Rendering with Environment Maps

Jaroslav Křivánek, KSVI, MFF UK

Jaroslav.Krivanek@mff.cuni.cz

Acknowledgement

- Mostly based on Ravi Ramamoorthi's slides available from http://inst.eecs.berkeley.edu/~cs283/fa10

Goal

- Real-time rendering with complex lighting, shadows, and possibly GI
- Infeasible – too much computation for too small a time budget

- Approaches
  - Lift some requirements, do specific-purpose tricks
    - Environment mapping, irradiance environment maps
    - SH-based lighting
  - Split the effort
    - Offline pre-computation + real-time image synthesis
    - “Pre-computed radiance transfer”

Environment mapping (a.k.a. image-based lighting)

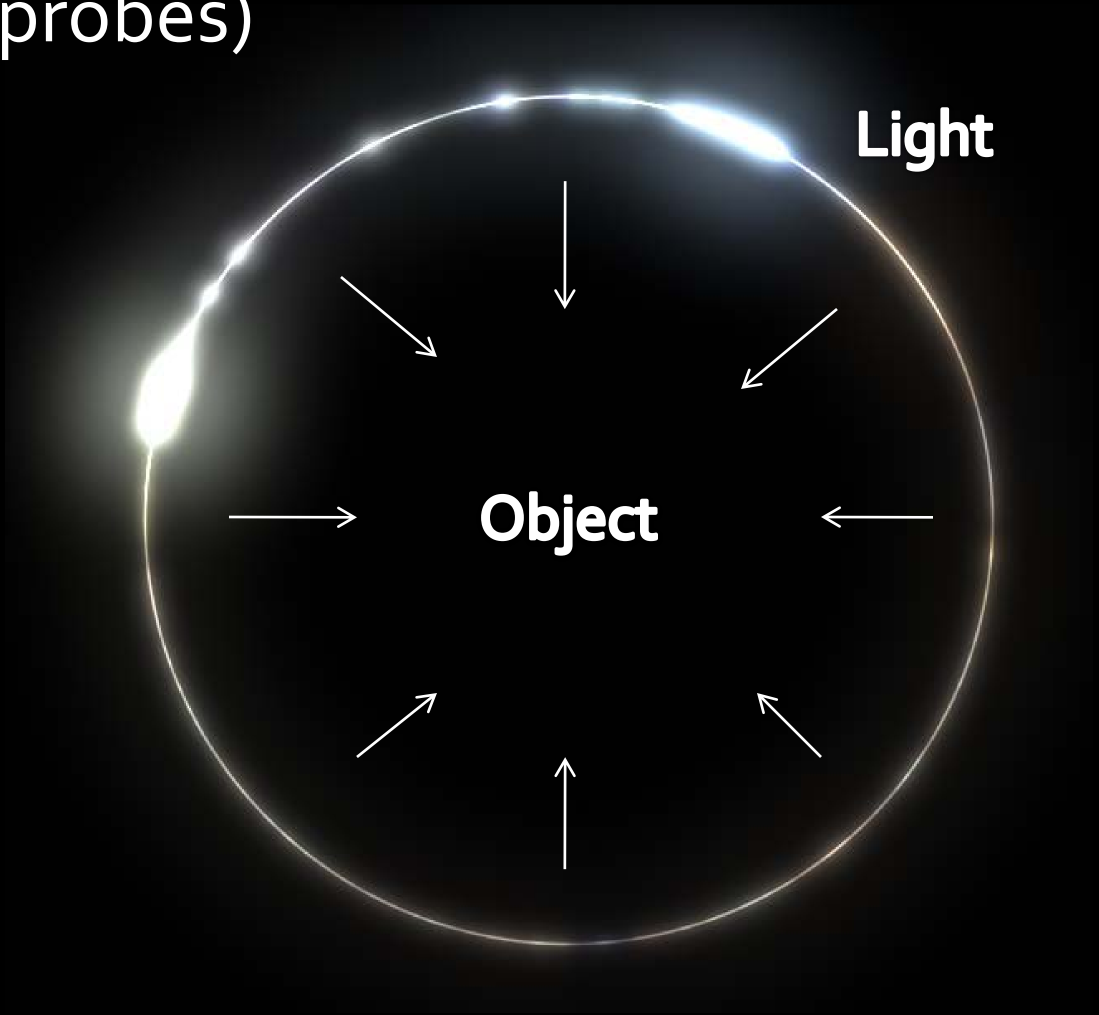
Miller and Hoffman, 1984
Later, Greene 86, Cabral et al, Debevec 97, …

Assumptions

- Distant illumination
- No shadowing, interreflection

Image-based lighting

- Illuminating CG objects using measurements of real light (=light probes)



