Path Tracing II

Computer Graphics
Fall Semester 2025 FHNW

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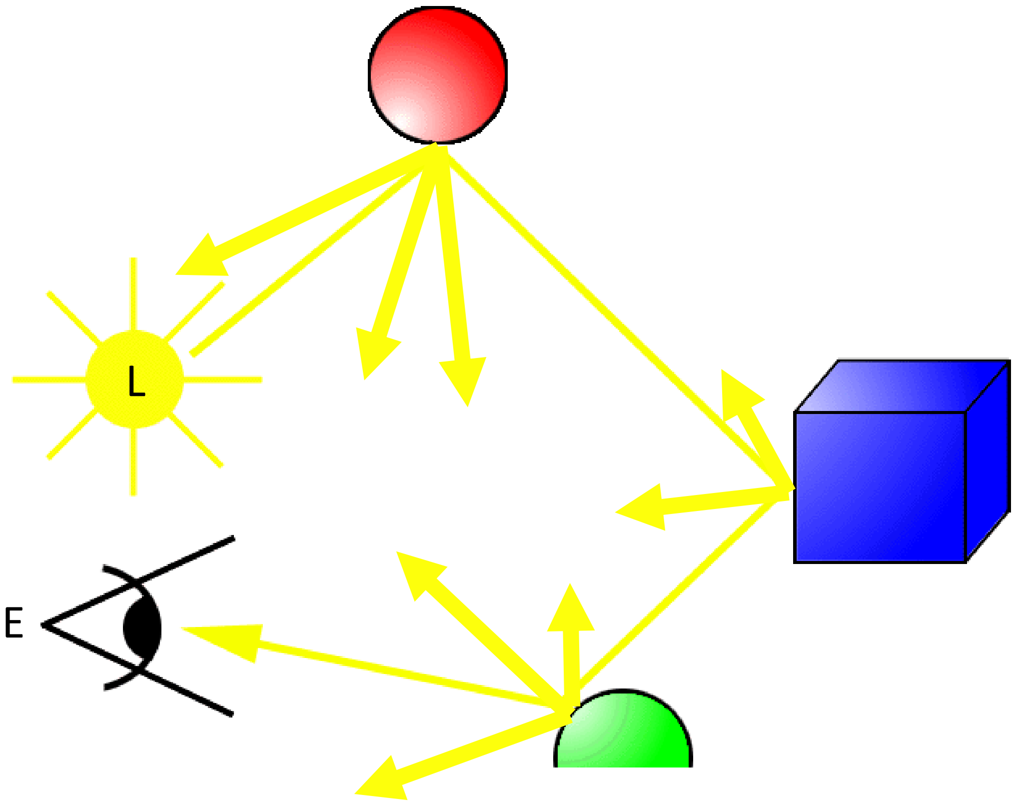
School of Computer Science

Light Paths

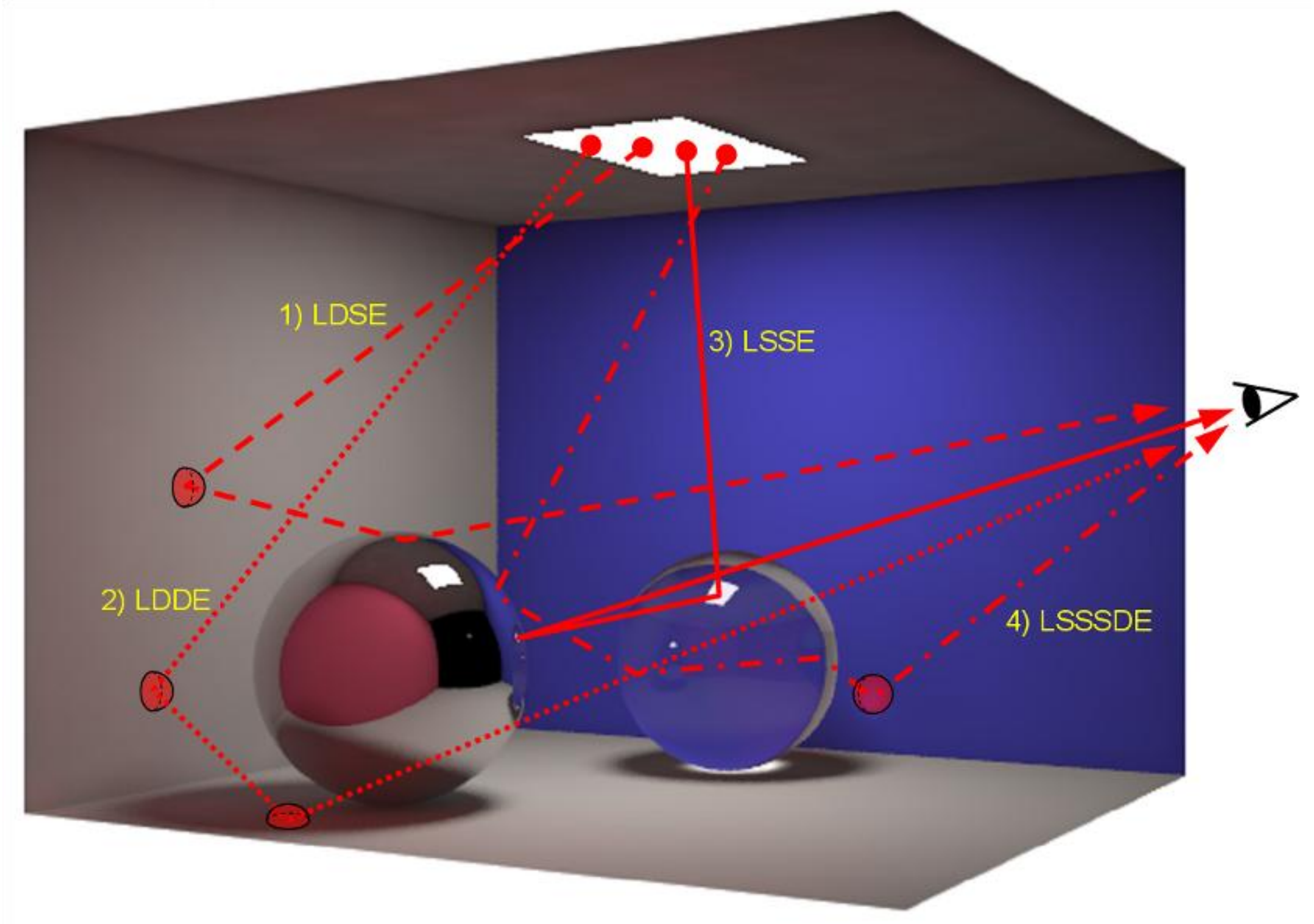


Light Source

Diffuse Reflection

Specular Reflection

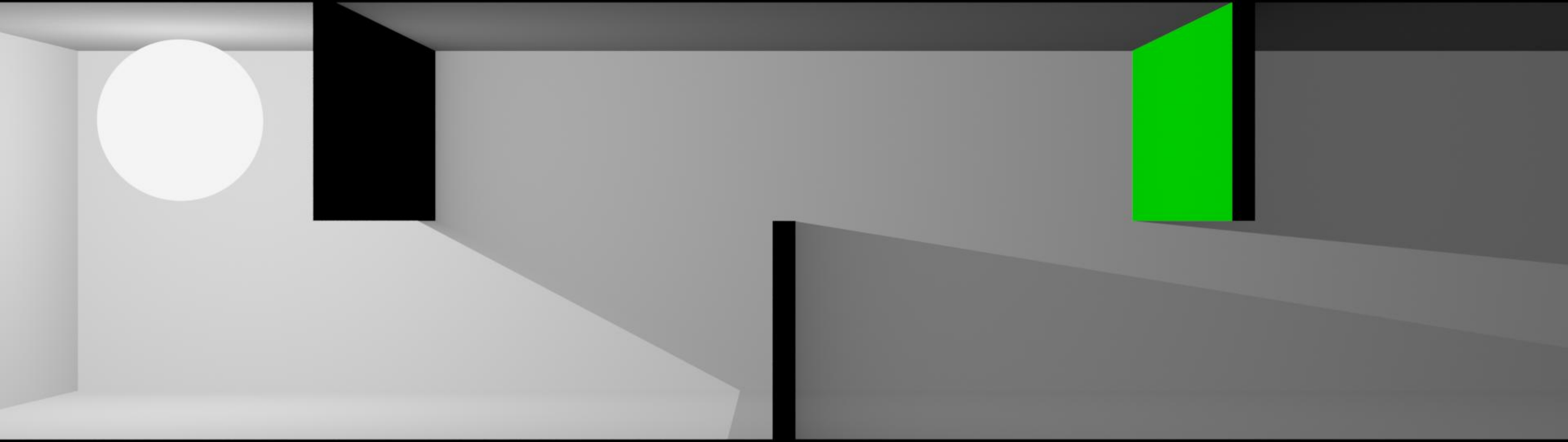
Eye

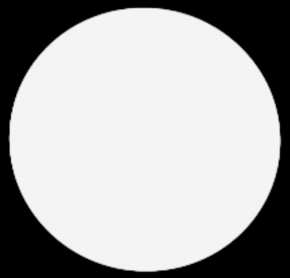


There are many kinds of light paths: **L(D|S)*E**

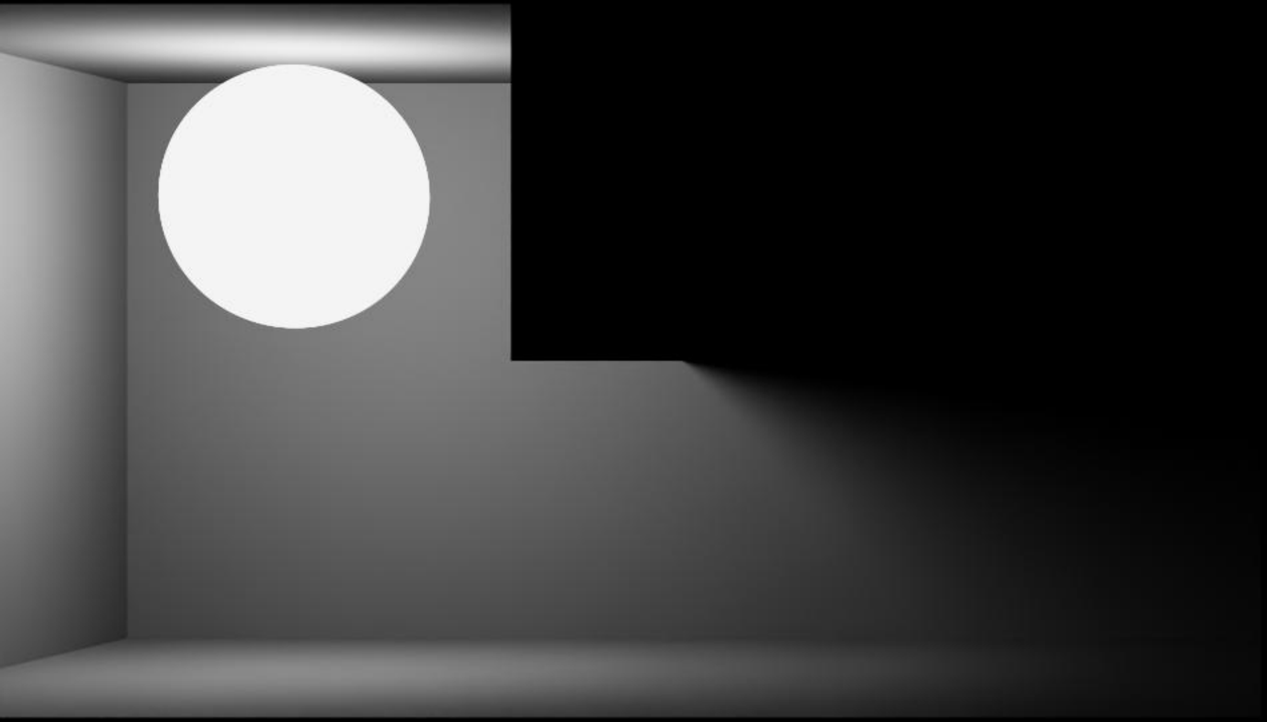
2) Floor illuminated by diffuse reflection of wall

