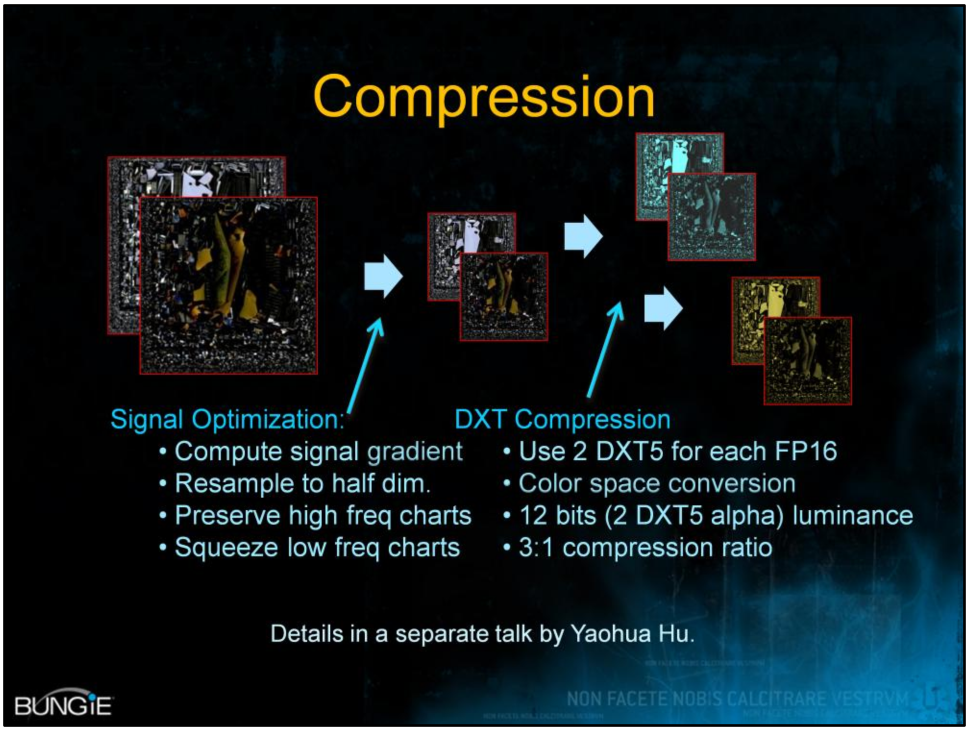
Compression
Signal Optimization:
• Compute signal gradient
• Resample to half dim.
• Preserve high freq charts
• Squeeze low freq charts
DXT Compression
• Use 2 DXT5 for each FP16
• Color space conversion
• 12 bits (2 DXT5 alpha) luminance
• 3:1 compression ratio
Details in a separate talk by Yaohua Hu.
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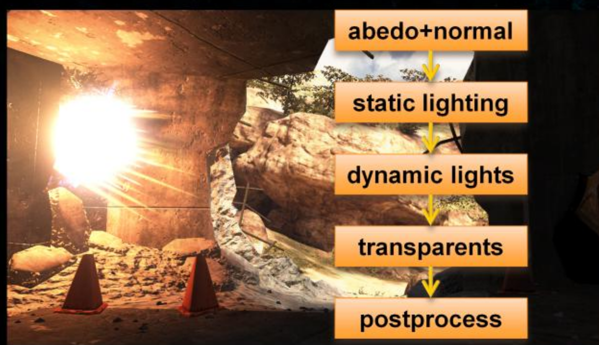
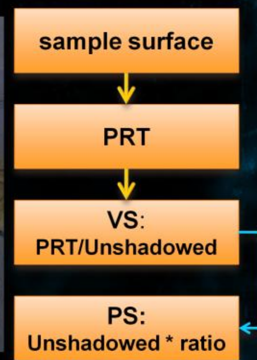
Rendering Passes



Object Lighting



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Optimization

- given a quadratic SH vecotor, i=0,…8
  - Pull out dominant light.
  - Store SH linear + dominant light.
  - In Shader, do N dot L + shirm(sh[] – c * Y(d), N)

$$E = \sum_{i=0,\dots 8} (\lambda_i - cY_i(d))^2, E' = 0$$

$$c = \sum_{i=0,\dots 8} (\lambda_i Y_i(d)) / \sum_{i=0,\dots 8} Y_i(d)^2$$

See Peter Pike Sloan's talk "Stupid Spherical Harmonics Tricks".