Point lighting

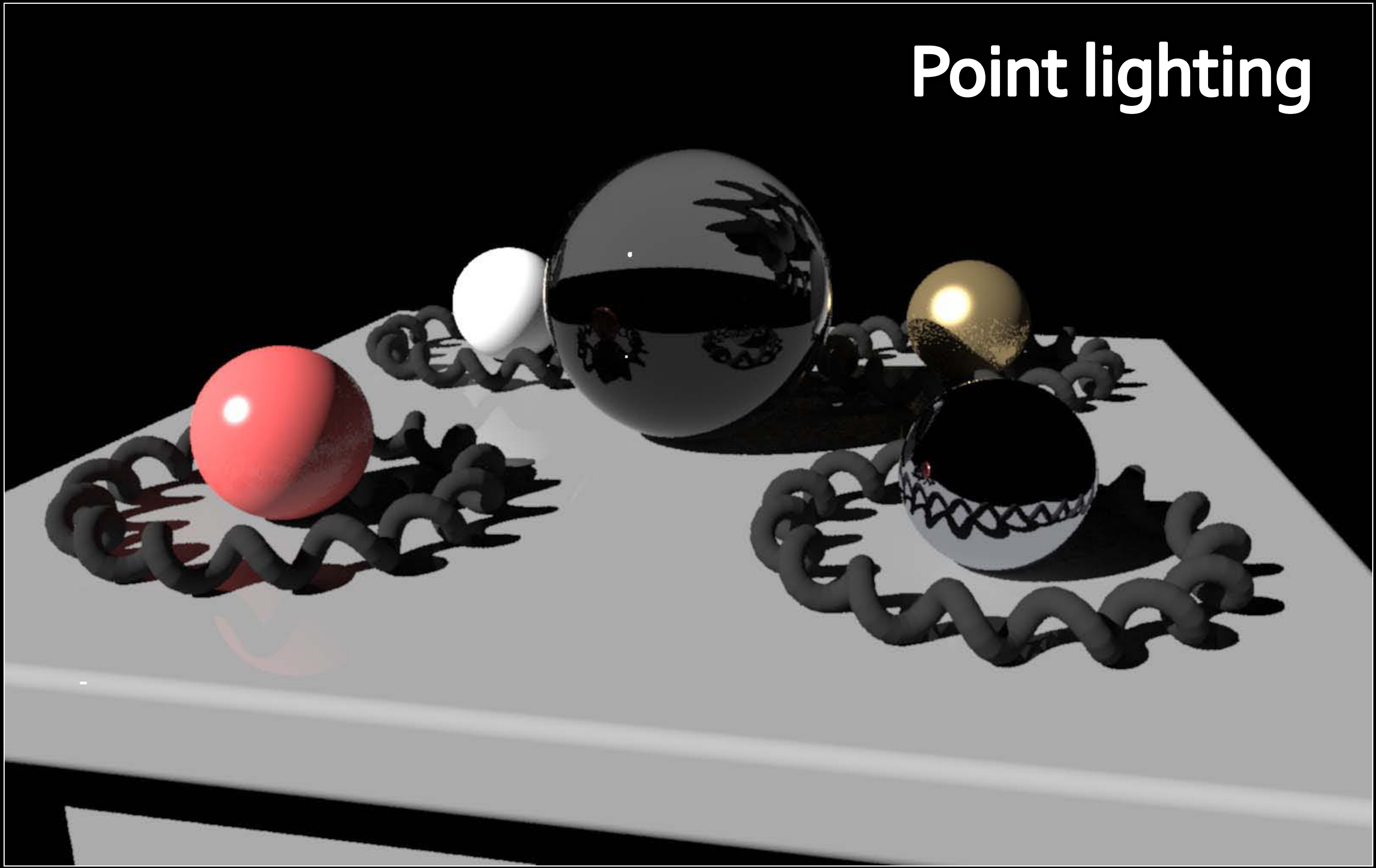


Image-based lighting