4) Wall illuminated by light passing through sphere

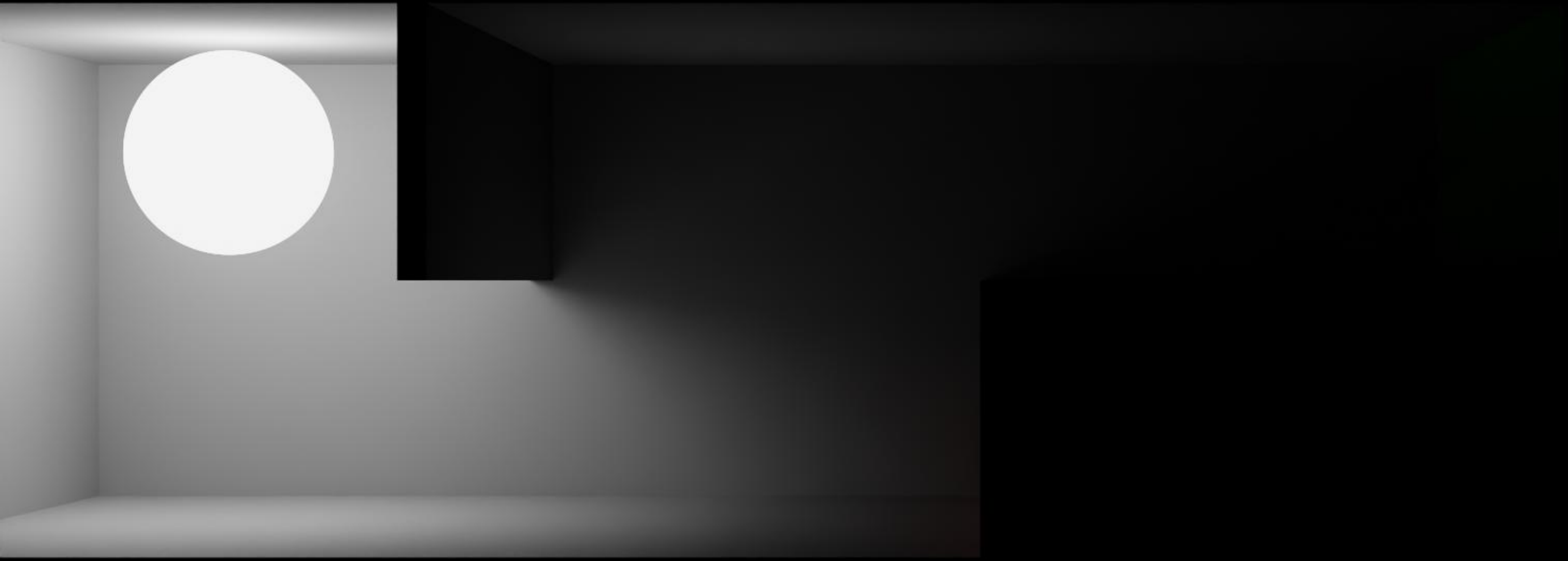




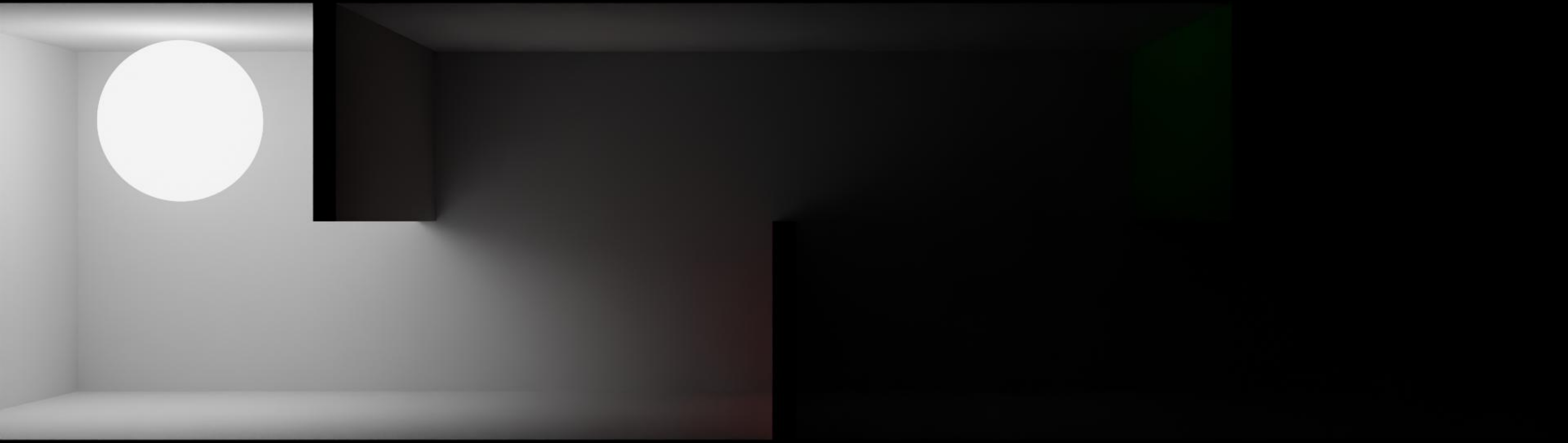
LE



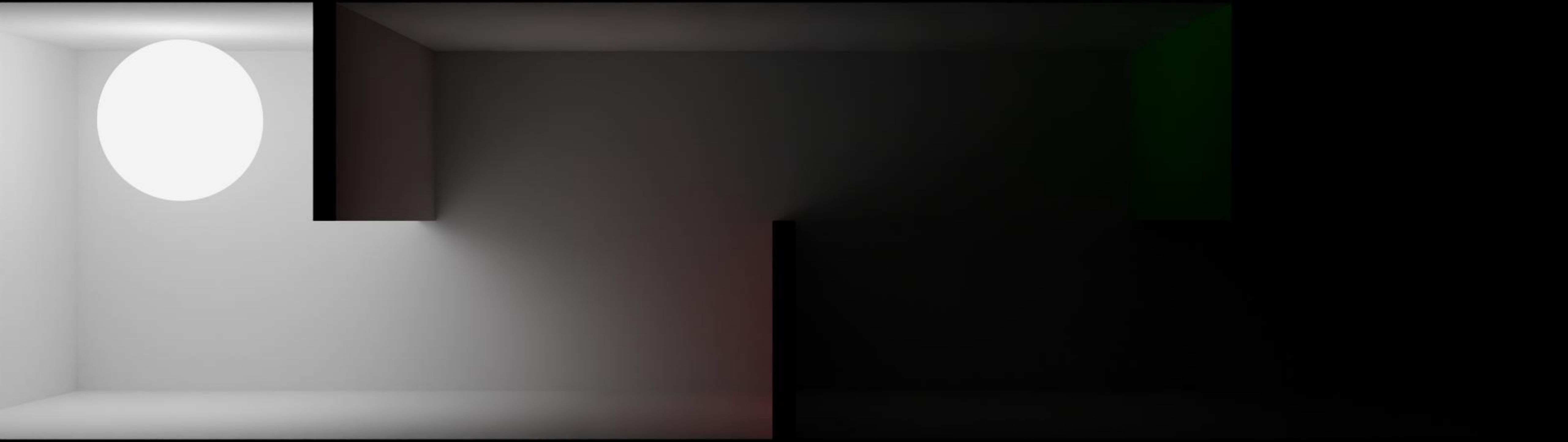
LD?E



LD{,2}E

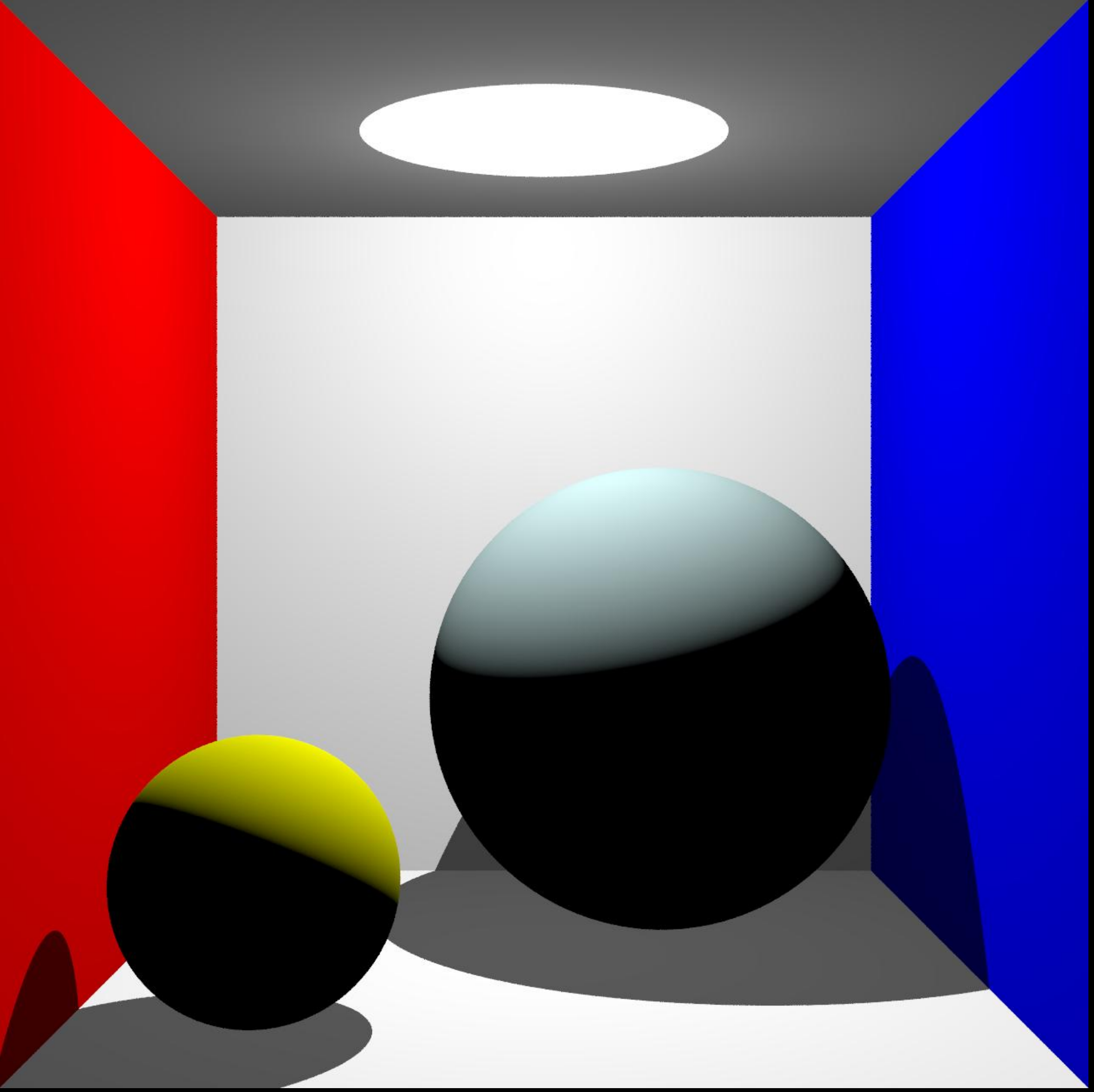


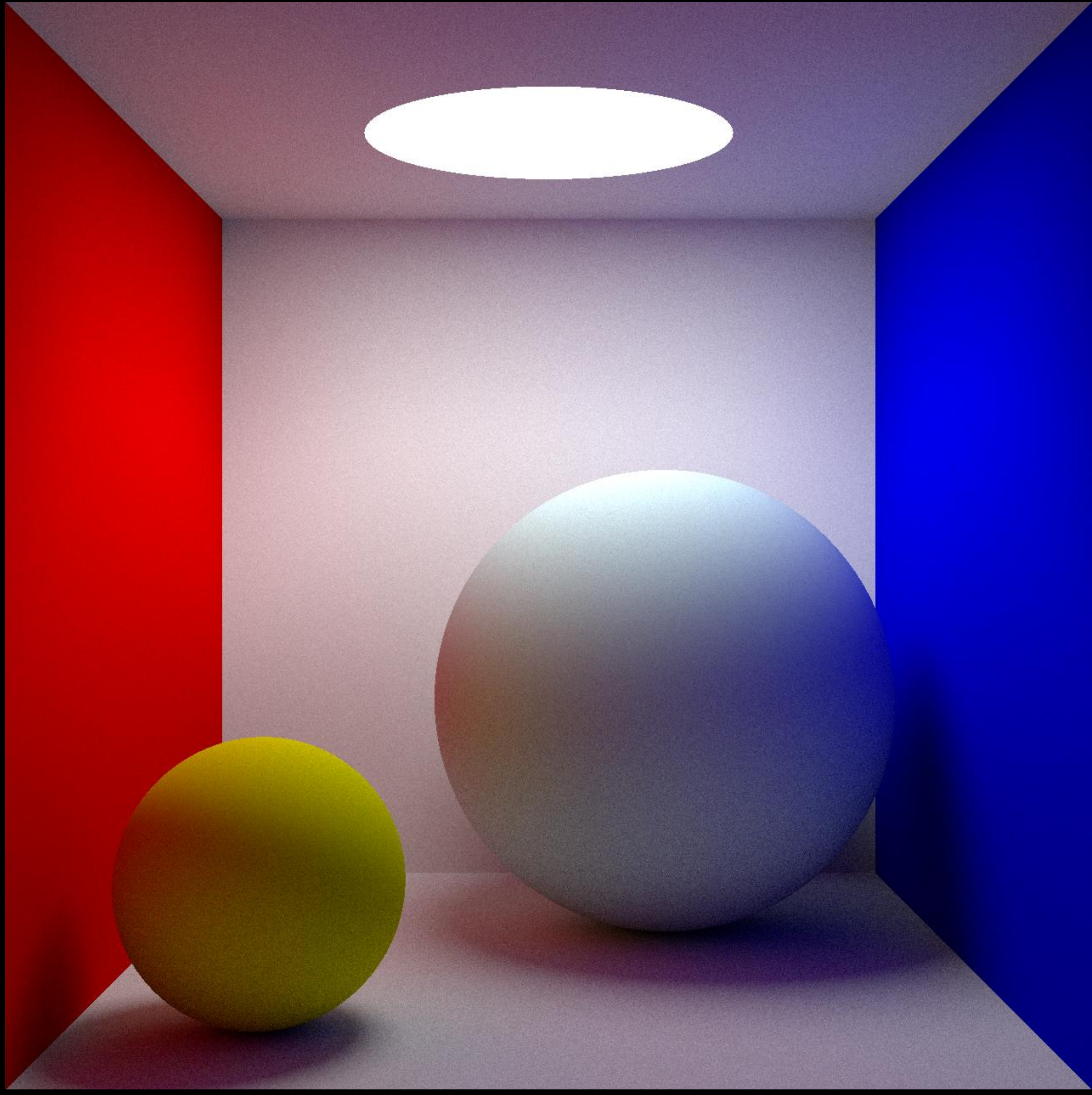
LD{,3}E

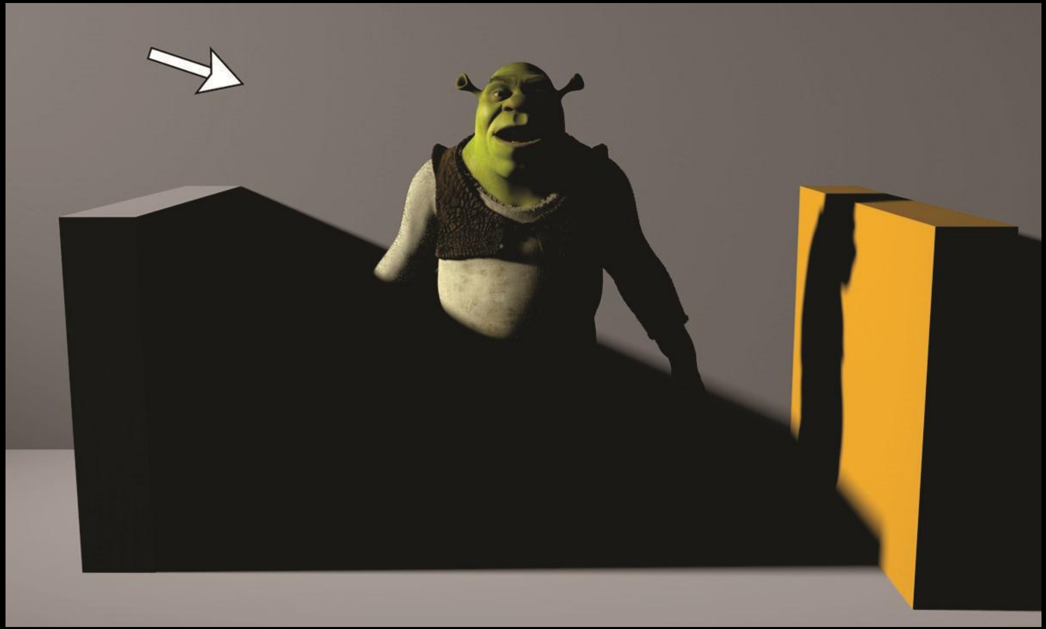


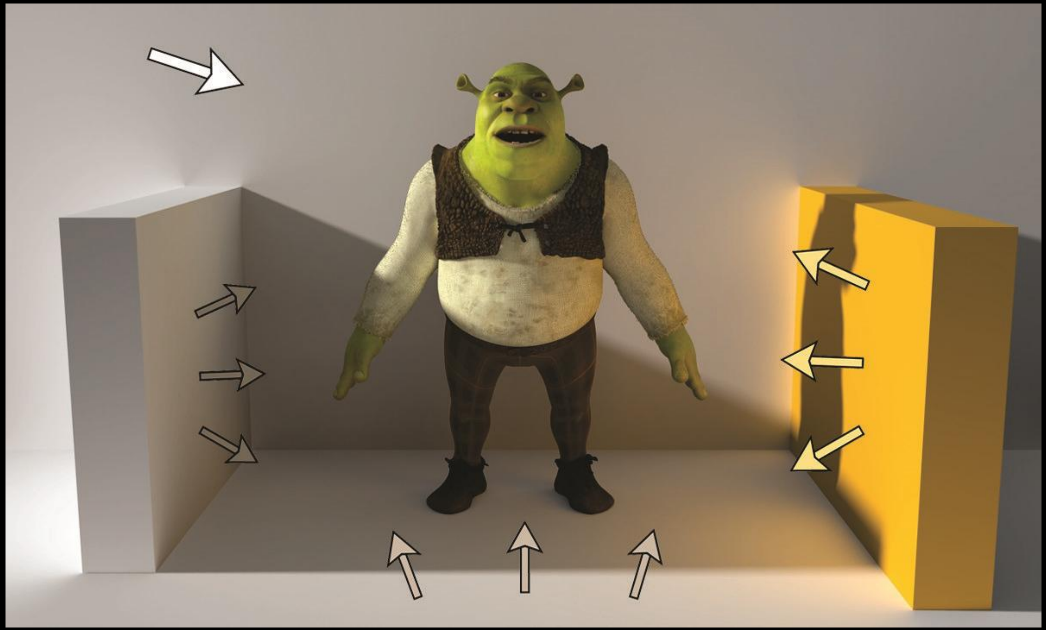
LD{,4}E

(Global Illumination)
LD*E


LD?E


LD*E (Global Illumination)



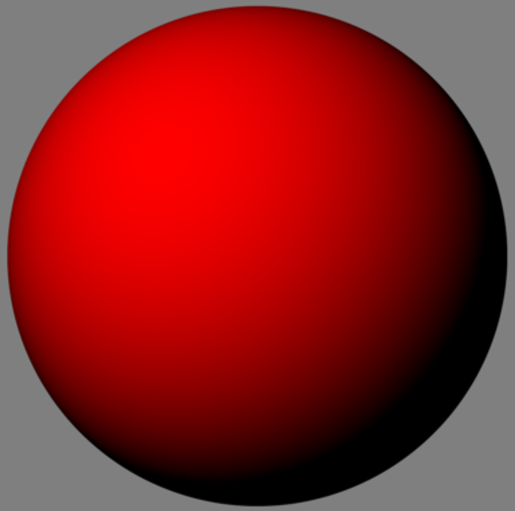


Global Illumination is being used in movies since 2004 (Shrek II)

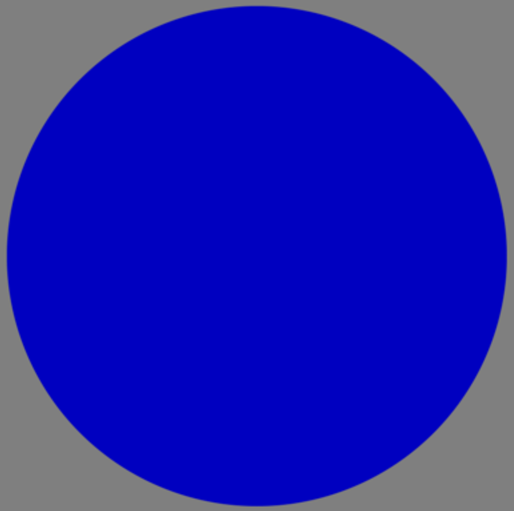