Lighting Examples

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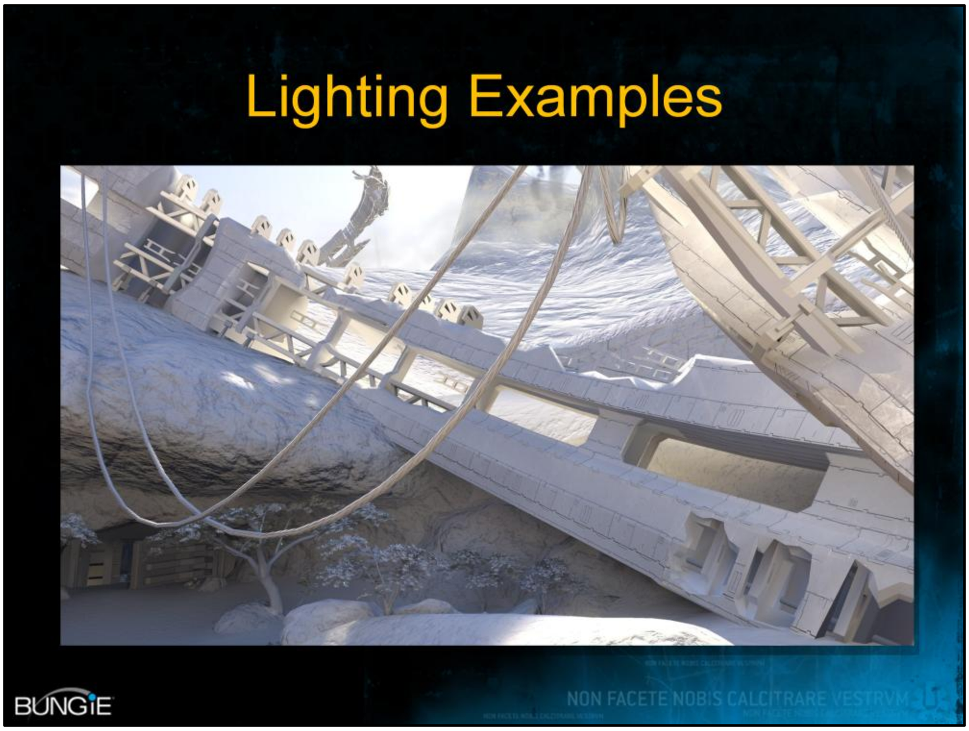
Lighting Examples


Lighting Examples
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Lighting Examples

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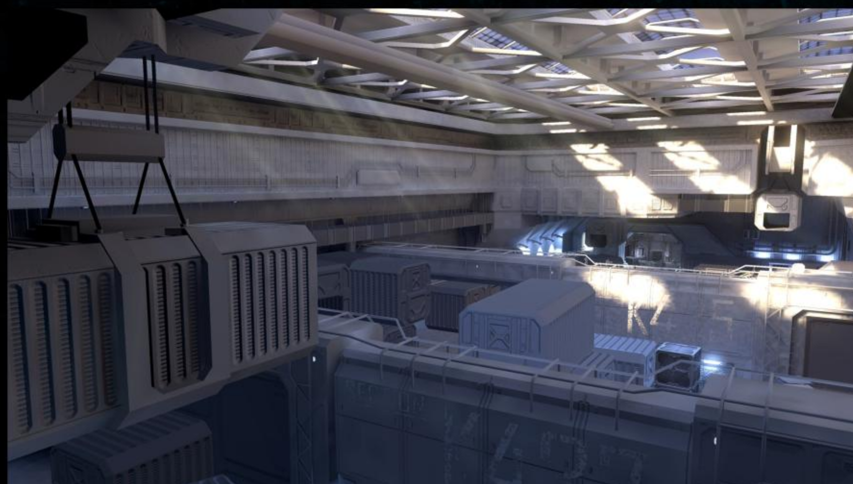
Lighting Examples