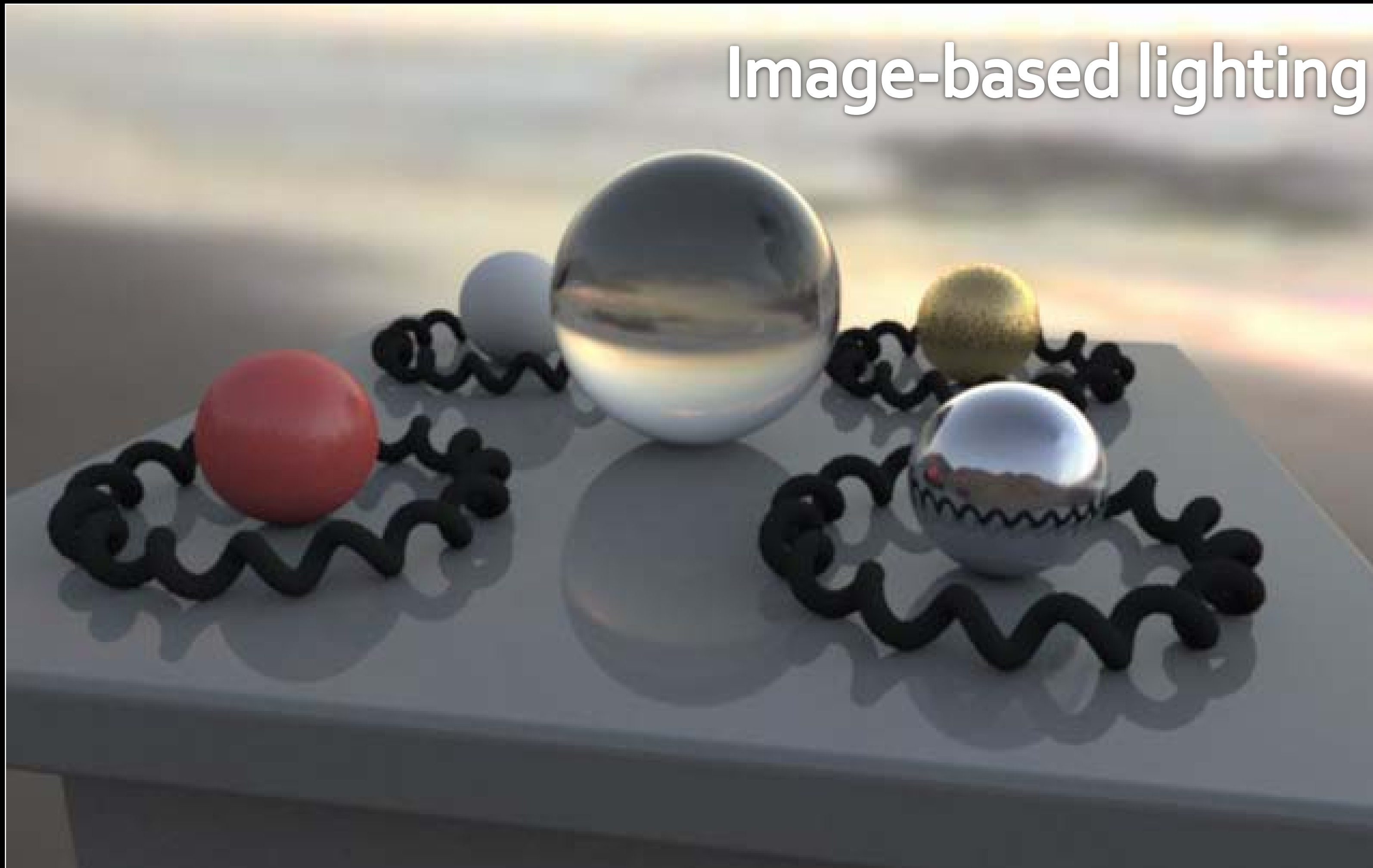


Image-based lighting

Image-based lighting

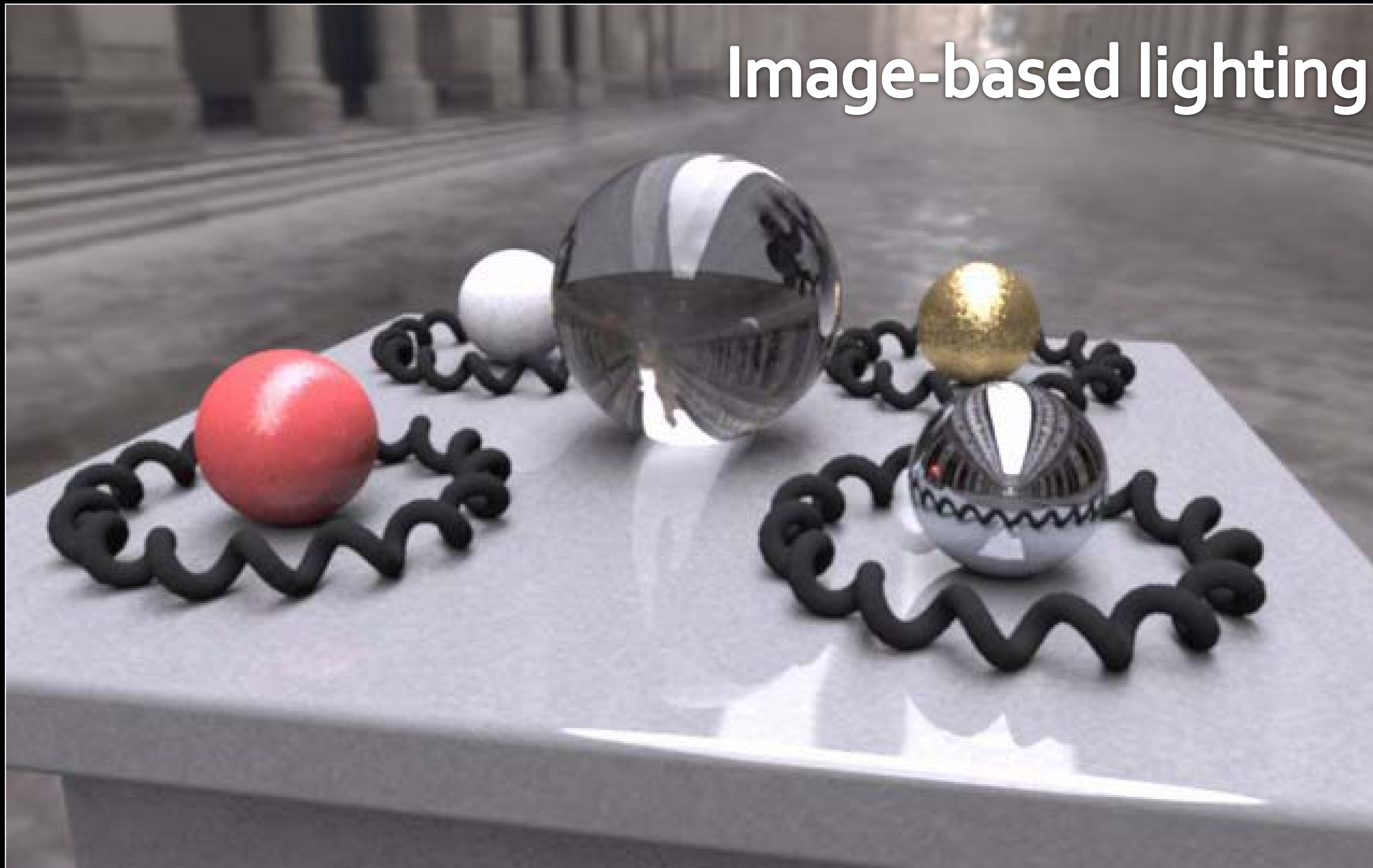