Accelerated with techniques like Importance Sampling, Manifold Exploration, Path Guiding, Irradiance Caching, Spatiotemporal Reservoir Sampling, Point-based GI, Radiosity, Photon Mapping, Screen-Space GI, Path Guiding, Reflective Shadow Maps and many others.

$$\begin{bmatrix}1\\1\\1\end{bmatrix} \qquad \begin{bmatrix}1\\0\\0\end{bmatrix} \qquad \begin{bmatrix}0\\0\\0.2\end{bmatrix} \qquad \begin{bmatrix}1\\0\\0.2\end{bmatrix}$$

$Light \odot$



$\odot \dots +$



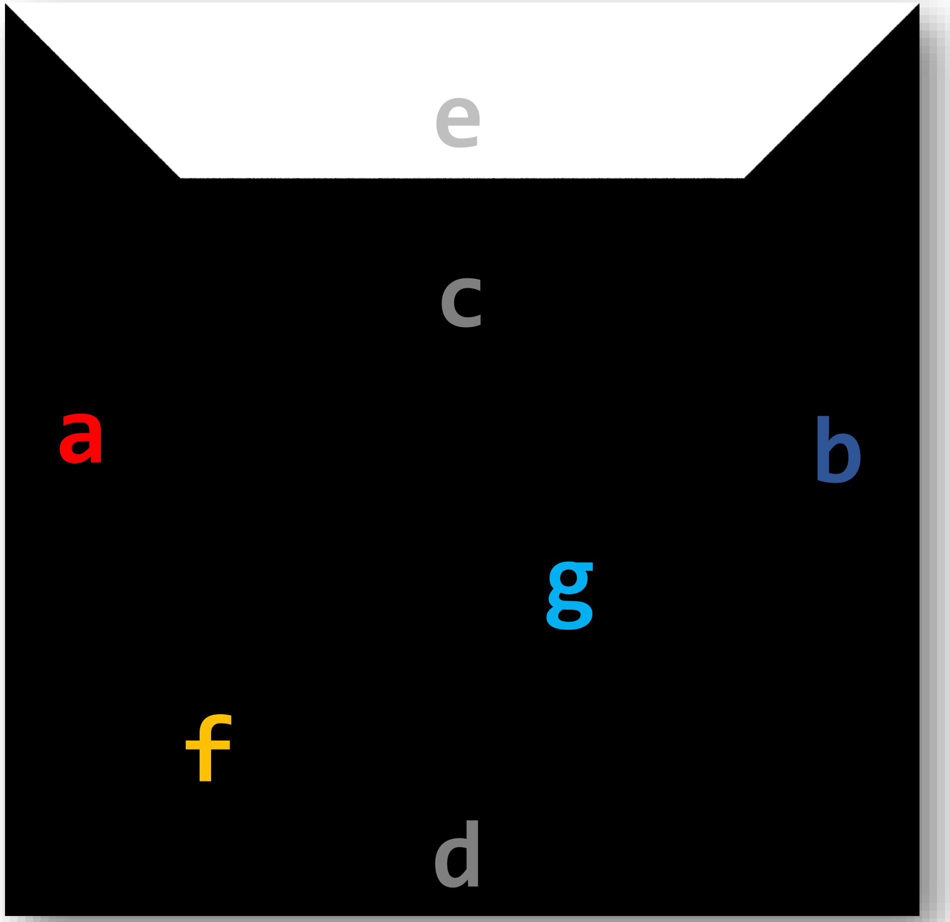
$=$

"Diffuse reflectance"
or "Lambert reflectance"
or "material color"
or "Albedo"