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Lighting Examples

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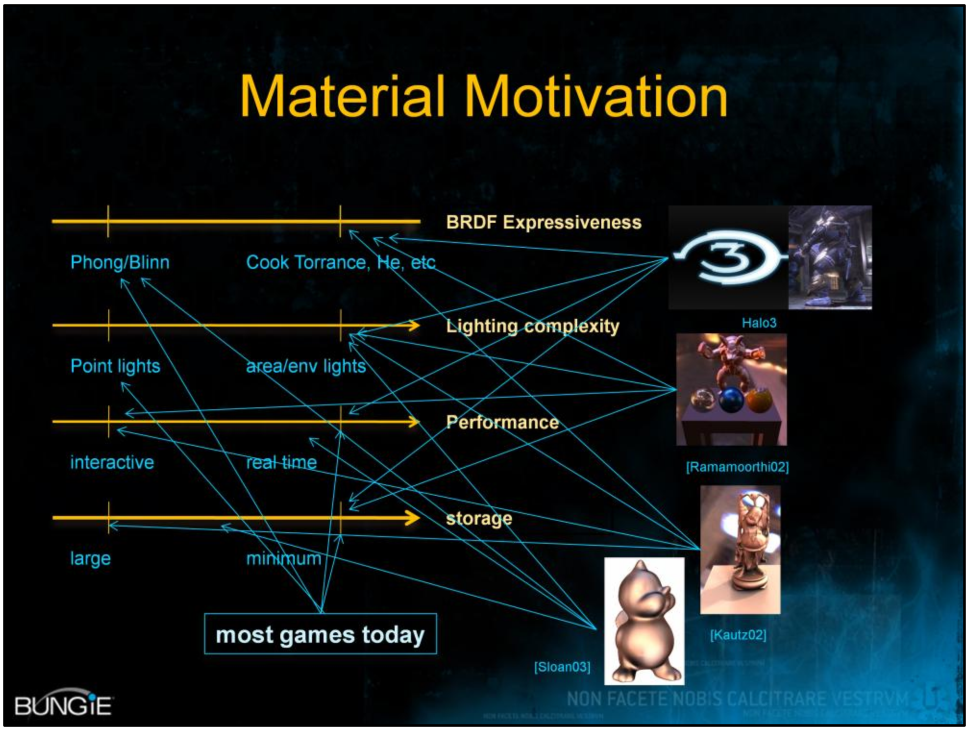
Material Motivation
BRDF Expressiveness
Phong/Blinn
Cook Torrance, He, etc
Lighting complexity
Point lights
area/env lights
Performance
interactive
real time
storage
large
minimum
most games today
Halo3
[Ramamoorthi02]
[Kautz02]
[Sloan03]
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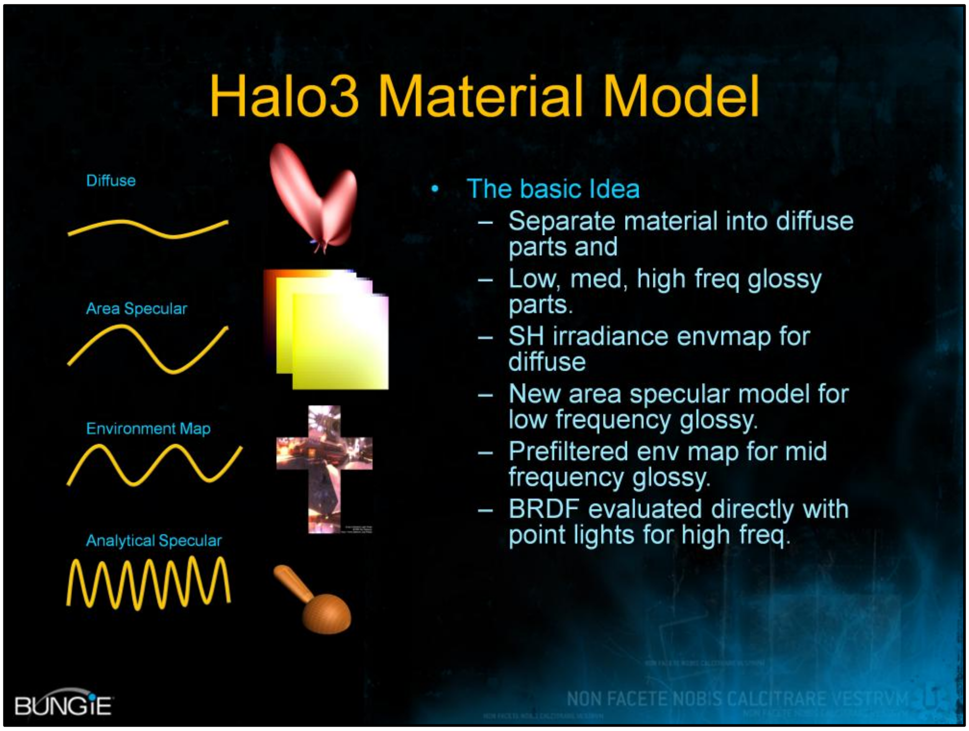
Halo3 Material Model
Diffuse
Area Specular
Environment Map
Analytical Specular
The basic Idea
Separate material into diffuse parts and
Low, med, high freq glossy parts.
SH irradiance envmap for diffuse
New area specular model for low frequency glossy.
Prefiltered env map for mid frequency glossy.
BRDF evaluated directly with point lights for high freq.
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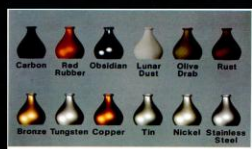
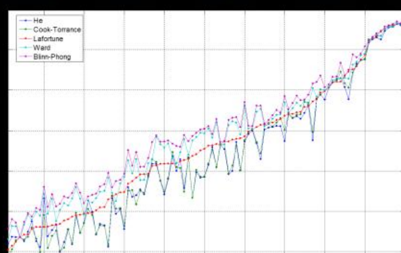
Cook Torrance BRDF