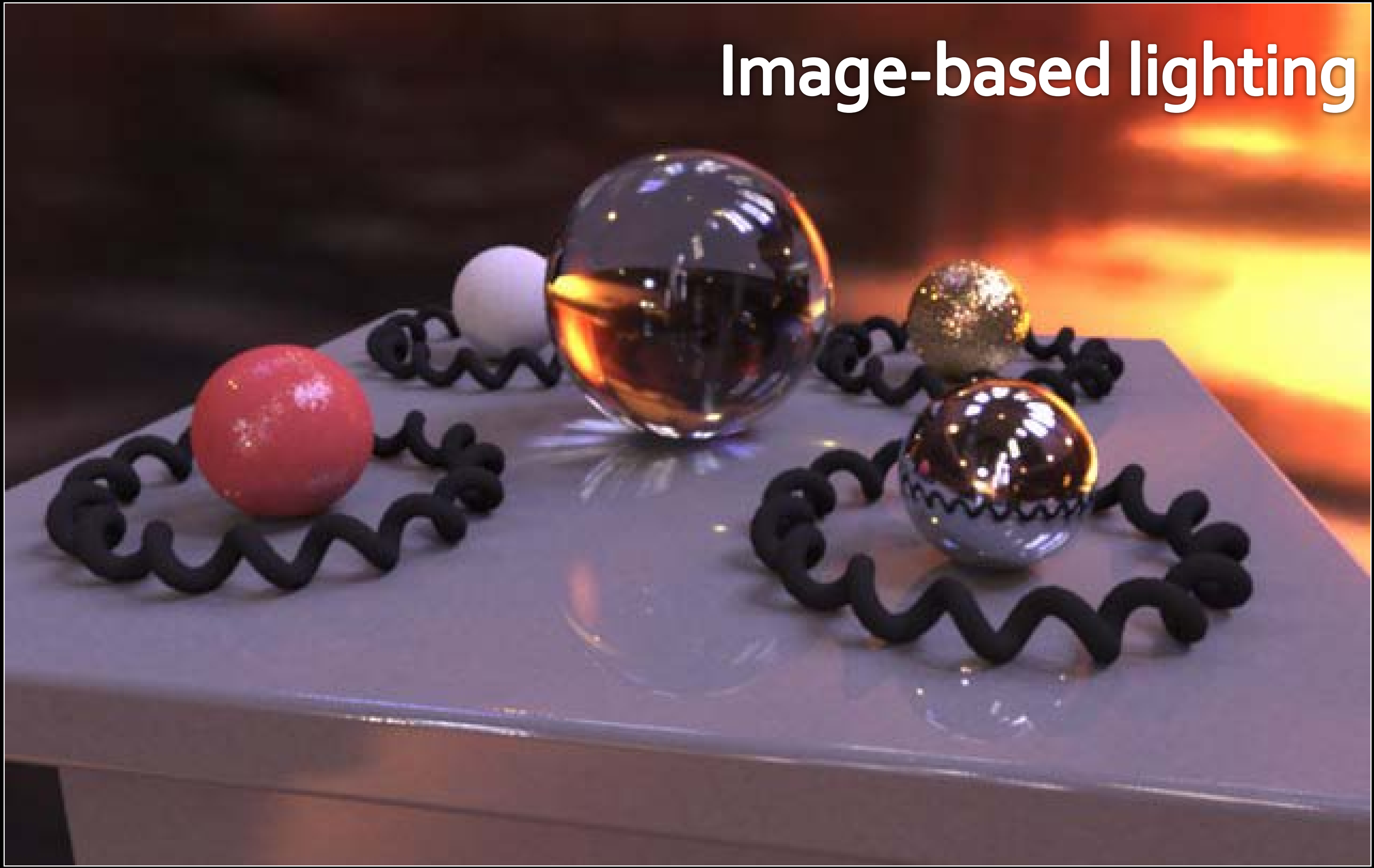
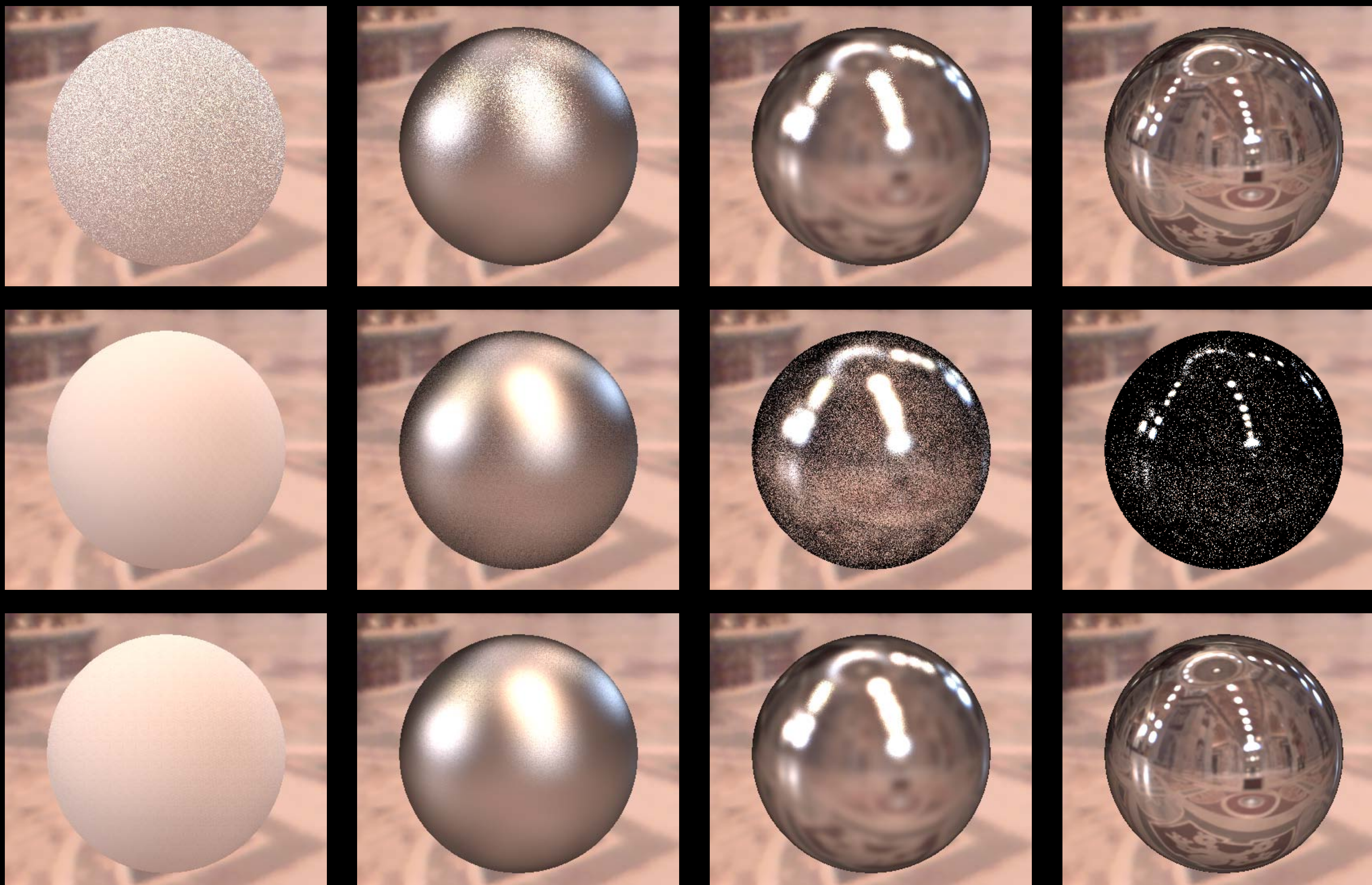