"Emission"
or "Luminance"

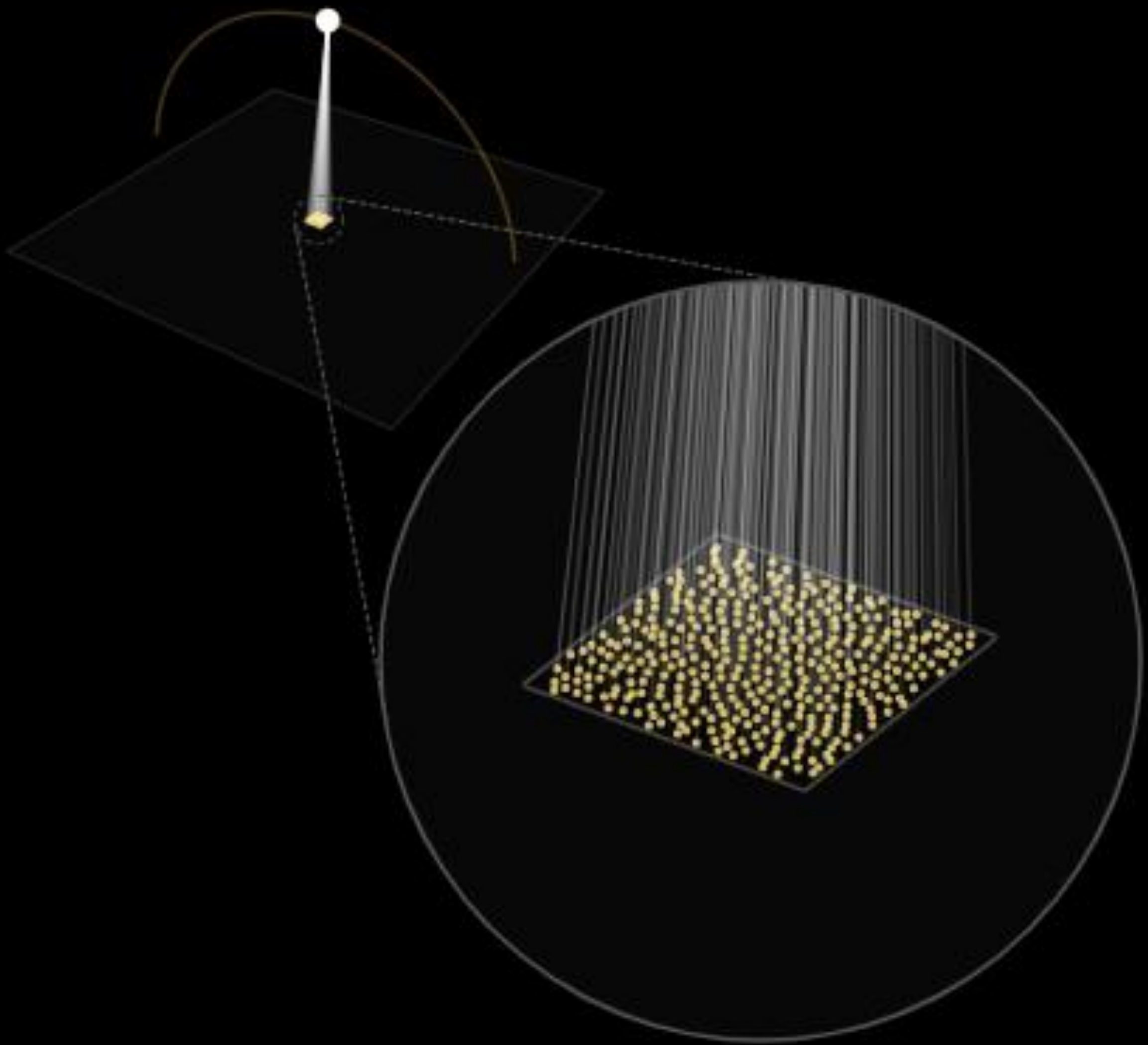
Combined result

Introducing Light Sources

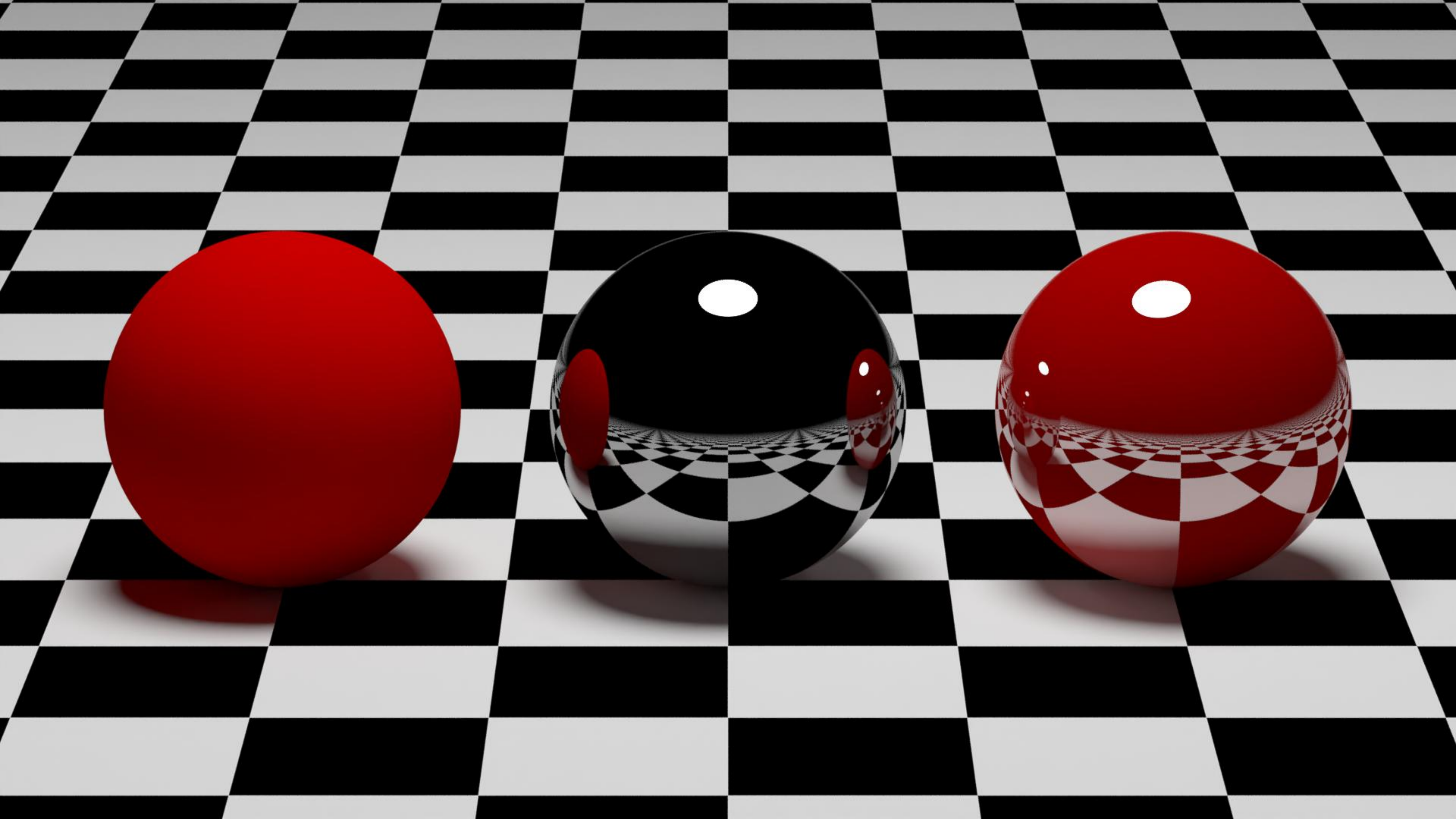



```
Scene
{
  Sphere(…, Diffuse=      Red, Emission=      Black) a
  Sphere(…, Diffuse=     Blue, Emission=      Black) b
  Sphere(…, Diffuse=     Gray, Emission=      Black) c
  Sphere(…, Diffuse=     Gray, Emission=      Black) d
  Sphere(…, Diffuse=    White, Emission= 2 * White) e
  Sphere(…, Diffuse=   Yellow, Emission=      Black) f
  Sphere(…, Diffuse=LightCyan, Emission=      Black) g
}
```

Why $\overrightarrow{\omega_i} \cdot \vec{n}$?



Animation: Bartosz Ciechanowski (https://ciechanow.ski/lights-and-shadows/)