[CookTorrance81]

$$f(V, L) = k_d R_d + k_s \cdot F \cdot R_m$$

view direction light direction diffuse & specular Fresnel specular lobe



[Ngan05]

$$R_m(V, L) = \frac{DG}{\pi (N \cdot L)(N \cdot V)}$$

D: microfacet distribution function

G: geomery term

Cook Torrance & Point Lights

- Option1: Evaluate directly in shader
  - E.g. [Dempski Viale 2005]
  - Somewhat expensive, not too bad.
- Option2: Store D, G, F, terms in textures.
- What about lights that are not point lights?
  - Need to integrate light from all directions.
  - Not trivial to do.

Light Integration

$$I(V) = \oint f(V,L)\cos(\theta)L(\omega)d\omega$$

$$k_d R_d \oint \cos(\theta)L(\omega)d\omega + k_s \oint F R_m(V,L)\cos(\theta)L(\omega)d\omega$$

↓

??

SH irradiance env. map

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Light Integration in SH

$$I_s(V) = k_s \oint F R_m(V, L) cos(\theta) L(\omega) d\omega$$

Project light into SH basis.

$$L(\omega) = \sum_{i=0}^{8} \lambda_i Y_i(\omega)$$

Project BRDF and cosine term in SH basis

$$B_{m,i}(V) = \oint \frac{F}{F_0} R_m(V, L) cos(\theta) Y_i(\omega) d\omega$$

$$I_s(V) = K_s F_0 \sum_{i=0}^{8} \lambda_i B_{m,i}(V)$$

Dot product to convolve

Light Integration in SH Cont.

$$F \approx F_0 + (1 - F_0)(1 - (L \cdot H))^5$$ [Shilick85]

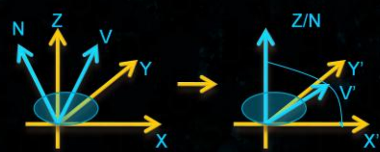
$$B_{m,i}(V) = \oint \frac{F_0 + (1 - F_0)(1 - (L \cdot H))^5}{F_0} R_m(V, L) \cos(\theta) Y_i(\omega) d\omega$$

$$C_{m,i}(V) = \oint R_m(V, L) cos(\theta) Y_i(\omega) d\omega$$

$$D_{m,i}(V) = \oint (1 - (L \cdot H)^5) R_m(V, L) cos(\theta) Y_i(\omega) d\omega$$

$$B_{m,i}(V) = C_{m,i}(V) + \frac{1 - F_0}{F_0} D_{m,i}(V)$$ ← **Preintegration**