Image-based lighting



- Video
  - Rendering with natural light
  - Fiat Lux

Sampling strategies



BRDF IS
600 samples

EM IS
600 samples

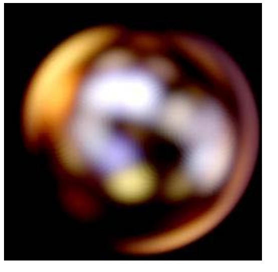
MIS
300 + 300 samples

Diffuse only | Ward BRDF, α=0.2 | Ward BRDF, α=0.05 | Ward BRDF, α=0.01

Real-time rendering

- Mirror surfaces easy
(just a texture look-up)

- What if the surface is rougher…



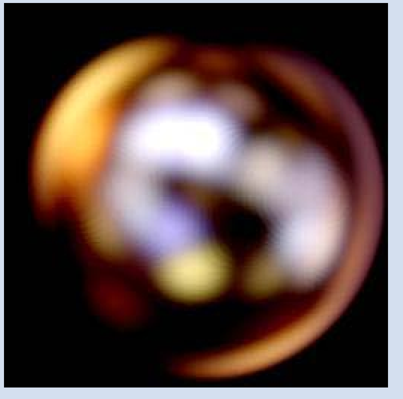
- Or completely diffuse?

Reflection Maps

- Phong model for rough surfaces
  - Illumination function of reflection direction R
- Lambertian diffuse surface
  - Illumination function of surface normal N

Matte Sphere

Chrome Sphere



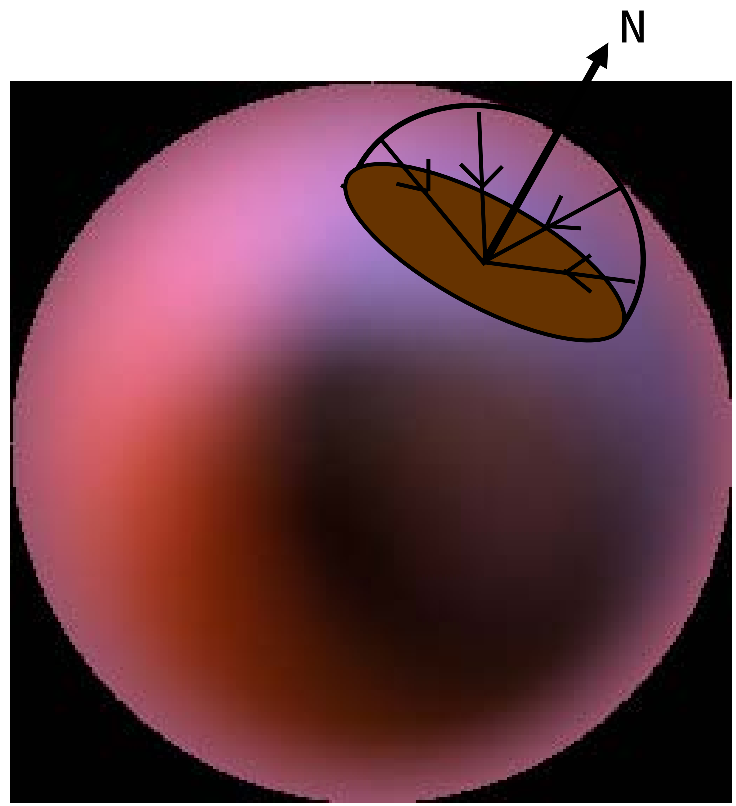
- Reflection Maps [Miller and Hoffman, 1984]
  - Irradiance (indexed by N) and Phong (indexed by R)

Reflection Maps

- Can’t do dynamic lighting
  - Slow blurring in pre-process

SH-based Irradiance Env. Maps

Incident Radiance
(Illumination Environment Map)