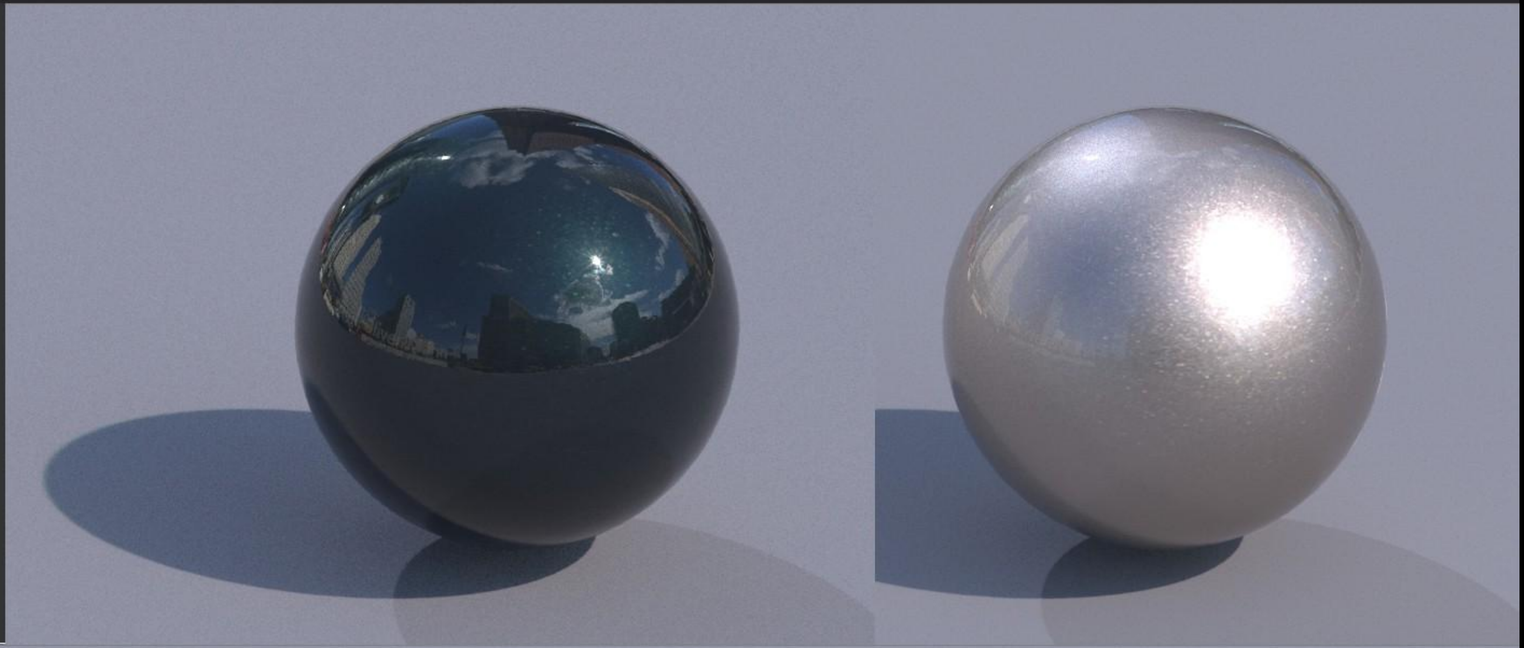


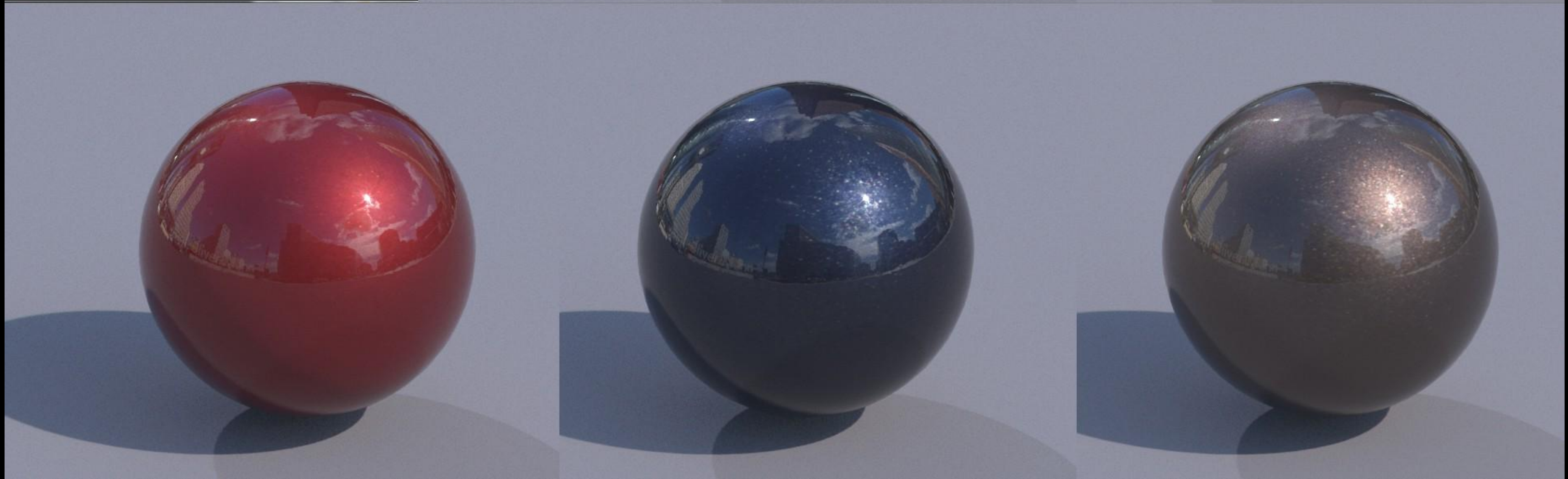
teamup

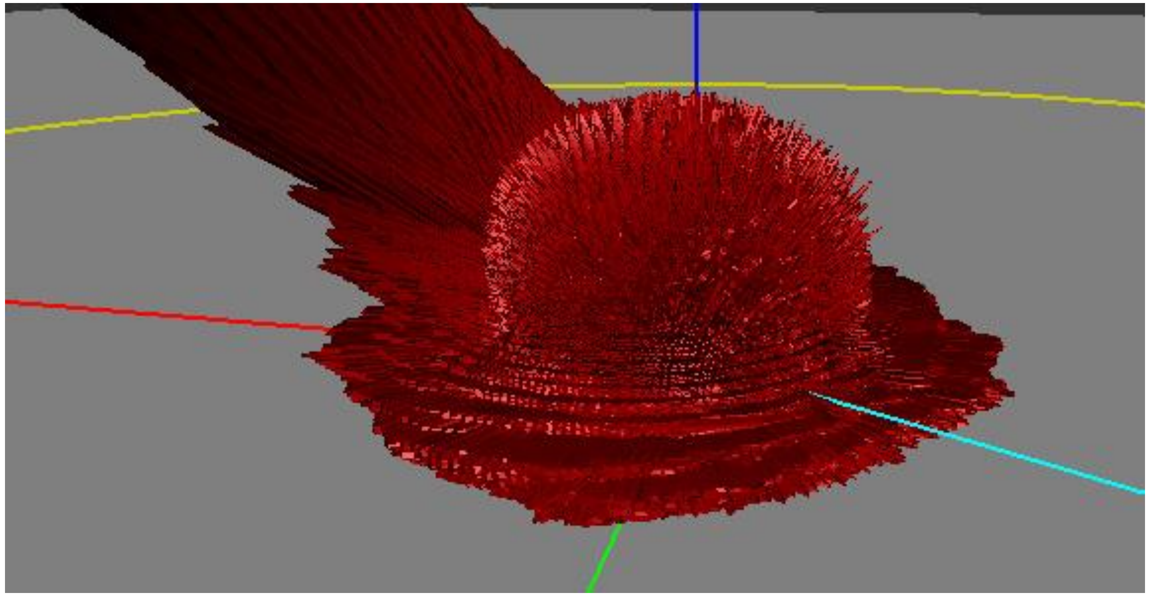
Rendered using Multi-Optics

Measured Carpaints.

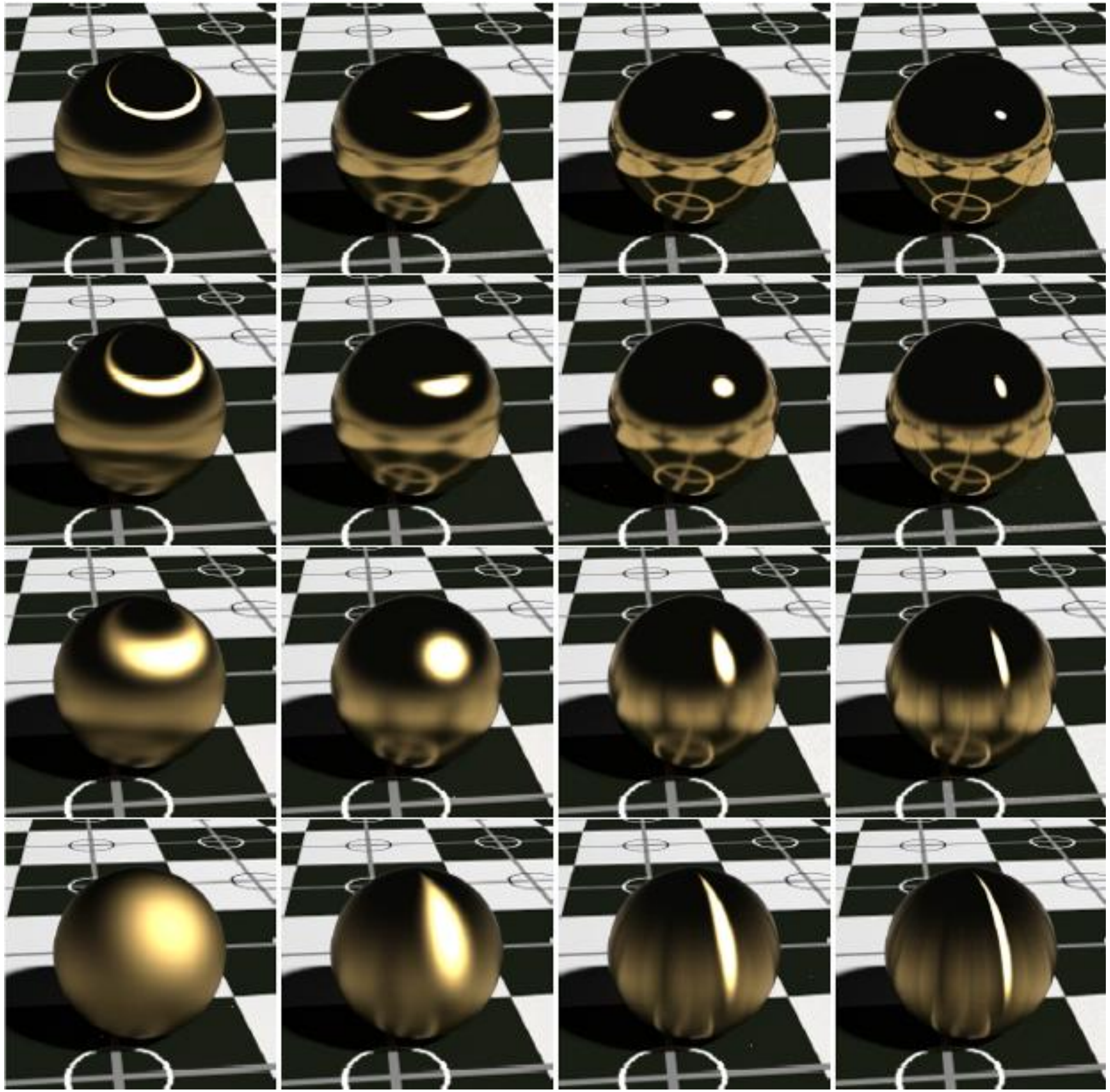
Editable Flakes and Colors.







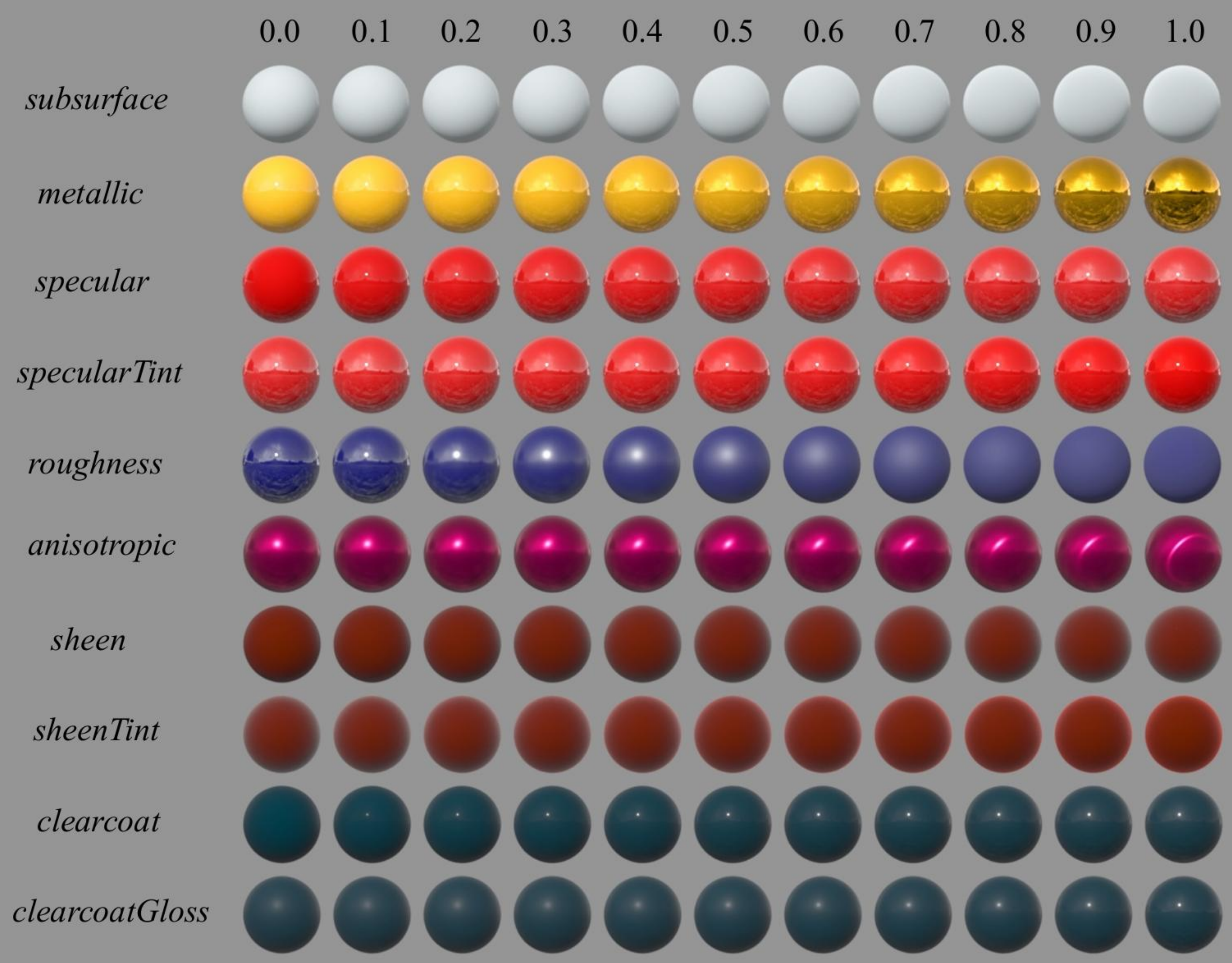
Nylon BRDF, Disney Research



An Anisotropic Phong BRDF Model, Ashikhmin et al.