Pre-integration

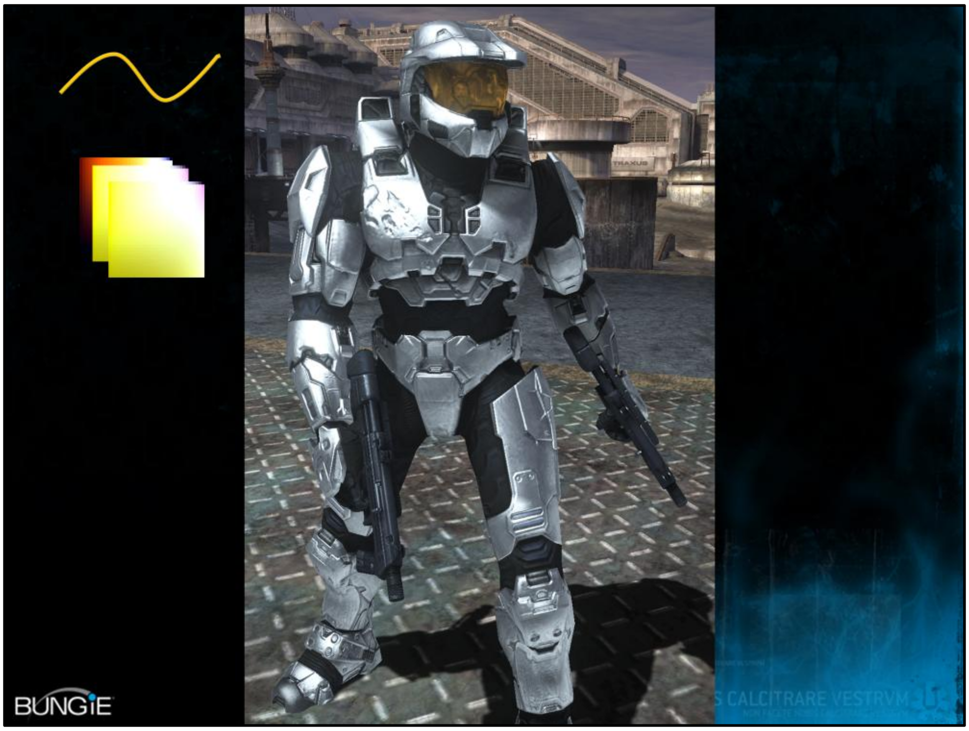


Reflective symmetry means:

$$C_{m,i}(V) = D_{m,i}(V) = 0, i = 1,4,5.$$

Isotropic BRDF = any coordinate frame16 m values, and 8 V directions is enough.

C (i=0,2,3,6) D (i=0,2,3,6) C,D (i=7,8)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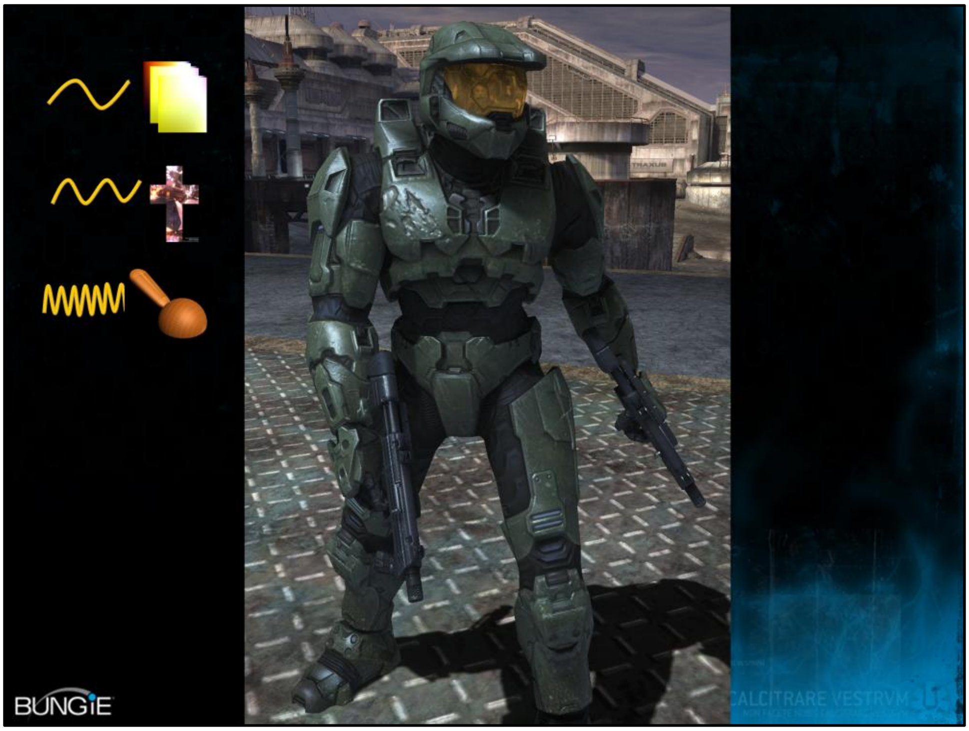