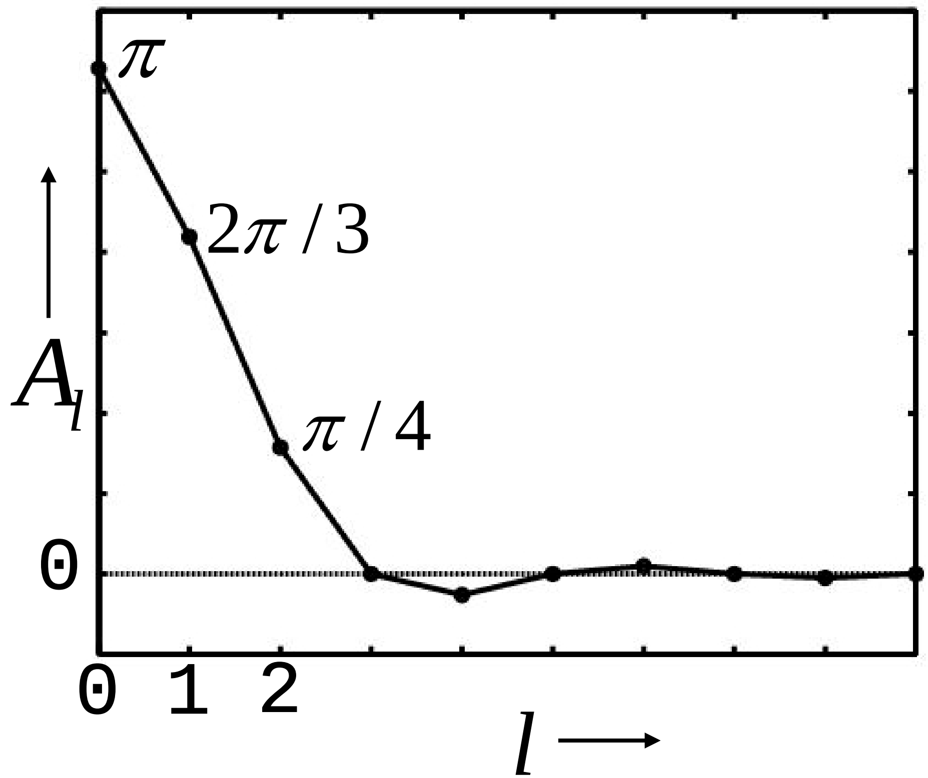


Irradiance Environment Map

Analytic Irradiance Formula

Lambertian surface acts like low-pass filter

$$E_{lm} = A_l L_{lm}$$

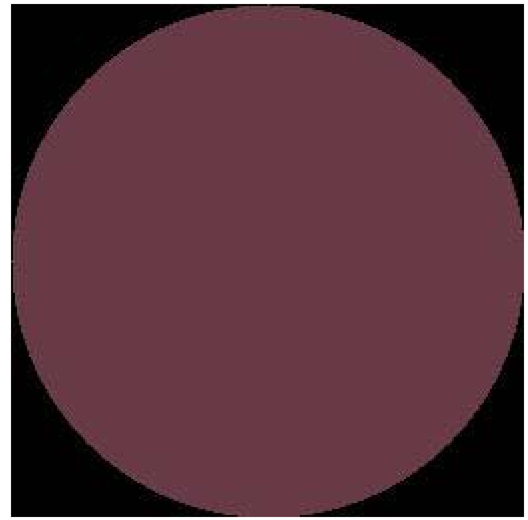


Ramamoorthi and Hanrahan 01
Basri and Jacobs 01

$$A_l = 2\pi \frac{(-1)^{\frac{l}{2}-1}}{(l+2)(l-1)} \left[\frac{l!}{2^l \left(\frac{l}{2}!\right)^2} \right] \quad l \text{ even}$$

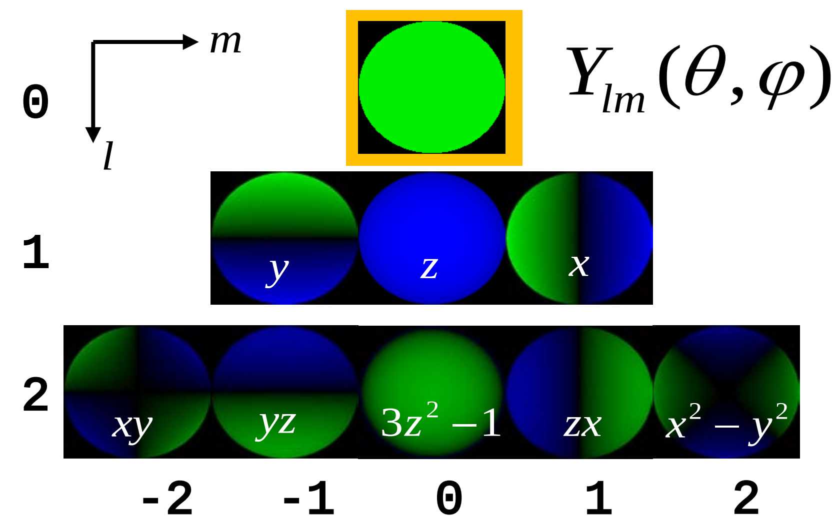
9 Parameter Approximation

Exact image



Order 0
1 term

RMS error = 25 %

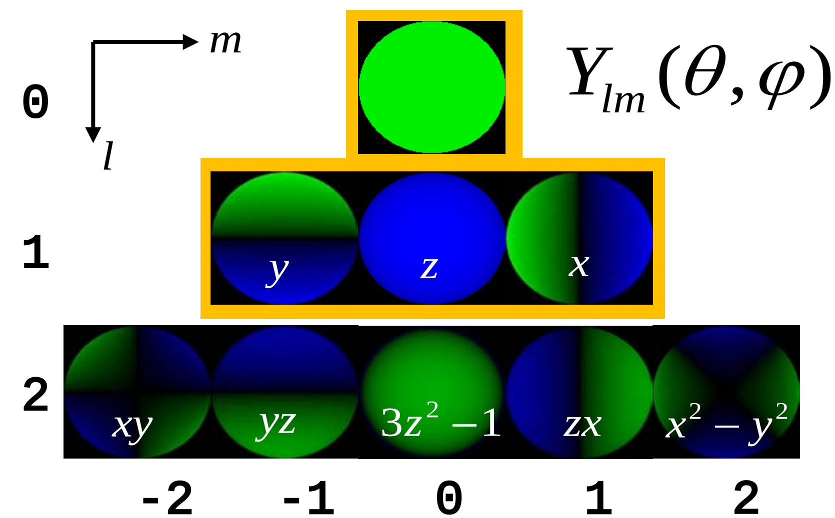


9 Parameter Approximation

Exact image

Order 1
4 terms

RMS Error = 8%

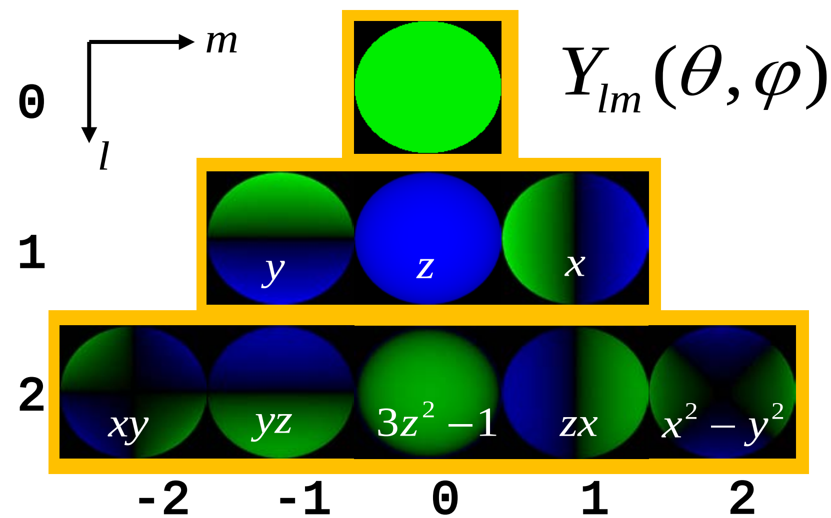


9 Parameter Approximation

Exact image

Order 2
9 terms

RMS Error = 1%



For any illumination, average error < 3% [Basri Jacobs 01]