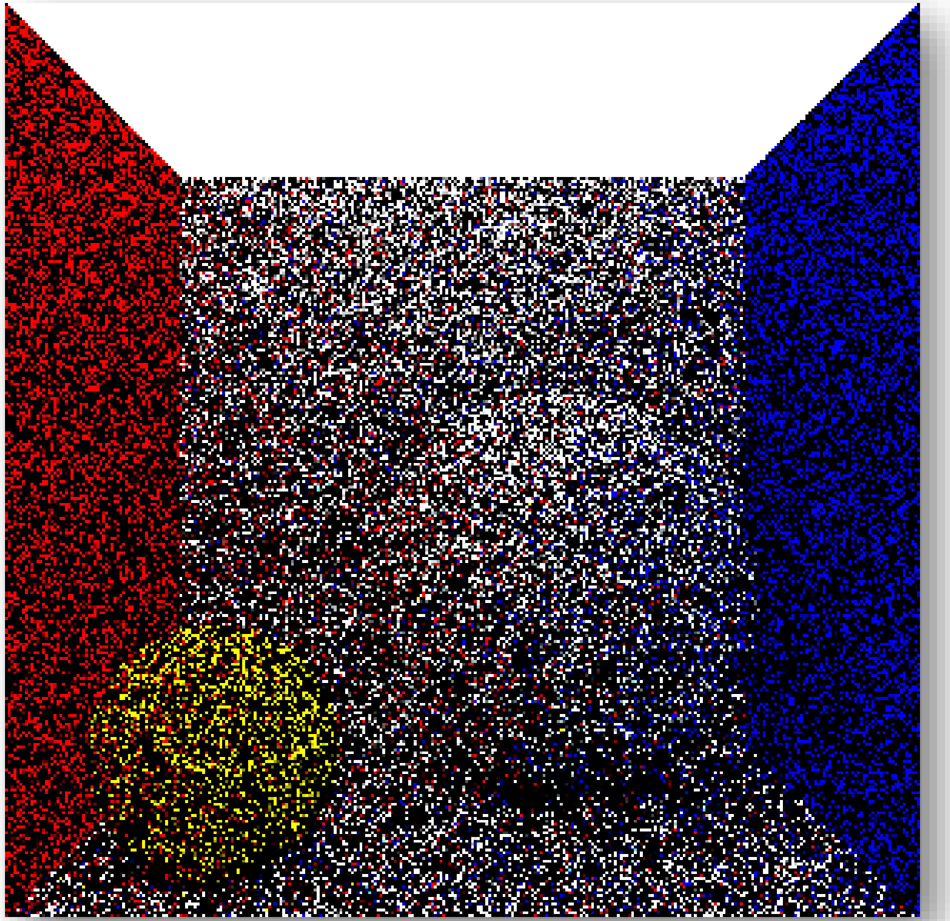
BRDFs describe **arbitrary** materials.

BRDFs may depend on more parameters than just ω_i and ω_o: Location, Wavelengths, Time, …



The [Disney BRDF](#) (Burley et al.) describes every material with 10 parameters.

Monte Carlo Path Tracing

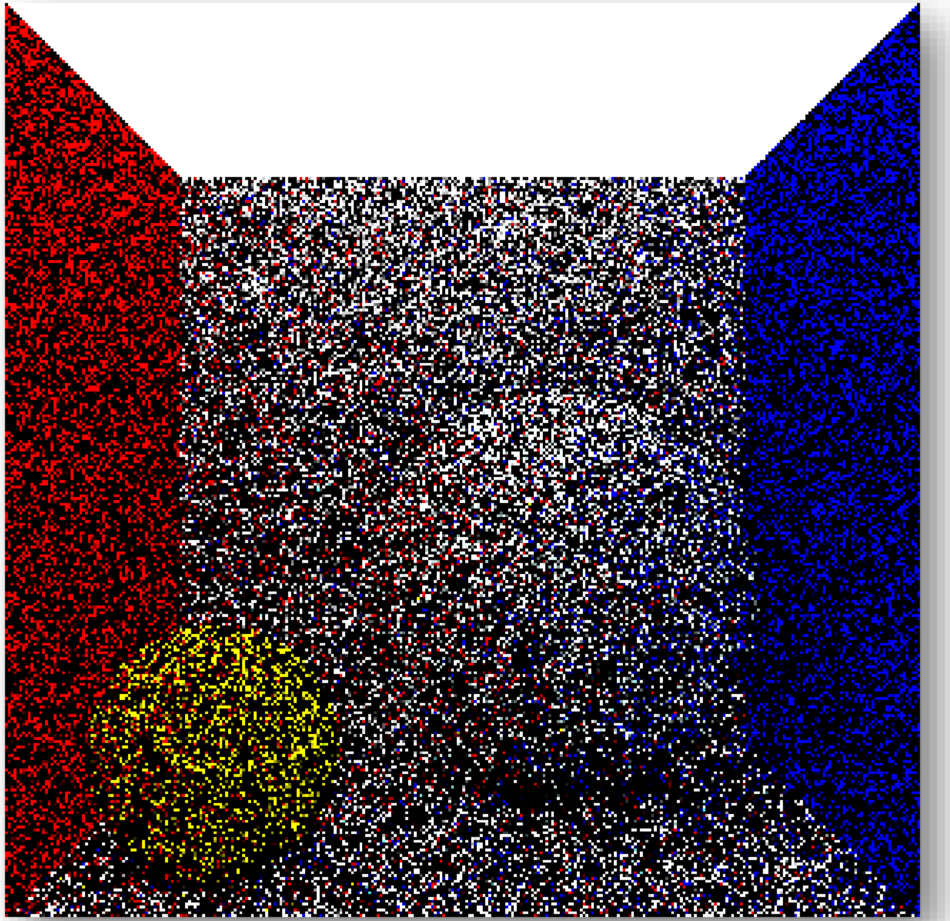


```
Vec3 ComputeColor(Vec3 O, Vec3 d⃗)
{
    hp ≔ Closest hitpoint of ray(O, d⃗) in scene



    Sample random direction ω_r ∈ Ω

    return hp_emission + 2π (ω_r · n) BRDF(d, ω_r) ⊙ ComputeColor(hp, ω_r)
}
```

$$hp_{emission} + 2\pi\left(\widehat{\vec{\omega_r}}\cdot\widehat{\vec{n}}\right)\mathrm{BRDF}(\widehat{\vec{d}},\widehat{\vec{\omega}}_r)\odot \mathrm{ComputeColor}(hp,\vec{\omega_r})$$

```
Vec3 BRDF(ω_I, ω_O)
{
    return Diffuse Color of hit object · 1/π
}
```

Monte Carlo Path Tracing



```
Vec3 ComputeColor(Vec3 O, Vec3 d)
{
    hp := Closest hitpoint of ray(O,d) in scene
    if x~U[0,1] < p
        return hp_emission

    Sample random direction ω_r ∈ Ω
    return hp_emission + 2π/(1−p) (ω_r · n) BRDF(d, ω_r) ⊙ ComputeColor(hp, ω_r)
}

Vec3 BRDF(ω_I, ω_O)
{
    return Diffuse Color of hit object · 1/π
}
```

$$\texttt{Vec3 ComputeColor(Vec3 O, Vec3 } \vec{d}\texttt{)}$$

$$hp \coloneqq \text{Closest hitpoint of } ray(O,\vec{d}) \text{ in scene}$$

$$\text{if } x \sim \mathcal{U}_{[0,1]} < p \quad \text{return } hp_{emission}$$

$$\text{Sample random direction } \widehat{\overrightarrow{\omega_r}} \in \Omega$$

$$\text{return } hp_{emission} + \frac{2\pi}{1-p}\left(\widehat{\overrightarrow{\omega_r}} \cdot \widehat{\vec{n}}\right) \mathrm{BRDF}(\widehat{\vec{d}}, \widehat{\vec{\omega}}_r) \odot \mathrm{ComputeColor}(hp, \overrightarrow{\omega_r})$$

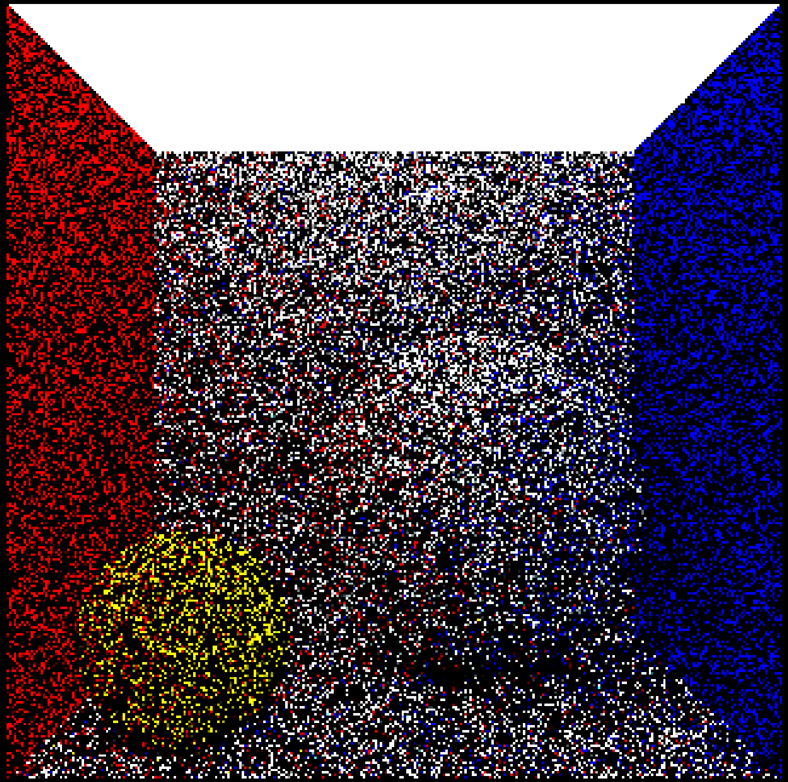
$$\texttt{Vec3 BRDF}(\widehat{\vec{\omega}}_I, \widehat{\vec{\omega}}_O)$$