HDR Rendering


HDR Rendering
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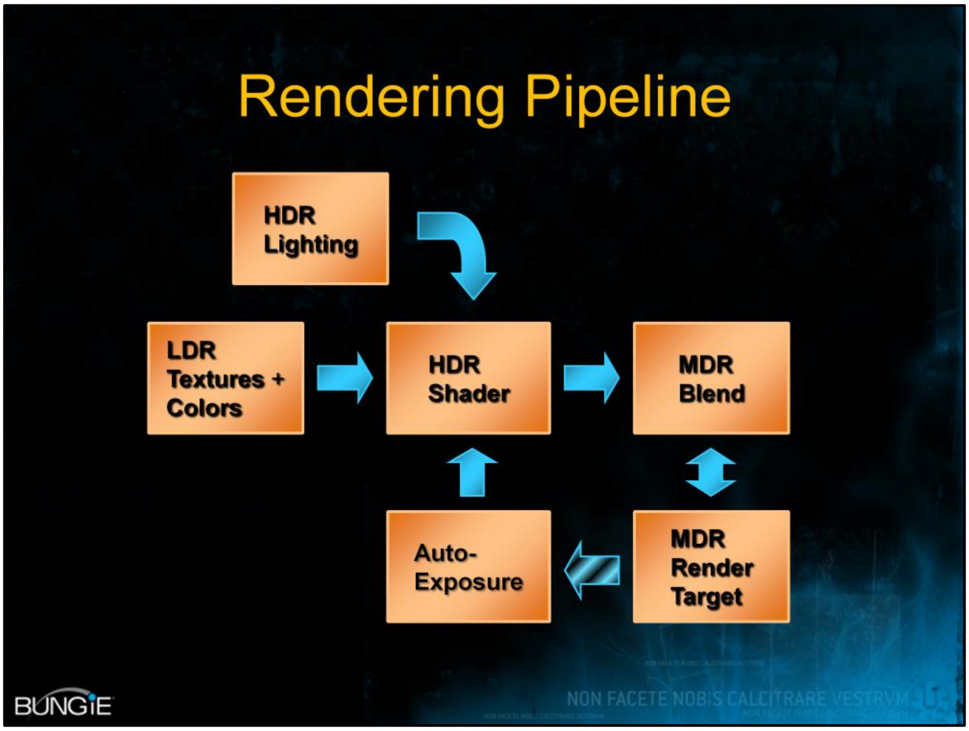
Rendering Pipeline
HDR Lighting
LDR Textures + Colors
HDR Shader
MDR Blend
Auto-Exposure
MDR Render Target
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Render Target Considerations

- Memory Size
- Render Speed
- Hardware Blend Support
- Dynamic Range
- Banding

(Dynamic Range, Banding) — Useable Exposure Range

Xbox 360 Render Targets

	16f	10-bit 7e3	10-bit lin.	8-bit xRGB	16-bit lin.
Exposure Range	30 stops	3 stops	0 stops	0 stops	5 stops
Blend Support	NO ☹	YES	YES	YES	YES
Memory Size	2x	1x	1x	1x	2x
Blend/Fill Rate	50%	50-100%	50-100%	50[illegible]%	50%

x 2

	8-bit xRGB + 8-bit xRGB
Exposure Range	7 stops
Blend Support	YES
Memory Size	2x
Blend/Fill Rate	25-50%