Real-Time Rendering

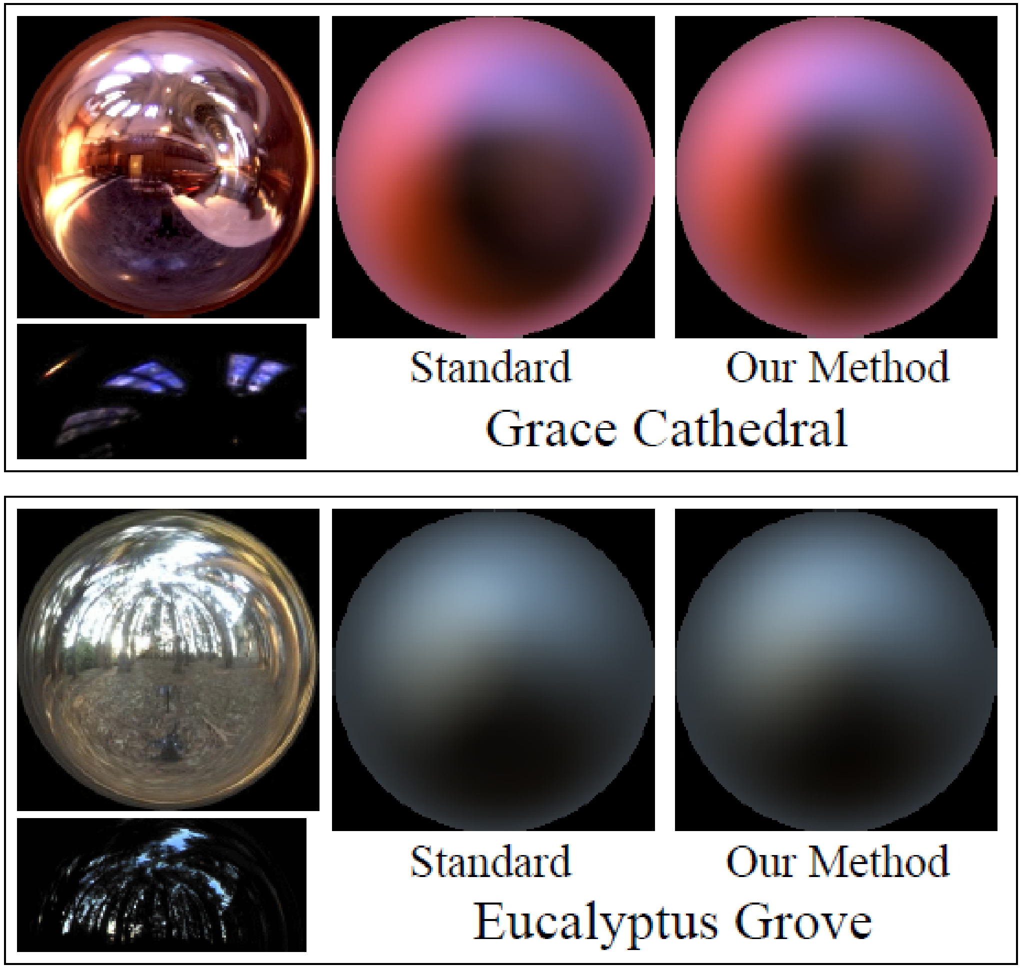
$$E(n) = n^t M n$$

- Simple procedural rendering method (no textures)
  - Requires only matrix-vector multiply and dot-product
  - In software or NVIDIA vertex programming hardware

- Widely used in Games (AMPED for Microsoft Xbox), Movies (Pixar, Framestore CFC, …)

```
surface float1 irradmat (matrix4 M, float3 v) {
        float4 n = {v , 1} ;
        return dot(n , M*n) ;
}
```

SH-based Irradiance Env. Maps



Images courtesy Ravi Ramamoorthi & Pat Hanrahan

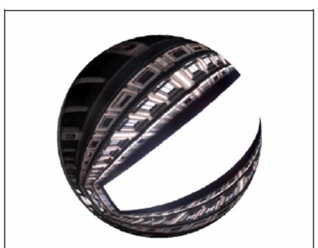
- Video – Ramamoorthi & Hanrahan 2001

SH-based Arbitrary BRDF Shading 1

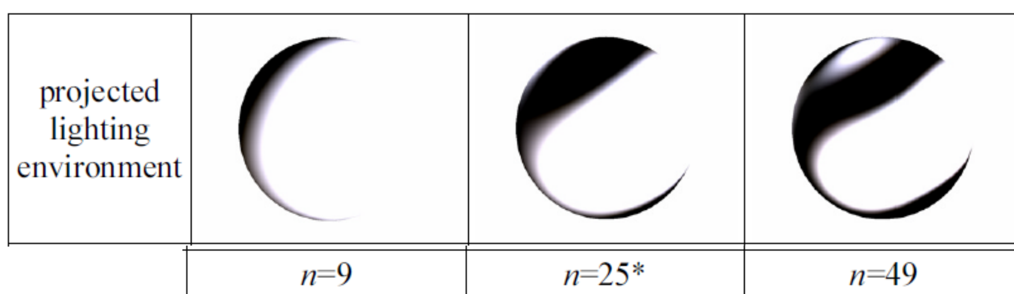
- [Kautz et al. 2003]
- Arbitrary, dynamic env. map
- Arbitrary BRDF
- No shadows

(a) point light (b) glossy (c) anisotropic

- SH representation
  - Environment map (one set of coefficients)
  - Scene BRDFs (one coefficient vector for each discretized view direction)