$$\text{return Diffuse Color of hit object} \cdot \frac{1}{\pi}$$

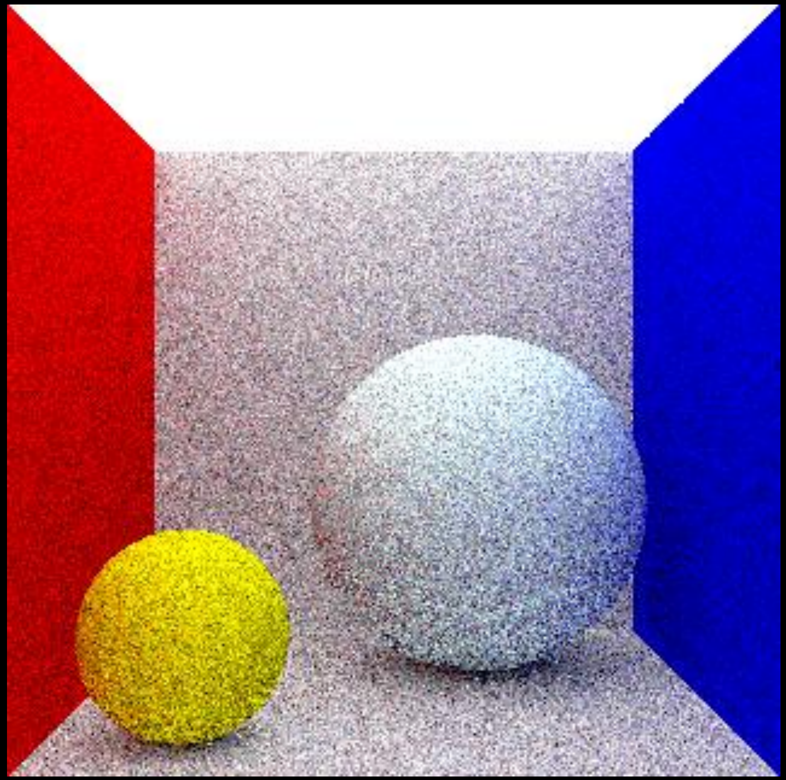
e.g. $0.05 < p < 0.5$

Monte Carlo Path Tracing

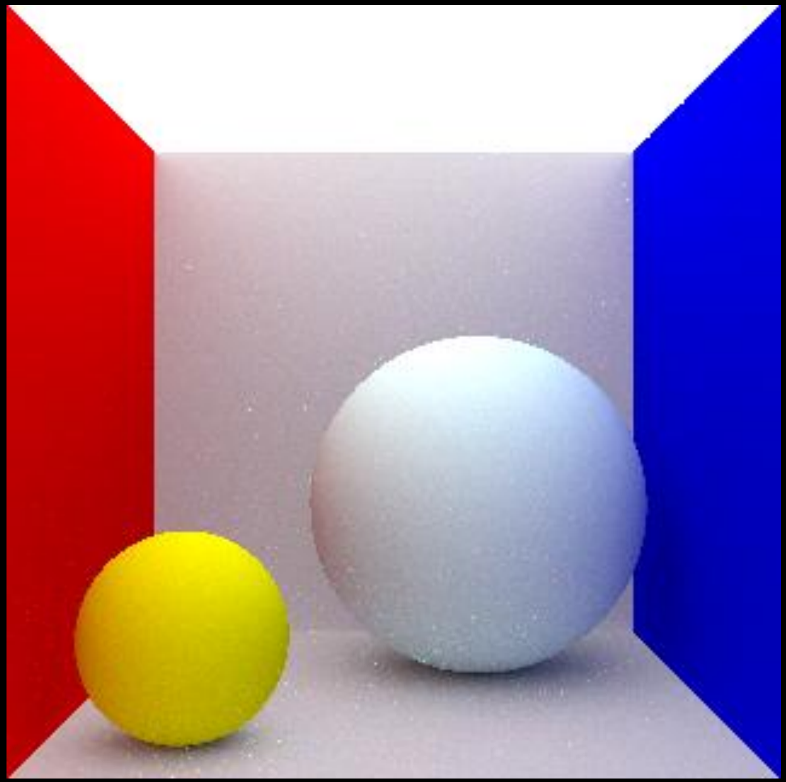
1 Ray/Pixel

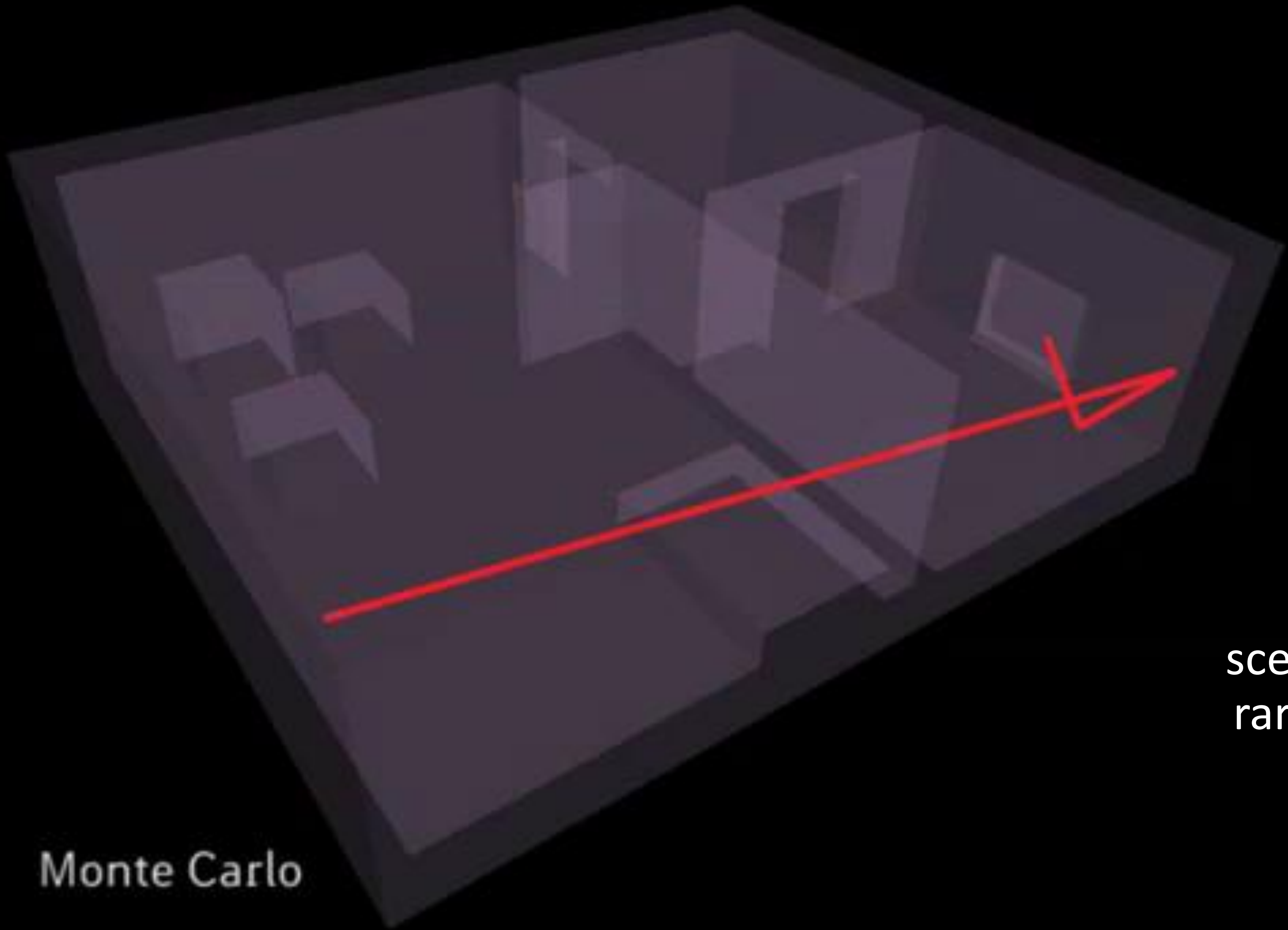


Averaging 32 Rays/Pixel



Averaging 4096 Rays/Pixel

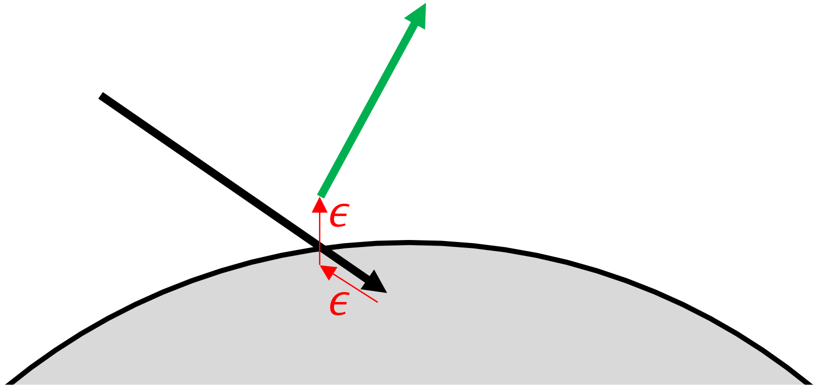




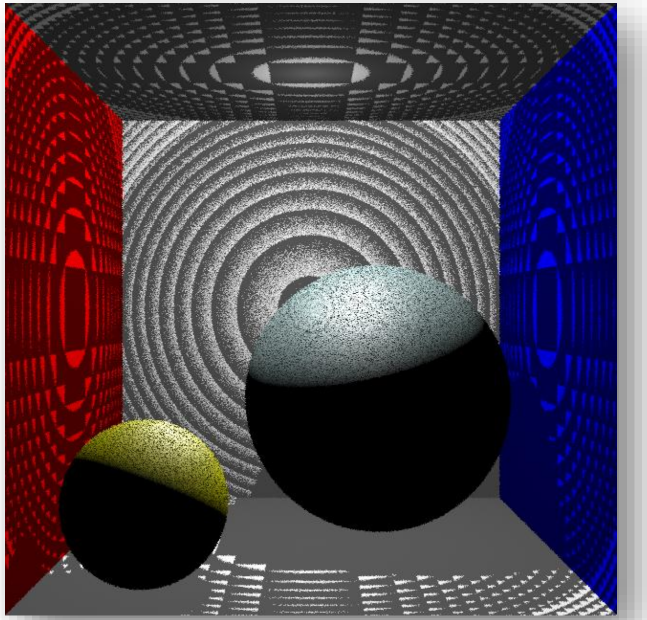
In challenging scenes, camera rays rarely find a way to a light source.

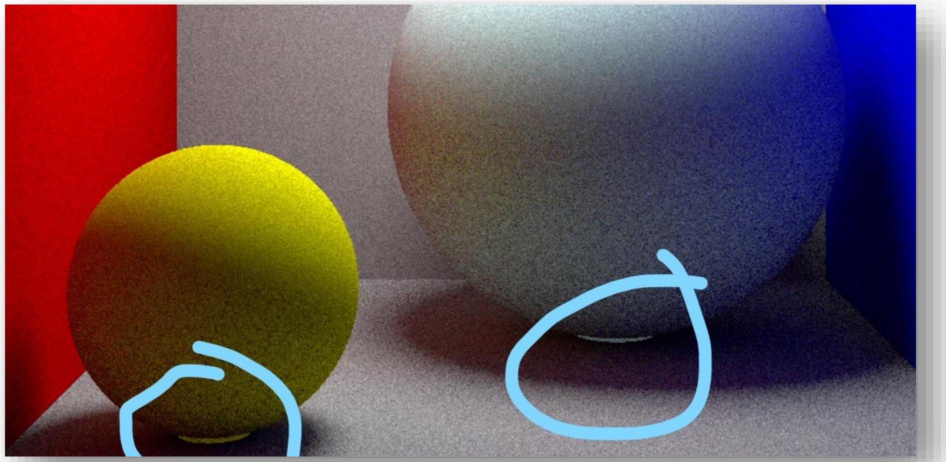
Working with Floating Point

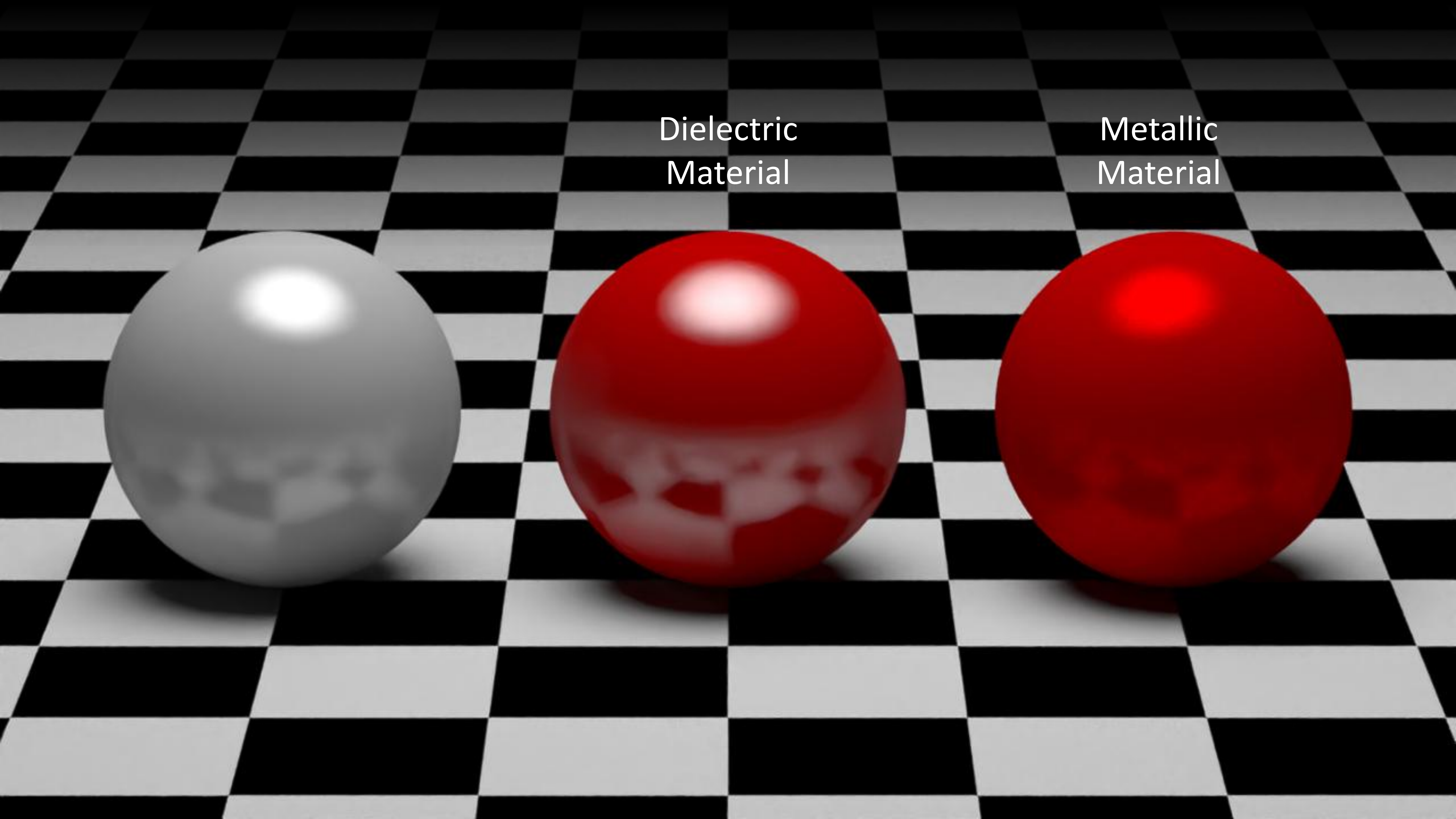
Limited accuracy means that intersections end up **inside** the object in 50% of the cases.