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Detail
Bloom
(-7 stops)
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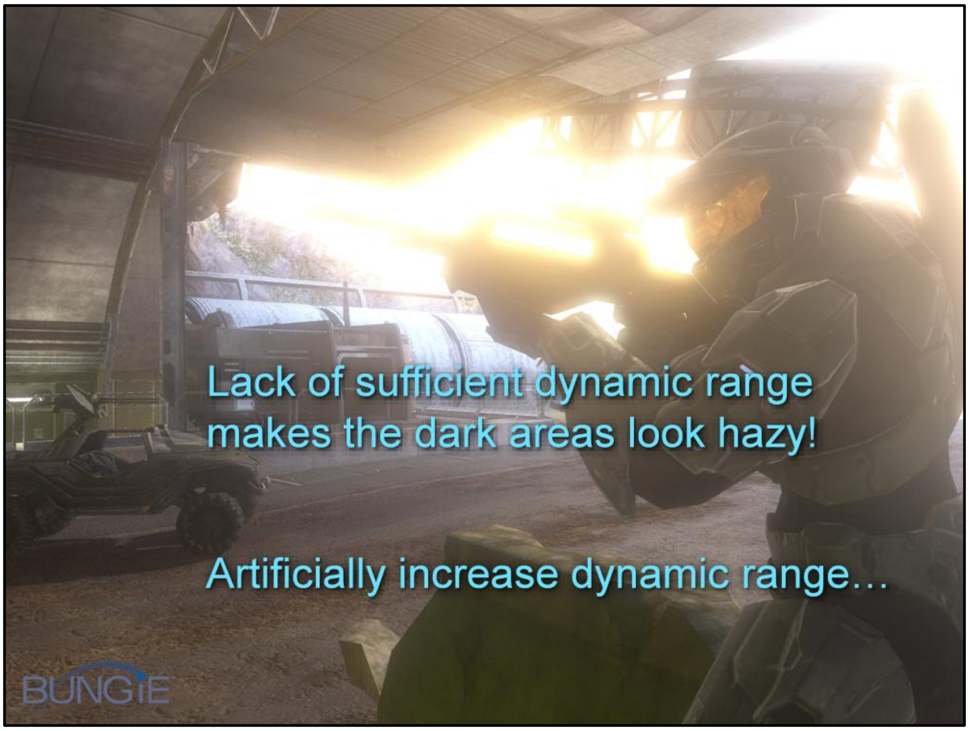
Lack of sufficient dynamic range
makes the dark areas look hazy!
Artificially increase dynamic range…
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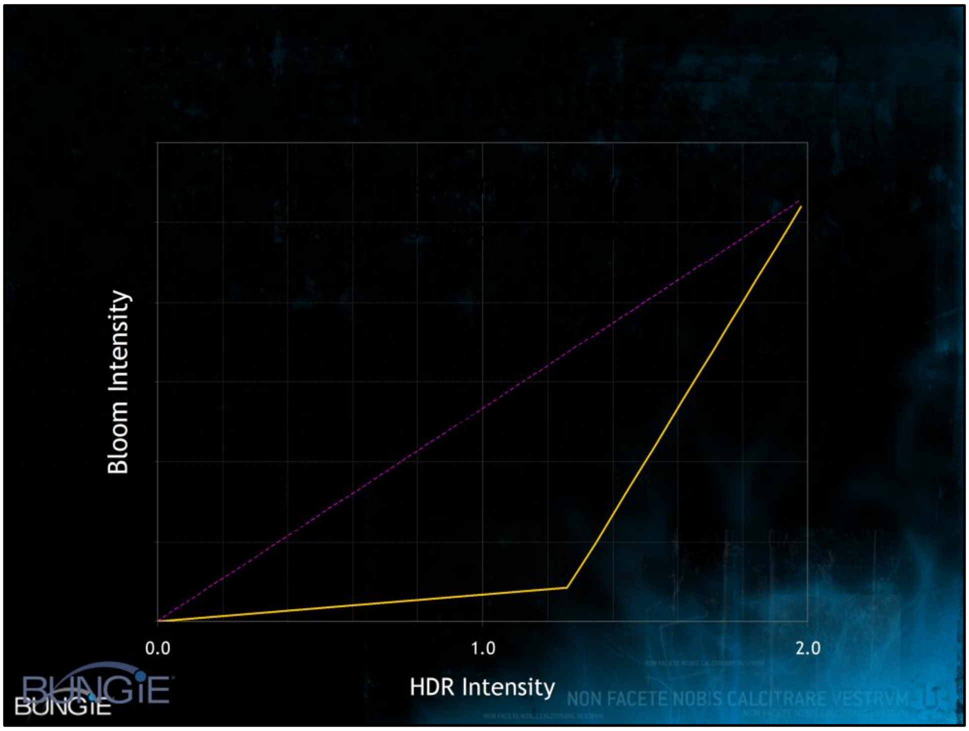
Bloom Intensity
0.0
1.0
2.0
HDR Intensity
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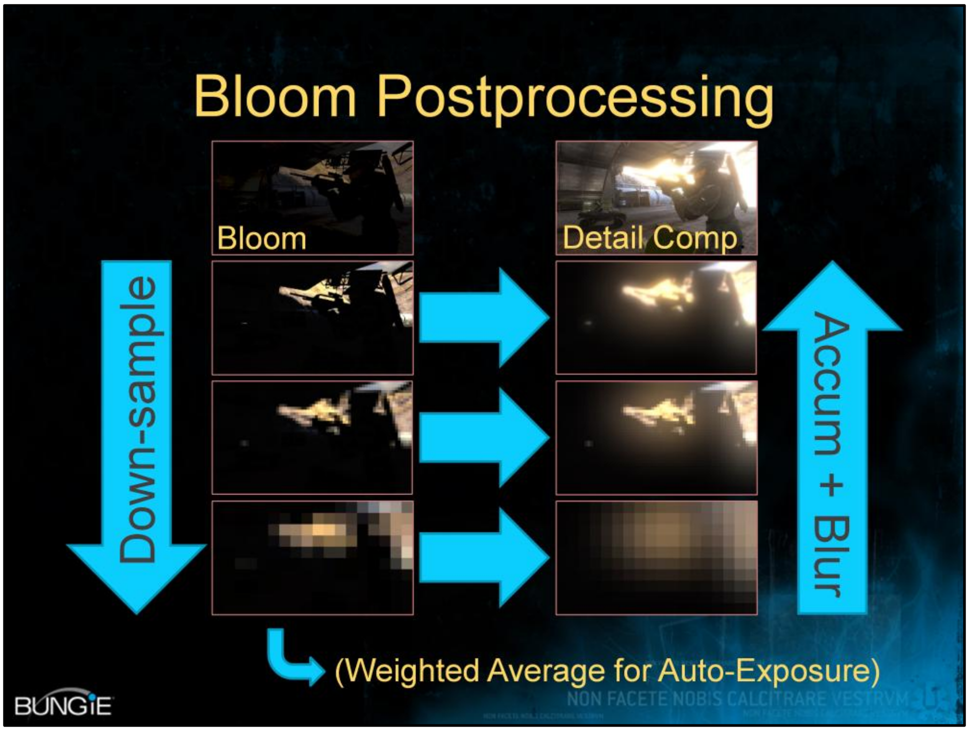
Bloom Postprocessing
Bloom
Detail Comp
Down-sample
Accum + Blur
(Weighted Average for Auto-Exposure)
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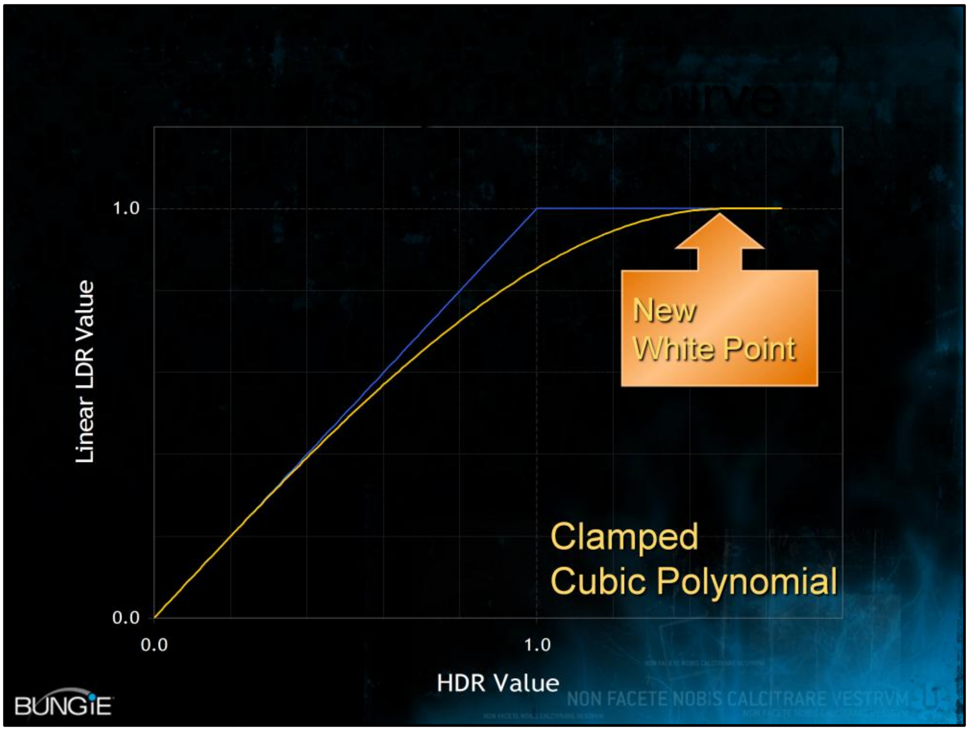
1.0
0.0
Linear LDR Value
0.0
1.0
HDR Value
New
White Point
Clamped
Cubic Polynomial
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No Tone Curve
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Tone Curve
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Conclusion

- SH light map is a natural extension to the traditional light-mapping pipeline.
- Separating material into layers is a good approximation for all frequency reflectance.
- Area specular is critical for achieving seamless lighting and material integration.
- ALU is cheap, and will get cheaper, take maximum advantage of it.

Future Work

- Global Illumination with local, moving lights.
- GI for dynamic and semi-dynamic scenes.
- Better lighting basis (less ringing, higher frequency).
- Area specular model with complex transport.
- Measured BRDF.
- Non photo-realistic rendering.

Acknowledgement

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  - Bungie: Hao Chen, Ben Wallace, Chris Tchou, David Cook, Xi Wang, Yaohua Hu.
  - MSRA: Xinguo Liu, Zhipeng Hu, Xin Huang, Minmin Gong, Kun Zhou.
- Special Thanks
  - Bungie artists.
  - Peter Pike Sloan, Baining Guo, Harry Shum
  - Kutta Srinivasan, Matt Lee, Mikey Wetzel.

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Q & A

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