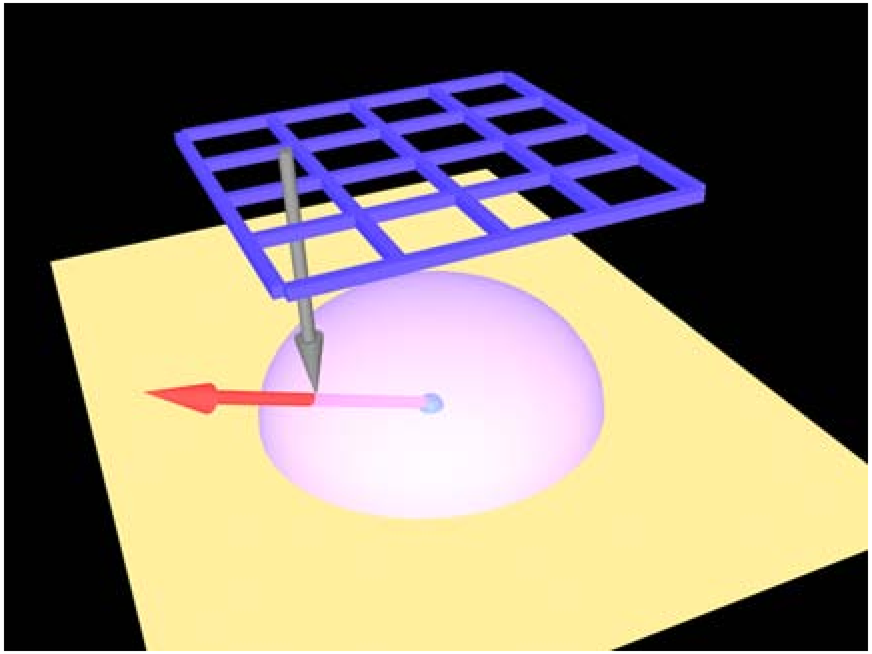


original lighting environment



SH-based Arbitrary BRDF Shading 2

- BRDF Representation
  - BRDF coefficient vector for a given ω_o, looked up from a texture (use e.g. paraboloid mapping to map ω_o to a texture coordinate)
  - BRDF coefficients pre-computed for all scene BRDFs (SH projection)

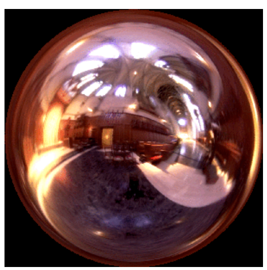


SH-based Arbitrary BRDF Shading 3

- Rendering: for each vertex / pixel, do

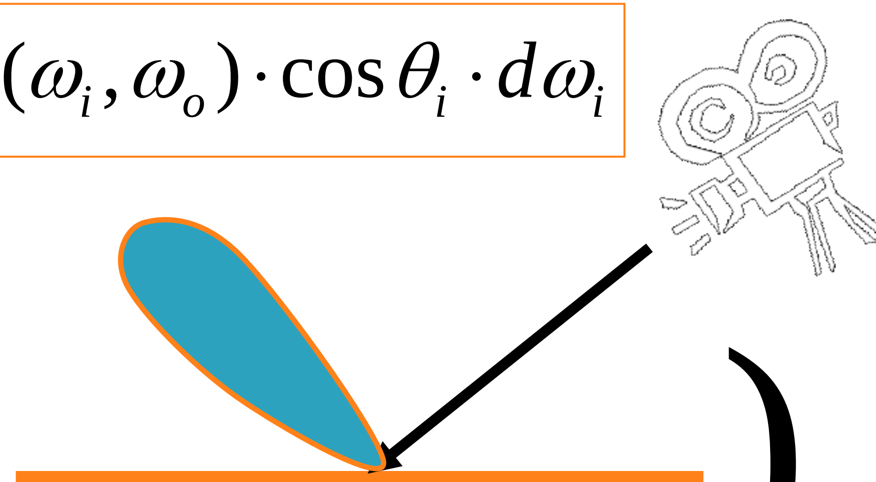
$$L_o(\omega_o) = \int_\Omega L_i(\omega_i) \cdot BRDF(\omega_i, \omega_o) \cdot \cos\theta_i \cdot d\omega_i$$

$\int ($



Environment map

$\bullet$



BRDF

$)$

= coeff. dot product

$$L_o(\omega_o) = \Lambda_{\text{intp}}(\mathbf{p}) \bullet F(\mathbf{p}, \omega_o)$$

SH-based Arbitrary BRDF Shading 4

- BRDF is in local frame
- Environment map in global frame
- Need coordinate frame alignment -> **SH rotation**

- SH closed under rotation
  - rotation matrix
  - Fastest known procedure is the *zxzxz*-decomposition [Kautz et al. 2003]

$$R_{SH} = \left[\begin{array}{c|ccc|ccccc|c}
\mathbf{1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots \\
\hline
0 & \mathbf{X} & \mathbf{X} & \mathbf{X} & 0 & 0 & 0 & 0 & 0 & \cdots \\
0 & \mathbf{X} & \mathbf{X} & \mathbf{X} & 0 & 0 & 0 & 0 & 0 & \cdots \\
0 & \mathbf{X} & \mathbf{X} & \mathbf{X} & 0 & 0 & 0 & 0 & 0 & \cdots \\
\hline
0 & 0 & 0 & 0 & \mathbf{X} & \mathbf{X} & \mathbf{X} & \mathbf{X} & \mathbf{X} & \cdots \\
0 & 0 & 0 & 0 & \mathbf{X} & \mathbf{X} & \mathbf{X} & \mathbf{X} & \mathbf{X} & \cdots \\
0 & 0 & 0 & 0 & \mathbf{X} & \mathbf{X} & \mathbf{X} & \mathbf{X} & \mathbf{X} & \cdots \\
0 & 0 & 0 & 0 & \mathbf{X} & \mathbf{X} & \mathbf{X} & \mathbf{X} & \mathbf{X} & \cdots \\
0 & 0 & 0 & 0 & \mathbf{X} & \mathbf{X} & \mathbf{X} & \mathbf{X} & \mathbf{X} & \cdots \\
\hline
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots
\end{array}\right]$$

SH-based Arbitrary BRDF Shading 5

Figure 3: *Brushed metal head in various lighting environments.*

(a) varying exponent *(b) varying anisotropy*

Figure 4: *Spatially-Varying BRDFs.*

- Video: Kautz 2003

Environment Map Summary

- Very popular for interactive rendering
- Extensions handle complex materials
- Shadows with precomputed transfer

- But cannot directly combine with shadow maps
- Limited to distant lighting assumption