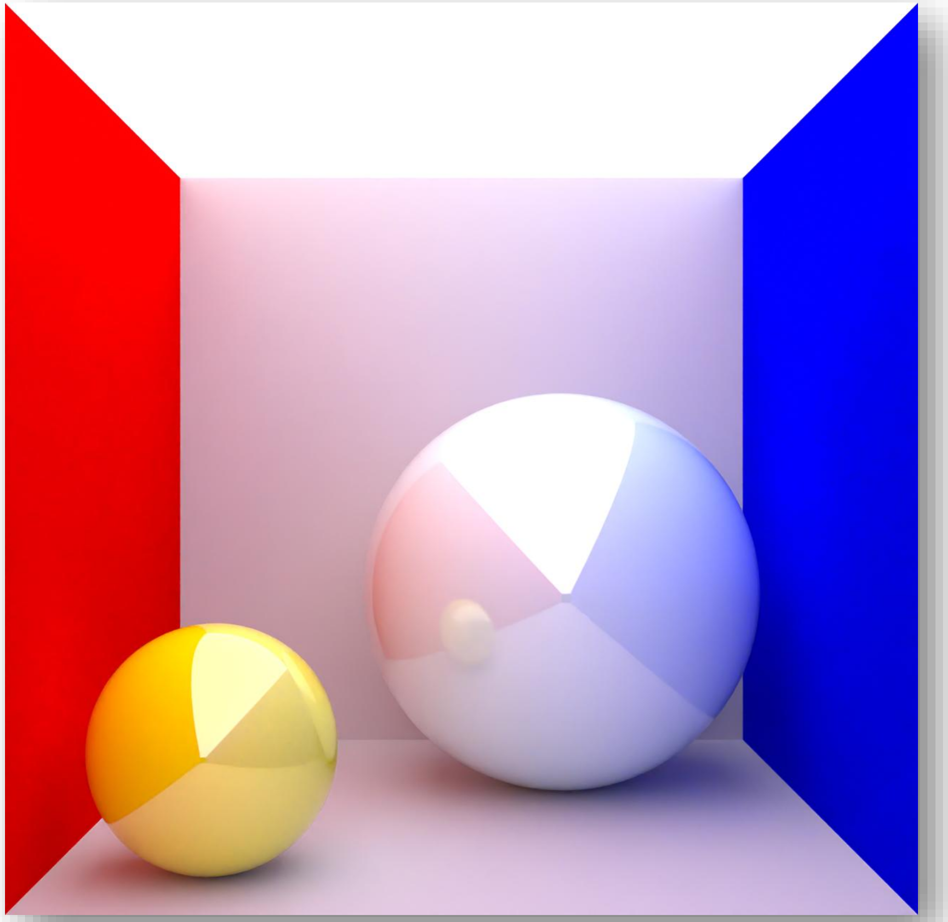
Start reflected rays **outside** the object, by *nudging* the starting point backwards and/or outwards.






Dielectric
Material
Metallic
Material

Reflective Materials



```
Color BRDF(…)
{
    d_r = Compute reflection of d on n
    if ω_r = d_r
        return Diffuse Color · 1/π + μ(Specular Color of object)
    else
        return Diffuse Color of object · 1/π
}
```

$\hat{\vec{d}}_r$ = Compute reflection of $\hat{\vec{d}}$ on $\hat{\vec{n}}$

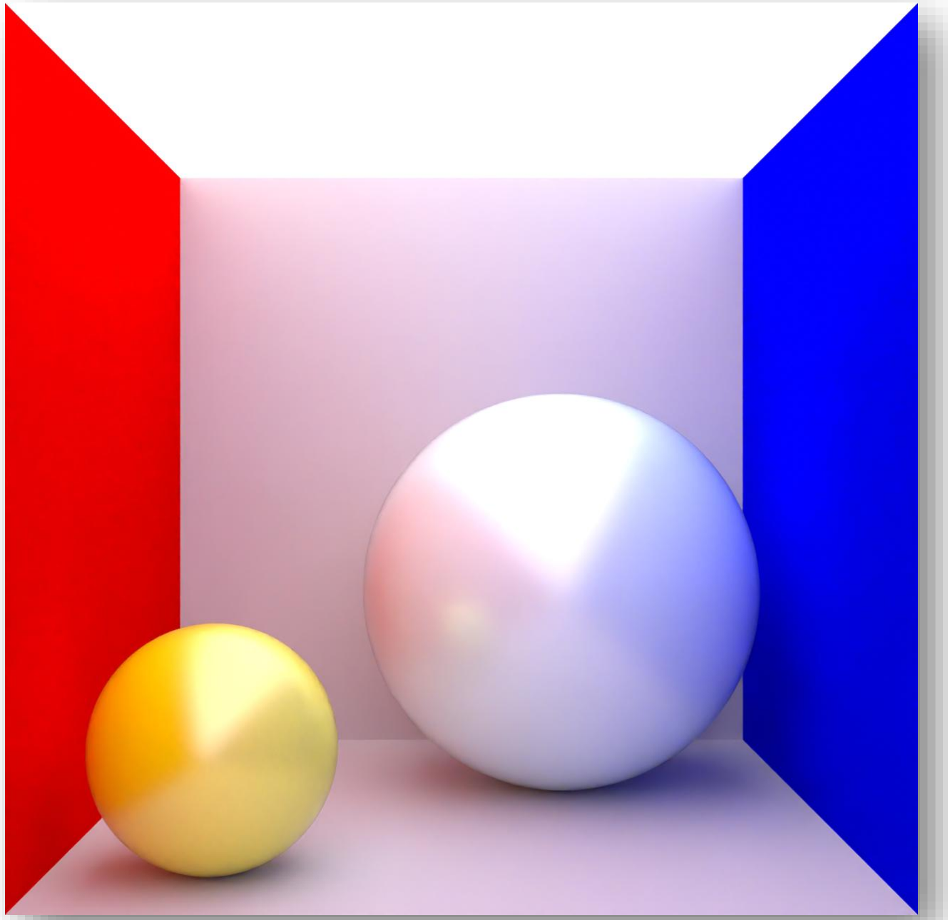
if $\widehat{\vec{\omega}_r} = \hat{\vec{d}}_r$

return Diffuse Color $\cdot \frac{1}{\pi}$ + μ(Specular Color of object)

else

return Diffuse Color of object $\cdot \frac{1}{\pi}$

Reflective Materials



```
Color BRDF(…)
{
    d_r = Compute reflection of d on n
    if ω_r · d_r > 1 − ε
        return Diffuse Color · 1/π + μ(Specular Color of object)
    else
        return Diffuse Color of object · 1/π
}
```

Where: $\widehat{\vec{d}}_r$ = Compute reflection of $\widehat{\vec{d}}$ on $\widehat{\vec{n}}$; if $\widehat{\vec{\omega}_r} \cdot \widehat{\vec{d}}_r > 1 - \epsilon$ return Diffuse Color $\cdot \frac{1}{\pi}$ + μ(Specular Color of object) else return Diffuse Color of object $\cdot \frac{1}{\pi}$

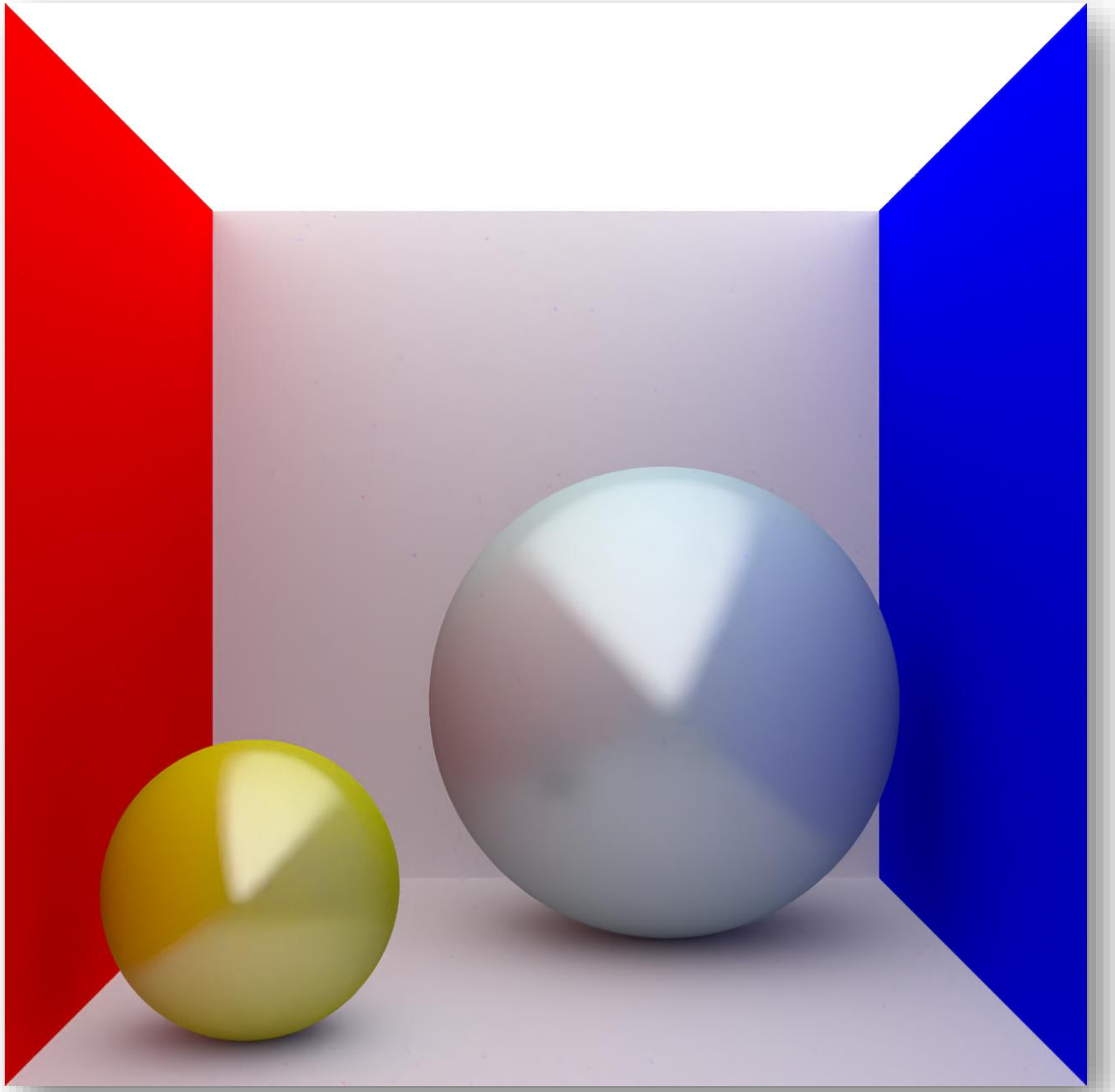
e.g. $\epsilon = 0.01, \mu = 10$

This Week's Lab

Extend the path tracer with:

- **Emissive** materials
- **Multiple rays** per pixel
- **Reflections** on a subset of objects

1. Comment out the code from last week
2. Take screenshots of the results



The first 11:11 of https://www.youtube.com/watch?v=gsZiJeaMO48
summarizes and visualizes a lot of today's lecture